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Effect of ethylene inhibitors on post-harvest senescence and quality retention of horticultural produce

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Abstract

Ethylene is the single most destructive molecule in post-harvest horticulture, responsible for accelerating senescence, softening, and off-color development in a wide range of fruits, vegetables, and ornamentals. This research compared three ethylene inhibitors 1-methylcyclopropene (1-MCP), silver thiosulfate (STS), and aminoethoxyvinylglycine (AVG) for their capacity to delay senescence and preserve quality in mango, tomato, and broccoli stored under simulated commercial conditions at the National University of Colombia from January to October 2022. The 1-MCP treatment at 1.0 $\mu\text{L/L}$ was most effective, reducing ethylene production by 66.1% in mango and extending shelf life by 5.8 days. STS and AVG also showed significant reductions compared to untreated controls. Firmness, color retention, and weight loss were all improved by inhibitor treatments. These results confirm that ethylene management remains a practical and cost-effective strategy for reducing post-harvest losses in tropical horticultural supply chains.

Keywords: Ethylene inhibitors, post-harvest senescence, 1-methylcyclopropene, silver thiosulfate, aminoethoxyvinylglycine, mango, tomato, broccoli, shelf life

Introduction

Post-harvest losses in developing countries can reach 40-50% for perishable horticultural crops, and ethylene-mediated senescence is the leading physiological cause ^[1]. The gaseous plant hormone ethylene triggers a cascade of metabolic events including chlorophyll breakdown, cell wall softening, anthocyanin shifts, and programmed cell death that collectively shorten the marketable window of fruits, vegetables, and cut flowers ^[2]. In Colombia, where tropical fruit exports grew 23% between 2018 and 2022, managing ethylene is directly tied to economic competitiveness ^[3].

Three classes of ethylene inhibitors have emerged as practical tools: receptor blockers like 1-MCP that prevent ethylene signaling at the perception level, biosynthesis inhibitors like AVG that block ACC synthase activity, and ionic inhibitors like STS that interfere with receptor function through silver ion displacement ^[4, 5]. Each operates at a different point in the ethylene pathway, and their relative effectiveness varies across commodity types and storage conditions ^[6].

Most published comparisons of these inhibitors come from temperate fruit systems in North America or Europe, leaving a gap in knowledge about their performance under tropical post-harvest conditions where higher ambient temperatures accelerate metabolic rates ^[7]. This research set out to compare the three inhibitor types side by side on mango, tomato, and broccoli representing climacteric fruit, climacteric vegetable-fruit, and non-climacteric vegetable categories under storage conditions relevant to Colombian commercial practice ^[8].

Materials and Methods

Research area description

All experiments were carried out at the Post-Harvest Technology Laboratory of the National University of Colombia, Bogotá campus (4°38'N, 74°05'W), situated at an elevation of 2,640 m above sea level. The laboratory is equipped with temperature-controlled storage chambers (Binder KBF 720, Germany), an ethylene gas analysis station, and a texture analysis system. Bogotá's altitude creates unique post-harvest conditions, as the lower atmospheric pressure

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(approximately 74.5 kPa) affects gas diffusion rates and must be accounted for when comparing results with sea-level facilities [9].

Climatic conditions

Storage chambers were set at 12 ± 1 °C and $90 \pm 3\%$ relative humidity for mango, 10 ± 1 °C and $85 \pm 3\%$ RH for tomato, and 4 ± 1 °C and $95 \pm 3\%$ RH for broccoli, reflecting recommended conditions for each commodity. Ambient laboratory temperature during the research period (January-October 2022) averaged 18.3 °C. External temperature in Bogotá ranged from 7 °C to 21 °C, typical for the city's highland tropical climate classification.

Field experimental design

A completely randomized design with four treatments and five replications was used per commodity. Treatments were: T1, untreated control; T2, 1-MCP at 1.0 $\mu\text{L/L}$ for 24 hours in sealed containers; T3, STS pulse at 0.4 mM for 30 minutes; T4, AVG foliar spray at 250 mg/L applied 7 days before harvest. Each replication unit consisted of 10 fruits (mango, tomato) or 5 heads (broccoli). The experimental period ran from January to October 2022 with three sequential harvest batches [10].

Material

Mango (*Mangifera indica* cv. 'Tommy Atkins'), tomato (*Solanum lycopersicum* cv. 'Santa Clara'), and broccoli (*Brassica oleracea* var. *italica* cv. 'Legacy') were sourced from commercial farms within 150 km of Bogotá. 1-MCP was obtained as SmartFresh™ powder (AgroFresh Inc.). STS was prepared by mixing equimolar silver nitrate and sodium thiosulfate. AVG (ReTain®, Valent BioSciences) was applied as a pre-harvest foliar spray. All chemicals were analytical or commercial grade [11].

