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Harmful Effects of Calcium Carbide-Ripened Fruits on Human Health: A Comprehensive Review

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ABSTRACT

Artificial ripening of fruits has become a common practice in many developing countries to satisfy the increasing market demand and reduce post-harvest losses. Among various artificial ripening agents, calcium carbide (CaC_2) has been widely used because of its low cost, easy availability, and rapid ripening ability. When calcium carbide comes into contact with moisture, it produces acetylene gas, which acts similarly to ethylene by accelerating the ripening process. However, commercial calcium carbide often contains hazardous impurities such as arsenic and phosphine, making its use a serious public health concern. Consumption of calcium carbide-ripened fruits has been associated with several adverse health effects, including irritation of the oral cavity, gastrointestinal disorders, respiratory complications, neurological symptoms, hepatic and renal dysfunction, reproductive toxicity, and potential carcinogenic risks. In addition to its direct effects on consumers, calcium carbide also adversely affects the nutritional quality, flavor, texture, aroma, and shelf life of fruits. Due to these health hazards, the use of calcium carbide for artificial fruit ripening has been prohibited in many countries, including India under the Food Safety and Standards Authority of India (FSSAI). Safer alternatives such as controlled ethylene ripening have been recommended for commercial fruit production. This review summarizes the chemistry of calcium carbide, mechanisms of artificial fruit ripening, toxicological effects on human health, impact on fruit quality, detection methods, current regulations, and safer alternatives. The review also highlights existing knowledge gaps and future research directions for improving food safety and protecting public health.

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1. INTRODUCTION

Fruits constitute an essential component of the human diet because they provide vitamins, minerals, dietary fiber, antioxidants, and numerous bioactive phytochemicals that contribute to disease prevention and overall health. Regular consumption of fresh fruits has been associated with a reduced risk of cardiovascular diseases, diabetes mellitus, obesity, hypertension, and several forms of cancer (World Health Organization [WHO], 2020). However, increasing urbanization, population growth, globalization of food markets, and rising consumer demand have encouraged the use of artificial fruit-ripening techniques to accelerate the marketing process and minimize post-harvest losses.

Ripening is a complex physiological and biochemical process involving changes in color, texture, aroma, sweetness, acidity, and nutritional composition. Naturally, ripening is regulated by the plant hormone ethylene, which initiates enzymatic reactions responsible for starch degradation, chlorophyll breakdown, pigment synthesis, cell wall softening, and volatile compound formation (Giovannoni, 2004). In commercial fruit production, controlled ethylene treatment is widely accepted as a safe and effective method for inducing uniform ripening. However, because of economic constraints and inadequate regulatory enforcement, many fruit vendors in developing countries continue to use calcium carbide as an inexpensive ripening agent (Mursalat et al., 2013).

Calcium carbide (CaC_2) is an industrial chemical primarily used in welding and metallurgical industries. When calcium carbide comes into contact with water, it undergoes hydrolysis to produce acetylene gas (C_2H_2), which acts as an ethylene analogue and stimulates fruit ripening. Although acetylene can trigger certain ripening responses, it is considerably less effective and less physiologically regulated than ethylene (Per et al., 2007). Moreover, commercially available calcium carbide is not food grade and frequently contains toxic contaminants such as arsenic and phosphorus compounds. During hydrolysis, these impurities may generate highly toxic gases, including arsine (AsH_3) and phosphine (PH_3), which pose significant health risks to consumers and handlers (Rahman et al., 2008).

The use of calcium carbide for artificial fruit ripening has become a major food safety concern in many Asian and African countries. Fruits commonly ripened with calcium carbide include mangoes, bananas, papayas, tomatoes, guavas, and sapotas. These fruits often exhibit an attractive external appearance while remaining internally immature, resulting in poor flavor development, reduced nutritional quality, and shortened shelf life (Mursalat et al., 2013). In addition to altering fruit quality, residues and toxic by-products associated with calcium carbide exposure have been implicated in a variety of adverse health effects.

Several experimental and epidemiological studies have reported that calcium carbide-ripened fruits may cause irritation of the mouth and gastrointestinal tract, abdominal pain, vomiting, diarrhea, dizziness, headache, respiratory distress, skin irritation, neurological disturbances, and long-term toxic effects on the liver and kidneys (Siddiqui & Dhua, 2010). Chronic exposure to arsenic and phosphine contaminants may also increase oxidative stress, DNA damage, endocrine disruption, and carcinogenic risk (Agency for Toxic Substances and Disease Registry [ATSDR], 2007). Children, pregnant women, older adults, and individuals with chronic illnesses may be particularly susceptible to these adverse effects because of their increased physiological vulnerability.

Recognizing these hazards, several national and international regulatory agencies have prohibited the use of calcium carbide for fruit ripening. In India, the Food Safety and Standards Authority of India (FSSAI) has banned the use of calcium carbide under the Food Safety and Standards Regulations, permitting only ethylene gas within prescribed safety limits for commercial ripening. Similar restrictions have been adopted in many other countries to safeguard public health and ensure food safety (FSSAI, 2018).

