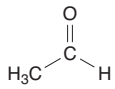
Acetaldehyde

CAS No. 75-07-0

Reasonably anticipated to be a human carcinogen

First listed in the *Sixth Annual Report on Carcinogens* (1991)

Also known as ethanal



Carcinogenicity

Acetaldehyde is *reasonably anticipated to be a human carcinogen* based on sufficient evidence of carcinogenicity from studies in experimental animals.

Cancer Studies in Experimental Animals

Exposure to acetaldehyde by inhalation caused tumors in two rodent species and at two different tissue sites. In rats of both sexes, it caused cancer of the nasal mucosa (squamous-cell carcinoma and adenocarcinoma), and in hamsters of both sexes, it caused cancer of the larynx (carcinoma) (IARC 1985, 1987). Inhalation of acetaldehyde also promoted the induction of respiratory-tract tumors by intratracheal instillation of the known carcinogen benzo[*a*]pyrene in hamsters of both sexes.

Since acetaldehyde was listed in the *Sixth Annual Report on Carcinogens,* an additional study in rats has been identified. Administration of acetaldehyde in drinking water increased the incidences of hemolymphoreticular cancer (leukemia and lymphoma combined), benign tumors of the pancreas (islet-cell adenoma), and cancer of the bone (osteosarcoma) and nasal cavity (carcinoma) in males and benign mammary-gland tumors (fibroma or fibroadenoma) in females (Soffritti *et al.* 2002). Increased incidences of tumors observed at other sites occurred only at one of the lower doses tested.

Cancer Studies in Humans

The data available from epidemiological studies are inadequate to evaluate the relationship between human cancer and exposure specifically to acetaldehyde. A survey of workers producing acetaldehyde and other aldehydes in Germany reported 9 cases of cancer, including 5 of lung cancer and 2 of oral-cavity cancer, among an unspecified number of workers; these incidences reportedly were higher than expected, but the observations were confounded by the fact that all cases of cancer occurred in tobacco smokers (IARC 1985, 1987).

Since acetaldehyde was listed in the *Sixth Annual Report on Carcinogens,* additional epidemiological studies have been identified, primarily case-control studies of populations exposed to acetaldehyde (the main initial metabolite of alcohol) following consumption of alcoholic beverages. Alcoholic beverage consumption is listed in the Report on Carcinogens as *known to be a human carcinogen*. In its 1999 review, the International Agency for Research on Cancer noted that three small case-control studies found increased risks of alcohol-related cancer (of the oral cavity, pharynx, larynx, and esophagus) among individuals with genetic variations (polymorphisms) that result in increased levels of acetaldehyde after alcohol consumption. However, IARC concluded that the data available were inadequate to evaluate the carcinogenicity of acetaldehyde (IARC 1999). Since then, a number of review articles and meta-analyses have summarized the results of subsequent studies that found dose-response relationships between alcohol consumption and cancer of the oral cavity, pharynx, larynx, and esophagus, and possibly the stomach and colorectum, among individuals with genetic polymorphisms that increase blood or salivary levels of acetaldehyde (Bagnardi *et al.* 2001, Zeka *et al.* 2003, Boffetta and Hashibe 2006, Baan *et al.* 2007, Boccia *et al.* 2009, Salaspuro 2009). In 2009, IARC concluded that acetaldehyde associated with alcohol consumption was carcinogenic to humans (Secretan *et al.* 2009). Few studies have been conducted on the association of these polymorphisms with cancer at other tissue sites, and the role of acetaldehyde in pancreatic, liver, bladder, or breast cancer is not clear (van Dijk *et al.* 2001, Terry *et al.* 2006, Seitz and Becker 2007, Visvanathan *et al.* 2007, Druesne-Pecollo *et al.* 2009).

