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Review Article

A Review of Post-Harvest Ripening Techniques and Their Correlation with Fruit Quality

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A B S T R A C T

This paper reviews different fruit ripening methods and how they affect fruit quality and consumer health. Calcium carbide is a commonly used ripening agent in developing coun- tries. It speeds up ripening but leads to nutrient loss, shorter shelf life, and higher levels of heavy metals and toxic residues. Natural ripening maintains moisture, organic acids, minerals, and sensory quality but takes more time and does not meet the requirements of the fruit supply chain. There are certain biological agents such as African bush mango fruits and Jatropha curcas leaves that provide safer options by maintaining higher nutrient levels and less contamination. Traditional smoke-based methods cause fast ripening but add polycyclic aromatic hydrocarbons and lead to uneven ripening. Ethylene treatment is the only globally accepted safe artificial ripening method as it achieves even ripening with significant nutritional retention. Ethephon assisted with vacuum speed up ripening but might lower vitamins and carotenoids. Other agents like potash, ethylene glycol, lauryl alcohol, propylene, and methyl jasmonate vary in safety and effectiveness. Overall, artificial methods speed up ripening but often reduce nutritional value and safety which highlights the need for regulating the process of artificial ripening.

Keywords: Post-Harvest Ripening, Fruit Quality, Post-Harvest Technology, Ripening Techniques

Introduction

Fruits play a vital role in human nutrition. They are rich sources of dietary fibre, antioxidants, vitamins, and minerals. Eating fruits regularly promotes physical and mental well- being and helps in preventing chronic health issues such as heart disease, obesity, and diabetes. Ripening is a complex process that involves significant biochemical and physiological changes. The full nutritional and sensory value of a fruit in- cluding aroma, colour, texture etc. emerges once it is ripened. For climacteric fruits like mango, banana, papaya, sapota (chikoo) etc. ripening continues even after harvest. The natural ripening of climacteric fruits is a process driven by a plant hormone called ”ethylene” (C_2H_4). Ethylene starts a series of enzyme reactions that lead to the transition of fruit from an unripe state to one ready for consumption. Key changes include the breakdown of chlorophyll pigments, which reveals underlying carotenoids such as xanthophylls and carotenes. Consequently, we observe noticeable shifts in fruit colour and reflectance properties (relevant for spectroscopy). At the same time, complex carbohydrates, mainly starch, are broken down into simpler sugars like sucrose, glucose, and fructose. This increases the fruit's sweetness and overall flavor. Enzymes like pectinases and cellulases alter the cell wall structures, causing the fruit to soften and lose firmness. This natural process is generally uniform, resulting in consistent colour, texture and chemical profile.

In fruit supply chains, the natural ripening process often conflicts with logistical needs. To extend shelf life, reduce damage, and enable long-distance transport, climacteric fruits are usually picked when they are still unripe, firm, and green. This creates a need for post-harvest ripening to make fruits ready to eat as they are sold. Natural ripening occurs slowly and is often uneven for different fruits, while market demands call for speed and uniformity of ripening for fruits in a batch. As a result, artificial ripening methods are commonly used.

In India, industrial-grade calcium carbide (CaC_2) is widely used for artificial ripening. Calcium carbide reacts with mois- ture to produce acetylene (C_2H_2) gas, which mimics ethylene and triggers the ripening process prematurely. However, this method does not completely ripen the fruit. While the break- down of chlorophyll occurs, conversion of starch to sugar is often incomplete, leaving the fruit starchy, acidic, and lacking in the desired flavour and aroma.

Apart from that, the process of ripening fruits with calcium carbide leaves behind residues of arsenic, phosphorus and other harmful heavy metals including Fe, Co, Hg, Pb etc., that accumulate in the fruit. This leads to health risks for people handling and consuming the fruit. Acute effects range from headaches to digestive issues, while chronic exposure can lead to neurological disorders and even cancer. (Hong et al.; Richard et al.)[1,2]

Indian law bans the use of calcium carbide for ripening under the Prevention of Food Adulteration Act, 1955 and the Food Safety and Standards Regulations Act, 2011. Further, to meet the need for controlled post-harvest ripening, the Food Safety and Standards Authority of India (FSSAI) allows the use of ethylene gas at low concentrations (up to 100 ppm), typically applied through ethephon (2-chloroethylphosphonic acid), for fruit ripening. Ethephon enables internal ethylene generation, triggering the natural ripening processes; ensuring uniform maturity without toxic residues, as in the case of CaC_2. Despite the legal restrictions, calcium carbide is still used for ripening fruits because of its low cost, effectiveness, and availability.