Despite regulatory measures, illegal use of calcium carbide continues because of inadequate enforcement, lack of awareness among vendors, and economic incentives. Public education, routine market surveillance, improved detection techniques, and adoption of safer ripening technologies are therefore essential to reduce consumer exposure and improve food safety.

The objective of the present review is to comprehensively examine the harmful effects of calcium carbide-ripened fruits on human health. Particular emphasis is placed on the chemistry of calcium carbide, mechanisms of toxicity, health consequences, effects on fruit quality, regulatory policies, detection methods, and safer alternatives for artificial fruit ripening.

2. Chemistry of Calcium Carbide

Calcium carbide (CaC_2) is a grayish-black crystalline compound produced industrially by heating calcium oxide (quicklime) with coke at temperatures above 2,000°C in an electric arc furnace. The principal industrial use of calcium carbide is the production of acetylene gas for welding, metal cutting, and chemical synthesis (Greenwood & Earnshaw, 2012).

The chemical reaction responsible for acetylene production is:

$$\mathbf{CaC_2 + 2H_2O \rightarrow C_2H_2 + Ca(OH)_2}$$

When calcium carbide comes into contact with atmospheric moisture or water, acetylene gas is rapidly released. Acetylene acts as an analogue of ethylene by stimulating certain biochemical pathways involved in fruit ripening. However, acetylene is considerably less efficient than ethylene and does not regulate ripening in the same controlled manner. Consequently, fruits ripened with calcium carbide often develop uneven coloration, inferior texture, reduced sweetness, and incomplete maturation (Per et al., 2007).

Commercial calcium carbide is manufactured for industrial applications rather than food use. As a result, it commonly contains impurities such as arsenic, phosphorus, sulfur compounds, and heavy metals. During hydrolysis, arsenic impurities may produce arsine gas, while phosphorus compounds generate phosphine gas. Both gases are highly toxic and have been associated with hematological, neurological, respiratory, hepatic, and renal toxicity in humans (ATSDR, 2007).

These toxic contaminants represent one of the major reasons why calcium carbide is considered unsuitable and unsafe for artificial fruit ripening.

3. Artificial Fruit Ripening Using Calcium Carbide

Artificial fruit ripening with calcium carbide is usually performed by placing small packets of calcium carbide in fruit storage rooms or transport containers. Moisture present in the environment reacts with the chemical to release acetylene gas, which accumulates around the fruits and accelerates ripening. The process generally produces marketable coloration within 24–48 hours, enabling rapid commercial distribution (Mursalat et al., 2013).

Although this method is inexpensive and convenient, it has several disadvantages. Fruits ripened with calcium carbide frequently exhibit rapid external color development while remaining physiologically immature internally. Such fruits often possess poor flavor, reduced aroma, lower vitamin content, uneven texture, and decreased shelf life. Furthermore, direct contact between calcium carbide and fruits may leave chemical residues on the fruit surface, increasing the risk of consumer exposure.

Several studies have demonstrated that calcium carbide-ripened fruits contain lower concentrations of vitamin C, reduced antioxidant capacity, and altered sugar metabolism compared with naturally ripened or ethylene-ripened fruits (Siddiqui & Dhua, 2010). These quality defects reduce both the nutritional value and consumer acceptability of artificially ripened fruits.

4. Mechanism of Toxicity of Calcium Carbide-Ripened Fruits

The adverse health effects associated with calcium carbide-ripened fruits primarily arise from toxic impurities present in commercial calcium carbide rather than from acetylene gas itself. Industrial-grade calcium carbide is manufactured for metallurgical and welding purposes and is not intended for food applications. During its production, impurities such as arsenic, phosphorus, sulfur compounds, and traces of heavy metals may remain in the final product. When calcium carbide comes into contact with moisture, it generates acetylene gas together with highly toxic by-products such as arsine (AsH_3) and phosphine (PH_3), both of which are recognized for their harmful effects on human health (Agency for Toxic Substances and Disease Registry [ATSDR], 2007; Food Safety and Standards Authority of India [FSSAI], 2018).

Although acetylene can stimulate certain ripening processes, it is much less effective than the natural plant hormone ethylene. Consequently, fruits exposed to acetylene often undergo incomplete physiological ripening, resulting in poor nutritional quality and uneven maturation. In addition, prolonged exposure to arsenic and phosphine residues may contribute to cumulative toxic effects in humans.

4.1. Toxic Components Associated with Calcium Carbide

Commercial calcium carbide contains several hazardous contaminants that may adversely affect consumers.

Table 1. Toxic Constituents of Commercial Calcium Carbide

Toxic constituent	Source	Major health effects
Arsenic compounds	Manufacturing impurity	Carcinogenicity, liver damage, kidney damage, neurological toxicity
Phosphorus compounds	Manufacturing impurity	Formation of phosphine gas, respiratory toxicity
Phosphine (PH_3)	Produced during hydrolysis	Pulmonary edema, cardiovascular toxicity, oxidative stress
Arsine (AsH_3)	Produced during hydrolysis	Hemolysis, renal failure, neurological disorders
Heavy metals (trace levels)	Industrial contamination	Chronic toxicity and organ damage

These contaminants are responsible for most of the health concerns associated with calcium carbide-ripened fruits rather than the ripening process itself.