Studies on Mechanisms of Carcinogenesis

Alcohol is metabolized to acetaldehyde by alcohol dehydrogenases (ADH), and acetaldehyde is metabolized to acetic acid by aldehyde dehydrogenases (ALDH). In some individuals, genetic polymorphisms in these enzymes can result in either higher rates of acetaldehyde production from alcohol or lower rates of acetaldehyde metabolism to acetic acid, resulting in higher blood acetaldehyde levels after a given level of alcohol intake than in individuals without these polymorphisms. Five ADH genes have been identified in humans, two of which have been shown to be polymorphic. The variant allele of the *ALDH2* gene, which is prevalent in Asians, encodes an enzyme that has almost no ability to detoxify acetaldehyde (IARC 1999).

Properties

Acetaldehyde is an aliphatic aldehyde that exists at room temperature as a colorless gas with a fruity, pungent odor. It is miscible with water, ether, benzene, gasoline, solvent naphtha, toluene, xylene, turpentine, and acetone. It is very flammable and is unstable in air (Akron 2009, HSDB 2009). Physical and chemical properties of acetaldehyde are listed in the following table.

Property	Information
Molecular weight	44.0[a]
Specific gravity	0.79 at 16°C/4°C[a]
Melting point	–124°C[a]
Boiling point	21°C[a]
Log K_{ow}	–0.34[b]
Water solubility	1,000 g/L at 25°C[a]
Vapor pressure	902 mm Hg at 25°C[a]
Vapor density relative to air	1.5[a]
Dissociation constant (pK_a)	13.6 at 25°C[a]

Sources: [a]HSDB 2009, [b]ChemIDplus 2009.

Use

Acetaldehyde is used primarily as a chemical intermediate in the production of acetic acid, pyridine and pyridine bases, peracetic acid, pentaerythritol, butylene glycol, and chloral. It is also used in the synthesis of crotonaldehyde, flavor and fragrance acetals, acetaldehyde 1,1-dimethylhydrazone, acetaldehyde cyanohydrin, acetaldehyde oxime, various acetic acid esters, paraldehyde, metaldehyde (a molluscicide widely used to kill slugs and snails), polymers, and various halogenated derivatives (IARC 1985, 1999). Acetaldehyde has been used in the manufacture of aniline dyes, plastics, and synthetic rubber, to silver mirrors, and to harden gelatin fibers. It has also been used in the production of polyvinyl acetal resins, in fuel compositions, to inhibit mold growth on leather, and in the manufacture of disinfectants, pesticides, drugs, explosives, lacquers and varnishes, photographic chemicals, phenolic and urea resins, and rubber accelerators and antioxidants (EPA 1994).

Acetaldehyde is considered by the U.S. Food and Drug Administration to be generally recognized as safe for use as a flavoring agent and adjuvant (Furia and Bellanca 1975, HSDB 2009). It is an important component of food flavorings and is added to milk products, baked

goods, fruit juices, candy, desserts, and soft drinks; it is especially useful for imparting orange, apple, and butter flavors. The concentration of acetaldehyde in food generally is up to 0.047%. In 1976, about 8,600 kg (19,000 lb) of acetaldehyde was used as food additives. Acetaldehyde is also used in the manufacture of vinegar and as a fruit and fish preservative. It is approved for use in phenolic resins in molded containers for contact with non-acidic foods. Acetaldehyde is no longer registered as an active ingredient in any pesticide. When it was used as a fumigant for storage of apples and strawberries, it was exempted from a residue tolerance (IARC 1985, EPA 1994, HSDB 2009).

Production

Acetaldehyde was first produced commercially in 1916 (IARC 1985). U.S. production was 63.5 million kilograms (140 million pounds) in 1940 and 408 million kilograms (899 million pounds) in 1960. Production peaked in 1969 at 748 million kilograms (1.65 billion pounds), decreasing to 281 million kilograms (619 million pounds) in 1982. In 2009, acetaldehyde was produced by 50 manufacturers worldwide (17 in China, 12 in India, 6 in East Asia, 5 in Europe, 5 in Central and South America, 2 in Mexico, 2 in the Middle East, and 1 in the United States) (SRI 2009) and was available from 49 suppliers, including 21 U.S. suppliers (ChemSources 2009). U.S. imports of acetaldehyde increased from 1,000 kg (2,200 lb) in 1989 to 414,000 kg (913,000 lb) in 2006 (USITC 2009). U.S. exports of acetaldehyde were 19 million kilograms (42.6 million pounds) in 1989, decreasing to 1.6 million kilograms (3.5 million pounds) in 2003 and remaining near this level from 2004 through 2008 (USITC 2009). Reports filed under the U.S. Environmental Protection Agency's Toxic Substances Control Act Inventory Update Rule indicated that U.S. production plus imports of acetaldehyde totaled 500 million to 1 billion pounds in 1986 and 1990 and 100 million to 500 million pounds in 1994, 1998, and 2002 (EPA 2004).

