

# Chemical Agents Used for Fruit Ripening and its impact on Human health: A Review

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## Abstract

This review critically examines the major chemical agents applied for ripening harvested fruits, focusing on their mechanisms, efficacy, health impacts and regulatory issues. Fruits like mangoes, bananas and papayas often undergo artificial ripening to meet market demand and reduce post-harvest losses. Key ripening agents include ethylene, calcium carbide (which releases acetylene), Carbon dioxide, Ethephon (2-chloroethylphosphonic acid) and other compounds which are used on post-harvest fruits. While some agents like ethylene and Ethephon are considered safe within regulated limits, others, especially calcium carbide, pose significant health risks due to toxic contaminants. The paper synthesizes information from scientific literature, regulatory reports and recent research to highlight both benefits and hazards associated with artificial ripening chemicals. The conclusion emphasizes safer ripening practices and regulatory compliance to protect consumer health.

**Keywords:** Chemical agents, fruit ripening, toxins, human health

## Introduction

Fruit ripening is a complex physiological process involving biochemical and molecular changes that alter texture, colour, aroma and taste. In climacteric fruits such as bananas, mangoes and papayas, ripening is regulated by the plant hormone ethylene, which accelerates enzymes that break down cell walls and convert starch to sugars. However, commercial pressures often lead producers and traders to use artificial chemical agents to hasten ripening after harvest (Nasir *et al.*, 2024). This review covers the commonly used ripening chemicals, their modes of action, associated risks and legislative aspects. Post-harvest diseases cause significant losses in fruits during storage, transportation and marketing. Conventional chemical fungicides, though effective, pose risks to human health, the environment and lead to resistant pathogen strains. Calcium carbide, commonly used due to its low cost, may contain arsenic and phosphorus hydride contaminants, posing significant toxicological risks when applied to fruits consumed by the public (Bhandare *et al.*, 2023). Ethephon, another widely used ripening chemical, decomposes to release ethylene but may leave chemical residues beyond safe limits if misused. Excessive use of these agents can cause premature softening, altered nutritional quality, reduced shelf-life and unsafe residue levels. Moreover, consumers are increasingly concerned about the adverse health effects associated with chemically ripened fruits, including gastrointestinal irritation, neurological symptoms and potential long-term toxicity (Silva *et al.*, 2022).

Understanding the scientific basis, application methods, regulatory framework and health implications of chemical ripening agents is essential for ensuring food safety and improving public awareness. This review paper sheds light on the commonly used chemical agents in fruit ripening, compares their effects with

natural ripening processes and puts forward the evaluated results that are associated with risks to human health. The study also highlights the need for safe alternatives, including controlled ethylene chambers and natural ripening methods, to promote consumer safety and maintain fruit quality.

## Natural vs. Artificial Ripening:

### Natural Ripening

Natural ripening is governed by endogenous ethylene production within fruits, which triggers metabolic shifts culminating in sensory traits desirable to consumers. This process generally occurs over several days and the timing is influenced by fruit maturity, temperature and storage conditions. The life of a fruit can be divided into three phases: fruit set, fruit development and fruit ripening. Fruit ripening is the initiation of fruit senescence, which is a genetically programmed, highly coordinated process of organ transformation from unripe to ripe stage to yield an attractive edible fruit (Perotti *et al.*, 2014). It is an irreversible phenomenon involving a series of biochemical, physiological and organoleptic changes (Joshi *et al.*, 2017).

**Table 1: Classification of fruits as climacteric and non-climacteric fruits (Bouzayen *et al.*, 2010)**

| Climacteric fruits | Non-climacteric fruits |
|--------------------|------------------------|
| Apple              | Cashew                 |
| Apricot            | Cherry                 |
| Avocado            | Strawberry             |
| Banana             | Grape                  |
| Blueberry          | Grapefruit             |
| Tomato             | Lemon                  |
| Guava              | Lime                   |
| Kiwifruit          | Litchi                 |
| Mango              | Mandarin               |
| Papaya             | Melon                  |
| Passion fruit      | Orange                 |
| Peach              | Pineapple              |
| Pear               | Pomegranate            |
| Persimmon          | Watermelon             |
| Plum               | Raspberry              |

