Plant Archives Vol. 26, Supplement 2, 2026 pp. 512-522 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2026.v26.supplement-2.055

INFLUENCE OF RIPYLENE-6 AND COLD CHAMBER STORAGE ON RIPENING BEHAVIOUR AND QUALITY ATTRIBUTES OF BANANA FRUITS

Pravin Dalavi[1*], Quraazah Akeemu Amin[2*], Towseef A. Wani[2], Shahnaz Parveen[2], Riddheshwar Shinde[2], Dnyaneshwar Ingole[3], Karthikeyan P.[2], Anirudh Gupta[2], Venkateshwaran K.[2] and Wajahat Hamid Dar[2]

[1]New Leaf Dynamic Technologies Private Limited, Shivajinagar- 411003, Pune, Maharashtra, India.
[2]Division of Food Science and Technology, SKUAST-K, India.
[3]Kay Bee Bio Organic Pvt. Ltd. Phaltan, Pune, India.
*Corresponding authors E-mails: pravindalavi98@gmail.com ; widaad57@gmail.com
(Date of Receiving : 17-04-2026; Date of Revision : 10-06-2026; Date of Acceptance : 01-07-2026)

ABSTRACT

The present study was conducted to evaluate the effect of Ripylene-6 and cold chamber storage on the ripening behaviour and quality attributes of G-9 (Grand Naine) banana fruits under different storage conditions. Three storage systems were used, namely ambient condition ripening, cold chamber storage without Ripylene-6 (22°C and 90% RH), and cold chamber storage with Ripylene-6 (22°C and 90% RH). Observations on firmness, total soluble solids (TSS), pH, titratable acidity, physiological loss in weight (PLW), colour values (L*, a*, b*), pulp moisture content, total sugar content, total chlorophyll content in peel, and pulp-to-peel ratio were recorded at regular intervals during ripening. The results revealed that banana fruits treated with Ripylene-6 under cold chamber conditions ripened faster and more uniformly than fruits stored under ambient conditions or in the cold chamber without Ripylene-6. Firmness, acidity, and total chlorophyll content decreased progressively during ripening, whereas TSS, pH, colour values, pulp moisture content, total sugar content, and pulp-to-peel ratio increased significantly. Ripylene-6-treated fruits attained marketable ripeness within 6 days, while fruits stored in the cold chamber without Ripylene-6 and under ambient conditions required 12 and 14 days, respectively. The lowest physiological loss in weight and better retention of fruit quality were observed under cold chamber storage, while Ripylene-6 treatment promoted rapid colour development, sugar accumulation, and uniform ripening. The study concluded that the combined application of Ripylene-6 and cold chamber storage at 22°C and 90% RH improved ripening uniformity, colour development, sweetness, overall fruit quality, and marketability of G-9 banana fruits while reducing the ripening duration.
Keywords **:** G-9 banana, Ripylene-6, Ethylene ripening, Cold chamber storage, Fruit quality, Postharvest ripening.

Introduction

Banana (*Musa* spp.), popularly known as the “Poor Man’s Fruit,” is one of the most important tropical and subtropical fruits cultivated worldwide due to its high nutritional value, year-round availability, affordability, and economic importance. India is the largest producer of bananas globally, contributing nearly 25–27% of the world's total banana production. In the year 2023-24, the area under banana cultivation was 9,87,000 hectares while the banana production was 3,81,45,000 tonnes (Dalavi, 2025). Among the commercially cultivated cultivars, Grand Naine (G-9) banana is widely preferred because of its high yield, uniform fruit size, excellent eating quality, attractive appearance, and suitability for both domestic consumption and export markets (Dalavi *et al.,* 2025). The cultivar is extensively used for fresh consumption and processing into chips, puree, flour, beverages, baby foods, and other value-added products due to its desirable physicochemical characteristics and high sugar content.

Banana is a climacteric fruit, characterized by a sharp increase in respiration rate and ethylene production after harvest, which enables continued ripening during storage. Ripening involves a series of physiological and biochemical changes including conversion of starch into soluble sugars, degradation of chlorophyll pigments, synthesis of carotenoids, reduction in acidity, softening of pulp tissues, and development of characteristic flavor and aroma compounds. During this process, important quality attributes such as total soluble solids (TSS), sugar content, firmness, peel color, moisture content, and pulp-to-peel ratio undergo significant changes. The peel color changes from green to yellow due to chlorophyll degradation and accumulation of carotenoid pigments, while the pulp becomes softer and sweeter as ripening progresses (Dadzie and Orchard, 1997; Zhou *et al.,* 2023). Traditionally, bananas are ripened under ambient conditions; however, natural ripening often results in non-uniform color development, uneven texture, inconsistent sweetness, and considerable postharvest losses. Therefore, the use of controlled ripening techniques and appropriate storage conditions has become essential to achieve uniform ripening, maintain fruit quality, and reduce postharvest losses during marketing and distribution.

Calcium carbide (CaC_2) is a harmful fruit ripening chemical that releases acetylene gas. It can reduce oxygen supply to the brain and may cause headache, dizziness, weakness, vomiting, stomach irritation, skin damage, and difficulty in swallowing. Industrial-grade calcium carbide may also contain toxic arsenic and phosphorus impurities which are dangerous to human health. Ethylene glycol ($C_2H_6O_2$) is another harmful chemical that may damage the kidneys if consumed in high amounts. Ethylene (C_2H_4) and methyl jasmonate ($C_{13}H_{20}O_3$) are safer ripening agents because they are less toxic and help fruits ripen naturally, although they are more expensive. Ethephon ($C_2H_6ClO_3P$) is also considered safe when used at recommended low concentrations and has no major harmful effects on human health (Islam *et al.,* 2016).

Ethylene gas plays a crucial role in initiating physiological and biochemical changes during ripening. It stimulates respiration and activates enzymes responsible for converting starch into sugars, resulting in sweeter fruits. Ethylene also accelerates chlorophyll degradation and carotenoid synthesis, producing desirable colour development such as green to yellow or orange transition in mangoes and bananas. In addition, it promotes softening of fruit tissues through breakdown of cell wall components like pectin, improving texture and eating quality. Ethylene further enhances aroma and flavour compound production, contributing to consumer acceptability. Controlled ethylene exposure ensures more uniform ripening across fruit lots, reducing uneven maturity and improving commercial value (Kader, 2002).