Exposure

There is high potential for exposure of the general population to acetaldehyde through ingestion, inhalation, and dermal contact and of workers through inhalation and dermal contact. The main source of exposure of the general population is through consumption of alcoholic beverages and the subsequent metabolism of alcohol to form acetaldehyde (HSDB 2009). Because acetaldehyde may form in wine and other alcoholic beverages after exposure to air (Hagemeyer 2002), alcoholic beverages (including wines, beer, and spirits) also frequently contain acetaldehyde as a volatile component (HSDB 2009).

Acetaldehyde is a product of most hydrocarbon oxidation reactions and is a normal intermediate in the respiration of most higher plants. It is found in trace amounts in many plant products, including apples, broccoli, coffee, grapefruit, grapes, lemons, mushrooms, onions, oranges, peaches, nectarines, pears, pineapples, raspberries, strawberries, cranberries, sour cherries, and mango. It has been detected in the essential oils of alfalfa, rosemary, balm, clary sage, daffodil, bitter orange, camphor, angelica, fennel, mustard, peppermint, and lychee, and in oak and tobacco leaves and cotton leaves and blossoms (IARC 1985, Burdon *et al.* 1996, Gorny *et al.* 1999, Gunes *et al.* 2002, Bonerz *et al.* 2007, Mahattanatawee *et al.* 2007). Acetaldehyde has also been detected in breast milk. Consumers may be exposed to acetaldehyde in many milk products, including all types of cheese, yogurt, and milk of varying fat content (Mistry and Hassan 1992, Barbieri *et al.* 1994, Jandal 1996, Beshkova *et al.* 1998, Van Aardt *et al.* 2001, Kondyli *et al.* 2002, Boscaini *et al.* 2003, Di Cagno *et al.* 2004, Fernandez-Garcia *et al.* 2004, Blagden and Gilliland 2005, Gadaga *et al.* 2007, Kaminarides *et al.* 2007). Acetaldehyde has also been detected in cooked beef, chicken, and fish (HSDB 2009, Yasuhara and Shibamoto 1995) and is used as a synthetic flavoring ingredient in processed foods, especially margarine (HSDB 2009).

According to EPA's Toxics Release Inventory, environmental releases of acetaldehyde have increased slightly since 1988, when 9.5 million pounds was released, 73% to air, 23% to underground injection wells, and the remainder to surface water and landfills. Since then, releases to underground injection wells have decreased, and releases to surface water have increased. In 2007, 11.4 million pounds of acetaldehyde was released from 336 facilities that processed, produced, or used the chemical; 29 facilities each released more than 100,000 lb. Of the total amount, 94% was released to air, 3.1% to underground injection wells, and 2.8% to water (TRI 2009). Acetaldehyde will volatilize rapidly from water or land, and it will leach into the ground, where it will biodegrade (HSDB 2009). Acetaldehyde is also degraded readily in soil, sewage, and natural waters by microorganisms (EPA 1987).

