PLANT SCIENCE TODAY
Vol 13(sp1): 1-7
https://doi.org/10.14719/pst.9639

eISSN 2348-1900

RESEARCH ARTICLE

Influence of ethephon concentration on colour uniformity and postharvest quality of paprika (*Capsicum annuum* L.) during storage

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Received: 26 May 2025; Accepted: 27 October 2025; Available online: Version 1.0: 31 March 2026

Cite this article: Arpan K, Mutum PD, Sanasam A, Ranjit C, Prodyut KP, Aditi C, Arunava G, Laishram H. Influence of ethephon concentration on colour uniformity and postharvest quality of paprika (*Capsicum annuum* L.) during storage. Plant Science Today. 2025; 13(sp1): 1-7. https://doi.org/10.14719/pst.9639

Abstract

This study was conducted to gain insights into the impact of ethephon on the ripening and quality of paprika fruits (cv. US 1039). Mature green paprika fruits were immersed in different concentrations of an ethephon aqueous solution (500, 1000 and 1500 ppm) for 5 min, then placed in a plastic tray and stored at room temperature. The fruits' physicochemical properties were assessed from the stage of mature green to the point of senescent maturation. Applying the aqueous ethephon solution at 1500 ppm resulted in the highest percentage of ripening. The percentages of both ripening and rotting increased as with increasing ethephon concentration (500−1500 ppm) and with the duration the fruits were allowed to ripen. Although the titratable acidity (TA) of the fruits gradually decreased, the levels of ascorbic acid and lycopene rose as the ripening process continued, irrespective of the treatment used. Fruits harvested at the green mature stage exhibited red colour development by the 9th day following the ethephon solution; however, the rotting rate exceeded 30–35 % by that time, rendering the fruits unmarketable. In the control group, the ripening, firmness, rotting and quality metrics were significantly lower compared to those treated with the aqueous ethephon solution and the fruits did not achieve red colouration.

Keywords: ethephon; paprika; shelf life; storage; ripening

Introduction

Paprika (*Capsicum annuum* L.) is a significant vegetable crop found in tropical and subtropical areas (1). Ripe paprika is a rich source of vitamins A (β-carotene) and C (ascorbic acid), making it a strong dietary source of antioxidants (2). The red hue of the paprika is due to lycopene, a compound recognised for its potential anti-cancer properties (3). Furthermore, it functions as an antioxidant; β-carotene plays a role in preventing and neutralising free radical chain reactions, while ascorbic acid is effective in scavenging superoxide, hydrogen peroxide, singlet oxygen and other free radicals (4).

The colour characteristics and quality parameters of fully ripened red paprika are key factors influencing both consumers and agricultural stakeholders (5). Throughout the growth and maturation stages, paprika undergoes various chemical and physical transformations that influence the quality of the fruit and its ripening characteristics post-harvest. The ripening process of paprika is marked by a decrease in chlorophyll levels and a swift increase in carotenoids, especially lycopene, as chloroplasts transform into chromoplasts (6). Low temperatures can hinder the breakdown of chlorophyll and the production of lycopene, disrupting the development of the fruit's colour, texture and flavour. Consequently, paprika fruits may not ripen properly, leading to uneven colour development.

In India, calcium carbide (CaC_2) is commonly used as a ripening agent to accelerate the ripening process during the winter months (7). Nevertheless, owing to health-related apprehensions, the application of CaC_2 is prohibited in India (8), thereby necessitating the exploration of alternative ripening agents. In this context, ethylene gas and ethephon have been recognised as potent ripening modulators in mature green tomatoes and have been effectively utilised in commercial practices across various countries to achieve uniform and expedited tomato ripening (7). Pre-harvest ethephon treatments of mature-green chili peppers, for instance, have been shown to significantly accelerate colour development, increasing red carotenoid pigments (capsanthin) and decreasing chlorophyll, thereby hastening ripening and improving overall fruit quality (9). In light of this context, it is imperative to develop a standardised protocol for ethephon-induced ripening of paprika to facilitate uniform maturation, thereby enhancing its market value in both domestic and international trade.