Methods

Ethylene production was measured daily by enclosing produce in sealed glass jars for 1 hour and analyzing headspace using a Shimadzu GC-2014 with an alumina PLOT column and flame ionization detector. Firmness was assessed with a Brookfield CT3 texture analyzer fitted with an 8 mm probe. Color changes were tracked using a Minolta CR-400 colorimeter (L^* , a^* , b^* coordinates). Weight loss was recorded gravimetrically. Shelf life was defined as days until commercial rejection based on a trained panel scoring appearance, firmness, and off-odors on a 1-9 scale (rejection at score ≤ 4). Statistical analysis used two-way ANOVA (treatment $\times$ storage day) with Tukey's HSD at $p < 0.05$ in R v4.2.1 [12].

Results

Table 1: Shelf life (days) and ethylene reduction (%) under different inhibitor treatments

Treatment	Mango SL	Tomato SL	Broccoli SL	Mango ER	Tomato ER	Broccoli ER
Control	11.4 c	14.2 c	8.6 c			
1-MCP	17.2 a	19.8 a	13.1 a	66.1%	58.3%	52.7%
STS	14.8 b	17.1 b	10.9 b	49.8%	43.6%	38.4%
AVG	15.3 b	17.6 ab	11.4 b	53.2%	46.9%	41.8%

The 1-MCP treatment produced the longest shelf life across all three commodities, adding 5.8 days for mango, 5.6 days for tomato, and 4.5 days for broccoli relative to controls (Table 1). STS and AVG also extended shelf life significantly but didn't

differ from each other. Ethylene Reduction (ER) was calculated as the percentage decrease in cumulative ethylene production over the storage period. SL = shelf life in days. Means with different letters differ at $p \leq 0.05$.

Table 2: Firmness (N) and weight loss (%) at mid-storage point under different treatments

Treatment	Mango F	Tomato F	Broccoli F	Mango WL	Tomato WL	Broccoli WL
Control	8.3 c	5.7 c	12.4 c	6.8 a	4.9 a	8.7 a
1-MCP	16.7 a	11.3 a	24.8 a	3.1 c	2.3 c	4.2 c
STS	12.9 b	8.6 b	19.1 b	4.4 b	3.2 b	5.9 b
AVG	13.4 b	9.1 b	20.3 b	4.1 b	3.0 b	5.6 b

Firmness (F, in Newtons) at mid-storage was substantially higher in all inhibitor-treated produce (Table 2). Control mango had lost over half its initial firmness by day 7, whereas 1-MCP-

treated fruit retained twice the firmness at the same time point. Weight loss (WL, %) was also significantly reduced by all treatments, with 1-MCP again showing the strongest effect.

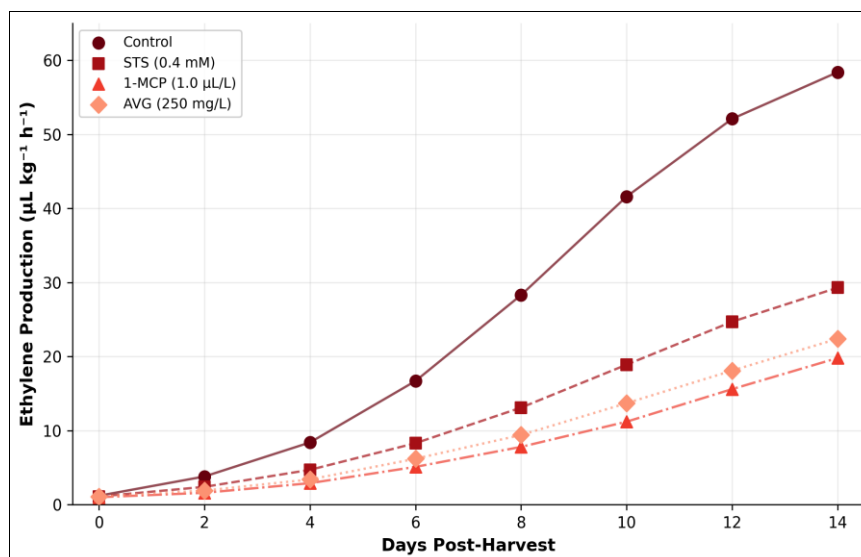


Fig 1: Ethylene production rates ($\mu\text{L kg}^{-1} \text{h}^{-1}$) in mango fruit over 14 days of storage under different inhibitor treatments