Ethylene gas is considered a safer and more scientific ripening agent than harmful chemicals such as calcium carbide and excessive acetylene because ethylene is a natural plant hormone produced by fruits during normal ripening. It stimulates natural biochemical processes including color development, softening, aroma formation, and sugar accumulation without leaving highly toxic residues when used at recommended concentrations. In contrast, chemicals like calcium carbide may contain harmful impurities such as arsenic and phosphorus, which are associated with health risks including neurological disorders, respiratory irritation, gastrointestinal problems, hormonal imbalance, and potential carcinogenic effects (Hussain *et al.,* 2024 ; Maduwanthi & Marapana, 2021). The Food Safety and Standards Authority of India (FSSAI) permits controlled ethylene gas application up to 100 ppm for commercial fruit ripening because it mimics the fruit's natural ripening mechanism. However, calcium carbide is banned in India due to its toxic nature and associated health hazards. Ethylene gas also influences sensory attributes including flavor, aroma, appearance, and consumer acceptability. Controlled ripening promotes development of characteristic volatile compounds responsible for the unique aroma of G9 bananas. Studies have shown that bananas exposed to ethylene gas for 18 hours exhibited better sensory quality, attractive peel color, desirable sweetness-acidity balance, and higher overall acceptability scores compared to untreated fruits.

Ripylene-6 is a commercial fruit ripening gas mixture widely used in ripening chambers for climacteric fruits such as mango, banana, papaya, and tomato. The formulation generally contains approximately 5% ethylene gas (C_2H_4) and 95% nitrogen gas (N_2). Ethylene is a naturally occurring plant hormone responsible for regulating fruit ripening processes, while nitrogen acts as an inert carrier gas that helps maintain a safe and controlled concentration of ethylene during application. The use of controlled ethylene treatment promotes uniform ripening and improves market quality without leaving harmful chemical residues on fruits (Chemtron Science Laboratories Pvt. Ltd., 2023).

Nitrogen present in Ripylene-6 serves mainly as a balancing and carrier gas. Since concentrated ethylene is highly reactive, nitrogen dilutes the ethylene concentration to safe operating levels and facilitates uniform gas distribution inside ripening chambers. This controlled atmosphere improves ripening efficiency and minimizes handling risks. Commercial ripening systems using ethylene-based formulations are preferred over hazardous chemicals such as calcium carbide because ethylene mimics natural fruit physiology and is considered safer when used according to recommended protocols (Watkins, 2006).

Ripylene-6 is selected for banana ripening because it is an ethylene-releasing ripening agent that provides safe, uniform, and controlled ripening. Ethylene is a natural plant hormone responsible for initiating physiological and biochemical changes such as colour development, softening, sugar accumulation, aroma formation, and reduction in acidity. Ripylene-6 helps achieve uniform ripening of bananas within a shorter duration while maintaining better fruit quality compared with harmful chemicals like calcium carbide. It is widely preferred in commercial ripening chambers because it produces consistent ripening, improves market appearance, and reduces postharvest losses. Studies on G9 bananas showed that ethylene treatment enhanced total soluble solids (TSS), improved colour, reduced firmness gradually, and maintained better eating quality (Kad *et al.,* 2017).

Cold chamber storage is important because low-temperature and high-relative-humidity conditions slow down respiration, moisture loss, microbial growth, and senescence of banana fruits. Proper cold storage maintains fruit firmness, reduces physiological loss in weight (PLW), and extends shelf life during transportation and marketing. However, excessively low temperatures may suppress ethylene biosynthesis and cause chilling injury in bananas. Research showed that storage at chilling temperature (5°C) reduced ethylene production, ACC oxidase activity, and normal ripening behaviour in banana fruits. Therefore, bananas are generally stored at safer temperatures around 12–15°C before ripening (Nair *et al.,* 2002). The combined effect of Ripylene-6 and cold chamber storage is highly beneficial for commercial mango handling. Cold storage delays over-ripening and preserves fruit quality during storage, while Ripylene-6 treatment initiates uniform ripening at the desired marketing stage. This combination improves colour development, sweetness, texture, shelf life, and consumer acceptability. Ethylene-induced ripening followed by controlled storage conditions also helps reduce wastage and maintain better biochemical quality. Research on modified atmosphere packaging and ethylene treatments reported improved fruit quality, enhanced TSS, better sugar accumulation, and prolonged shelf life when ethylene ripening was combined with controlled storage systems (Singh & Janes, 2000).

Therefore, it is important for optimizing ripening conditions such as ethylene concentration, exposure duration, temperature, and humidity in order to achieve maximum fruit quality and shelf life. Understanding the biochemical and physiological changes during ripening can help develop improved postharvest handling technologies and reduce losses during storage and marketing. Such studies will be valuable for enhancing export quality, increasing farmer profitability, and strengthening the banana processing industry (Kad *et al.,* 2017).

The quality parameters of ripened banana fruits were evaluated using standard analytical methods. Total Soluble Solids (TSS) were determined using a digital hand refractometer and the results were expressed as °Brix. The pH of mango pulp was measured using a calibrated digital pH meter. Titratable acidity was estimated by titrating a known quantity of mango juice against standardized 0.1 N sodium hydroxide (NaOH) solution using phenolphthalein as an indicator, and the results were expressed as percentage citric acid. Fruit firmness was measured using a digital fruit firmness tester (penetrometer) by applying pressure to the peeled fruit surface and recording the force required for penetration. All measurements were carried out at regular intervals during the ripening period to assess changes in fruit quality. The quality parameters of ripened banana fruits were evaluated using standard analytical methods. Pulp moisture content was determined by the hot air oven method, wherein a known quantity of pulp sample was dried at 105 ± 2°C until constant weight was achieved, and the results were expressed as percentage moisture. Total sugar content was estimated by the Anthrone method using a UV-Visible spectrophotometer, and the results were expressed as percentage total sugars. Total chlorophyll content in the peel was determined by extracting chlorophyll pigments with 80% acetone and measuring absorbance at 645 and 663 nm using a UV-Visible spectrophotometer. The chlorophyll content was calculated using Arnon's equation and expressed as mg/100 g peel. The pulp-to-peel ratio was determined by separately weighing the pulp and peel portions of the fruit and calculating their weight ratio. All measurements were carried out at regular intervals during the ripening period to assess changes in the physicochemical quality attributes of banana fruits.