The objective of this research was to assess how varying ethephon concentrations affect the consistent development of red colour and the quality characteristics of paprika stored under ambient conditions after harvest.

Materials and Methods

Fruit materials

The paprika fruits of the cultivar US 1039 (Nunhems India Pvt. Ltd.) were collected at the mature green stage from the Instructional field of the Department of Vegetable and Spice Crop at Uttar Banga Krishi Viswavidyalaya, located in Pundibari, Cooch Behar, West Bengal, India, during the year 2024. The fruits were pre-cooled using cold water at a temperature of 25 °C. Following the pre-cooling process, any fruits exhibiting bruising or signs of disease were systematically excluded. Only healthy, uniformly sized fruits were retained for the study. A random selection of 10 paprika fruits from each plot was conducted to assess their physicochemical properties before applying ripening treatments.

Treatment

Paprika fruits from each hybrid were divided into 4 distinct groups. The first 3 groups were subjected to treatment through immersion in an ethephon solution at concentrations of 500, 1000 and 1500 ppm respectively, for a duration of 5 min. The 4th group served as a control and was not treated. Afterwards, the fruits' surfaces were air-dried, placed in a plastic tray and stored at room temperature. Various physicochemical properties were recorded at 2-day intervals until the fruits reached an acceptable condition for marketing.

Fruit quality assessment

The total soluble solids (TSS) content in the fruit flesh was quantified using a hand-held refractometer (Tokyo, Japan), with measurements expressed in °Brix at 20 °C. The titratable acidity (TA) of the pulp was determined in accordance with the methodology described earlier (10). Briefly, 10 g of the fresh fruit sample was diluted in 90 mL of distilled water and titrated with 0.1 N sodium hydroxide (NaOH) solution until the endpoint pH of 8.1 was reached. The results were expressed as a percentage of citric acid.

To quantify ascorbic acid content, a 10 g aliquot of the fresh fruit sample was homogenised with 25 mL of metaphosphoric acid (MPA) solution. The total volume was then adjusted to 100 mL using additional MPA and the resulting mixture was filtered to obtain a clear extract. A 10 mL aliquot of the filtrate was then titrated using a standard indophenol solution. The endpoint was determined by the appearance of a light pink colour that remained visible for approximately 15 sec. The amount of standard indophenol solution used for the 10 g sample was recorded and expressed as milligram of ascorbic acid per 100 g of fresh weight. The ascorbic acid concentration was determined using the formula: V × S × D, where V denotes the volume of the standard indophenol solution consumed during titration, S represents the standardisation factor (mg ascorbic acid per mL of indophenol solution) and D indicates the dilution factor. The dilution factor (D) was calculated using the equation: (A / (B × C)) × 100, where A is the total volume of the prepared solution, B is the volume of the aliquot used for analysis and C is the mass of the sample analysed.

Lycopene content was determined by extracting a 20 g sample of fresh fruit using 40–50 mL of acetone in 4–5 separate aliquots. The resulting extracts were filtered and the acetone was evaporated under reduced pressure until a dry residue remained. Petroleum ether was then added to the residue and the final volume was adjusted to 25 mL. The optical density (OD) at 505 nm was measured using a spectrophotometer. Lycopene concentration was calculated using the formula: (A / B) × OD at 505 nm, where A represents the final solution volume (25 mL) and B denotes the initial sample mass (20 g). Results were expressed as milligram of lycopene per 100 g of fresh weight.

Measurement of fruit firmness, physiological weight loss, ripening percentage and percentage of rotting

The firmness of randomly chosen fruits (3 from each group) was assessed using a Texture Analyzer (Model TA-Hdi, Stable Microsystem, UK) with a stainless-steel probe measuring 2 mm in diameter and the results were reported in grams of force (g force).

