Ethylene

Processing

Identification

Chemical Names ethylene
Other Names: ethene, elayl, olefiant gas

CAS Numbers: 74-85-1
Other Codes: DOT #: UN 1962/UN 1938

Characterization

Composition C_2H_4 (CH_2=CH_2)

Properties:
A colorless, flammable gas with a slightly sweet odor, soluble in water.

How Made:
Made from hydrocarbon feedstocks, such as natural gas liquids or crude oil. Produced almost exclusively from the pyrolysis of hydrocarbons in tubular reactor coils installed in externally fired heaters. These heaters are operated at high temperatures (750-900°C), short residence times (0.1-0.6s), and low hydrocarbon partial pressure. Steam is added.

Ethylene may also be produced from ethanol in fixed or fluid-bed reaction systems. This means it could be made from biomass fermentation, but that is not currently done in the U.S. The amount of heat necessary for this process would still result in what may be considered a "synthetic" material.

Ethylene is given off naturally by ripening fruit and by some micro-organisms. These sources of ethylene have never been harnessed commercially.

Specific Uses:
Ripening and coloring fruit, including bananas, pears, mangoes, tomatoes and citrus. Fruit ripening applications may either be made in the field or after harvest for different crops. Induces flowering in pineapples when applied in the field. Can be used to improve growth and appearance of bean sprouts.

Action:
Ethylene is known as a plant hormone that triggers the ripening of fruit and generally promotes plant senescence in plant tissues. While the mode of action is not entirely understood, there are a number of theories that offer possible explanations. Ethylene biosynthesis from L-methionine is completely described in Rennema (1992). In general the gas is produced in fruit when physiological maturity is reached and the gas triggers the chemical changes which take place at ripening. In pineapple, the gas is generated at vegetative maturity of the plant which triggers the flowering and fruiting cycle.

Recent evidence indicates that ethylene gas acts to stimulate cyanide-resistance respiration in plant tissue. Additionally, the concentration of ethylene required to initiate fruit ripening declines as the fruit approaches full development of growth (Rennema, 1992). Additionally ethylene acts on both climacteric (apple, apricot, avocado, banana, feijoa, mango, papaya, passion fruit, peach, pear, plum, tomato and watermelon) and non-climacteric (blueberry, cherry, cucumber, fig, grape, grapefruit, lemon, melon, olive, orange, pineapple, strawberry and tamarillo) (Rennema, 1992).

Combinations:
One of the more commonly used forms is the ethylene generating chemical, (2-chloroethyl) phosphonic acid, known as ethephon. This is mostly used for pre-harvest applications with the only post-harvest one being the degreening of lemons in Florida (Sherman, 1985). "Banana gas" is pure ethylene gas in a compressed cylinder which is diluted with an inert gas, usually nitrogen.

Status

OFPA

In processing this would be considered a processing aid. For crop use it could be considered a production aid but is not specifically mentioned in any of the exempt categories in 6517(1)(B)(i).

Regulatory

Ethylene is regarded legally as a pesticide for regulatory purposes. It must be registered with the EPA and appropriate state agencies.

Status among Certifiers

Allowed for use on bananas only. (NOSB recommendation, OMRI list)

Historic Use

Allowed for use on bananas by many organic certifiers and state programs. Some certifiers have certified tropical fruit drying facilities that use ethylene for mango ripening.

International

IFOAM - not mentioned. CODEX - not mentioned specifically.

OFPA 2119(m) Criteria

(1) The potential of such substances for detrimental chemical interactions with other materials used in organic farming systems. As this is a processing material, the substance is not used in organic farming systems.

(2) The toxicity and mode of action of the substance and of its breakdown products or any contaminants, and their persistence and areas of concentration in the environment. See processor criteria 3 below.

(3) The probability of environmental contamination during manufacture, use, misuse or disposal of such substance. This is considered below under item (2).

(4) The effect of the substance on human health. This is considered in the context of the effect on nutrition (3) below as well as the and the consideration of GRAS and residues (5) below.

(5) The effects of the substance on biological and chemical interactions in the agroecosystem, including the physiological effects of the substance on soil organisms (including the salt index and solubility of the soil), crops and livestock. As this is not released into the agroecosystem, there is no direct effect.

(6) The alternatives to using the substance in terms of practices or other available materials. See discussion of alternatives in (1) below.

(7) Its compatibility with a system of sustainable agriculture. This is considered more specifically below in the context of organic handling in (6) below.