Materials and Methods

Banana fruits were harvested during the early morning hours, preferably between 7:00 AM and 10:00 AM (Temp. 27°C and 56% RH) in 4 April 2024, when the field temperature was low and the fruits remained fresh with minimum moisture loss. Harvesting was avoided during hot afternoon conditions because high temperature increased respiration rate, sap burn, and postharvest deterioration. Mature bananas were carefully harvested. To reduce latex injury and mechanical damage.

After harvesting, the fruits were kept under shade and transported quickly to the cold chamber or packhouse in clean plastic crates to avoid bruising and compression damage. During transportation, the temperature was maintained around 13–15°C with 90% relative humidity to preserve freshness and reduce physiological weight loss. Gentle handling during loading and unloading was followed because bananas were highly sensitive to impact injury.

At the packhouse, the fruits were sorted and graded based on maturity, size, colour, shape, and absence of diseases or physical defects. Damaged, diseased, and immature fruits were removed to ensure uniform ripening and better market quality. All banana hands were first washed in running tap water to remove dirt, followed by treatment with 1% alum solution (w/v) for 10 minutes. They were then treated with 1% Benomyl solution for another 10 minutes. Pre-cooling was carried out before storage or ripening treatment. Bananas were pre-cooled at 13–15°C for about 4–6 hours depending on fruit size and field heat. Pre-cooling removed field heat rapidly, slowed respiration, reduced moisture loss, maintained firmness, and improved shelf life and ripening uniformity during cold storage and ripening chamber operations. The New Leaf Dynamic Technologies Pvt. Ltd. cold room having dimensions of 22 ft × 12 ft × 9 ft, the total room volume was calculated as 2376 cubic feet. The room volume was then converted into cubic meters and found to be approximately 67.3 m³. Generally, one Ripylene-6 bottle is recommended for about 40 m³ chamber volume for proper mango ripening. Therefore, the number of Ripylene-6 bottles required for a 67.3 m³ cold room was calculated by dividing 67.3 by 40, which gave 1.68 bottles. Hence, approximately 2 Ripylene-6 bottles were required to maintain the recommended ethylene concentration for uniform and effective banana ripening in the cold room.

Ripylene-6 was used for banana ripening in a sealed ripening chamber under controlled temperature and humidity conditions. Mature and healthy banana fruits were first sorted, graded, and pre-cooled before being placed uniformly inside plastic crates in the ripening chamber. The chamber temperature was maintained at about 22°C with 90% relative humidity for effective ripening. Based on the chamber volume, the required number of Ripylene-6 bottles was calculated and connected to the ripening system to release ethylene gas uniformly inside the chamber. The chamber was kept closed for about 24 hours to allow proper exposure of the fruits to ethylene gas. After treatment, ventilation was provided to remove excess gas, and the fruits were kept under suitable storage conditions until uniform colour development, softening, and ripening were achieved. Ripylene-6 helped in obtaining uniform ripening, better colour development, improved flavour, and enhanced market quality of banana fruits. The pre-cooled bananas were placed carefully in plastic crates (45 cm × 30 cm × 20 cm). The crates were then kept inside the cold room under controlled temperature and humidity conditions. At night, around 11:00 PM, Ripylene-6 was sprayed inside the cold room for banana ripening. The cold room was then kept closed for 24 hrs to allow uniform exposure of ethylene gas for effective and uniform ripening of banana fruits.

Three treatments were used for banana ripening during the experiment. In the first treatment, banana fruits were ripened under ambient room conditions without any controlled environment. In the second treatment, the fruits were kept in a cold chamber maintained at 22°C temperature and 90% relative humidity without Ripylene-6 treatment. In the third treatment, the banana fruits were placed in a cold chamber maintained at 22°C temperature and 90% relative humidity and were treated with Ripylene-6 for uniform ripening. The observations related to ripening and quality parameters were recorded at regular intervals during the storage period. Changes in colour, firmness, physiological loss in weight, total soluble solids, and overall fruit quality were observed and recorded for all treatments. The treatment details given below

Treatment No.	Treatment Details
T_1	Ambient condition ripening
T_2	Cold chamber without Ripylene-6 (22°C, 90% RH)
T_3	Cold chamber with Ripylene-6 (22°C, 90% RH)

Flow Chart of Mango Ripening Process in Cold Chamber

Bananas are placed in plastic crates of 15 kg each

↓

Crates are stacked in the ripening chamber floor

↓

Set a temperature of 22°C and 90% RH

↓

Sensor of data logger is inserted in the fruit in the middle crate to record fruit pulp temperature

↓

Chamber door is closed hermetically

↓

Once set temperature is achieved, Ethylene is released @ 100 ppm into the chamber

↓

After 24 hours of ethylene injection, door is opened to release CO_2

↓

After every 24 hours further, the door is opened for release of excess CO_2

↓

After achieving desired color, the fruit crates are removed from the chamber

(Rao *et al.*, 2020)

Result and Discussion

Market Specifications of Ripe (G-9) Banana

The ripe Grand Naine (G-9) banana fruits selected for marketing exhibited firmness values ranging from 1 to 3 kg cm^{-2}, indicating an optimum texture suitable for consumer acceptance. The Total Soluble Solids (TSS) content ranged between 18 and 22 °Brix, reflecting adequate sweetness developed during ripening. The pH values were observed between 5.2 and 5.8, while titratable acidity ranged from 0.15 to 0.25%, indicating desirable eating quality and a balanced sugar-acid ratio. Physiological Loss in Weight (PLW) was maintained within 4–8%, which was considered acceptable for marketability and shelf-life retention. Total sugar content ranged from 15 to 22%, demonstrating the conversion of starch into soluble sugars during ripening. The pulp-to-peel ratio varied from 2.2 to 3.0, indicating advanced ripening and a higher proportion of edible pulp. These physicochemical characteristics were considered optimum indicators of market-ready ripe G-9 banana fruits and were in agreement with previous findings reported for ripened Cavendish and Grand Naine bananas by Mohapatra *et al.* (2010).