The percentage of weight loss during each storage interval was determined by deducting the final weight from the initial weight of the fruits, allowing evaluations of physiological weight loss. This physiological weight loss was calculated based on fresh weight, following the formula:

$$(A-B) / A \times 100$$

where A represents the weight of the fruit before storage and B denotes the weight after the storage period.

The percentage of fruit ripening was determined by assessing the total number of ripe fruits and evaluating their appearance and preferred colour using the Royal Horticultural Society (RHS) Colour Chart. These findings were represented as percentages. The formula used to calculate the ripening percentage is:

$$A/B \times 100$$

where A stands for the number of fully ripe fruits and B indicates the total number of fruits.

To estimate the percentage of rotten fruits, the total number of rotten specimens was counted based on their appearance and the results were also presented as a percentage. The formula for calculating the rotting percentage is:

$$A/B \times 100$$

where A represents the number of rotten fruits and B is the total number of fruits.

Statistical analysis

The experiment was conducted as a two-factor factorial arrangement in a completely randomized design (CRD) and all data were expressed as the mean value of triplicate replications. Differences between treatments were assessed for significance using the critical difference test at a 5 % level of significance ($p \leq 0.05$), as outlined in the Fisher and Yates table (11).

Result and Discussion

Physiological loss in weight (PLW)