Methods Used for Ripening of Fruits

The postharvest ripening of fruits can be achieved through various methods that manipulate exposure to ethylene (C_2H_4) or its analogues to induce biochemical changes. Natural ripen- ing relies on the production of ethylene by the fruit itself at controlled temperature and humidity, while chemical methods, such as using ethephon sachets or calcium carbide in powder form, any some other agents to accelerate ripening. These methods vary in their mechanisms, time frames, safety, and suitability for commercial or experimental purposes.

Calcium Carbide Based Ripening

Calcium Carbide(CaC_2) is industrially produced by burning lime(CaO) and coke(C) at a temperature of around 2000 °C in an electrical furnace, and trace elements such as arsenic (As) and Phosphorus (P), are usually present as impurities in both, coke and lime.

$$CaO + 3C \rightarrow- CaC_2 + CO \quad (1)$$

During the heating process in the electric furnace, arsenic traces combine with calcium to form calcium arsenide(Ca_3As_2), while phosphorus impurities form calcium phosphide. (Ca_3P_2). These impurities become even more dan- gerous when calcium carbide comes in contact with moisture, as toxic gases Arsine(AsH_3) and Phosphine(PH_3) are released; both of which are carcinogenic to human beings. (Ekanem et al. 2021).[3]

When calcium Carbide (CaC_2) comes in contact with mois- ture present in the air, it releases acetylene(C_2H_2), which accelerates fruit ripening by mimicing the effects of ethylene.

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

There are different methods to ripen fruits using Calcium Carbide, like in Sogo-Temi et al. (2014)[4] method involves wrapping calcium carbide in polythene and placing it with the bananas. This method causes the fastest ripening turning the bananas fully yellow by the third day. However, it leads to the lowest protein content at 1.77%, reducing the protein value to less than 50% of its original level. Additionally, it produces the highest ash content at 2.75% and a moisture content of 70.25%. Method discussed in Hussain et al. (2024)[5] involves placing sachets of industrial-grade calcium carbide at concentrations of 1 g, 5 g, and 10 g per kilogram of fruit at the bottom of containers to ripen the mangoes. Using calcium carbide at 10 g/kg speeds up ripening to just 2 days but cuts the shelf life to only 3 days. This treatment leads to a major decrease in moisture, fiber, and protein content while increasing the ash and carbohydrate content. It also causes a significant loss of organic acids, including ascorbic, citric, and malic acids, along with minerals. In Maduwanthi and Marapana (2021),[6] bananas are exposed to 1000 ppm of acetylene gas produced from calcium carbide for 24 hours. It results in high pectin content making the flesh extra soft, increase in tannin levels, reduction of moisture content and total sugar content. Also there is nearly 40% drop in total carotenoids in the peel. While in Adeyemi et al. (2018)[7] calcium carbide is used in concentrations of 1 g/kg, 5 g/kg, and 10 g/kg to speed up ripening. The chemical is wrapped in paper, placed

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at the bottom of a container and moistened with water to release acetylene gas. Calcium carbide speeds up the ripening process, achieving full ripening in just 2 days (48 hours) for mangoes, bananas, and pawpaws at the 10 g/kg concentration but this reduced ripening time also reduces shelf life. In terms of nutritional content, there is decrease in moisture, Vitamin C, protein, and carbohydrates. On the other hand, it increases ash, fiber, and lipids in the fruits.

The acetylene produced from CaC_2 comprises of phosphine and arsenic up to 95 and 3 ppm, respectively. (et al. Siddiqui and Dhua, 2010; Maduwanthi and Marapana, 2019)[8,9] This acetylene ripens the fruits but arsenic and phosphorus residues will accumulate in the fruits along with other harmful heavy metals like lead (Pb), cadmium (Cd), Iron (Fe), mer- cury (Hg) etc. Consuming arsenic is linked to serious health problems,[1] including higher chances of various cancers (skin, lung, liver, bladder), skin lesions, heart disease, nerve disorders, kidney damage, and immune system issues. Acute arsenic poisoning can lead to stomach pain, weakness, trouble swallowing, numbness, low blood pressure, and can be deadly. Too much phosphorus can upset mineral balance, resulting in bone loss, kidney problems, and artery calcification.[2] Moreover, the acetylene gas produced during the ripening process acts as a nervous system depressant. Breathing it in can cause headaches, dizziness, mood changes, memory loss, and seizures. Workers handling calcium carbide are at risk too, facing possible respiratory issues, skin and eye irritation, or burns from direct contact. But even after the legal implication, and severe health risks involved; a survey conducted by Direc- torate of Marketing and Inspection (Ministry of Agriculture, Government of India) in 2016 showed that 99% of the fruits were ripened artificially by using CaC_2 of industrial origin.