4.2. Production of Acetylene Gas

The ripening action of calcium carbide depends upon the production of acetylene gas through hydrolysis.

Chemical Reaction

$$CaC_2 + 2H_2O \rightarrow C_2H_2 + Ca(OH)_2$$

Acetylene gas acts as an ethylene analogue by stimulating several enzymes involved in fruit ripening. However, because acetylene has lower biological activity than ethylene, it cannot precisely regulate the complex physiological pathways involved in natural ripening (Giovannoni, 2004).

As a result, calcium carbide-ripened fruits frequently exhibit:
- Uneven color development
- Reduced sweetness
- Poor aroma
- Hard internal tissues
- Reduced nutritional value
- Shortened shelf life

4.3. Oxidative Stress
Oxidative stress is considered one of the principal mechanisms responsible for calcium carbide toxicity.

Exposure to arsenic and phosphine increases the production of reactive oxygen species (ROS), including:
- Superoxide anion ($O_2^{\bullet-}$)
- Hydroxyl radical ($\bullet OH$)
- Hydrogen peroxide (H_2O_2)

Under normal physiological conditions, antioxidant enzymes such as:
- Superoxide dismutase (SOD)
- Catalase (CAT)
- Glutathione peroxidase (GPx)

neutralize excessive free radicals.

However, chronic exposure to toxic contaminants overwhelms the antioxidant defense system, leading to oxidative stress (Halliwell & Gutteridge, 2015).

Oxidative stress causes:
- Lipid peroxidation
- Protein oxidation
- DNA damage
- Mitochondrial dysfunction
- Cellular apoptosis

These cellular events contribute to tissue injury in multiple organs, including the liver, kidneys, nervous system, lungs, and reproductive organs.

Figure 1. Mechanism of Calcium Carbide Toxicity

Industrial Calcium Carbide
↓
Hydrolysis with Moisture
↓
Acetylene + Arsine + Phosphine
↓
Reactive Oxygen Species (ROS)
↓
Oxidative Stress
↓
DNA Damage + Lipid Peroxidation + Protein Oxidation
↓
Cell Injury
↓
Human Disease

4.4. Cellular Toxicity
Reactive oxygen species attack cellular membranes by initiating lipid peroxidation.

Lipid peroxidation causes:
- Membrane instability
- Loss of membrane fluidity
- Increased membrane permeability
- Cell death

Proteins are also oxidized, leading to:
- Enzyme inactivation
- Structural protein damage
- Impaired cellular metabolism

Oxidative modification of DNA may produce:
- Single-strand breaks
- Double-strand breaks
- Base modification
- Chromosomal abnormalities

Persistent DNA damage has been associated with increased cancer risk (IARC, 2012).

4.5. Mechanism of Arsenic Toxicity
Arsenic is one of the most hazardous contaminants found in commercial calcium carbide.

Following ingestion:
Arsenic is rapidly absorbed through the gastrointestinal tract and distributed throughout the body.

It accumulates primarily in:
- Liver
- Kidney
- Skin
- Hair
- Nails

Arsenic interferes with cellular respiration by inhibiting mitochondrial enzymes involved in ATP production.

Consequently:
- Energy production decreases.
- Free radical generation increases.
- Cellular apoptosis occurs.

Long-term arsenic exposure has been associated with:
- Skin cancer
- Lung cancer
- Liver cancer
- Bladder cancer
- Peripheral neuropathy
- Cardiovascular disease

(IARC, 2012)

4.6. Mechanism of Phosphine Toxicity
Phosphine gas is another toxic by-product released from impure calcium carbide.

Phosphine enters the body primarily through inhalation but may also contaminate fruits during artificial ripening.

The toxic effects include:
- Inhibition of mitochondrial respiration
- Reduction in ATP synthesis
- Increased oxidative stress
- Damage to pulmonary tissues

Clinical manifestations include:
- Chest pain
- Difficulty breathing
- Pulmonary edema
- Hypotension
- Cardiac arrhythmia

Severe poisoning may result in multiple organ failure (ATSDR, 2007).

4.7. Effect on the Gastrointestinal Tract

Consumption of calcium carbide-ripened fruits may irritate the digestive system.

Common symptoms include:
- Burning sensation in mouth
- Sore throat
- Nausea
- Vomiting
- Abdominal pain
- Diarrhea

These symptoms result from chemical irritation produced by toxic contaminants and residual calcium carbide particles.

4.8. Effect on Liver

The liver is one of the primary target organs for arsenic toxicity.

Oxidative stress damages hepatocytes leading to:
- Increased ALT
- Increased AST
- Increased ALP
- Fatty degeneration
- Hepatic inflammation

Experimental studies have shown that chronic arsenic exposure alters hepatic antioxidant enzymes and promotes lipid peroxidation (WHO, 2020).

4.9. Effect on Kidney

The kidneys eliminate arsenic and other toxic metabolites from the body.

Prolonged exposure may result in:
- Reduced glomerular filtration
- Tubular degeneration
- Increased serum creatinine
- Increased blood urea nitrogen
- Renal oxidative stress

These alterations may eventually progress to chronic kidney disease.

4.10. Effect on the Nervous System

Arsenic readily crosses the blood–brain barrier and affects neuronal function.