During the ripening process, paprika fruits exhibited a gradual

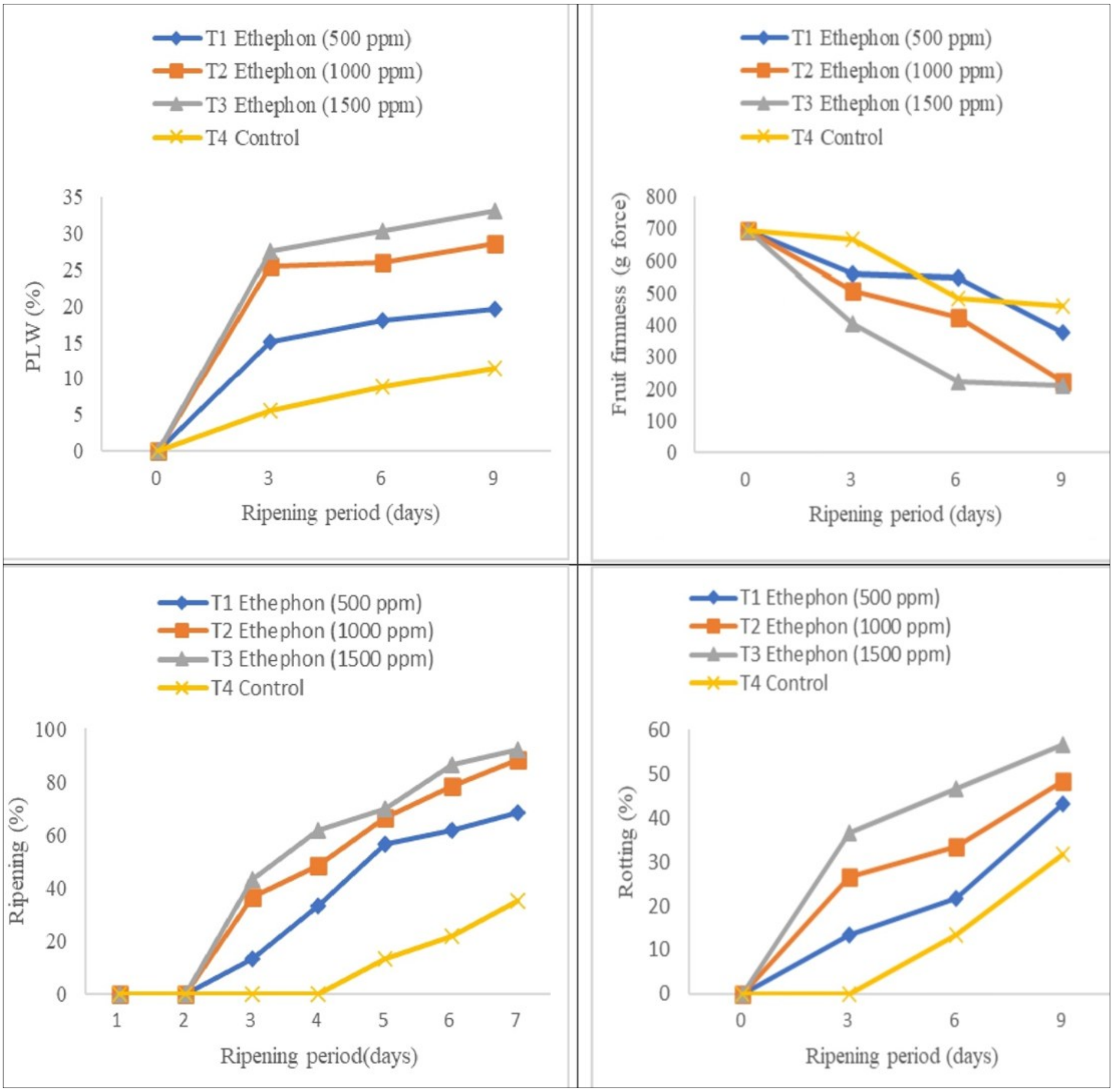

Fig. 1 . Effect of ethephon on PLW (%), fruit firmness (g force), ripening (%) and rotting (%) of mature green paprika.

increase in physiological weight loss as ethephon concentration increased, with statistically significant differences among treatments (Fig. 1). The control fruits exhibited the minimal Physiological loss in weight (PLW) at 6.44 %, whereas the application of 1500 ppm ethephon induced the maximum PLW, reaching 22.01 %. Intermediate concentrations of ethephon, specifically 1000 and 500 ppm, resulted in PLW values of 20.01 % and 13.12 % respectively. Throughout the ripening period of 3–9 days, untreated fruits maintained the lowest weight loss, ranging from 5.51–11.40 %, compared to the 1500 ppm ethephon treatment, which showed PLW values between 27.55 % and 33.15 % during the same timeframe. The increase in ethephon concentration led to a higher ripening percentage due to enhanced respiratory climacteric, resulting in greater moisture loss and, consequently, more weight loss compared to the control. The heightened PLW observed in paprika fruits subjected to 1500 ppm ethephon during ripening may be ascribed to an augmented metabolic respiration rate. Similar increases in weight loss during ripening, induced by ethephon or its analogues, have been reported in tomato and banana fruits (7, 12, 13). The correlation between higher ethephon concentrations and increased respiration rates is believed to be responsible for the observed PLW during ripening. As ethephon concentration rose, the ripening percentage also increased. Additionally, a significant interaction was noted between the treatment and the ripening period.

Fruit firmness

The study on fruit firmness revealed that various treatments significantly affected the firmness of paprika fruits during ripening. The data indicated a general downward trend in fruit firmness as ripening progressed (Fig. 1). Throughout all stages of ripening, the control fruits retained the greatest firmness, measuring 575.5 g force, with fruits treated with 500 ppm ethephon displaying a slightly lower firmness of 543.3 g force. In contrast, the lowest mean firmness was observed in fruits subjected to 1500 ppm ethephon treatment, recording a value of 382.7 g force. Throughout the ripening process, untreated fruits and those treated with 500 ppm ethephon retained higher firmness compared to fruits treated with higher ethephon concentrations (1000 and 1500 ppm). A correlation was observed between increasing ethephon concentration (500–1500 ppm) and decreasing fruit firmness during ripening. Over the 9 day ripening period, control fruits maintained the highest firmness, ranging from 693.3– 460.2 g force. In contrast, fruits treated with 1500 ppm ethephon experienced rapid firmness loss, ranging from 693.3–210.4 g force, resulting in excessive softening and shrivelling. Fruits treated with 500 ppm ethylene showed a more gradual decrease in firmness (693.3–376.3 g force) over the 9 day period. The interaction effect between treatment and ripening duration was found to be statistically nonsignificant. The decline in fruit firmness observed during ripening is primarily associated with enzymatic breakdown of insoluble protopectin into soluble pectin, as well as cellular degradation mechanisms that increase plasma membrane permeability (14). The disintegration of pectic substances within the middle lamella of the cell wall is considered a pivotal event in the ripening process, leading to compromised cell wall structure and progressive softening of the fruit tissue (15). Comparable findings were reported in tomato (16).

