

Allyl Isothiocyanate

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Allyl isothiocyanate is a phytochemical paradox. Few materials used in our industry today present such a complex nature as allyl isothiocyanate and its many other related analogues found in natural products consumed by humans and animals. Isothiocyanates are found in numerous plants and consumed via seeds, foliage and roots or extracts derived from these portions of the plant. Allyl isothiocyanate is just one of these phytochemicals, but an excellent example as it is consumed in far greater amounts than its other isothiocyanate analogues by humans.

In order to illustrate this paradox, one might ask the question: What aroma chemical is used in flavors and fragrances, appears on the FEMA/GRAS list, is not recommended for use in fragrances by IFRA, is toxic, flammable, a strong lachrymator and skin vesicant and may be a key anti-carcinogen? The answer is: allyl isothiocyanate.

This pungent, penetrating, eye tearing, sinus clearing, skin blistering agent is used in many flavors and in "negative" perfumery. It belongs to a group of natural products being studied by the National Cancer Institute's Diet and Cancer branch in its current research program, as it appears to have potential of preventing cancer in humans and animals.⁴ The NCI data indicates that isothiocyanates as a group are one of a class of 14 phytochemicals offering

significant hope in preventing the development of cancer and may play a role in the future to construct "designer foods" used to control cancer.

Allyl isothiocyanate—more commonly referred to as mustard oil or synthetic oil of mustard as it is found in mustard seed—more often recalls the odor of horseradish in which it is used as a flavor fortifier. It is used in flavor formulations where a pungent spice effect is needed to recall mustard, radish, onion, garlic, etc.

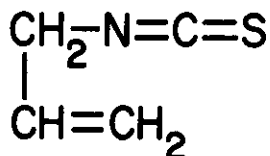
In fragrances, it has been essentially proscribed, yet continues to be useful in "negative perfumery" where it is the fragrance industry's answer to the flavor industry's bitter agent Bitrex[®] which is added to various household cleaning products to induce a repelling bitter taste and thus prevent young children from drinking otherwise pleasant smelling products.

Allyl isothiocyanate is also being used as a repellent odor in various organic solvent-based glues, paint dope products and typewriter eraser paints to prevent their use as an inhalation intoxicant via the breathing of the vapors. Check the odor of your typewriter white-out liquid!

Allyl isothiocyanate has an exceptionally strong, pen-

* denatonium benzoate

Allyl Isothiocyanate



Mwt 99 C₄H₅NS

CAS 57-06-7 FEMA/GRAS 2034

Classification:

An aliphatic unsaturated primary isothiocyanate.

Additional Names:¹⁻³

This material is seldom referred to by its chemical name; normally the term "mustard oil" is used as its designation.

Allyl mustard oil

Allyl iso-rhodanide

Synthetic oil of mustard

Oil of Sinapis

French: D'huile Moutarde

German: Senföl

Portugese: Oleo de Mostarda

Spanish: Oleo de Mostaze

Physical Data:

Appearance: colorless to yellow mobile liquid

Specific gravity 20°C: 1.013

Melting Point: -80°C

Boiling Point: 150°C

Refractive Index 20°C: 1.5300

Solubility: 0.2% in H₂O at 20°C, soluble in most organic solvents, i.e. propylene glycol, DEP, esters, alcohols, ketones, chlorinated solvents and aliphatic and aromatic hydrocarbons.

Allyl isothiocyanate is listed in the FCC and is on a negative list "not recommended for use in fragrances" by IFRA.

Allyl Isothiocyanate

etrating, stinging-repulsive, irritating effect on the nose and mucous membranes. Its odor and taste are reminiscent of mustard-horseradish. The process used to produce this material yields a pure product which is used in such low concentrations and is so strong that no accompanying byproduct taste or odor is noted!

As this material ages, even with added stabilizers, it slowly darkens and forms insoluble polymeric impurities. The general shelf-life of unopened containers is less than six months.

All commercially-available material is of synthetic origin as natural material produced from mustard seed would cost in excess of \$100/lb to produce. About 95% of the world consumption is for flavors with only about 5% being used in negative perfumery or repelling notes.

Natural Sources

Allyl isothiocyanate is found in a great number of plants humans consume as vegetables. The most common are members of the species *Brassica*, which includes broccoli, brussels sprouts, cabbage, cauliflower, collards, kale, mustard, rutabaga and turnips. It has also been identified in garlic, horseradish and onions. Allyl isothiocyanate is only one of a series of isothiocyanates found in nature in a broad range of plants, including seeds, roots and foliage, as a glycoside,^{4,5} which must be hydrolyzed by an enzyme in order to release it in active form.

Its most potential commercial source is black or brown mustard seed (*Brassica nigra* L. Koch) in which it is found at 0.5 to 1% of the seed weight. However, little, if any of this oil is produced from the seeds, despite the fact that 600 million tons of brown mustard seed are produced annually at a price of 26 cents/lb. Thus, about \$115 worth of mustard seeds would produce about 1 kg of pure natural oil of mustard which is 98% isothiocyanate. Instead, synthetic oil of mustard is compounded to make it appear as natural in most of the cases of commercially available material. Only a few stray imports out of India indicate that some natural oil is being produced. The US standards of identity for mayonnaise alone have helped create this need for natural mustard oil as mayonnaise made with the cheaper synthetic oil of mustard would have to be labeled "imitation mayonnaise." Thus, synthetic products relabeled "natural" often command a \$20-30/lb. premium over synthetic material without the "natural" label.