### Artificial Ripening

Artificial ripening aims to shorten post-harvest ripening time by exposing fruits to external agents that mimic or stimulate ethylene responses. The involvement of ethylene in fruit ripening was initially reported a long time ago (Burg *et al.*, 1962). Common artificial agents include Ethylene gas, which is a plant hormone used industrially due to its direct role in ripening. Small concentrations initiate natural ripening pathways. Ethephon (2-chloroethylphosphonic acid) decomposes inside fruit to release ethylene under humid conditions and increases the rate of ripening (Moniruzzaman *et al.*, 2015). Calcium carbide ( $\text{CaC}_2$ ) reacts with moisture to produce acetylene gas, another gaseous compound with ethylene-like effects (Islam *et al.*, 2016). Due to its nature, commercial  $\text{CaC}_2$  is consistently found to contain impurities such as Arsenic

and other toxic and carcinogenic chemicals. Few studies have only reported acute associative effects of CaC<sub>2</sub>, whereas there is only sparse evidence of its chronic and long-term impact (Okeke *et al.*, 2022). Other organic agents like ethanol, ethylene glycol and propylene derivatives have been reported in the literature.

| Parameter                 | Natural Ripening                  | Artificial Ripening                                            |
|---------------------------|-----------------------------------|----------------------------------------------------------------|
| <b>Source of Ethylene</b> | Produced inside the Fruit         | External agents such as ethylene, ethephon and Calcium Carbide |
| <b>Process Speed</b>      | Slow and gradual                  | Rapid, accelerated to meet market demand                       |
| <b>Fruit Quality</b>      | Better flavour, aroma and texture | Sometimes uneven, depending on the agent used                  |
| <b>Chemical Residues</b>  | None                              | Calcium Carbide                                                |
| <b>Health Impact</b>      | Safe                              | Safe if ethylene-based, unsafe with calcium Carbide            |
| <b>Regulation</b>         | Not Regulated                     | Strict regulation on allowed chemicals                         |
| <b>Shelf Life</b>         | Relative Longer                   | May reduce shelf life if misused                               |
| <b>Colour Development</b> | Natural Pigmentation              | Sometimes artificial or Patchy                                 |

## Major Chemical Ripening Agents:

### Ethylene Gas

Ethylene is a naturally occurring plant hormone that serves as the primary biochemical trigger for ripening in climacteric fruits. When applied artificially, it accelerates the natural ripening process by activating genes involved in pigment synthesis, cell wall degradation and sugar production. Ethylene gas is widely accepted and recommended for commercial ripening due to its predictable effects and lower toxicity at regulated levels (Liu *et al.*, 2015). The main Advantages of ethylene gas are that it mimics the natural ripening mechanisms of fruits. It produces uniform and high-quality ripening, generally safe when used at controlled concentrations. Though it has limitations, like it requires specialized chambers for controlled application and can be costlier than some other alternatives present in the market (Siddiqui *et al.*, 2010). A Standard Operating Procedure (SOP) detailing all aspects of artificial ripening of fruits by ethylene gas has been developed by the Working Group constituted at FSSAI on the recommendation of the Scientific Panel on Fruits & Vegetables and their Products (*Guidance Note* No.04/2018)

### Ethephon

Ethephon is an ethylene-releasing compound applied as a spray or in treatment chambers. In the presence of moisture, ethephon breaks down to produce ethylene, facilitating ripening. Studies show it can provide better coloration and shelf life compared to some traditional agents but with safety protocols as it is considered safer than calcium carbide when applied correctly. It is also permitted by regulatory authorities in specific concentrations. Ethephon has the potential to cause severe skin and eye irritation (Toxicity Category I), but otherwise is moderately acutely toxic. An organophosphate pesticide, it has the potential

to cause cholinesterase inhibition. Ethephon is classified as a “Group D” carcinogen because there is insufficient weight of evidence regarding its cancer-causing potential. Inhalation of calcium carbide dust or fumes can cause respiratory irritation, coughing and shortness of breath. Prolonged exposure to calcium carbide can lead to chronic bronchitis, asthma and other respiratory disorders (Bhandare *et al.*, 2023). Ingestion of calcium carbide can be very dangerous and can cause serious health effects. Calcium carbide reacts with water to produce acetylene gas and calcium hydroxide, which can cause gastrointestinal irritation, vomiting, abdominal pain and even coma or death in severe cases. Contact with calcium carbide can cause skin irritation and chemical burns and exposure to the eyes can cause irritation, redness and vision problems. Prevention of calcium carbide exposure involves using appropriate protective measures, such as wearing gloves and a face mask when handling the chemical and avoiding inhalation or ingestion of calcium carbide. It is also important to properly store and handle calcium carbide and to seek medical attention immediately if exposure occurs (Bhandare *et al.*, 2023).