Acetaldehyde is a natural product of photooxidation of hydrocarbons commonly found in the atmosphere and occurs naturally as emissions from forest fires, volcanoes, and animal wastes. In the 1990s, annual emissions of acetaldehyde from all sources in the United States were estimated at 12.1 million kilograms (27 million pounds) (IPCS 1995). Burning wood produces acetaldehyde at approximately 0.7 g/kg of wood, and fireplace emissions range from 0.083 to 0.20 g/kg of wood burned (HSDB 2009). In the 1990s, annual emissions from residential burning in the United States were estimated at 5,000 metric tons (11 million pounds) (IPCS 1995). Acetaldehyde is also a combustion product of some plastics (e.g., polycarbonate) and some hard and soft polyurethane foams. It also occurs in gasoline exhaust (1.4 to 8.8 mg/m^3) and diesel exhaust (0.05 to 6.4 mg/m^3); however, very little is emitted from small engines such as lawn mowers or leaf blowers (IARC 1985, Baldauf *et al.* 2006).

Many individuals are exposed to acetaldehyde by inhalation. The highest ambient-air concentrations of acetaldehyde were reported for urban or suburban areas or near sources of combustion (HSDB 2009). In ambient air, concentrations of acetaldehyde generally averaged 5 $\mu g/m^3$. Indoor air concentrations were higher than ambient concentrations in all locations where acetaldehyde air concentrations were measured, both in the United States and in other countries (Miguel *et al.* 1995, Mukund *et al.* 1996, Brickus *et al.* 1998, MacIntosh *et al.* 2000, Possanzini *et al.* 2002, Baez *et al.* 2003, Hellen *et al.* 2004, Hodgson *et al.* 2004, Park and Ikeda 2004, Saijo *et al.* 2004, Sax *et al.* 2004, Shendell *et al.* 2004, Gilbert *et al.* 2005, Cavalcante *et al.* 2006, Ohura *et al.* 2006, Pang and Mu 2006, Sax *et al.* 2006, Hodgson *et al.* 2007, Possanzini *et al.* 2007). Acetaldehyde is also found in tobacco and marijuana cigarette smoke (1,220 µg per cigarette) and tobacco cigarettes (980 to 1,370 µg per cigarette).

In 1988–89, acetaldehyde was detected in 4 of 10 surveyed water supplies (EPA 1987). In surface water, concentrations generally are less than 0.1 µg/L, and the contribution from drinking water to human exposure is considered negligible (IPCS 1995).

The National Occupational Exposure Survey (conducted from 1981 to 1983) estimated that 216,533 workers, including 97,770 women, potentially were exposed to acetaldehyde (NIOSH 1990). Workers potentially exposed include those involved in the manufacture or use of industrial organic chemicals, dyes, fabricated rubber, plastics, urea-formaldehyde foam insulation, fuels, drugs, explosives, varnishes, pesticides, food additives, leather goods, and mirrors (IARC 1985, EPA 1994).

Regulations

Coast Guard, Department of Homeland Security

Minimum requirements have been established for safe transport of acetaldehyde on ships and barges.

Department of Transportation (DOT)

Acetaldehyde is considered a hazardous material, and special requirements have been set for marking, labeling, and transporting this material.

Environmental Protection Agency (EPA)

Clean Air Act

Mobile Source Air Toxics: Listed as a mobile source air toxic for which regulations are to be developed.
National Emission Standards for Hazardous Air Pollutants: Listed as a hazardous air pollutant.
New Source Performance Standards: Manufacture of acetaldehyde is subject to certain provisions for the control of volatile organic compound emissions.
Prevention of Accidental Release: Threshold quantity (TQ) = 10,000 lb.
Urban Air Toxics Strategy: Identified as one of 33 hazardous air pollutants that present the greatest threat to public health in urban areas.

Clean Water Act

Designated a hazardous substance.

Comprehensive Environmental Response, Compensation, and Liability Act

Reportable quantity (RQ) = 1,000 lb.

Emergency Planning and Community Right-To-Know Act

Toxics Release Inventory: Listed substance subject to reporting requirements.

Resource Conservation and Recovery Act

Listed Hazardous Waste: Waste code for which the listing is based wholly or partly on the presence of acetaldehyde = U001.

Occupational Safety and Health Administration (OSHA)

While this section accurately identifies OSHA's legally enforceable PELs for this substance in 2010, specific PELs may not reflect the more current studies and may not adequately protect workers.
Permissible exposure limit (PEL) = 200 ppm (360 mg/m^3).
Considered a highly hazardous chemical: Threshold quantity (TQ) = 2,500 lb.