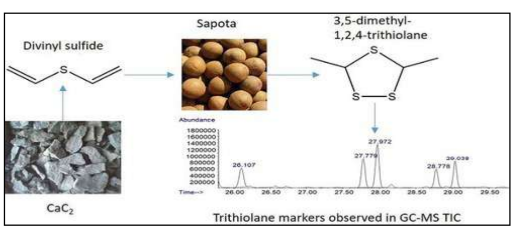

Figure 1. Trithiolane markers observed in sapota fruits using GC-MS. Source: Vemula et al.[10]

Ethylene Ripening

Ethylene treatment uses a natural plant hormone called ethylene to trigger fruit ripening. Its application is the only globally accepted safe method for ripening. This method drives the ripening process until the fruit starts producing its own ethylene (Hewajulige and Premaseela, 2020)[8] In a study by Maduwanthi and Marapana (2019),[11] bananas are placed in a controlled temperature and humidity condition inside a ripening chamber where catalytic generators are used to release the gas . A concentration of 100 ppm for 12 hours quickly increases carbon dioxide production as respiration rate increases and ethylene levels inside the fruits, are raised by the introduction of external ethylene that speeds up ripening. The treatment reduces fruit firmness by about eleven times within two days and affects cell wall hydrolase activity. According to findings from a study done by Hussain et al. (2024),[5] for commercial ripening of mangoes, ethylene is applied at concentrations of 100 µL, 500 µL, and 1000 µL per kilogram. At higher concentrations of ethylene (1500 µL/L), ripening in induced in 3 days having a shelf life of 5 days. Use of ethylene produces the highest levels of reducing sugars and carbohydrates in mangos, the shelf life and moisture content in ethylene ripened mangoes is higher than carbide ripened and lower then naturally ripened mangoes, although organic acids are reduced compared to natural ripening. Ethylene provides uniform color development calcium carbide, but negatively affects the taste and aroma as compared to natural ripening. Research also shows that naturally ripened bananas have a different sucrose and polyphenol content as compared to treated samples, also they have a higher total aromatic concentration (Maduwanthi and Marapana, 2019).[11] Since ethylene is a natural hormone found in fruits, it has no health risks to consumers. However, careful handling is required in commercial chambers because it is highly explosive at high concentrations. (Hewajulige and Premaseela, 2020).[8]

Maduwanthi and Marapana (2021)[6] reported that liquid ethephon (2-chloroethylphosphonic acid), also known as ethrel generates ethylene when in the presence of a base, or it breaks down into ethylene when mixed with water. In the study, bananas are placed in a closed chamber with a mixture of 1000 ppm ethephon and 1000 ppm NaOH for 24 hours. This treatment speeds up ripening, changing green fruit to a fully yellow stage in just 2 days, but in the contrary it keeps higher levels of chlorophyll a and b even when the fruit is fully yellow, that significantly drops total carotenoids in both the peel and flesh. While in Sabuz et al. (2019),[12] postharvest ethephon application involves dipping mature green mangoes into water solutions of ethephon (2-chloroethyl phosphonic acid) at concentrations of 250, 500, 750, 1000, and 10000 ppm for 5 minutes. Fruits treated with 750 to 1000 ppm develop a uniform, attractive yellow color within 4 days, while the 10000 ppm concentration causes rotting by day 6. Additionaly there is increase in total soluble solids (TSS), sugars, and the TSS/acid ratio of the fruit. A study shows that bananas and mangoes treated with ethephon may have lower nutritional value, having less ascorbic acid, -carotene, and mineral content compared to naturally ripened bananas (Maduwanthi and Marapana, 2019; Sabuz et al. 2019).[11,12] The most important nutritional impact is on Vitamin C, as there is nearly a 50% loss of Vitamin C at the eat-ripe stage