### Calcium Carbide and Acetylene

Calcium carbide is perhaps the most widely misused artificial ripening agent in developing countries due to its low cost and ready availability. When  $\text{CaC}_2$  reacts with moisture, it produces acetylene gas, which mimics ethylene's effect on fruit ripening (Mursalat *et al.*, 2016). Despite its effectiveness, calcium carbide is banned in many countries, including India, because agricultural-grade or industrial carbide often contains toxic impurities like arsenic and phosphorus, which pose significant health risks. Underdeveloped nations regularly use chemicals like calcium carbide ( $\text{CaC}_2$ ), ethylene glycol and ethephon to artificially initiate the ripening process (Food Safety and Standards).  $\text{CaC}_2$  and fruit moisture interact to create acetylene gas, an ethylene substitute that hastens fruit ripening. In most cases, when the fruit is artificially ripened, the external peel will be golden, but the interior tissue will either remain unripe or remain green and raw. The synthetic ripening agent ethylene releases ethylene in neutral to basic environments, frequently above pH 5, whereas ethephon produces an acidic solution in water. Consequently, a variety of health hazards have been associated with the incorrect use of these substances. Regular consumption of fruits that have been artificially ripened has been associated with heart conditions, light-headedness and skin ulcers (Igilebor *et al.*, 2023).

### Imazalil

In agriculture, fungicides are extensively used to preserve freshness, prevent decay and control fungal infections of fruits, vegetables and ornamental plants. The extensive use of fungicides, however, comes at a cost as fungicides can enter the body via inhalation, ingestion, or absorption and pose potential health risks to humans (Jin *et al.*, 2016).

Imazalil (IMZ; 1-[2-(2, 4-dichlorophenyl)-2-(2-propenyloxy) ethyl]-1*H*-imidazole; also known as enilconazole) is a highly effective, broad-spectrum fungicide widely used to prevent and treat fungal diseases in plants and animals (Sepulveda *et al.*, 2015). Alarming, several recent studies have demonstrated that IMZ can be detected in soil, vegetables, fruit, as well as fruit juice treated with this fungicide (Ruiz-Rodríguez *et al.*, 2015). Even though IMZ is currently classified as a compound with only medium toxicity, it can cause dermatitis and eczema if touched directly and endocrine and nervous system dysfunction if ingested in mice, rats and zebrafish (Tanaka, 1995; Jin *et al.*, 2016).

## Health Hazards

Impurities can cause dizziness, nausea, skin irritation and serious long-term effects such as neurological disruption. Failure of the kidneys to excrete excess bicarbonate is due to the presence of a mechanism that leads to the maintenance of metabolic alkalosis. The drop in glomerular filtration may explain the decrease in bicarbonate filtration (Sanches *et al.*, 2023).

Acetylene exposure can reduce oxygen supply to the brain, leading to hypoxia and central nervous system effects. Sub-chronic inhalation of crude acetylene induced metabolic dysfunction characterized by impaired glucose regulation, hepatic steatosis and oxidative stress; health risks associated with acetylene exposure need regulatory measures to limit its use in fruit ripening (Gitonga *et al.*, 2025). Artificial ripening agents vary in their impact on human health: Ethylene and ethephon are generally considered safer when used according to guidelines. Calcium carbide poses multiple hazards due to contaminants and improper application and its use has been prohibited under food safety laws in India since 2011. Other agents like ethylene glycol and ethanol are also reported, but may have toxicity at higher exposures.  $\text{CaC}_2$  irritates the oral and nasal mucosae, in addition to causing gastrointestinal discomfort<sup>1–3</sup>. Acetylene gas is soluble in water and can build up in fruits and affect the neurological system. The impurities found in  $\text{CaC}_2$ , such as traces of arsenic and phosphorus, can lead to acute irritation of the mouth and nose, vomiting, skin ulcers and even kidney damage (Okeke *et al.*, 2022). Sodium benzoate is a widely used food preservative that inhibits mold, yeast and bacteria in acidic food, extending shelf life by preventing spoilage and fermentation. Sodium benzoate affects the inhibition of neopterin production and tryptophan degradation (Maier *et al.*, 2010).

Tryptophan is a precursor for the biosynthesis of other crucial compounds. Thus, it can be speculated that an abnormal level of this amino acid results in the incorrect formation of direct and indirect products of its metabolism, including serotonin and melatonin (Mann *et al.*, 2001; Essa *et al.*, 2013).