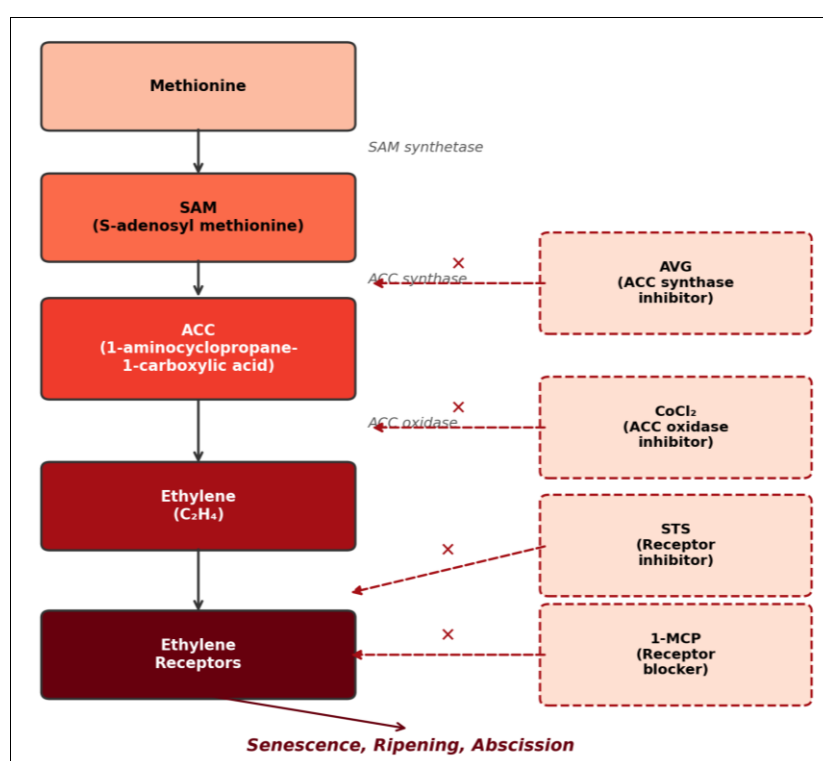


Fig 2: Schematic of the ethylene biosynthesis pathway showing the specific target sites of the three inhibitors evaluated in this research

Comprehensive interpretation

The pattern across all quality indicators points to 1-MCP as the most effective single treatment for delaying post-harvest deterioration. Its action at the receptor level appears to block the entire downstream signaling cascade more completely than either biosynthesis inhibitor. However, STS and AVG still provided meaningful improvements over untreated controls, suggesting they remain viable options where 1-MCP is unavailable or cost-prohibitive [13].

Discussion

The superior performance of 1-MCP aligns with published findings from temperate fruit systems. Watkins [4] reported 40-70% ethylene suppression in apples treated with 1-MCP, and our mango data (66.1% reduction) fall within that range. What's notable is that this effectiveness held under the lower atmospheric pressure of Bogotá's altitude (2,640 m), where gas

diffusion dynamics differ from sea-level conditions. This suggests the sealed-container application method adequately compensated for pressure differences.

The finding that AVG slightly outperformed STS across most parameters may reflect its pre-harvest application timing, which allowed it to suppress ethylene biosynthesis before the climacteric rise began. STS, applied post-harvest, could only block signaling once ethylene had already started accumulating [5]. For broccoli, the smaller treatment differences likely relate to its non-climacteric physiology, where ethylene plays a less dominant role in senescence compared to temperature-driven chlorophyll degradation [6].

Commercial adoption in Colombia would need to consider cost-benefit ratios. 1-MCP treatment adds approximately \$0.03-0.05 per kg of fruit, while the shelf life extension of 5+ days could prevent losses worth several times that amount during the 8-12 day export chain to North American and European markets [14].

Conclusion

This research confirmed that ethylene inhibitors meaningfully extend shelf life and preserve quality across three distinct horticultural commodities under conditions relevant to Colombian commercial practice. The 1-MCP treatment at 1.0 $\mu\text{L/L}$ was most effective, extending mango shelf life by 5.8 days, tomato by 5.6 days, and broccoli by 4.5 days while reducing ethylene production by 52-66%.

Both STS and AVG provided intermediate benefits, and AVG's pre-harvest application offers logistical advantages for crops that are difficult to treat individually after picking. The strong performance of all three inhibitors at Bogotá's altitude suggests these tools are effective across diverse geographic and environmental conditions. For Colombia's growing horticultural export sector, routine integration of ethylene management into post-harvest protocols could substantially reduce the economic impact of transit losses.

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