Guidelines

American Conference of Governmental Industrial Hygienists (ACGIH)

Threshold limit value – ceiling (TLV-C) = 25 ppm.

National Institute for Occupational Safety and Health (NIOSH)

Immediately dangerous to life and health (IDLH) limit = 2,000 ppm.
Listed as a potential occupational carcinogen.

References

Akron. 2009. *The Chemical Database.* The Department of Chemistry at the University of Akron. http://ull.chemistry.uakron.edu/erd and search on CAS number. Last accessed: 7/2/09.

Baan R, Straif K, Grosse Y, Secretan B, El Ghissassi F, Bouvard V, Altieri A, Cogliano V. 2007. Carcinogenicity of alcoholic beverages. *Lancet Oncol* 8(4): 292-293.

Baez A, Padilla H, Garcia R, Torres MD, Rosas I, Belmont R. 2003. Carbonyl levels in indoor and outdoor air in Mexico City and Xalapa, Mexico. *Sci Total Environ* 302(1-3): 211-226.

Bagnardi V, Blangiardo M, La Vecchia C, Corrao G. 2001. A meta-analysis of alcohol drinking and cancer risk. *Br J Cancer* 85(11): 1700-1705.

Baldauf R, Fortune C, Weinstein J, Wheeler M, Blanchard F. 2006. Air contaminant exposures during the operation of lawn and garden equipment. *J Expo Sci Environ Epidemiol* 16(4): 362-370.

Barbieri G, Bolzoni L, Careri M, Mangia A, Parolari G, Spagnoli S, Virgili R. 1994. Study of the volatile fraction of Parmesan cheese. *J Agric Food Chem* 42(5): 1170-1176.

Beshkova D, Simova E, Frengova G, Simov Z. 1998. Production of flavour compounds by yogurt starter cultures. *J Ind Microbiol Biotechnol* 20(3-4): 180-186.

Blagden TD, Gilliland SE. 2005. Reduction of levels volatile components with the "beany" flavor in soymilk by lactobacilli and streptococci. *J Food Sci* 70(3): M186-M189.

Boccia S, Hashibe M, Galli P, De Feo E, Asakage T, Hashimoto T, *et al.* 2009. Aldehyde dehydrogenase 2 and head and neck cancer: A meta-analysis implementing a Mendelian randomization approach. *Cancer Epidemiol Biomarkers Prev* 18(1): 248-254.

Boffetta P, Hashibe M. 2006. Alcohol and cancer. *Lancet Oncol* 7(2): 149-156.

Bonerz D, Würth K, Dietrich H, Will F. 2007. Analytical characterization and the impact of ageing on anthocyanin composition and degradation in juices from five sour cherry cultivars. *Eur Food Res Technol* 224(3): 355-364.

Boscaini E, Van Ruth S, Biasioli F, Gasperi F, Märk TD. 2003. Gas chromatography-olfactometry (GC-O) and proton transfer reaction-mass spectrometry (PTR-MS) analysis of the flavor profile of Grana Padano, Parmigiano Reggiano, and Grana Trentino cheeses. *J Agric Food Chem* 51(7): 1782-1790.

Brickus LSR, Cardoso JN, Neto FRD. 1998. Distributions of indoor and outdoor air pollutants in Rio de Janeiro, Brazil: Implications to indoor air quality in bayside offices. *Environ Sci Technol* 32(22): 3485-3490.

Burdon J, Dori S, Marinansky R, Pesis E. 1996. Acetaldehyde inhibition of ethylene biosynthesis in mango fruit. *Postharvest Biol Technol* 8(2): 153-161.

Cavalcante RM, Campelo CS, Barbosa MJ, Silveira ER, Carvalho TV, Nascimento RF. 2006. Determination of carbonyl compounds in air and cancer risk assessment in an academic institute in Fortaleza, Brazil. *Atmos Environ* 40(29): 5701-5711.