Ripening

Significant variations in ripening percentage were observed among different treatments during the ripening process (Fig. 1). The maturation of paprika fruits progressed throughout the ripening period. After 9 days, the ethephon 1500 ppm treatment yielded the highest ripening percentage (50.57 %), while the control group showed the lowest at 10.00 %. As ethephon concentration increased from 500–1500 ppm over the 9 day ripening period, the fruit ripening percentage rose. However, this also led to over 35 % fruit rot, rendering the produce unsellable. A notable interaction was found between treatments and ripening duration. The data indicated that higher ethephon concentrations correlated with increased ripening percentages. The expedited ripening induced by postharvest ethephon application is attributed to the binding of ethylene to its receptors, leading to the formation of an activated receptor-ethylene complex that initiates a cascade of physiological responses, including the activation of ripening mechanisms. Comparable acceleration of the ripening process following postharvest application of ethylene or its synthetic analogues has been reported in various fruit species: pepper (17), tomato (18–20), mango (21, 22), guava (23) and kiwi fruit (24, 25).

Rotting/decay

The study on paprika fruit decay showed that different treatments significantly influenced fruit deterioration during the ripening process (Fig. 1). The decay percentage was observed to increase as the ripening period progressed. The lowest overall spoilage (11.25 %) in terms of decay was noted in untreated fruits, followed by fruits treated with ethephon at 500 ppm (19.58 %). Paprika fruits treated with 1500 ppm ethephon exhibited the highest spoilage of 35.00 %, ranging from 36.67–56.67 % over a 3 to 9 day ripening period. In contrast, untreated fruits had the lowest decay percentage (13.33–31.67 %), while fruits treated with ethephon at 500 ppm showed decay ranging from 13.33–43.33 % during the same period. A significant interaction was found between treatment and ripening duration. The incidence of decay exhibited a positive correlation with the duration of the ripening period. As ethephon concentration increased (500–1500 ppm), both decay and ripening percentage rose simultaneously. After the 6th day of ripening, the decay percentage exceeded acceptable limits in fruits treated with 1000 and 1500 ppm ethephon, reaching 33.33 % and 56.67 % respectively, rendering them unmarketable. The higher decay rates in ethephon-dipped treatments may be attributed to direct water contact with fruits, as undetected injuries on the fruit's surface could absorb water during dipping, creating entry points for fungal infections. Increased decay with higher ethephon doses is expected due to accelerated respiration rates, leading to excessive softening and fruit spoilage. Untreated (control) and 500 ppm ethephon-treated paprika fruits showed minimal decay of less than 20 % during the 9 day ripening period while achieving maximum and uniform ripening. Similar results were reported in tomato and avocado. The increased incidence of decay observed in fruits subjected to ethephon dip treatments may be attributed to direct contact of the fruits with water. Minor, often imperceptible surface injuries or bruises may facilitate water absorption during dipping, subsequently serving as potential entry sites for fungal pathogens. Furthermore, the higher concentration of ethephon likely accelerates the respiration rate, resulting in excessive softening of the fruit tissues and predisposing them to rapid deterioration and microbial spoilage (26, 27).