The chronic exposure of p, p'-DDE and  $\beta$ -HCH could significantly alter the relative abundance and composition of gut microbiota in mice, increasing the relative abundances of *Firmicutes* and *Proteobacteria* and decreasing that of *Bacteroidetes*, *Verrucomicrobia*, *Actinobacteria*, *Candidatus* and *Saccharibacteria* (Zhou *et al.*, 2021). Organochloride pesticides (OCPs) can persistently accumulate in the body and threaten human health. Bile acids and intestinal microbial metabolism have emerged as important signalling molecules in the host; chronic exposure to OCPs could impair intestinal microbiota; as a result, hepatic and enteric bile acid profiles and metabolism were influenced. The findings in this study draw our attention to the hazards of chronic OCPs exposure in modulating bile acid metabolism that might cause metabolic disorder and their potential to cause related diseases in humans (Liu *et al.*, 2017).

## Regulatory Framework

Calcium Carbide should not be used for the ripening of fruit as this is punishable under PFA–1955, Rule no 44-AA (Pandit, 2011). Governments and food safety authorities have established regulations to prevent harmful practices. India's Food Safety and Standards Authority of India (FSSAI) prohibits the use of calcium carbide for ripening and recommends ethylene-based methods within specific concentration limits. Penalties and inspections are enacted to enforce compliance and ensure public health protection. As per Food Safety and Standards Regulations, 2011, 2.3.5 of Food Safety and Standards Regulations (Prohibition and Restriction on sales) Regulations, 2011: Prohibition of use of carbide gas in ripening of fruits: No person shall sell or offer or expose for sale or have in his premises for the purpose of sale under

any description, fruits which have been artificially ripened by use of acetylene gas, commonly known as carbide gas (FSSAI 2018).

## Discussion

The choice of ripening agent affects fruit quality, safety and marketability. While ethylene and Ethephon offer controlled and relatively safe ripening, misuse or deviation from recommended protocols can still have adverse effects. Calcium carbide remains a challenge due to ongoing illegal use, particularly in informal markets, despite known health risks and legislative bans. As artificial fruit ripening using calcium carbide poses a greater threat to human health, most of the SAARC countries have banned the use of calcium carbide as an artificial fruit ripening agent. Recent research also explores alternative compounds and technological solutions, such as modified atmosphere storage and ripening chambers that enhance bio-control and reduce the hazards and toxicity of harsh chemicals. In the study, which involved 357 consumers and 20 fruit sellers, with a majority being females (54.9% of consumers; 80.0% of sellers) and aged predominantly between 18–27 years and 28–39 years. The findings revealed that the use of (50%)  $\text{CaC}_2$  and natural ripening methods (100%) were common among fruit sellers. Sellers cited cancer (60%), bacterial infections (35%) and chest tightness (15%) as associated risks with  $\text{CaC}_2$  usage. Similarly, consumers expressed concerns about consuming ripened  $\text{CaC}_2$  fruits, attributing risks such as abdominal burns (70%), cancer (70.6%) and diarrhoea (67.3%). A significant proportion of sellers (90%) exhibited poor knowledge regarding the risks associated with  $\text{CaC}_2$ , while 24.6% of consumers demonstrated fair knowledge on the subject (Orko *et al.*, 2014).

## Conclusion

Artificial ripening is a critical practice in modern horticulture, facilitating timely market supply and reducing post-harvest losses. However, the chemical agents used must balance effectiveness with consumer safety. Ethylene and Ethephon remain preferred options due to their alignment with natural ripening pathways and regulatory acceptance when properly used. In contrast, calcium carbide, although inexpensive and effective, presents significant health risks due to toxic residues and should not be used. Stricter enforcement of food safety laws, public awareness and adoption of safer ripening technologies are necessary to ensure that fruit quality and consumer health are not compromised. Numerous investigations have also found that SB has remarkable therapeutic potential via a variety of pathways, including for neurodegenerative illnesses. However, because it is widely found in food, the total dose consumed by patients cannot be totally regulated, necessitating the development of methods to detect the quantity of the substance used in food preparation. Anyway, as a general conclusion, it could be concluded that the recruitment of sodium benzoate (SB) with any dose may not cause toxic effects. However, it should be used in minimal doses. Analytical methods may help us measure and determine the amount of this dose (Leila *et al.*, 2024).

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