Reported neurological manifestations include:
- Headache
- Dizziness
- Memory impairment
- Peripheral neuropathy
- Reduced concentration
- Muscle weakness

Experimental studies indicate that oxidative stress and mitochondrial dysfunction contribute significantly to arsenic-induced neurotoxicity (ATSDR, 2007).

4.11. Effect on the Immune System

Oxidative stress produced by toxic contaminants suppresses immune function by:
- Reducing lymphocyte proliferation
- Altering cytokine production
- Impairing macrophage activity

Consequently, chronic exposure may reduce resistance to infectious diseases.

4.12. Effect on the Endocrine System

Several studies suggest that arsenic acts as an endocrine disruptor.

Possible effects include:
- Altered thyroid hormone metabolism
- Impaired insulin signaling
- Reproductive hormone imbalance

These endocrine disturbances may contribute to metabolic disorders and impaired reproductive health.

4.13. Summary of Toxic Mechanisms

Table 2. Organ-wise Toxic Effects

Organ	Major toxic mechanism	Clinical outcome
Liver	Oxidative stress	Hepatic injury
Kidney	Tubular damage	Renal dysfunction
Brain	Neuronal oxidative stress	Neurotoxicity
Lung	Phosphine toxicity	Respiratory distress
Blood	Hemolysis	Anemia
Skin	Arsenic accumulation	Hyperkeratosis, pigmentation changes
Gastrointestinal tract	Chemical irritation	Nausea, vomiting, diarrhea

The toxicity associated with calcium carbide-ripened fruits is largely attributable to impurities such as arsenic and phosphine rather than acetylene itself. These contaminants induce oxidative stress, disrupt mitochondrial function, damage DNA and cellular proteins, and impair the normal function of multiple organs. The cumulative evidence supports the prohibition of industrial-grade calcium carbide for fruit ripening and underscores the need for safer alternatives.

5. Harmful Effects of Calcium Carbide-Ripened Fruits on Human Health

The consumption of fruits artificially ripened with calcium carbide has emerged as an important public health concern, particularly in developing countries where the chemical is still used illegally despite regulatory restrictions. The health hazards are mainly associated with impurities such as arsenic and phosphorus present in industrial-grade calcium carbide rather than acetylene itself. Continuous exposure to these toxic substances through contaminated fruits may adversely affect several organ systems, including the gastrointestinal tract, nervous system, respiratory system, cardiovascular system, liver, kidneys, endocrine organs, and reproductive system (WHO, 2020; FSSAI, 2018).

The severity of toxic effects depends upon several factors, including the amount of contaminated fruit consumed, duration of exposure, age, nutritional status, and underlying health conditions. Children, pregnant women, older adults, and immunocompromised individuals are particularly vulnerable because of their increased physiological sensitivity to toxic contaminants (ATSDR, 2007).

5.1. Acute Toxic Effects

Acute exposure generally occurs following the consumption of freshly ripened fruits containing residues of calcium carbide or its toxic by-products. Clinical manifestations may appear within a few hours after ingestion.

The most frequently reported symptoms include:
- Burning sensation in the mouth and throat
- Excessive salivation
- Nausea
- Vomiting
- Abdominal pain
- Diarrhea
- Dizziness
- Headache
- Generalized weakness

These symptoms are primarily attributed to the irritant effects of phosphine and arsenic impurities on the gastrointestinal mucosa and nervous system (Siddiqui & Dhua, 2010).

In severe cases, dehydration resulting from persistent vomiting and diarrhea may require hospitalization.

5.2. Gastrointestinal Toxicity

The gastrointestinal tract is the first organ system exposed to toxic contaminants present in calcium carbide-ripened fruits. Industrial-grade calcium carbide contains alkaline residues and impurities that can irritate the oral cavity, esophagus, stomach, and intestines.

Common gastrointestinal symptoms include:
- Oral ulceration
- Burning sensation
- Gastritis
- Loss of appetite
- Indigestion
- Abdominal cramps
- Loose stools

Long-term exposure may alter the integrity of the intestinal mucosa, resulting in impaired nutrient absorption and increased oxidative damage to gastrointestinal tissues (Rahman et al., 2008).

Table 3. Gastrointestinal Effects of Calcium Carbide-Ripened Fruits

Toxic contaminant	Target organ	Clinical manifestations
Calcium carbide residues	Oral cavity	Burning sensation, ulcers
Phosphine	Stomach	Gastritis, nausea
Arsenic	Intestine	Diarrhea, abdominal pain
Heavy metals	Digestive tract	Chronic irritation, poor digestion

5.3. Neurological Effects
The nervous system is particularly susceptible to arsenic toxicity because arsenic readily crosses the blood–brain barrier and interferes with neuronal metabolism. Chronic exposure has been associated with oxidative stress, mitochondrial dysfunction, altered neurotransmitter synthesis, and neuronal degeneration (ATSDR, 2007).

Neurological manifestations include:
- Persistent headache
- Dizziness
- Fatigue
- Irritability
- Difficulty concentrating
- Memory impairment
- Peripheral neuropathy
- Tingling sensation in hands and feet
- Muscle weakness

Experimental studies have demonstrated that arsenic-induced oxidative stress damages neuronal cell membranes, resulting in impaired cognitive function and neurobehavioral abnormalities (Flora, 2011).