Parameter	Optimum Range for Marketing
Firmness (Kg/Cm^2)	1–3
TSS (°B)	18–22
pH	5.2–5.8
Titratable Acidity	0.15–0.25
PLW (%)	4–8
Total sugar (%)	15-22
Pulp/Peel ratio	2.2-3.0

Table 1 : Changes in Firmness, TSS, pH and Acidity of Mango during Ripening under Different Treatments

Param-eters	Ambient condition									Cold Chamber without Ripylene-6								Cold Chamber with Ripylene-6				
	Days									Days								Days				
	0	2	4	6	8	10	12	14	Mean	0	2	4	6	8	10	12	Mean	0	2	4	6	Mean
Firmness (Kg/Cm^2)	7.74 ± 0.15	7.20 ± 0.24	6.30 ± 0.18	5.02 ± 0.28	3.80 ± 0.35	2.70 ± 0.25	1.20 ± 0.32	0.52 ± 0.24	4.31	7.74 ± 0.15	7.16 ± 0.18	6.72 ± 0.22	6.48 ± 0.24	5.85 ± 0.20	5.32 ± 0.32	3.70 ± 0.24	6.14	7.45 ± 0.34	6.12 ± 0.24	4.32 ± 0.15	2.7 ± 0.22	5.15
TSS (°B)	5.10 ± 0.10	8.20 ± 0.20	10.40 ± 0.10	11.7 ± 0.30	13.4 ± 0.30	15.10 ± 0.20	17.90 ± 0.30	20.20 ± 0.20	12.75	5.50 ± 0.10	8.80 ± 0.20	10.8 ± 0.10	13.4 ± 0.20	15.2 ± 0.30	16.4 ± 0.30	18.20 ± 0.30	12.61	5.39 ± 0.20	11.70 ± 0.20	18.40 ± 0.20	22.2 ± 0.30	14.42
pH	3.12 ± 0.19	3.25 ± 0.23	3.38 ± 0.17	3.65 ± 0.25	3.92 ± 0.27	4.30 ± 0.36	4.52 ± 0.32	4.80 ± 0.22	3.87	3.01 ± 0.24	3.10 ± 0.19	3.25 ± 0.15	3.55 ± 0.22	3.85 ± 0.25	4.12 ± 0.30	5.00 ± 0.20	3.70	4.05 ± 0.24	4.65 ± 0.22	5.18 ± 0.25	5.62 ± 0.28	4.88
Acidity (%)	3.75 ± 0.23	3.65 ± 0.21	3.52 ± 0.17	3.20 ± 0.14	2.88 ± 0.21	2.45 ± 0.25	1.85 ± 0.33	1.02 ± 0.23	2.79	3.56 ± 0.17	3.13 ± 0.19	2.75 ± 0.23	2.32 ± 0.20	1.88 ± 0.24	1.25 ± 0.23	0.89 ± 0.20	2.25	3.55 ± 0.25	2.62 ± 0.23	1.55 ± 0.27	0.28 ± 0.23	2.00

During the ripening period, Table 1 and Fig. 1 showed that the firmness of G-9 banana fruits gradually decreased in all treatments. Under ambient conditions, firmness declined from 7.74 kg cm^{-2} at day 0 to 0.52 kg cm^{-2} by day 14. In the cold chamber without Ripylene-6, the reduction in firmness was slower, decreasing from 7.74 kg cm^{-2} to 3.70 kg cm^{-2} over 12 days. In contrast, fruits stored in the cold chamber with Ripylene-6 showed accelerated softening, with firmness decreasing from 7.45 kg cm^{-2} at day 0 to 2.70 kg cm^{-2} by day 6, indicating faster ripening. The Total Soluble Solids (TSS) content increased continuously throughout the ripening period. Under ambient conditions, TSS increased from 5.10 °Brix to 20.20 °Brix by day 14. In the cold chamber without Ripylene-6, TSS increased gradually from 5.50 °Brix to 18.20 °Brix over 12 days. However, fruits treated with Ripylene-6 in the cold chamber exhibited a rapid increase in TSS from 5.39 °Brix to 22.20 °Brix within 6 days, demonstrating enhanced ripening and sugar accumulation. The pH of the fruits increased during ripening under all treatments. Under ambient conditions, pH rose from 3.12 to 4.80 during 14 days of storage. In the cold chamber without Ripylene-6, pH increased gradually from 3.01 to 5.00 by day 12. Fruits exposed to Ripylene-6 in the cold chamber showed a faster increase in pH, reaching 5.62 by day 6 from an initial value of 4.05. Titratable acidity decreased steadily as ripening progressed. Under ambient conditions, acidity declined from 3.75% to 1.02% during 14 days of storage. In the cold chamber without Ripylene-6, acidity decreased from 3.56% to 0.89% by day 12. Similarly, fruits stored in the cold chamber with Ripylene-6 exhibited a rapid reduction in acidity from 3.55% to 0.28% within 6 days. The decrease in acidity, accompanied by increases in TSS and pH, indicated the conversion of organic acids into sugars and other metabolites during the ripening process. Similarly, pH values increased gradually, whereas acidity percentage decreased throughout the ripening period in all treatments. The fastest reduction in acidity and quickest ripening were observed in the cold chamber with Ripylene-6 treatment.