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compared to naturally ripened fruit which is significant for consumers since Vitamin C is vital for human nutrition. (Maduwanthi and Marapana, 2021)[6] As studied in Tovar et al. (2011),[13] vacuum treatment involves putting mangoes in a vacuum of 34 kPa for 20 minutes. This vacuum causes internal expansion of gases and creates stress on the fruit tissue which in result increases the respiration and ethylene production rates. The vacuum alone does not significantly improve the uniformity of ripening or external color so vacuum is combined with exogenous ethylene. This involves placing mangoes in a vacuum of 34 kPa for 20 minutes, followed by equilibration at atmospheric pressure with ethylene concentrations of 500, 1000, or 1500 µL /L for 30 minutes. The most noticeable effects are obtained at concentration of 1500 µL/L. This treatment helps ethylene enter the fruit because of the pressure difference and gas transfer. As a result, these fruits have a higher respiration rate and reach their climacteric peak one day earlier than the other treatments. This process speeds up the physiochemical changes, achieves a uniform color development and shortens the ripening time by three days.

Another safe method of postharvest ripening, also permitted by FSSAI (Guidance Note No. 04/2018).[14] is controlled exposure of fruits to ethylene gas in regulated ripening cham- bers that maintain optimal temperature (15°-25°C) and relative humidity (90-95%), with ethylene concentration not exceeding 100 ppm. Proper ventilation in these chambers is essential to avoid carbon dioxide buildup (maintained below 5000 ppm), as ethylene is very flammable at higher concentrations. The sources of ethylene gas in ripening chambers are -

I. Ethylene gas cylinders

II. Compressed ethylene gas (aerosol cans)

III. Catalytic converters for dehydrating ethanol+

$$C_2H_5OH \rightarrow - C_2H_4 + H_2O(\text{Water Vapour}) \quad (3)$$

IV. Ethephon (39% SL) with alkali (usually NaOH pellets)

$$C_2H_6ClO_3P + OH^- \rightarrow - C_2H_4 + Cl^- + H_2PO_4^- \quad (4)$$

The International Agency for Research on Cancer rates ethephon as non-carcinogenic. However, it is an organophos- phorus compound that can irritate human skin and eyes, studies also suggest that it may damage the liver because organophos- phorus compound is quickly absorbed in the gut and can turn into ethylene oxide, ethanediol, and other substances that might suppress the activity of Streptomyces present in gut (Maduwanthi and Marapana, 2019; Sabuz et al. 2019)[11,12] In Sabuz et al. (2019),[12] study finds that the because of volatile nature of ethephon, its residue on fruits decrease over time. At concentrations of 750 to 1000 ppm, the residue levels after 6 days of storage are between 0.50 and 0.54 ppm, which is below the maximum residue limit (MRL) of 2 ppm. Some reports suggest that regular consumption may lead to dizziness, weakness, skin ulcers, and heart-related issues if not used within safe limits. (Hewajulige and Premaseela, 2020)[8]

Proximate composition of mangoes ripened through different techniques							
(a)	Concentration (g/kg)	Moisture (%)	Ash (%)	Fat (%)	Fibre (%)	Protein (%)	Carbohydrates (%)
Mature mangoes ripened with calcium carbide	1	78.36 ± 0.08c	4.94 ± 0.02c	2.65 ± 0.01c	3.05 ± 0.02bc	3.23 ± 0.04b	7.83 ± 0.05e
	5	77.53 ± 0.06d	5.27 ± 0.01b	2.77 ± 0.03b	2.95 ± 0.06c	3.12 ± 0.04c	8.36 ± 0.06b
	10	75.85 ± 0.06e	5.46 ± 0.01a	2.99 ± 0.02a	2.51 ± 0.04d	3.03 ± 0.03c	9.90 ± 0.03a
(b)	Concentration (µL/kg)	Moisture	Ash	Fat	Fibre	Protein	Carbohydrates
Mature mangoes ripened with artificial ethylene	500	79.45 ± 0.08b	4.19 ± 0.04e	2.35 ± 0.01d	3.49 ± 0.03a	3.49 ± 0.02a	6.92 ± 0.07f.
	1000	78.23 ± 0.05c	4.69 ± 0.01d	2.60 ± 0.03c	3.15 ± 0.04b	3.30 ± 0.04b	8.04 ± 0.06d
	1500	77.63 ± 0.06d	5.15 ± 0.02b	2.77 ± 0.02b	3.05 ± 0.01bc	3.12 ± 0.05c	8.26 ± 0.02c
(c)	Moisture	Ash	Fat	Fibre	Protein	Carbohydrates	
Mature mangoes ripened naturally	80.21 ± 0.09a	4.74 ± 0.03d	2.10 ± 0.04e	3.57 ± 0.04a	3.05 ± 0.05c	6.27 ± 0.07 g	