ChemIDplus. 2009. *ChemIDplus Advanced*. National Library of Medicine. http://chem.sis.nlm.nih.gov/chemidplus/chemidheavy.jsp and select Registry Number and search on CAS number. Last accessed: 7/2/09.

ChemSources. 2009. *Chem Sources - Chemical Search*. Chemical Sources International. http://www.chemsources.com/chemonline.html and search on acetaldehyde. Last accessed: 7/2/09.

Di Cagno R, Tamborrino A, Gallo G, Leone C, De Angelis M, Faccia M, Amirante P, Gobbetti M. 2004. Uses of mares' milk in manufacture of fermented milks. *Int Dairy J* 14(9): 767-775.

Druesne-Pecollo N, Tehard B, Mallet Y, Gerber M, Norat T, Hercberg S, Latino-Martel P. 2009. Alcohol and genetic polymorphisms: Effect on risk of alcohol-related cancer. *Lancet Oncol* 10(2): 173-180.

EPA. 1987. *Health Assessment Document for Acetaldehyde*. EPA/600/8-86-015A. Research Triangle Park, NC: U.S. Environmental Protection Agency.

EPA. 1994. *Chemical Summary for Acetaldehyde.* U.S. Environmental Protection Agency. http://www.epa.gov/chemfact/s_acetal.txt.

EPA. 2004. *Non-confidential IUR Production Volume Information.* U.S. Environmental Protection Agency. http://www.epa.gov/oppt/iur/tools/data/2002-vol.html and search on CAS number.

Fernandez-Garcia E, Carbonell M, Gaya P, Nuñez M. 2004. Evolution of the volatile components of ewes raw milk Zamorano cheese. Seasonal variation. *Int Dairy J* 14(8): 701-711.

Furia TE, Bellanca N. 1975. *Fenaroli's Handbook of Flavour Ingredients*, vol. 2, Cleveland, OH: CRC Press.

Gadaga TH, Viljoen BC, Narvhus JA. 2007. Volatile organic compounds in naturally fermented milk and milk fermented using yeasts, lactic acid bacteria and their combinations as starter cultures. *Food Technol Biotechnol* 45(2): 195-200.

Gilbert NL, Guay M, Miller JD, Judek S, Chan CC, Dales RE. 2005. Levels and determinants of formaldehyde, acetaldehyde, and acrolein in residential indoor air in Prince Edward Island, Canada. *Environ Res* 99(1): 11-17.

Gorny JR, Hess-Pierce B, Kader AA. 1999. Quality changes in fresh-cut peach and nectarine slices as affected by cultivar, storage atmosphere and chemical treatments. *J Food Sci* 64(3): 429-432.

Gunes G, Liu RH, Watkins CB. 2002. Controlled-atmosphere effects on postharvest quality and antioxidant activity of cranberry fruits. *J Agric Food Chem* 50(21): 5932-5938.

Hagemeyer HJ. 2002. Acetaldehyde. In *Kirk-Othmer Encyclopedia of Chemical Technology,* vol. 1. Online edition. New York: John Wiley & Sons. pp. 99-114.

Hellen H, Hakola H, Reissell A, Ruuskanen TM. 2004. Carbonyl compounds in boreal coniferous forest air in Hyytiala, Southern Finland. *Atmos Chem Phys* 4: 1771-1780.

Hodgson AT, Shendell DG, Fisk WJ, Apte MG. 2004. Comparison of predicted and derived measures of volatile organic compounds inside four new relocatable classrooms. *Indoor Air* 14(s8): 135-144.

Hodgson AT, Destaillats H, Sullivan DP, Fisk WJ. 2007. Performance of ultraviolet photocatalytic oxidation for indoor air cleaning applications. *Indoor Air* 17(4): 305-316.

HSDB. 2009. *Hazardous Substances Data Bank.* National Library of Medicine. http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?HSDB and search on CAS number. Last accessed: 7/2/09.