Of all the isothiocyanates found in nature, allyl isothiocyanate is the only one found on the FEMA/GRAS list. The following analogous materials have been identified in nature.^{5,7} Among them the phenylethyl derivative finds some use in perfumery. Table I lists the natural sources for the isothiocyanate analogous materials.

History

The human consumption of natural allyl isothiocyanate goes back into our dawn of history in the form of dietary use of plants containing the material. In particular, mustard seed's use is conspicuous even in early writings of the

Table I. Natural sources of isothiocyanates

Isothiocyanate	Found in
methyl	<i>Cleome Spinosa</i>
ethyl	<i>Lepidium Menzieli</i>
t-butyl	<i>Putranjiva Roburghii</i>
i-butanyl-4	rape seed
isophenyl	horseradish
benzyl	garden cress, <i>Nasturtium</i>
p-hydroxy benzyl	white mustard
phenyl ethyl	water cress
3-indoyl methyl	Brassica species
2-hydroxy-3-butenyl	Brassica species
n-methoxy-3-indoylmethyl	Brassica species

Greeks as early as 530 B.C.⁶ The name mustard (used in most Latin-based languages) results from the Latin "must" (expressed juice of grape) and the word "ardens" or hot and the Roman custom of mixing ground mustard seed with acid grape juices. Mustard seed became the world's second most consumed spice after pepper and was so common by the 1500s that California padres used the seed to mark their trails from mission to mission. Even today, some of these mustard trails are still visible. In medieval northern Europe, mustard seed was called senapium, leading to the botanical term *Sinapis* for the plant and the names Senape (Italian), Senf (German), and Senap (Swedish) used today for the plant and seed.

The chemical investigation and synthesis of isothiocyanates began more than a century ago.⁸ Workers in this field quickly discovered that the sharp, pungent principles in plants containing isothiocyanate groupings fell in two classes: volatile (recoverable via steam distillation) and nonvolatile. However, most synthetic commercial routes for the production of allyl isothiocyanate were not developed until after 1940, most likely due to the lack of commercial availability of the key raw material, allyl chloride, which was first commercialized by Shell Chemical in the late 1940s. Today, Shell remains the sole world source of this material.

In the 1950s, Norda and Fritzsche produced allyl isothiocyanate in the US, but ceased production in the 1970s due to odor pollution problems and more competitive pricing from European and Japanese sources. Moreover, allyl chloride is a fairly toxic material and a carcinogen, so its use and the generation of the allyl isothiocyanate (itself an irritant) demands very tight production facilities, to say the least. These problems and the relatively low volume of global sales have tended to concentrate the manufacture of this product in a few hands.

Current Producers

Worldwide allyl isothiocyanate is currently being produced by only a few firms, which include H&R, Takasago, Quest and Sluys. Production is accomplished by the reaction of allyl chloride with potassium or ammonium thiocyanate (also known as rhodanide salts) in aqueous media. The relatively insoluble allyl isothiocyanate is steam dis-

Table II. Estimated world consumption of allyl isothiocyanate

	Natural*	Synthetic
North America	92,000 kg	24,000 kg
All of Europe, including eastern areas	248,000	25,000
Japan	42,000	20,000
Other	73,000	10,000
Total	455,000	79,000

*via direct plant materials

tilled away from the reaction media as it forms. Then it is collected, separated from the water and fractionated to yield a pure synthetic oil of mustard free of allyl chloride.

Supply

At current levels of world consumption, no supply problems are foreseen as most manufacturers have excess capacity and consumption growth is estimated at about 3% per annum. The use of mustard seed and its large volume of production and consumption fill a large consumer need in the natural product area that prevents the expansion of synthetic mustard oil in the food industry.

World Consumption

Table II shows the estimated world consumption for allyl isothiocyanate from both natural sources and synthetic product. The predominance of the large natural consumption via plant material is noteworthy, as almost none is consumed via the isolated oil. About 5% of US and European consumption is realized outside the flavor industry.

Pricing

Current pricing of synthetic allyl isothiocyanate is in the

area of \$11/lb while "natural" oil of mustard is selling for \$20-40/lb. Prices have risen in the last few years due to exchange rate fluctuations and more stringent international and local shipping and packaging regulations.

Imports

All US commercially available material is imported and falls under the TSUS harmonized tariff category of 2930.90.40, with a duty of 3.9% ad valorem.

Substitutes and Analogues

The general group of alkyl and aryl isothiocyanates examined to date all show a strong family organoleptic similarity in both volatile and nonvolatile materials. However, as only one appears on the FEMA/GRAS list (allyl isothiocyanate), their organoleptic nuances currently remain only of academic interest. In fragrances, phenylethyl isothiocyanate is produced by Hercules-PFW and is characterized by a pungent horseradish odor. It is found in various "Reseda" specialties used in minor amounts in fragrance compositions.

References

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