Figure 2.Composition of mangoes ripened using Calcium Carbide, Ethylene and Naturally. Each value is the Mean ± SD. Means with similar alphabetical letters in a column indicates non-significant results, whereas means with different alphabetical letters in a column indicates significant results (p ¡ 0.05). Source: Hussain et al. (2024)[5]

Chemical constituents of mangoes ripened through different techniques							
(a)	Concentration (g/kg)	Total soluble solids (Brix)	Titratable acidity (%)	Reducing sugar (%)	Ascorbic acid (mg/g)	Citric acid (mg/g)	Malic acid (mg/g)
Mature mangoes ripened with calcium carbide	1	14.20 ± 0.01e	0.36 ± 0.01a	5.20 ± 0.03f	49.49 ± 0.03b	3.29 ± 0.02cd	0.97 ± 0.01c
	5	15.05 ± 0.02b	0.32 ± 0.01ab	6.97 ± 0.04b	43.27 ± 0.07e	2.75 ± 0.03e	0.78 ± 0.02d
	10	15.78 ± 0.04a	0.29 ± 0.02b	7.35 ± 0.02a	35.94 ± 0.04g	02.12 ± 0.02f	0.63 ± 0.01e
(b)	Concentration (µL/kg)	Total soluble solids (Brix)	Titratable acidity (%)	Reducing sugar (%)	Ascorbic acid (mg/g)	Citric acid (mg/g)	Malic acid (mg/g)
Mature mangoes ripened with artificial ethylene	500	13.95 ± 0.01g	0.33 ± 0.04ab	5.45 ± 0.02e	45.26 ± 0.04c	3.54 ± 0.02b	1.02 ± 0.02b
	1000	14.30 ± 0.04d	0.31 ± 0.01b	6.38 ± 0.01d	43.87 ± 0.06d	3.44 ± 0.05bc	1.17 ± 0.03b
	1500	14.86 ± 0.02c	0.29 ± 0.02b	7.19 ± 0.04a	40.28 ± 0.03f	3.22 ± 0.03d	1.06 ± 0.02c
(c)	Total soluble solids (Brix)	Titratable acidity (%)	Reducing sugar (%)	Ascorbic acid (mg/g)	Citric acid (mg/g)	Malic acid (mg/g)	
Mature mangoes ripened naturally	14.10 ± 0.01f.	0.31 ± 0.01b	6.60 ± 0.03c	52.29 ± 0.05a	3.76 ± 0.06a	1.37 ± 0.04a	

Figure 3.Total soluble solids, titratable acidity, reducing sugars, ascorbic acid, citric acid and malic acid contents in mangoes ripened using Calcium Carbide, Ethylene and Naturally. Each value is the Mean ± SD. Means with similar alphabetical letters in a column indicates non-significant results, whereas means with different alphabetical letters in a column indicates significant results (p ¡ 0.05). Source: Hussain et al. (2024)[5]

Natural and Traditional Methods

In natural methods no chemical is introduced externally to the fruit. It relies on natural ethylene present inside the fruits for ripening. But this method is implemented in different ways like in Adeyemi et al. (2018)[7] fruits are stored in clean polyethylene bags without any chemical ripening agents, Sabuz et al. (2019)[12] involves dipping the fruits in tap water for 5 minutes without using any ripening solution and in Hus- sain et al. (2024)[5] mangoes ripen in controlled conditions at a room temperature of 25±2°C and a relative humidity of 85-90% without any chemical agents. Bananas ripen naturally without any outside agents has slow ripening, taking 6 days for the fruit to become fully ripe (Sogo-Temi et al. 2014)[4] Naturally ripened mangoes hold the highest moisture content (80.21%) and show much higher levels of ascorbic acid, citric acid, and malic acid than artificially ripened fruits. They also have the highest amounts of essential minerals such as iron, zinc, copper, phosphorus, and potassium, also it is better in taste, aroma, firmness but they do not have the uniform color found in artificially ripened fruit. (Hussain et al. 2024).[5]