IARC. 1985. Acetaldehyde. In *Allyl Compounds, Aldehydes, Epoxides, and Peroxides*. IARC Monographs on the Evaluation of Carcinogenic Risk of Chemicals to Humans, vol. 36. Lyon, France: International Agency for Research on Cancer. pp. 101-132.

IARC. 1987. Acetaldehyde. In *Overall Evaluations of Carcinogenicity*. IARC Monographs on the Evaluation of Carcinogenic Risk of Chemicals to Humans, suppl. 7. Lyon, France: International Agency for Research on Cancer. pp. 77-78.

IARC. 1999. Acetaldehyde. In *Re-evaluation of Some Organic Chemicals, Hydrazine, and Hydrogen Peroxide*. IARC Monographs on the Evaluation of Carcinogenic Risk of Chemicals to Humans, vol. 71. Lyon, France: International Agency for Research on Cancer. pp. 319-335.

IPCS. 1995. *Environmental Health Criteria No. 167. Acetaldehyde*. International Programme on Chemical Safety. http://www.inchem.org/documents/ehc/ehc/ehc167.htm.

Jandal JM. 1996. Studies on dried fermented dairy products prepared from sheep milk. *Small Rumin Res* 21(3): 217-220.

Kaminarides S, Stamou P, Massouras T. 2007. Comparison of the characteristics of set type yoghurt made from ovine milk of different fat content. *Int J Food Sci Tech* 42(9): 1019-1028.

Kondyli E, Katsiari MC, Masouras T, Voutsinas LP. 2002. Free fatty acids and volatile compounds of low-fat Feta-type cheese made with a commercial adjunct culture. *Food Chem* 79(2): 199-205.

MacIntosh DL, Zimmer-Dauphinee SA, Manning RO, Williams PL. 2000. Aldehyde concentrations in ambient air of coastal Georgia, USA. *Environ Monit Assess* 63(3): 409-429.

Mahattanatawee K, Perez-Cacho PR, Davenport T, Rouseff R. 2007. Comparison of three lychee cultivar odor profiles using gas chromatography—Olfactometry and gas chromatography—Sulfur detection. *J Agric Food Chem* 55(5): 1939-1944.

Miguel AH, Neto FBD, Cardoso JN, Vasconcellos PD, Pereira AS, Marquez KSG. 1995. Characterization of indoor air-quality in the cities of Sao-Paulo and Rio-de-Janeiro, Brazil. *Environ Sci Technol* 29(2): 338-345.

Mistry VV, Hassan HN. 1992. Manufacture of nonfat yogurt from a high milk protein powder. *J Dairy Sci* 75(4): 947-957.

Mukund R, Kelly TJ, Spicer CW. 1996. Source attribution of ambient air toxic and other VOCs in Columbus, Ohio. *Atmos Environ* 30(20): 3457-3470.

NIOSH. 1990. *National Occupational Exposure Survey (1981-83)*. National Institute for Occupational Safety and Health. Last updated: 7/1/90. http://www.cdc.gov/noes/noes1/01038sic.html.

Ohura T, Amagai T, Senga Y, Fusaya M. 2006. Organic air pollutants inside and outside residences in Shimizu, Japan: Levels, sources and risks. *Sci Total Environ* 366(2-3): 485-499.

Pang XB, Mu YJ. 2006. Seasonal and diurnal variations of carbonyl compounds in Beijing ambient air. *Atmos Environ* 40(33): 6313-6320.

Park JS, Ikeda K. 2004. Exposure to the mixtures of organic compounds in homes in Japan. *Indoor Air* 14(6): 413-420.

Possanzini M, Di Palo V, Cecinato A. 2002. Sources and photodecomposition of formaldehyde and acetaldehyde in Rome ambient air. *Atmos Environ* 36(19): 3195-3201.

Possanzini M, Tagliacozzo G, Cecinato A. 2007. Ambient levels and sources of lower carbonyls at Montelibretti, Rome (Italy). *Water Air Soil Pollut* 183(1-4): 447-454.