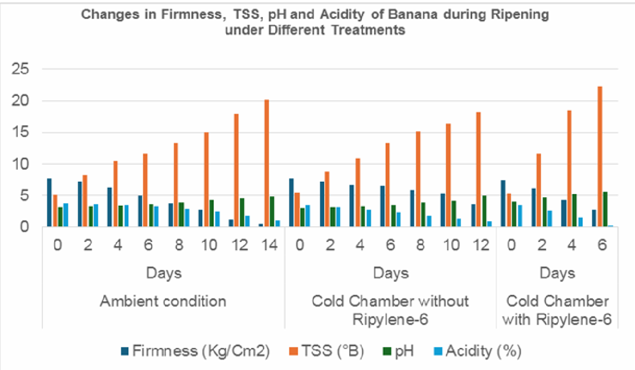


Fig. 1 : Changes in Firmness, TSS, pH and Acidity of Banana during Ripening under Different Treatments

During the ripening period, firmness of banana fruits decreased gradually in all treatments due to the degradation of protopectin into soluble pectin and the breakdown of cell wall polysaccharides. The fastest reduction in firmness was observed in the cold chamber with Ripylene-6 treatment, indicating accelerated ripening because ethylene stimulated the activity of softening enzymes such as polygalacturonase, pectin methyl esterase, and cellulase. Similar findings were reported by Dadzie and Orchard (1997), Mebratie *et al.* (2015) and Chiwate *et al.* (2023), who observed rapid softening of banana fruits during ethylene-induced ripening. Total soluble solids (TSS) increased continuously during the ripening period in all treatments. The increase in TSS occurred because stored starch was hydrolyzed into simple sugars such as glucose, fructose, and sucrose during ripening. The highest and fastest increase in TSS was observed in Ripylene-6-treated fruits due to enhanced ethylene action and faster metabolic conversion of carbohydrates into sugars. Similar increases in TSS during banana ripening were reported by Mohapatra *et al.* (2010), Aruwajoye *et al.* (2025), and Zhou *et al.* (2023). The pH values increased gradually throughout the ripening period. The increase in pH was mainly due to the degradation and utilization of organic acids during respiration and ripening processes. Ripylene-6-treated bananas showed a more rapid increase in pH because ethylene accelerated biochemical and metabolic activities associated with ripening. Similar observations were reported by Onwuka and Onwuka (2005), Chiwate *et al.* (2023), and Zhou *et al.* (2023), who found increasing pH values during banana ripening. Acidity percentage decreased progressively in all treatments during storage and ripening. Organic acids were utilized as respiratory substrates during fruit metabolism; therefore, acidity decreased as ripening advanced. The greatest reduction in acidity was observed in Ripylene-6-treated fruits due to enhanced respiration and ethylene-induced ripening activity. Similar results were reported by Eliwa *et al.* (2026), Mohapatra *et al.* (2010) and Aruwajoye *et al.* (2025), who observed significant reductions in acidity during banana ripening under ethylene treatment.

Table 2 : Changes in Colour Values (*L**, *a**, b*) of Banana during Ripening under Different Treatments

Para-meters (Colour values)	Ambient condition									Cold Chamber without Ripylene-6								Cold Chamber with Ripylene-6				
	Days									Days								Days				
	0	2	4	6	8	10	12	14	Mean	0	2	4	6	8	10	12	Mean	0	2	4	6	Mean
L*	47.43 ± 0.75	48.95 ± 0.72	51.40 ± 0.53	53.32 ± 0.75	56.25 ± 0.72	59.10 ± 0.65	62.40 ± 0.69	65.90 ± 0.75	55.59	48.12 ± 0.75	50.80 ± 0.74	53.20 ± 0.60	57.70 ± 0.76	60.70 ± 0.80	63.60 ± 0.79	66.70 ± 0.82	57.26	48.62 ± 0.66	57.98 ± 0.79	63.33 ± 0.73	69.22 ± 0.72	59.79
a*	-12.68 ± 0.53	-10.70 ± 0.74	-8.90 ± 0.66	-5.50 ± 0.69	-2.80 ± 0.73	1.40 ± 0.85	3.82 ± 0.63	5.50 ± 0.77	-3.11	-10.48 ± 0.55	-8.40 ± 0.65	-5.90 ± 0.66	-2.45 ± 0.68	1.02 ± 0.72	4.80 ± 0.81	6.20 ± 0.85	-2.17	-10.38 ± 0.75	-3.70 ± 0.83	2.70 ± 0.80	7.02 ± 0.82	-1.09
b*	30.72 ± 0.69	32.20 ± 0.65	35.70 ± 0.62	38.49 ± 0.69	41.50 ± 0.71	44.90 ± 0.85	48.10 ± 0.72	50.20 ± 0.61	40.23	30.72 ± 0.63	34.20 ± 0.65	38.65 ± 0.75	42.84 ± 0.77	45.30 ± 0.69	49.42 ± 0.81	51.02 ± 0.83	41.74	29.95 ± 0.78	41.70 ± 0.85	47.22 ± 0.71	52.08 ± 0.92	42.74

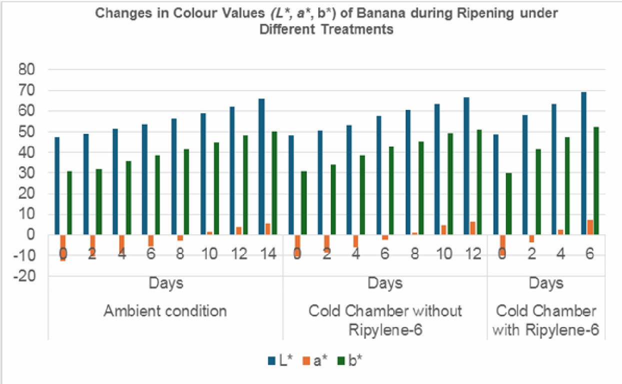


Fig. 2 : Changes in Colour Values *(L*, a*, b*) of Banana during Ripening under Different Treatments