5.4. Respiratory Effects
During handling of calcium carbide, phosphine and acetylene gases may be released into the surrounding atmosphere. Occupational exposure among fruit handlers and vendors may therefore produce respiratory toxicity.

Reported respiratory symptoms include:
- Persistent cough
- Chest tightness
- Breathlessness
- Wheezing
- Sore throat
- Pulmonary irritation

High-level phosphine exposure may cause:
- Pulmonary edema
- Acute respiratory distress syndrome (ARDS)
- Respiratory failure

Although consumers are generally exposed to much lower concentrations than workers handling calcium carbide, repeated exposure to contaminated fruits may still contribute to cumulative toxic effects.

5.5. Hepatic Toxicity
The liver plays a major role in detoxifying toxic chemicals absorbed from the gastrointestinal tract. Arsenic and phosphine increase oxidative stress within hepatocytes, leading to lipid peroxidation, mitochondrial dysfunction, and inflammatory changes.

Experimental studies have demonstrated:
- Increased serum ALT
- Increased AST
- Increased alkaline phosphatase
- Fatty degeneration
- Hepatic necrosis

Histopathological examinations have revealed degeneration of hepatic cells following chronic arsenic exposure (WHO, 2020).

5.6. Renal Toxicity
The kidneys are responsible for eliminating arsenic metabolites from the body and are therefore highly susceptible to toxic injury.

Reported renal effects include:
- Increased serum creatinine
- Elevated blood urea nitrogen
- Tubular degeneration
- Reduced glomerular filtration rate
- Oxidative stress in renal tissue

Persistent renal injury may progress to chronic kidney disease if exposure continues over prolonged periods (ATSDR, 2007).

5.7. Cardiovascular Effects
Emerging evidence suggests that chronic arsenic exposure is associated with cardiovascular disorders.

Potential cardiovascular effects include:
- Hypertension
- Endothelial dysfunction
- Cardiac arrhythmias
- Increased oxidative stress
- Reduced vascular elasticity
- Increased risk of ischemic heart disease

Oxidative damage to vascular endothelial cells is believed to contribute to these pathological changes (Flora, 2011).

5.8. Reproductive Toxicity
Several experimental studies indicate that chronic arsenic exposure may adversely affect male and female reproductive systems.

In Males

Reported effects include:
- Reduced sperm count
- Decreased sperm motility
- Increased abnormal sperm morphology
- Oxidative damage to testicular tissue
- Reduced testosterone synthesis

In Females

Reported reproductive effects include:
- Menstrual irregularities
- Hormonal imbalance
- Impaired ovarian function
- Reduced fertility

Oxidative stress and endocrine disruption are considered major mechanisms responsible for reproductive toxicity (Agarwal et al., 2022).

Table 4. Reproductive Effects of Calcium Carbide Contaminants

Reproductive parameter	Reported effect
Sperm count	Decreased
Sperm motility	Reduced
Testicular oxidative stress	Increased
Testosterone	May decrease with chronic exposure
Female fertility	May be adversely affected
Hormonal balance	Disrupted

5.9. Effects on Pregnant Women

Pregnant women are considered a high-risk population because toxic contaminants may cross the placenta and affect fetal development.

Potential adverse outcomes include:
- Increased oxidative stress
- Impaired placental function
- Reduced fetal growth
- Developmental abnormalities
- Increased risk of adverse pregnancy outcomes

Although direct evidence from calcium carbide-ripened fruits is limited, the known toxicity of arsenic exposure during pregnancy supports precautionary measures (WHO, 2020).

5.10. Effects on Children

Children are particularly vulnerable because:
- Their detoxification systems are immature.
- They consume relatively larger amounts of fruit per unit body weight.
- Developing organs are more sensitive to toxic chemicals.

Potential health effects include:
- Gastrointestinal disorders
- Reduced cognitive development
- Learning difficulties
- Behavioral abnormalities
- Impaired immune function

Public health agencies therefore recommend minimizing children's exposure to artificially ripened fruits.

5.11. Carcinogenic Potential

One of the greatest concerns associated with commercial calcium carbide is contamination with arsenic.

The **International Agency for Research on Cancer (IARC)** classifies inorganic arsenic compounds as **Group 1 carcinogens**, indicating sufficient evidence of carcinogenicity in humans (IARC, 2012).

Chronic arsenic exposure has been associated with increased risk of:
- Skin cancer
- Lung cancer
- Bladder cancer
- Liver cancer
- Kidney cancer

Carcinogenesis is believed to involve:
- Oxidative DNA damage
- Chromosomal instability
- Epigenetic alterations
- Impaired DNA repair mechanisms

Although consumption of calcium carbide-ripened fruits alone has not been conclusively shown to cause cancer, repeated exposure to arsenic-contaminated foods may contribute to cumulative cancer risk.