A review article by Maduwanthi et al.[11] shows naturally occurring ethylene released from other ripening fruits like apple, pear, tomato also accelerates ripening, while a method discussed in Sogo-Temi et al. (2014)[4] uses biological materials, specifically African bush mango fruits or Jatropha curcas leaves, placed in bags with the bananas. Physiologically, these agents result in higher protein retention of about 2.52% for African bush mango and 3.04% for Jatropha as compared to the chemical agents. Ripening with Jatropha curcas leaves leads to the highest moisture content (74.0%), highest fat (1.72%), and highest fiber content (1.75%). In contrast, African bush mango treatment results in the lowest fat and fiber contents. The lead (Pb) content for these biological agents is 0.10 ppm for African bush mango and 0.16 ppm for Jatropha which is almost same as the naturally ripened. This indicates a reduced risk of contamination as compared to chemical agents.

A traditional method studied in Maduwanthi and Marapana (2019),[11] Hewajulige and Premaseela (2020)[8] involves exposing banana bunches to smoke from burning kerosene stoves or banana leaves inside sealed chambers. This process releases ethylene, along with small amounts of acetylene and carbon monoxide, while also raising the temperature inside the chamber. Although it ripens bananas quickly but causes some issues like black scars on the peel, uneven ripening, poor yellow color development, and shorter shelf life. From a health perspective, the practice of smoke-based ripening is hazardous because it deposits Polycyclic Aromatic Hydrocar- bons (PAHs) onto the banana peels. Specifically, carcinogenic compounds such as benzo[a]pyrene, benzo[a]anthracene, and benzo[b] fluoranthene have been observed to persist on the peel even after three days of storage

Mineral composition of mangoes ripened through different techniques								
		Minerals (mg/100 g)						
(a)	Concentration (g/kg)	P	K	Mg	Fe	Zn	Ca	Cu
Mature mangoes ripened with calcium carbide	1	16.39 ± 0.02e	126.67 ± 0.05d	12.41 ± 0.02d	0.36 ± 0.03d	0.15 ± 0.01cd	8.47 ± 0.02d	0.14 ± 0.01bc
	5	15.90 ± 0.03f	124.27 ± 0.05e	12.07 ± 0.05e	0.33 ± 0.02e	0.13 ± 0.02d	8.12 ± 0.06e	0.12 ± 0.01c
	10	15.56 ± 0.05g	121.51 ± 0.06f	11.32 ± 0.03f	0.29 ± 0.04e	0.12 ± 0.01d	7.99 ± 0.03e	0.11 ± 0.01c
(b)	Concentration (μL/kg)	P	K	Mg	Fe	Zn	Ca	Cu
Mature mangoes ripened with artificial ethylene	500	17.56 ± 0.03d	131.21 ± 0.06c	12.95 ± 0.05c	0.39 ± 0.03c	0.15 ± 0.03 cd	8.81 ± 0.03c	0.15 ± 0.02abc
	1000	18.61 ± 0.06c	133.48 ± 0.07b	13.45 ± 0.04b	0.45 ± 0.05b	0.17 ± 0.01b	9.57 ± 0.02b	0.16 ± 0.02ab
	1500	19.27 ± 0.07a	136.01 ± 0.08a	14.49 ± 0.06a	0.52 ± 0.02a	0.20 ± 0.01b	10.24 ± 0.05a	0.18 ± 0.01a
(c)	P	K	Mg	Fe	Zn	Ca	Cu	
Mature mangoes ripened naturally	18.85 ± 0.04b	135.61 ± 0.06a	13.28 ± 0.05a	0.45 ± 0.04b	0.24 ± 0.02a	8.89 ± 0.05c	0.17 ± 0.02a	

Figure 4.Mineral composition of mangoes ripened using Calcium Carbide, Ethylene and Naturally. Each value is the Mean ± SD. Means with similar alphabetical letters in a column indicates non-significant results, whereas means with different alphabetical letters in a column indicates significant results (pi 0.05). Source: Hussain et al. (2024)[5]