Total soluble solids

The impact of varying ethephon concentrations on paprika fruit TSS showed a notable shift during ripening, exhibiting an upward trend as shown in Table 1. Fruits treated with ethephon at 1500 ppm exhibited the highest mean TSS content (12.49 °B), followed by those treated with 1000 ppm (11.82 °B), with both treatments differing significantly. Untreated control fruits displayed the lowest mean TSS content (10.40 °B). A gradual and consistent increase in TSS content was observed across all treatments throughout the ripening process. Mean TSS increased from 7.58–15.13 °B over 0–9 days of ripening. This rise in TSS during ripening may be attributed to increased organic solute concentration due to water loss. Furthermore, it may be attributable to the activation of diverse anabolic and catabolic pathways in the fruits as they undergo physiological preparations for senescence (28). The observed increase in TSS may be attributed to moisture loss from the fruit tissues and the enzymatic hydrolysis of starch and other complex polysaccharides into soluble sugars. This conversion enhances the concentration of soluble carbohydrates, thereby contributing to the overall rise in TSS during ripening or postharvest storage. Untreated fruits showed the lowest mean TSS, while the 1500 ppm treatment yielded the highest. Comparable findings were reported in tomatoes (16, 29), guava (23) and peach (30). After the 9th day of

Table 1. Effect of ethephon treatments on total soluble solids (%) of mature green paprika

Treatments	0D	3D	6D	9D	Mean
Ethephon (500 ppm)	7.580	10.437	11.703	13.837	10.889
Ethephon (1000 ppm)	7.580	10.903	12.703	16.103	11.823
Ethephon (1500 ppm)	7.580	11.037	13.247	18.093	12.489
Control	7.580	10.197	11.297	12.490	10.391
Mean	7.580	10.643	12.238	15.131	
	Days (D)		Treatment (T)		D × T
S. Em. ±	0.032		0.032		0.064
CD (0.05)	0.092		0.092		0.184

storage, TSS gradually decreased, possibly due to advanced ripening leading to substantial sugar utilisation. Consequently, TSS data was only recorded until the 9th day of storage. A statistically significant interaction effect was detected between the treatment variables and the ripening duration.

Titratable acidity

Paprika fruits treated with ethephon showed a decreasing trend in TA during ripening. The highest acidity was found in the 1500 ppm treatment (0.52 %), followed by 1000 ppm (0.48 %), while control fruits exhibited the lowest acidity (0.42 %). A significant interaction effect was identified between the treatment and ripening period (Table 2). The gradual decline in TA throughout the ripening process can be attributed to the metabolic consumption of organic acids via pyruvate decarboxylation, a key pathway involved in fruit maturation (31, 32). Additionally, increased membrane permeability during ripening facilitates the accelerated respiration of acids previously sequestered within vacuoles. Similar observations were reported in tomatoes (16, 33, 34). Comparable results were also noted in guava (23) and mango (21, 22).

Ascorbic acid

Significant differences were observed among treatments regarding ascorbic acid content, as well as the interaction between treatment and ripening period (Table 3). Ascorbic acid concentration increased as ripening progressed. The highest ascorbic acid (57.52 mg/100 g fruit weight) was found in fruits treated with ethephon at 1500 ppm, while the lowest (26.48 mg/100 g fruit weight) was observed in untreated (control) fruits. The elevated ascorbic acid concentration may be attributed to the upregulation of metabolic pathways that enhance the biosynthesis of intermediates, thereby increasing the availability of precursors for ascorbic acid synthesis (21). Increased ascorbic acid content in tomato treated with ethephon was also reported (17, 39). Comparable findings were noted in guava also (23).

Lycopene concentration

Analysis of the data revealed that lycopene levels increased as the ripening period progressed (Table 4). Pronounced variations were detected across all treatment conditions and their interactions throughout the ripening process. The ethephon treatment at 1500 ppm yielded the highest lycopene content (72.65 mg/100 g fruit weight), while control fruits exhibited the lowest concentration (54.37 mg/100 g fruit weight). A statistically significant interaction was detected between the applied treatment and the length of the ripening period. The lycopene concentration in the fruits exhibited a positive correlation with the length of the ripening period. The ethylene 1500 ppm treatments produced the highest lycopene levels, whereas untreated (control) fruits showed the lowest lycopene content during ripening. Comparable findings were reported on tomatoes (34).