Table 5. Organ System and Major Toxic Effects

Organ System	Major Toxic Effects
Gastrointestinal	Nausea, vomiting, diarrhea, abdominal pain
Nervous	Headache, dizziness, neuropathy
Respiratory	Cough, breathlessness, pulmonary irritation
Liver	Hepatic inflammation, oxidative damage
Kidney	Renal dysfunction, tubular degeneration
Cardiovascular	Hypertension, endothelial dysfunction
Reproductive	Reduced fertility, endocrine disruption
Immune	Decreased immune response
Skin	Hyperpigmentation, keratosis (chronic arsenic exposure)

Consumption of calcium carbide-ripened fruits may expose individuals to toxic contaminants, particularly arsenic and phosphine, which can adversely affect multiple organ systems. Acute exposure may produce gastrointestinal and neurological symptoms, whereas chronic exposure has been linked to hepatic, renal, cardiovascular, reproductive, and potentially carcinogenic effects. These findings reinforce the importance of enforcing food safety regulations, promoting public awareness, and replacing calcium carbide with safer ripening technologies.

6. Effect of Calcium Carbide on Fruit Quality and Nutritional Composition

Fruit ripening is a highly coordinated physiological process involving biochemical, structural, and molecular changes that determine the final quality characteristics of fruits. Naturally ripened fruits develop desirable characteristics such as appropriate color, aroma, flavor, sweetness, nutritional composition, and texture through regulated enzymatic processes controlled mainly by ethylene. However, artificial ripening using calcium carbide disrupts these natural processes and often produces fruits with inferior nutritional and sensory qualities (Giovannoni, 2004).

Although calcium carbide accelerates external ripening characteristics, it does not allow complete physiological maturation. As a result, calcium carbide-treated fruits may appear attractive externally but remain nutritionally inferior internally. The imbalance between external appearance and internal maturity is one of the major concerns associated with artificial ripening practices (Siddiqui & Dhua, 2010).

6.1. Effect on Carbohydrate Metabolism and Sugar Content

During natural fruit ripening, complex carbohydrates such as starch are gradually converted into simple sugars including glucose, fructose, and sucrose. This process increases sweetness and improves consumer acceptability.

Ethylene regulates enzymes involved in carbohydrate metabolism, including:

- Amylase
- Invertase
- Sucrose synthase

However, acetylene released from calcium carbide does not regulate these pathways as effectively as natural ethylene. Consequently, calcium carbide-ripened fruits may show:

- Lower sugar accumulation
- Reduced sweetness
- Poor flavor development
- Incomplete starch degradation

Studies have reported that artificially ripened fruits may exhibit altered sugar profiles compared with naturally ripened fruits (Mursalat et al., 2013).

6.2. Reduction in Vitamin Content

Fruits are important dietary sources of vitamins, especially vitamin C (ascorbic acid), vitamin A precursors, and several antioxidant compounds.

Artificial ripening with calcium carbide may negatively affect vitamin composition because incomplete biochemical maturation reduces the synthesis and accumulation of important nutrients.

Reported changes include:

- Decreased vitamin C concentration
- Reduced antioxidant capacity

- Lower carotenoid accumulation
- Altered phenolic compound content

Vitamin C is highly sensitive to oxidative degradation; therefore, increased oxidative stress during artificial ripening may accelerate nutrient loss (Lee & Kader, 2000).

6.3. Effect on Antioxidant Compounds

Natural fruit ripening involves accumulation of antioxidant compounds such as:

- Phenolics
- Flavonoids
- Anthocyanins
- Carotenoids

These compounds protect plant tissues against oxidative damage and provide health benefits to consumers.

Calcium carbide-induced ripening may disturb antioxidant metabolism, resulting in:

- Reduced phenolic content
- Decreased radical scavenging activity
- Lower antioxidant potential

Reduced antioxidant capacity decreases the nutritional value of fruits and may reduce their protective effects against oxidative stress-related diseases.

Table 6. Nutritional Changes Associated with Calcium Carbide Ripening

Nutritional component	Effect of calcium carbide ripening
Vitamin C	Decreased
Total phenolics	Reduced
Flavonoids	Reduced
Antioxidant activity	Decreased
Natural sugars	Altered
Carotenoids	Irregular accumulation
Mineral content	May be affected

6.4. Effect on Fruit Color Development

Color development is one of the most visible indicators of fruit ripening.
During natural ripening:

- Chlorophyll degradation occurs.
- Carotenoids and anthocyanins accumulate.
- Fruit develops characteristic color.

Calcium carbide causes rapid external color development, but the process may not correspond with internal biochemical maturity.

Common observations include:

- Bright yellow appearance
- Uneven coloration
- Green patches internally
- Poor taste despite attractive appearance

This phenomenon creates a false perception of quality among consumers.

6.5. Effect on Aroma and Flavor

Fruit aroma results from the production of volatile organic compounds such as:

- Esters
- Alcohols
- Aldehydes
- Terpenoids

These compounds are synthesized during natural ripening through ethylene-regulated pathways.

Calcium carbide-induced ripening may reduce the formation of these volatile compounds, leading to:

- Weak aroma

- Poor flavor
- Reduced consumer acceptance

Although fruits may become soft and colored, they often lack the characteristic smell and taste of naturally ripened fruits.