NOSB Processing Criteria

A SYNTHETIC PROCESSING AID OR ADJUVANT may be used if;

1. An equivalent substance cannot be produced from a natural source and has no substitutes that are organic ingredients.
   Natural ripening alternatives: temperature control, mix with apples for natural ethylene generation. Calcium carbide used to form acetylene is used to ripen fruit in some countries. See discussion for details.

2. Its manufacture, use and disposal does not contaminate the environment.
   Ethylene or olefin plants require extensive support facilities to comply with environmental regulations. These include boiler feed water preparation, treatment of noxious effluents, and steam and electric generation.

3. If the nutritional quality of the food is maintained and the material itself or its breakdown products do not have any adverse effect on human health.
   Significant precautions must be followed to ensure that handling of ethylene gas does not result in human injury, either by explosion or over-exposure. (Far greater risks exist in the actual ethylene factory than in the ripening room.) Naturally-emitted ethylene generally does not exist in high enough concentrations to warrant these considerations. Tanks of compressed gas must always be treated with care, regardless of the source. Ethylene is highly flammable and explosive. Exposure to gas causes dizziness and could cause suffocation from decreasing the amount of oxygen. The effect of ethylene application to fruits post-harvest does not indicate conclusively negative effects on the nutritive value of the product. Further research is warranted in this area, to further analyze the effects on constituent nutrients in fruits which are ripened naturally versus those treated with supplemental ethylene, be it from a natural or synthetic source.

4. Is not a preservative or used only to recreate/improve flavors, colors, textures, or nutritive value lost during processing except in the latter case as required by law.
   Ethylene application is not a preservative treatment. There is nothing to indicate that synthetic and naturally-occurring ethylene are anything but exactly the same in molecular structure or action (combination products obviously notwithstanding). Furthermore, so far as is known, the ethylene emitted by one type of ripening fruit is the same as that from other ripening fruits. For the time being, it may therefore be safe to conclude that ethylene in and of itself does not pose concerns regarding negative impact on human nutrition.

5. Is Generally Recognized as Safe (GRAS) by FDA when used in accordance with Good Manufacturing Practices (GMP), and contains no residues of heavy metals or other contaminants in excess of the tolerances established by FDA.
   It is not on the GRAS list because it is regulated by the EPA instead of the FDA. It does not have any residues because it goes off as a gas into the air.

6. Is compatible with the principles of organic handling.
   See the discussion section below for comments on the compatibility of ethylene with organic handling.

7. There is no other way to produce a similar product without its use and it is used in the minimum quantity required to achieve the process.
   Fruit will ripen without using ethylene gas. It does not ripen evenly and this necessitates more handling in the form of sorting. It is used at the minimum concentration necessary to get a consistent reponse.

Discussion

History

The first use of natural ethylene in fruit ripening was described in the Bible. The prophet Amos was described as a "gasher and gatherer" of figs. Gashing figs was known to promote stress ethylene production mimicking the action of the wasps when they exit pollinated fruits, and this triggered ripening. Also in ancient times the Chinese placed weighted lids on growing bean sprouts to promote hypocotyl thickening and crispness (Abeles, 1992). Ethylene was used unknowingly to ripen bananas in both East Africa and Samoa by burying them in fire-warmed pits, thus using residual ethylene from the smoke of the fire as the ripening agent.

In more recent times it was discovered that warming citrus fruit with kerosene heaters in closed spaces caused a degreening effect that wasn't just due to the heat (Denny, 1924). In the 1920's it was shown that the cause of this ripening effect was ethylene gas, which fortunately was already being produced commercially for other purposes (Chace, 1934). In the 1930's it was verified that ethylene was indeed produced by plants and that this gas was the same composition as that given off by the kerosene heaters (Abeles, 1992). In the years following this, researchers determined that ethylene produced a variety of effects in plants and it could be classified as a plant hormone, or more correctly, a plant growth regulator.

Concern was voiced early on in the commercial exploitation of ethylene about the residual effects of ethylene treatment; that it would be used to allow inferior fruit to be sold at a higher price. Researchers then showed that the ethylene treated fruit were equivalent in quality and "healthfulness" to naturally ripened fruit (Chace, 1934). This is largely because the fruit must have reached its physiological green maturity stage in order to respond to external ethylene, and then the ripening changes triggered by ethylene are essentially the same between the treated and naturally ripened fruit. These changes include starch and sugar content, acidity and concentration of pectic substances (Clendennen, 1997). There have been no consistent studies indicating any difference in flavor between bananas ripened with or without ethylene (Scriven et al., 1989; Watada, 1986).