During the ripening period, Table 2 and Fig. 2 showed significant changes in colour values (L*, a* and b*) of G-9 banana fruits under all storage conditions. The L* value, which represents fruit brightness or lightness, increased progressively throughout ripening. Under ambient conditions, L* values increased from 47.43 at day 0 to 65.90 by day 14. In the cold chamber without Ripylene-6, L* values increased from 48.12 to 66.70 during 12 days of storage. Fruits stored in the cold chamber with Ripylene-6 exhibited the fastest increase in lightness, where L* values increased from 48.62 to 69.22 within 6 days, indicating accelerated ripening and rapid development of bright yellow peel colour. The a* values showed a gradual shift from negative to positive values during ripening. Under ambient conditions, a* values increased from −12.68 to 5.50 during 14 days of storage. In the cold chamber without Ripylene-6, a* values increased from −10.48 to 6.20 by day 12. Fruits treated with Ripylene-6 exhibited the most rapid increase, changing from −10.38 at day 0 to 7.02 by day 6. The transition from negative to positive a* values indicated the loss of green colour and development of yellow coloration associated with ripening. Similarly, b* values, representing yellowness, increased continuously throughout the ripening period. Under ambient conditions, b* values increased from 30.72 to 50.20 during 14 days of storage. In the cold chamber without Ripylene-6, b* values increased from 30.72 to 51.02 by day 12. However, fruits stored in the cold chamber with Ripylene-6 showed a rapid increase in b* values from 29.95 to 52.08 within 6 days, indicating enhanced yellow pigment development and accelerated ripening. The colour development observed during ripening was primarily associated with chlorophyll degradation and carotenoid synthesis in the banana peel. Ripylene-6 treatment accelerated these biochemical changes, resulting in faster colour transformation and earlier attainment of marketable ripeness.

The L* values increased gradually throughout the ripening period in all treatments. The increase in L* values indicated enhanced peel brightness due to degradation of chlorophyll pigments and development of yellow colour. The highest increase in L* values was observed in fruits treated with Ripylene-6, suggesting accelerated ripening through ethylene-mediated metabolic activity. Similar increases in L* values during banana ripening were reported by Dadzie and Orchard (1997), Chiwate *et al.* (2023), and Zhou *et al.* (2023). The a* values increased continuously from negative to positive values during storage. Negative a* values represented green colour, whereas positive values indicated loss of greenness and progression towards yellow coloration. The rapid increase in a* values observed in Ripylene-6-treated fruits demonstrated faster chlorophyll degradation and colour change due to enhanced ethylene action. Similar observations were reported by Zhou *et al.* (2023), who reported a progressive increase in a* values during banana ripening. The b* values increased significantly throughout ripening under all treatments. The increase in b* values reflected the accumulation of carotenoid pigments responsible for yellow peel colour in ripe bananas. Ripylene-6-treated fruits showed the highest increase in b* values because ethylene accelerated carotenoid biosynthesis and chlorophyll breakdown. Similar findings were reported by Mohapatra *et al.* (2010) and Chiwate *et al.* (2023) who observed increased yellowness and carotenoid accumulation during banana ripening. Overall, the colour parameters clearly demonstrated that fruits stored in the cold chamber with Ripylene-6 achieved faster colour development and attained desirable marketable yellow colour earlier than fruits stored under ambient conditions or in the cold chamber without Ripylene-6.

Table 3 : Changes in Physiological Loss in Weight (PLW), Pulp Moisture, Total Sugar, Total Chlorophyll in Peel and Pulp/Peel ratio of Banana during Storage and Ripening under Different Treatments

Parameters	Ambient condition									Cold Chamber without Ripylene-6								Cold Chamber with Ripylene-6				
	Days									Days								Days				
	0	2	4	6	8	10	12	14	Mean	0	2	4	6	8	10	12	Mean	0	2	4	6	Mean
PLW (%)	0 ± 0.0	3.32± 1.23	5.25 ± 1. 36	7.45 ± 1.55	9.82 ± 1.45	12.28 ± 1.37	15.12 ± 1.56	16.20 ± 1.35	8.68	0 ± 0.0	2.42 ± 1.22	4.35 ± 1.34	6.24 ± 1.26	8.72 ± 1.42	10.12 ± 1.62	11.35 ± 1.52	6.17	0 ± 0.0	2.85 ± 1.33	5.32 ± 1.43	6.23 ± 1.45	3.60
Pulp Moisture (%)	70.63 ± 1.02	71.09 ± 1.04	71.58 ± 1.05	72.12 ± 1.08	72.72 ± 1.10	73.23 ± 1.23	73.76 ± 1.42	74.32 ± 1.43	72.43	70.28 ± 1.23	71.33 ± 1.28	72.46 ± 1.42	73.37 ± 1.22	74.42 ± 1.32	75.25 ± 1.28	76.23 ± 1.22	73.33	70.58 ± 2.25	73.65 ± 2.76	76.45 ± 3.02	78.25 ± 2.45	74.73
Total Sugar (%)	5.23 ± 1.23	6.98 ± 2.12	8.72 ± 2.02	10.78 ± 2.05	12.02 ± 2.08	13.56 ± 1.88	14.36 ± 1.65	15.93 ± 1.76	10.95	5.66 ± 2.23	7.26 ± 2.25	9.23 ± 2.02	11.32 ± 2.08	13.72 ± 1.88	15.22 ± 1.75	17.35 ± 1.66	11.39	5.76 ± 1.28	11.26 ± 2.05	16.78 ± 2.33	21.23 ± 2.34	13.76
Total Chlorophyll in Peel (mg/100g peel)	24.36 ± 2.22	22.13 ± 2.12	18.63 ± 1.98	16.28 ± 1.88	14.69 ± 2.01	12.47 ± 2.12	11.02 ± 2.32	9.34 ± 2.23	16.12	24.98 ± 2.20	21.35 ± 2.10	17.37 ± 2.32	14.87 ± 2.36	12.57 ± 2.66	10.28 ± 2.55	8.42 ± 2.46	15.69	25.34 ± 1.12	18.43 ± 1.32	11.21 ± 1.54	5.23 ± 1.65	15.05
Pulp/Peel ratio	1.2 ± 0.21	1.38 ± 0.23	1.47 ± 0.22	1.59 ± 0.25	1.68 ± 0.28	1.76 ± 0.22	1.89 ± 0.20	2.5 ± 0.23	1.68	1.42 ± 0.22	1.57 ± 0.25	1.72 ± 0.23	1.85 ± 0.28	2.02 ± 0.21	2.21 ± 0.24	2.24 ± 0.23	1.86	1.5 ± 0.22	1.8 ± 0.25	2.2 ± 0.23	2.8 ± 0.28	2.08