6.6. Effect on Texture and Firmness

Fruit softening occurs through enzymatic breakdown of cell wall components.
Important enzymes involved include:

- Polygalacturonase
- Pectin methylesterase
- Cellulase

Artificial ripening may cause abnormal softening because these enzymes are not activated in a controlled physiological manner.

Consequences include:

- Uneven texture
- Excessive softness
- Reduced firmness
- Shorter storage life

Such fruits deteriorate faster during transportation and storage.

6.7. Effect on Shelf Life

Calcium carbide-ripened fruits generally have reduced shelf life compared with naturally ripened fruits.

Reasons include:

- Incomplete maturation
- Increased microbial susceptibility
- Excessive moisture loss
- Abnormal tissue softening

Reduced shelf life results in:

- Increased food wastage
- Economic losses
- Greater risk of microbial contamination

6.8. Comparison Between Natural, Ethylene-Ripened, and Calcium Carbide-Ripened Fruits

Table 7. Comparison of Different Ripening Methods

Parameter	Natural ripening	Ethylene ripening	Calcium carbide ripening
Ripening hormone	Natural ethylene	Controlled ethylene	Acetylene
Safety	Safe	Safe when regulated	Unsafe
Nutritional quality	Highest	Comparable to natural	Reduced
Color development	Uniform	Uniform	Often uneven
Flavor	Normal	Good	Poor
Shelf life	Longer	Moderate	Shorter
Toxic risk	None	Minimal	High

6.9. Microbial Safety Concerns

Calcium carbide-treated fruits may also create conditions favorable for microbial contamination.

Factors contributing to microbial risk include:

- High moisture content
- Rapid softening
- Surface chemical residues
- Improper storage conditions

Contaminated fruits may support growth of:

- Bacteria
- Yeasts
- Fungi

Consumption of contaminated fruits may result in foodborne illnesses.

7. Detection Methods for Calcium Carbide-Ripened Fruits

Detection of artificially ripened fruits is important for consumer protection and regulatory enforcement. Several physical, chemical, and instrumental methods have been developed.

7.1. Physical Indicators

Common signs of calcium carbide-ripened fruits include:
- Unnatural bright color
- Uneven ripening
- Lack of typical aroma
- Hard interior despite soft outer skin
- Short shelf life
- Excessive softness

However, visual detection alone is unreliable because external appearance can be similar to naturally ripened fruits.

7.2. Chemical Detection Methods

7.2.1. Silver Nitrate Test

Silver nitrate reacts with arsenic compounds to produce detectable changes, allowing identification of arsenic contamination.

7.2.2. Phosphine Detection

Specialized gas detection methods can identify phosphine released from calcium carbide impurities.

7.2.3. Spectroscopic Methods

Advanced techniques include:
- Atomic Absorption Spectroscopy (AAS)
- Inductively Coupled Plasma Mass Spectrometry (ICP-MS)
- Gas Chromatography (GC)

These methods provide accurate detection of toxic residues.

Table 8. Methods for Detection of Calcium Carbide Exposure

Method	Principle	Application
Visual examination	Physical changes	Preliminary screening
Silver nitrate test	Arsenic detection	Chemical confirmation
Gas chromatography	Gas analysis	Laboratory detection
AAS	Heavy metal estimation	Arsenic measurement
ICP-MS	Elemental analysis	Highly sensitive detection

7.3. Modern Biosensor-Based Detection

Recent research has focused on developing rapid detection systems using:
- Nanotechnology-based sensors
- Electrochemical sensors
- Biosensors

These methods offer advantages such as:
- Rapid analysis
- High sensitivity
- Field applicability

Future development of portable detection devices may improve food safety monitoring.

Calcium carbide not only creates health risks through toxic contaminants but also negatively affects the nutritional and sensory quality of fruits. Artificially ripened fruits may show attractive external appearance while possessing reduced vitamin content, lower antioxidant capacity, poor flavor, and decreased shelf life. Development of reliable detection methods and strict regulatory monitoring are essential to prevent consumer exposure.

8. Regulatory Status of Calcium Carbide Use in Fruit Ripening

The use of calcium carbide for artificial fruit ripening has become a major food safety issue worldwide because of its potential health hazards. Due to the presence of toxic impurities such as arsenic and phosphorus compounds, many countries have prohibited or strictly restricted its use in food processing. Regulatory agencies have emphasized the adoption of scientifically approved ripening technologies, particularly controlled ethylene application, as safer alternatives.

8.1. Regulation by Food Safety and Standards Authority of India (FSSAI)

In India, the use of calcium carbide for artificial ripening of fruits is prohibited under the **Food Safety and Standards Regulations**. The Food Safety and Standards Authority of India (FSSAI) has specifically banned calcium carbide because industrial-grade calcium carbide may contain toxic impurities capable of causing serious health hazards.

According to FSSAI guidelines:
- Calcium carbide shall not be used directly or indirectly for fruit ripening.
- Only food-grade ethylene gas within prescribed limits is permitted for artificial ripening.
- Food business operators must follow safe ripening practices to protect consumers.