Environmental Concerns

The main safety concern in relation to ethylene use has been due to the explosive nature of the gas in the air. This is of primary concern in design and operation of ethylene application facilities. Both the EPA, local fire marshal rules, and insurance companies have very specific labelling and registration requirements for the ethylene itself and the process used to apply it, down to the electirical wiring and piping used in ripening rooms. Note that the gas is explosive in air at concentrations from 3.1% to 32% (31,000 to 320,000 ppm). The minimum explosive concentration (3.1%) exceeds the suggested ethylene concentrations for tomato ripening and citrus degreening respectively by 200 and 6200 times (Sherman, 1985). The "banana gas" and catalytic generator sources of ethylene are considered the safest because they are more easily monitored, but explosive accidents have happened in the past and operaors should be well trained and prepared (Sherman, 1985).

Another concern with ethylene is the issue of air pollution. The amount of ethylene given off from either manufacturing or ethylene treatment facilities is miniscule compared to the ethylene released into the air from hydrocarbon emissions from auto exhaust, petrochemical plants or even fires. There are no national air quality standards for ethylene levels, but there are some from the American Industrial Hygiene Association (Abeles, 1992). Ethylene is degraded in the atmosphere by UV light present in sunlight. Ethylene air pollution can reduce ozone pollution. It can however be present in strong enough concentration to produce phytotoxic effects.

Nutrition Effects

While the effects of ethylene on the ripening process have been studied well for both bananas and pineapple, there is no clear and consistent evidence that artificially ripened or induced fruit has any more or less nutritive value than naturally ripened fruit (Chace, 1934; Abeles, 1992; Clendennen, 1997). If anything, pineapple treated with ethylene had increased sugars, proteins, fruit acid and soluble solids, but lower fruit weight (Mwaule, 1985; Ahmed, 1987)

Specific Uses: Mango

The situation with mangoes is similar to that with bananas in several ways (Sarnataro, 1999). Mango trees ripen their fruit unevenly on the tree so generally whole trees are picked by hand at an average maturity time, resulting in a mixture of maturities of fruit. Ethylene treatment results in even ripening which cuts down the extensive fruit handling and sorting needed for untreated fruit when they are being cut for drying (Sarnataro, 1999). Fruits harvested at their physiologically mature and half-mature stages develop good quality characteristcs when treated. Immature fruit will not respond properly to ethylene and will not be useful for drying (Abeles, 1992).

The concentration used to treat bananas is generally about 100ppm for a 12 to 24 hour period. Mangoes generally would receive about the same treatment. It has been shown for bananas that only 1 ppm would be suficient to hasten ripening, but more is used to ensure treatment of fruits located in the center of the pallets, and to compensate for leakage from the treatment rooms (Watada, 1986).

The tropical fruit drying operations typically process bananas, mangos and/or papayas in the same facility and are currently allowed to use ethylene on the bananas but not the other fruits. From a certification point of view it has been very difficult to enforce the use of the gas for bananas only in these situations with just one annual inspection, and several certifiers have gone ahead and certified the use of ethylene on mangoes and papayas.

Conclusion

This is one of the more difficult subjects facing the NOSB in the National List process. Ethylene as used today is a synthetic analog of a natural gas produced by plants. There is precedent in the previous NOSB recommendations for the approval of analogs of natural materials such as magnesium sulfate, copper sulfate, hydrogen peroxide and ethylene for bananas. There is also precedent for materials being used as plant growth regulators being approved by the NOSB, such as natural gibberelic acid and possibly amino acids.

The basic argument in force here is that agriculture is inherently not the same as a natural system, but organic agriculture can be thought of as an augmented natural system. The augmentation takes the form of materials and practices designed to acheive agricultural production of crops in sufficient quality and quantity for human consumption while maintaining the ecosystem without adding chemicals that have a lasting degradative impact. Ethylene fits this argument in most respects.

On the other hand, this material is being used out of its strictly natural context and is being used as a plant growth regulator to potentially "trick" plants into doing something they may not be ready to do naturally. It is formed from a synthetic process which could have negative environmental impacts from its manufacture. It may be able to be made from a natural starting point at some time in the future if the economic pressure is applied for that to happen.

Condensed Reviewer Comments

None of the reviewers has a direct commercial or financial interest in ethylene. Reviewer 1 states his indirect interest below.

Reviewer 1
For bananas, the problem being dealt with is that a banana stalk does not ripen evenly. There can be up to a two week difference between the time the top of the stalk is ready to when the bottom is ready. For the home gardener this may work out quite conveniently. For the larger scale grower, this may lead to marketing problems. Retailers will only buy fruit with predicable ripening times and known shelf life.