Organoleptic parameters of mangoes ripened through different techniques							
(a)	Concentration (g/kg)	Color	Aroma	Taste	Off odour	Firmness	Overall acceptability
Mature mangoes ripened with calcium carbide	1	6.65 ± 0.03c	8.06 ± 0.03b	6.09 ± 0.02e	5.12 ± 0.02d	7.45 ± 0.03c	6.82 ± 0.03d
	5	7.20 ± 0.04b	6.42 ± 0.06d	5.12 ± 0.03f	4.74 ± 0.02e	6.86 ± 0.02d	6.23 ± 0.02e
	10	7.90 ± 0.06a	5.06 ± 0.06e	4.35 ± 0.06g	4.49 ± 0.03f	5.37 ± 0.04e	5.21 ± 0.05f
(b)	Concentration (μL/kg)	Color	Aroma	Taste	Off odour	Firmness	Overall acceptability
Mature mangoes ripened with artificial ethylene	500	5.94 ± 0.06d	7.35 ± 0.05c	6.35 ± 0.03d	6.49 ± 0.04c	7.41 ± 0.05c	7.60 ± 0.02c
	1000	6.61 ± 0.06c	7.80 ± 0.02b	6.85 ± 0.04c	6.60 ± 0.04bc	7.79 ± 0.03b	8.09 ± 0.03b
	1500	7.15 ± 0.02c	8.45 ± 0.05a	7.83 ± 0.07b	6.73 ± 0.03b	8.26 ± 0.02a	8.53 ± 0.06a
(c)	Color	Aroma	Taste	Off odour	Firmness	Overall acceptability	
Mature mangoes ripened naturally	7.29 ± 0.05b	8.62 ± 0.07a	8.12 ± 0.03a	8.35 ± 0.05a	8.43 ± 0.06a	8.50 ± 0.05a	

Figure 5.Organoleptic parameter of mangoes ripened using Calcium Carbide, Ethylene and Naturally. Each value is the Mean ± SD. Means with similar alphabetical letters in a column indicates non-significant results, whereas means with different alphabetical letters in a column indicates significant results (pi 0.05). Source: Hussain et al. (2024)[5]

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Other Ripening Techniques

There are some other methods that are not very popularly used like wrapping potash in polythene and placing it with the fruit. Potash speeds up ripening like calcium carbide does, with fruits reaching full yellow color by day 3. The fruit has a protein content of 1.99% and a carbohydrate content of 27.89%. In terms of health, bananas ripened with potash show high lead (Pb) levels at 0.18 ppm. This is similar to the high levels found in fruits ripened with carbide (Sogo-Temi et al. 2014).[4] A study in Maduwanthi and Marapana (2019)[11] mentions the use of ethylene glycol to speeds up the ripening of fruits in cooler climates when mixed with water. Alkyl alcohols with 6 to 14 carbon atoms, especially lauryl alcohol is also effective in ripening. Treatment with 0.01% lauryl alcohol changes green bananas to completely yellow within 48 hours without affecting their taste. Hewajulige and Premaseela (2020)[8] discusses propylene and methyl jasmonate as other ethylene analogues that induce ripening. Propylene triggers reactions similar to ethylene, but it needs a concentration 100 times greater. Some of these methods like methyl jasmonate is non-toxic for humans, while some like ethylene glycol are harmful.

Conclusion

A comprehensive assessment of ripening methods shows that the biochemical, physiological, and toxicological effects during fruit ripening depends heavily on the ripening agent taken in use. Natural ripening preserves the metabolic compo- nents, including moisture, organic acids, carotenoids, essential micronutrients, and also they have no toxic contamination. There are certain biological ripening agents like African bush mango and Jatropha curcas leaves that have similar effect on fruits.

Ethylene is the only artificial method that is proven to be safe when used correctly. It is applied at controlled levels in standardized ripening chambers, that triggers climacteric responses closely resembling the effect of natural ethylene present inside fruits leading to consistent color development and good sensory quality with minimal chemical risks.

On the other hand, chemicals like calcium carbide and potash significantly change fruit physiology by speeding up starch breakdown and altering how cell walls soften. It also leads to harmful increases in ash, fiber, and heavy metals. Smoke induced ripening, use of ethylene glycol or high doses of ethephon introduce external toxic substances, including Polycyclic Aromatic Hydrocarbons (PAH) , organophosphate breakdown products, and heavy metals. These substances have a negative effect on fruit quality by disrupting contents such as vitamins, carotenoids, and total soluble solids.

The widespread use of harmful ripening agents highlights the need for effective detection and diagnostic systems to identify illegal and harmful ripening practices throughout the supply chain. Future efforts should focus on creating fast, non- destructive tools to detect traces of contaminants and changed metabolic markers linked to unsafe ripening. It is crucial to improve monitoring systems, enforcement of strict regulations, and awareness about safer methods like ethylene to protect public health and maintaining overall quality of ripened fruits.

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