Saijo Y, Kishi R, Sata F, Katakura Y, Urashima Y, Hatakeyama A, *et al.* 2004. Symptoms in relation to chemicals and dampness in newly built dwellings. *Int Arch Occup Environ Health* 77(7): 461-470.

Salaspuro M. 2009. Acetaldehyde as a common denominator and cumulative carcinogen in digestive tract cancers. *Scand J Gastroenterol* 44(8): 912-925.

Sax SN, Bennett DH, Chillrud SN, Kinney PL, Spengler JD. 2004. Differences in source emission rates of volatile organic compounds in inner-city residences of New York City and Los Angeles. *J Expo Anal Environ Epidemiol* 14(suppl. 1): S95-S109.

Sax SN, Bennett DH, Chillrud SN, Ross J, Kinney PL, Spengler JD. 2006. A cancer risk assessment of inner-city teenagers living in New York City and Los Angeles. *Environ Health Perspect* 114(10): 1558-1566.

Secretan B, Straif K, Baan R, Grosse Y, El Ghissassi F, Bouvard V, *et al.* 2009. A review of human carcinogens—Part E: tobacco, areca nut, alcohol, coal smoke, and salted fish. *Lancet Oncol* 10(11): 1033-1034.

Seitz HK, Becker P. 2007. Alcohol metabolism and cancer risk. *Alcohol Res Health* 30(1): 38-47.

Shendell DG, Winer AM, Stock TH, Zhang L, Zhang J, Maberti S, Colome SD. 2004. Air concentrations of VOCs in portable and traditional classrooms: Results of a pilot study in Los Angeles County. *J Expo Anal Environ Epidemiol* 14(1): 44-59.

Soffritti M, Belpoggi F, Lambertini L, Lauriola M, Padovani M, Maltoni C. 2002. Results of long-term experimental studies on the carcinogenicity of formaldehyde and acetaldehyde in rats. *Ann N Y Acad Sci* 982: 87-105.

SRI. 2009. *Directory of Chemical Producers*. Menlo Park, CA: SRI Consulting. Database edition. Last accessed: 7/2/09.

Terry MB, Gammon MD, Zhang FF, Knight JA, Wang Q, Britton JA, Teitelbaum SL, Neugut AI, Santella RM. 2006. ADH3 genotype, alcohol intake and breast cancer risk. *Carcinogenesis* 27(4): 840-847.

TRI. 2009. *TRI Explorer Chemical Report.* U.S. Environmental Protection Agency. Last updated: 6/07. http://www.epa.gov/triexplorer and select Acetaldehyde. Last accessed: 7/2/09.

USITC. 2009. *USITC Interactive Tariff and Trade DataWeb.* United States International Trade Commission. http://dataweb.usitc.gov/scripts/user_set.asp and search on HTS no. 2912120000. Last accessed: 7/2/09.

Van Aardt M, Duncan SE, Bourne D, Marcy JE, Long TE, Hackney CR, Heisey C. 2001. Flavor threshold for acetaldehyde in milk, chocolate milk, and spring water using solid phase microextraction gas chromatography for quantification. *J Agric Food Chem* 49(3): 1377-1381.

Van Dijk BAC, Van Houwelingen KP, Witjes JA, Schalken JA, Kiemeney LALM. 2001. Alcohol dehydrogenase type 3 (ADH3) and the risk of bladder cancer. *Eur Urol* 40(5): 509-514.

Visvanathan K, Crum RM, Strickland PT, You X, Ruczinski I, Berndt SI, *et al.* 2007. Alcohol dehydrogenase genetic polymorphisms, low-to-moderate alcohol consumption, and risk of breast cancer. *Alcohol Clin Exp Res* 31(3): 467-476.

Yasuhara A, Shibamoto T. 1995. Quantitative analysis of volatile aldehydes formed from various kinds of fish flesh during heat treatment. *J Agric Food Chem* 43(1): 94-97.

Zeka A, Gore R, Kriebel D. 2003. Effects of alcohol and tobacco on aerodigestive cancer risks: A meta-regression analysis. *Cancer Causes Control* 14(9): 897-906.