D. Should it be added to National List of Allowed Synthetics?
a. Based on the rating of 8 (see appendix 1 "Criteria for Compatibility of Synthetic Materials in Organic Production") It should be allowed with restrictions to mitigate the dangers to the person applying the material and also the manufacture of the material. The restrictions may be worded as follows; All safety requirements during application must be strictly followed and purchases of materials should come from producers who are in compliance with EPA environmental regulations.

b. It should be allowed in all cases and be considered as a synthetic-safe material

B. What if any changes should be made
1. Should also be allowed in all other cases, including but not limited to, ripening mangos, pears, tomatoes and citrus; setting fruit for pineapple; improving growth in bean sprouts, drying operations and sanitation procedures.

2. Restrictions to mitigate its harmful effects, as mentioned above should be included in the changes
Personal commercial or financial interest in the material
I have no commercial or financial interest in ethylene. I have grown non commercial amounts of organic pineapple and have inspected farms that grow limited amounts of organic pineapple.

Reviewer 2
The fundamental question that should be asked: Is ethylene, produced from hydrocarbons, 100% pure? If it is, then it should be classified as an allowed synthetic. My reasoning is based on the fact that C2H4 produced from hydrocarbon is obviously synthetic. Its allowability should be based on how pure the gas is; therefore I would recommend that only 100% pure ethylene be classified as synthetic. Overall, the information provided on the NOSB database is reasonably accurate and I am in agreement with NOSB criteria for processing.

There does not appear to be an effective substitute or alternative for ethylene.

I feel that pure ethylene would be compatible with organic production and handling as an allowed synthetic and I recommend that it be added to the National List of Allowed Synthetics.

Regarding its present status, I do not agree with its classification as a processing aid. Technically, it is a plant hormone and acts on fruit by stimulation of biochemical pathways. Processing aids, on the other hand, do not modulate or regulate biochemical systems. Therefore, I recommend that it be classified as a plant hormone. EPA has put it into the pesticide classification simply for regulatory control at the state and federal level.

After reviewing all of the attached documents I would suggest that ethylene be allowed for bananas, pineapple, mango and dried fruit processing. I can not justify that ethylene be restricted to banana. I additionally was not able to find any documentation as to why ethylene is only allowed for banana ripening while all other fruit applications are not allowed. Biochemically, this does not make sense. Furthermore I would add as a proposed annotation that ethylene gas must be documented to be free from impurities during manufacturing and documented by gas chromatography analysis by the manufacturer. Addition of inert gas should be restricted to i.e. nitrogen produced only from oil free grades from a non-oil source (OMRI p. 40).

Reviewer 3
In and of itself, the role that ethylene plays in food production systems should not disqualify it from organic systems; it is the synthetic nature of the material which is too problematic too warrant approval. It is easy to imagine that strong arguments could be made which would support use of synthetic ethylene for a number of agricultural commodities. In all of these cases, the main reasoning is about increasing yields, decreasing labor, and providing the market with commodities which otherwise might be too expensive or rare. If this rationale were extended to other materials and other crops, there might be possibilities to introduce fruits into certain marketplaces which have never been there before, because they either ripened too slowly or too quickly, were too delicate, too small, grew too slowly, or were not worth transporting for any number of other reasons. Exemptions to the OFPA and NOSB criteria should be strongly discouraged in all cases.

Although it is not an easy decision to make, synthetic forms of ethylene should be prohibited for post-harvest treatment of all organic products. Naturally-generated forms should be allowed.

Reviewer 4
It is clear that ethylene treatment is necessary for commercial production of these commodities. It is not acceptable to expect growers to get inferior production and/or sort out fruit in order to go to market, which is their only option if ethylene treatment is not allowed. Growers should be able to compete with conventional production of these commodities and provide products that are acceptable to consumers. In addition, there is no viable organic pineapple or bean sprout production without its use as well.

My recommendation would be to list ethylene as an allowed synthetic for the production of bananas, tropical fruit and bean sprouts.

In addition, OMRI should recommend that a research program be undertaken to move the industry away from ethylene as an allowed synthetic analog material to one only produced by natural means. The article by Sherman (1985) states that ethylene from natural ripening fruit should be commercially viable. This is clearly the best option in the long term and the most compatible with organic production. Once this natural process has been proven to be commercially viable for each of the commodities, the synthetic analog would be removed from the Allowed Synthetics list.

This recommended course of events would allow development of organic commodity production with a clear path to a better alternative for the future.

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