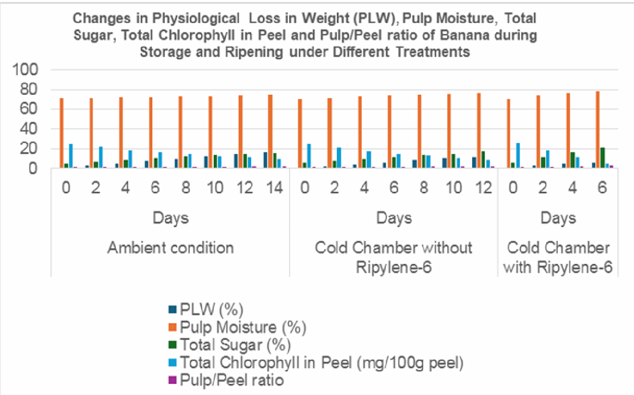
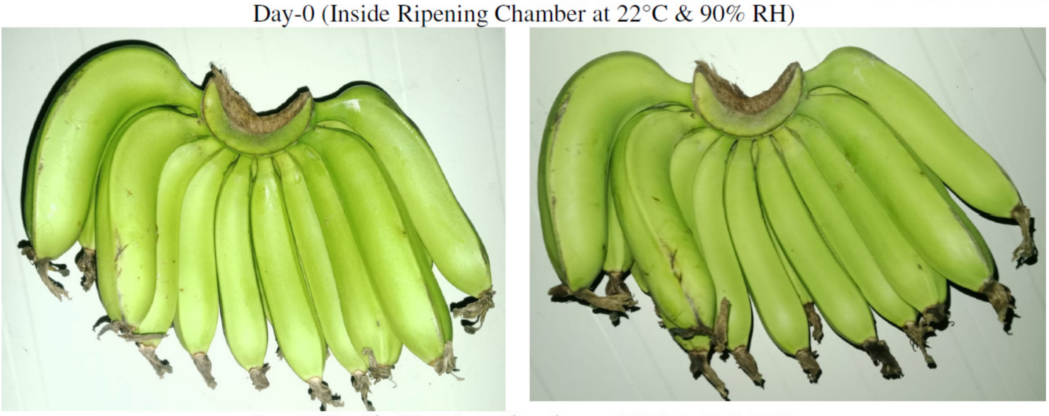


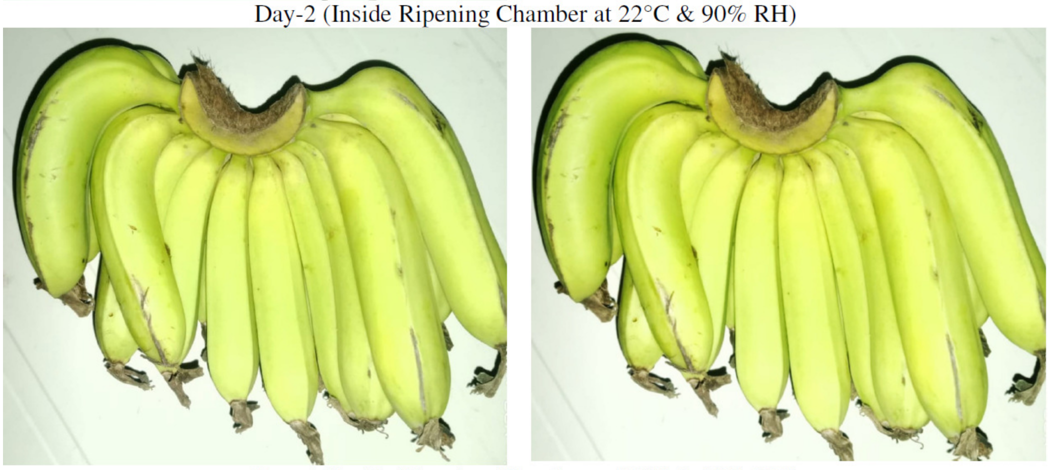
Fig. 3 : Changes in Physiological Loss in Weight (PLW) and Rot Percentage of Mango during Storage and Ripening under Different Treatments

During the ripening period, Table 3 and Fig. 3 showed significant changes in physiological and biochemical characteristics of G-9 banana fruits under different storage conditions. Physiological Loss in Weight (PLW) increased progressively throughout storage in all treatments. Under ambient conditions, PLW increased from 0.00% at day 0 to 16.20% by day 14. In the cold chamber without Ripylene-6, PLW increased gradually from 0.00% to 11.35% by day 12. Fruits stored in the cold chamber with Ripylene-6 showed a rapid increase in PLW from 0.00% to 6.23% within 6 days, indicating accelerated ripening and moisture loss. Pulp moisture content increased gradually during ripening under all treatments. Under ambient conditions, moisture content increased from 70.63% to 74.32% during 14 days of storage. In the cold chamber without Ripylene-6, moisture content increased from 70.28% to 76.23% by day 12. Fruits treated with Ripylene-6 exhibited the fastest increase in pulp moisture, increasing from 70.58% to 78.25% within 6 days. Total sugar content increased continuously throughout the ripening period. Under ambient conditions, total sugar increased from 5.23% to 15.93% during 14 days of storage. In the cold chamber without Ripylene-6, total sugar increased from 5.66% to 17.35% by day 12. However, fruits treated with Ripylene-6 showed the most rapid increase in total sugar, rising from 5.76% to 21.23% within 6 days, indicating rapid starch degradation and sugar accumulation. Total chlorophyll content in the peel decreased steadily during ripening. Under ambient conditions, chlorophyll content declined from 24.36 mg/100 g peel to 9.34 mg/100 g peel by day 14. In the cold chamber without Ripylene-6, chlorophyll content decreased from 24.98 to 8.42 mg/100 g peel by day 12. Fruits treated with Ripylene-6 exhibited the fastest reduction in chlorophyll content, decreasing from 25.34 to 5.23 mg/100 g peel within 6 days, indicating rapid loss of green colour and accelerated peel yellowing. Similarly, the pulp-to-peel ratio increased continuously throughout ripening. Under ambient conditions, the ratio increased from 1.20 to 2.50 during 14 days of storage. In the cold chamber without Ripylene-6, the ratio increased from 1.42 to 2.24 by day 12. Fruits exposed to Ripylene-6 showed the fastest increase, rising from 1.50 to 2.80 within 6 days, indicating rapid pulp development and advancement of ripening.