Conclusion

In India, ripe paprika fruits are generally cultivated for pickle production because a large portion of Indians are vegetarian and consume pickles on a daily basis, with the main course. Ripe or colour-developed paprika fruits have a potential market to fulfil this demand. However, the development of full red in paprika fruit takes a long time. Therefore, in order to overcome such difficulties, fully mature fruits could be treated with different concentrations of ethephon after harvesting. In our research findings, when fully mature green paprika fruits were treated with 1500 ppm ethephon solution then it took 9 days for full red colour development, as compared to other concentrations of ethephon, i.e., 500 and 1000 ppm. However, the demerit is that physiological loss in weight, fruit firmness and fruit rotting was found to be the highest. On the other hand, treatment with 500 ppm showed inferior colour development compared to the higher doses. Although paprika fruit treated with 1000 ppm ethephon showed an intermediate effect of both the higher and lower dose and hence, full red colour development was more or

Table 2. Effect of ethephon treatments on titratable acidity (%) of mature green paprika

Treatments	0D	3D	6D	9D	Mean
Ethephon (500 ppm)	0.630	0.500	0.390	0.300	0.455
Ethephon (1000 ppm)	0.630	0.520	0.433	0.340	0.481
Ethephon (1500 ppm)	0.630	0.573	0.467	0.403	0.518
Control	0.630	0.477	0.360	0.220	0.422
Mean	0.630	0.518	0.413	0.316	
	Days (D)		Treatment (T)		D × T
S. Em. ±	0.007		0.007		0.014
CD (0.05)	0.020		0.020		0.040

Table 3. Effect of ethephon treatments on ascorbic acid (mg/100 g) of mature green paprika

Treatments	0D	3D	6D	9D	Mean
Ethephon (500 ppm)	16.027	21.373	36.300	40.933	28.658
Ethephon (1000 ppm)	16.027	24.117	44.000	83.300	41.861
Ethephon (1500 ppm)	16.027	26.620	74.800	112.660	57.527
Control	16.027	20.223	31.190	38.500	26.485
Mean	16.027	23.083	46.573	68.848	
	Days (D)		Treatment (T)		D × T
S. Em. ±	1.751		1.751		3.501
CD (0.05)	5.066		5.066		10.132

Table 4. Effect of ethephon treatments on lycopene content (mg/100 g) of mature green paprika

Treatments	0D	3D	6D	9D	Mean
Ethephon (500 ppm)	0.727	64.257	77.367	85.433	56.946
Ethephon (1000 ppm)	0.727	75.637	80.003	105.490	65.464
Ethephon (1500 ppm)	0.727	79.097	91.200	119.600	72.656
Control	0.727	59.653	74.347	82.753	54.370
Mean	0.727	69.661	80.729	98.319	
	Days (D)		Treatment (T)		D × T
S. Em. ±	0.224		0.224		0.447
CD (0.05)	0.647		0.647		1.295

less at par with paprika fruits when treated with 1500 ppm ethephon solution and also showed better physiochemical quality as compared to the other ethephon concentration. Thus, we can recommend ethephon at 1500 ppm for immediate use, such as the local market or short-distance market. However, for long-distance markets, we can recommend ethephon at 1000 ppm, so that the fruits get quality time during transportation or storage or at the processing unit where the treated fruits show maximum desirable characteristics and most importantly the gradual development of full red colour.

Acknowledgements

The authors are grateful for the financial help provided by the Department of Pomology and Post Harvest Technology, Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar 736 165 West Bengal, India.

Authors' contributions

AK and SA carried out the data recording, statistical analysis and writing of the original draft. MPD, PKP, RC, AC, AG and LH, the remaining authors, suggested the final editing and suggestions for the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

Declaration of generative AI and AI-assisted technologies in the writing process

Grammarly and ChatGPT AI tools are used to enhance the sentence's meaning and correct grammatical mistakes.

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