The ban applies particularly to fruits commonly subjected to artificial ripening, including:
- Mango
- Banana
- Papaya
- Sapota
- Guava
- Tomato

(FSSAI, 2018)

Despite regulatory restrictions, illegal use continues in some regions due to:
- Lack of awareness among vendors
- Economic benefits
- Inadequate monitoring
- Consumer demand for early-season fruits

Therefore, effective enforcement and public awareness programs remain essential.

8.2. International Regulations

Several international organizations have recommended avoiding the use of calcium carbide for food ripening.

World Health Organization (WHO)

The WHO emphasizes that food safety systems should prevent exposure to chemical contaminants and recommends strict control of toxic substances entering the food chain.

Arsenic contamination is considered a major global food safety concern because chronic exposure is associated with:
- Cancer
- Cardiovascular disease
- Neurological disorders
- Developmental problems

(WHO, 2020)

8.3. Food and Agriculture Organization (FAO)

The Food and Agriculture Organization (FAO) promotes safe post-harvest handling technologies and recommends the use of approved ripening agents that do not compromise consumer health.

FAO emphasizes:
- Good agricultural practices
- Safe storage conditions
- Proper post-harvest management
- Reduction of chemical contamination

(FAO, 2019)

Table 9. International Position on Calcium Carbide Use

Organization/Country	Regulatory position
India (FSSAI)	Calcium carbide prohibited for fruit ripening
WHO	Recommends control of chemical contaminants
FAO	Supports safe post-harvest technologies
European Union	Restricts unsafe chemical food treatments
United States	Calcium carbide not approved as a fruit-ripening agent

9. Safer Alternatives to Calcium Carbide for Fruit Ripening

Because calcium carbide poses significant health risks, researchers and regulatory agencies recommend safer alternatives for commercial fruit ripening.

The most scientifically accepted alternative is **ethylene-based ripening technology**.

9.1. Ethylene-Based Ripening

Ethylene (C_2H_4) is a naturally occurring plant hormone responsible for fruit maturation. It regulates:
- Chlorophyll degradation
- Pigment formation
- Sugar accumulation
- Aroma production
- Texture modification

Controlled application of ethylene allows fruits to ripen uniformly while maintaining nutritional quality.

Advantages of ethylene ripening include:
- Safe for consumers
- Natural biological mechanism
- Better flavor development
- Improved texture
- Longer shelf life

(Giovannoni, 2004)

9.2. Ethylene Ripening Chambers

Modern fruit industries use controlled ripening chambers where:
- Temperature is regulated
- Humidity is maintained
- Ethylene concentration is controlled
- Ripening occurs uniformly

These chambers minimize chemical contamination and improve fruit quality.

9.3. Other Natural Ripening Methods

Traditional methods such as storage with naturally ethylene-producing fruits are also practiced.

Examples include:
- Banana with mature fruits
- Mango storage with ripe bananas
- Controlled straw storage methods

However, these methods require careful management to avoid microbial spoilage.

9.4. Biological and Herbal Ripening Approaches

Recent research has explored environmentally friendly alternatives, including:
- Plant-derived ethylene sources
- Microbial biocatalysts
- Natural ripening enhancers

These approaches aim to provide sustainable solutions without chemical hazards.

Table 10. Comparison of Ripening Technologies

Feature	Calcium carbide	Ethylene	Natural ripening
Safety	Unsafe	Safe under regulation	Safe
Mechanism	Acetylene release	Natural hormone pathway	Natural process
Nutritional quality	Reduced	Maintained	Highest
Toxic residue risk	High	Minimal	None
Commercial suitability	Not recommended	Recommended	Limited

10. Public Health Strategies for Prevention

Reducing exposure to calcium carbide-ripened fruits requires coordinated action involving government agencies, food industries, vendors, and consumers.

10.1. Consumer Awareness

Consumers should be educated about:
- Risks associated with artificially ripened fruits
- Identification of suspicious fruits
- Importance of washing fruits before consumption
- Preference for naturally ripened seasonal fruits

10.2. Strengthening Food Monitoring Systems

Authorities should implement:
- Regular market inspections
- Random chemical testing
- Strict penalties for illegal use
- Certification systems for safe fruit supply chains

10.3. Training of Fruit Vendors

Many vendors use calcium carbide because of economic reasons and lack of awareness.

Training programs should focus on:
- Health risks
- Legal consequences
- Safe alternatives
- Proper storage techniques

11. Conclusion

Calcium carbide-induced artificial fruit ripening represents a significant food safety challenge, particularly in developing countries where illegal use continues despite regulatory restrictions. Although calcium carbide accelerates external fruit maturation through acetylene production, it does not replicate the natural physiological ripening process and may significantly reduce fruit quality.

More importantly, industrial-grade calcium carbide contains toxic impurities such as arsenic and phosphorus compounds that can generate harmful substances including arsine and phosphine. Continuous exposure to these contaminants may contribute to gastrointestinal disorders, neurological impairment, respiratory problems, liver and kidney damage, reproductive dysfunction, and increased carcinogenic risk.

The evidence reviewed in this article emphasizes that calcium carbide should not be used for fruit ripening. Adoption of safer alternatives, especially controlled ethylene technology, provides an effective and scientifically supported solution. Strengthened regulatory enforcement, improved detection systems, vendor education, and consumer awareness are essential steps toward ensuring food safety and protecting public health.

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