Day-0 (Inside Ripening Chamber at 22°C & 90% RH)



Day-2 (Inside Ripening Chamber at 22°C & 90% RH)



Day-4 (Inside Ripening Chamber at 22°C & 90% RH)

Day-6 (Inside Ripening Chamber at 22°C & 90% RH)

Fig. 4: Interval Day-wise Photographs (Cold chamber with Ripylene-6 (22°C, 90% RH)

During the ripening period, PLW increased gradually in all treatments due to continuous transpiration and respiratory losses. The highest increase in PLW was observed under ambient conditions because of greater moisture loss to the surrounding environment. Ripylene-6-treated fruits showed rapid weight loss within a shorter ripening period due to enhanced metabolic activity induced by ethylene. Similar increases in PLW during banana ripening were reported by Mohapatra *et al.* (2010) and Aruwajoye *et al.* (2025). Pulp moisture content increased progressively throughout ripening. The increase in moisture content could be attributed to the breakdown of complex carbohydrates and the movement of water from peel tissues into pulp tissues during fruit maturation. Ripylene-6-treated fruits exhibited the highest moisture accumulation due to accelerated ripening processes. Similar observations were reported by Onwuka and Onwuka (2005), Chiwate *et al.* (2023), and Zhou *et al.* (2023). Total sugar content increased continuously during ripening under all treatments. This increase occurred because starch reserves were hydrolyzed into simple sugars such as glucose, fructose, and sucrose. The highest sugar accumulation was observed in Ripylene-6-treated fruits due to enhanced ethylene action and rapid conversion of carbohydrates into sugars. Similar findings were reported by Mohapatra *et al.* (2010) and Aruwajoye *et al.* (2025). Total chlorophyll content in the peel decreased significantly throughout the ripening period. Chlorophyll degradation is one of the most important biochemical changes associated with banana ripening and is responsible for the transition of peel colour from green to yellow. The fastest reduction in chlorophyll content was observed in Ripylene-6-treated fruits because ethylene accelerated chlorophyllase activity and pigment breakdown. Similar reductions in chlorophyll content during banana ripening were reported by Dadzie and Orchard (1997), Zhou *et al.* (2023), and Munoz *et al.* (2024). The pulp-to-peel ratio increased progressively during storage and ripening. The increase in pulp-to-peel ratio was associated with pulp expansion, moisture accumulation, and softening of peel tissues during ripening. Ripylene-6-treated fruits recorded the highest pulp-to-peel ratio due to accelerated physiological and biochemical changes. Similar increases in pulp-to-peel ratio during banana ripening were reported by Chiwate *et al.* (2023). Overall, the results indicated that fruits stored in the cold chamber with Ripylene-6 exhibited the fastest ripening, characterized by rapid increases in total sugar, moisture content, and pulp-to-peel ratio, along with rapid decreases in chlorophyll content. In contrast, fruits stored in the cold chamber without Ripylene-6 showed slower ripening and better retention of quality attributes over an extended storage period.

Conclusion

The present study demonstrated that the combination of Ripylene-6 and cold chamber storage (22°C and 90% RH) significantly enhanced the ripening efficiency and quality attributes of G-9 (Grand Naine) banana fruits compared with ambient storage and cold chamber storage without Ripylene-6. Ripylene-6-treated fruits achieved market-ready ripeness within 6 days and exhibited desirable quality characteristics including optimum firmness (2.70 kg cm^{-2}), high total soluble solids (22.20 °Brix), optimum pH (5.62), reduced titratable acidity (0.28%), attractive yellow peel colour, high total sugar content (21.23%), and a favourable pulp-to-peel ratio (2.80). The treatment also resulted in acceptable physiological loss in weight (6.23%) and rapid chlorophyll degradation, indicating uniform colour development and attainment of marketable maturity. In contrast, fruits stored under ambient conditions required a longer ripening period of 14 days and exhibited excessive physiological loss in weight (16.20%) and slower quality development. Cold chamber storage without Ripylene-6 delayed ripening and required 12 days to attain acceptable quality attributes. The accelerated ripening observed in Ripylene-6-treated fruits was attributed to enhanced ethylene-mediated biochemical changes including starch hydrolysis, sugar accumulation, degradation of organic acids, chlorophyll breakdown, cell wall degradation, and carotenoid synthesis, which collectively improved sweetness, texture, colour, and consumer acceptability.

Overall, the findings confirmed that Ripylene-6, when used under controlled cold chamber conditions, provided a rapid, uniform, safe, and commercially effective ripening system for G-9 banana fruits. This technology not only reduced ripening duration but also improved colour development, sweetness, marketability, and overall fruit quality while minimizing postharvest losses. Therefore, the adoption of Ripylene-6-assisted cold chamber ripening can be highly beneficial for banana growers, ripening facilities, traders, and supply chains seeking to deliver superior-quality fruits to consumers and maximize economic returns.

Acknowledgement

The authors are grateful to the Directors of New Leaf Dynamic Technologies Pvt. Ltd., Shivajinagar, Pune, Maharashtra- 411 003 for providing excellent facilities for conducting this research. Financial assistance provided by the New Leaf Dynamic Technologies Pvt. Ltd. Pune, Maharashtra, India is highly appreciated.

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