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# Differential effects of postharvest application of ethylene inhibitors on guava stored under ambient conditions

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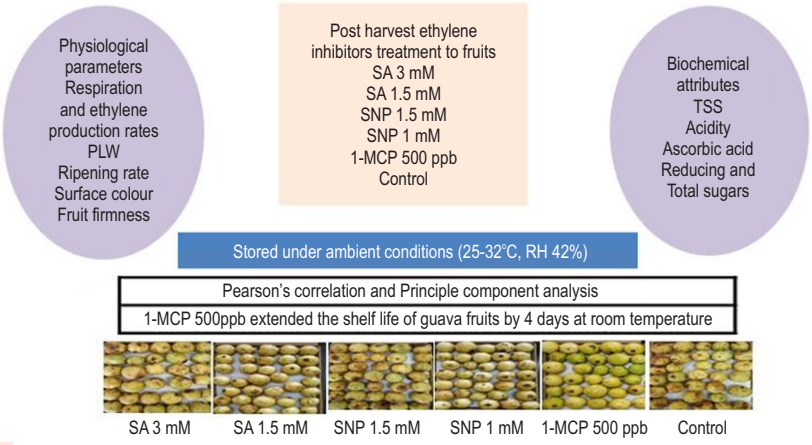
## Abstract

**Aim:** To assess the efficiency of ethylene synthesis and action inhibitors on postharvest shelf life of guava fruits under ambient conditions.

**Methodology:** Mature green guava fruits (*P. guajava* L. cv. Arka Mridula) were harvested and treated with ethylene inhibitors. Various physiological, physical and nutritional changes of the treated fruits in comparison with untreated ones were monitored during ambient temperature storage. Multivariate analysis approach was used for interpreting the data on quality changes during storage.




**Results:** Significant positive correlation ($p<0.01$) was observed among rates of ethylene production, respiration, ripening and Hunter's a* value. Biplot from principal component analysis of eleven parameters showed that 1-MCP (500 ppb) treated fruits were grouped together with freshly harvested fruits throughout storage period, and proved superior over other treatments in delaying ripening and quality maintenance. Seven days stored 3.0 mM Salicylic acid and 1.5 mM Sodium nitroprusside treated fruits were grouped together with 5 days stored control fruits, suggesting their effectiveness in extending the shelf life by additional two days.

**Interpretation:** Postharvest application of 1-MCP on guava fruits can extend the shelf life by four days when compared with control. Even PCA indicated that the study of major ripening attributes (L*, a*, b*, Hue, texture, acidity, ethylene rate and respiration rate) was quite sufficient to know the ripening status of the fruits.

**Key words:** Ethylene inhibitors, Guava, Principal component analysis, Ripening rate, Surface color

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## Introduction

Guava (*Psidium guajava* L.), generally referred as apple of tropics, is a major fruit crop of South Asia, with India being the major producer (Horticulture Statistics, 2018). The fruit is highly preferred for table purpose due to excellent taste and high nutritional attributes such as high ascorbic acid, dietary fibre, pectin and minerals. Guava, being a climacteric fruit, is highly perishable, undergoes rapid postharvest ripening in few days under ambient conditions and gets overripe and mealy within a week (Gill 2016). It has highest postharvest losses reported among fruit crops of India with an average of 15.88% (Sain *et al.,* 2013; Jha *et al.,* 2015). The role of autocatalytic production of ethylene leading to rapid ripening and tissue breakdown in climacteric fruits is a well-established scientific fact (Reyes and Paull 1995; Pech *et al.,* 2008). In view of such circumstances, use of safe compounds to reduce the ethylene production and to curtail the postharvest losses is emerging as new method to extend the shelf life of fruits. Compounds like Salicylic acid, Sodium nitroprusside (NO donor) acts as ethylene synthesis inhibitors and have been successfully reported to extend the shelf life of climacteric and non-climacteric fruits (Manjunatha *et al.,* 2012; Chen *et al.,* 2019). The ethylene action inhibitor compound, 1- Methylcyclopropene (1-MCP) is also reported as successful agent in delay of ripening and shelf-life extension in several fruits (Blankenship and Dole 2003). The effect of different ethylene inhibitors in extending the shelf-life of fruits varies with species and variety, ripening stages, exposure temperature, concentration and duration. There are no reports on testing the relative effectiveness of different ethylene inhibitors on post-harvest quality of fruits such as guava.

Ethylene synthesis inhibitors like SNP and SA are easy to apply on the fruits as they can be applied as liquid formulations, while 1-MCP application in gaseous form requires an airtight chamber. Arka Mridula is a white flesh guava variety released by ICAR-IIHR and becoming popular among farmers due to its soft seeded nature. Parameters like surface colour, texture, physiological loss in weight, ripening rate, TSS, acidity, ascorbic acid, total sugars, respiration rate and ethylene production rate are well coordinated during natural ripening of fruit. However, application of exogeneous ethylene regulators may hamper this harmony, thus affecting the overall quality attributes of the fruit. Much research has been carried out on the effect of ethylene inhibitors on storage life of several fruits, but finding the relationship and correlation between the variables for ripening to provide better scientific insights through multivariate analysis is not attempted. Thus, the objective of this study was to determine the relationship between the ripening attributes and their correlations in guava (cv. Arka Mridula) treated with different ethylene inhibitors (synthesis and action) stored at ambient temperature and to find out a practical approach for extending the shelf life of guava fruits.

## Materials and Methods

Guava (*P. guajava* L. cv. Arka Mridula) were freshly harvested at their harvest maturity (mature green stage) from guava orchards at ICAR-IIHR, Bengaluru during August 2018-2019. Fruits were then sorted to discard the blemished ones if any and graded for uniformity in size and subjected to the following treatments. Fruits were treated with Salicylic acid (SA) at 1.5 mM and 3 mM and Sodium nitroprusside (SNP) at 1 mM and 1.5 mM. Fruits were dipped for 30 min in these solutions separately, surface dried and 3 Kg fruits of each treatment were packed in ventilated CFB boxes in triplicates (20 fruits per replication). In case of 1-MCP treatment, 18 mg of amorphous 1-MCP (0.018% purity) was weighed accurately and taken into a 15 ml test tube. Through an airtight rubber septa fixed to the test tube, 1ml of distilled water was injected into it using calibrated syringe. 1-MCP powder inside the test tube was dissolved by shaking gently to liberate 1-MCP gas.

From the test tube calculated amount (to make it 500 ppb final concentration) of 0.6 ml gaseous 1-MCP was taken using calibrated syringe and injected into the 18 l capacity airtight desiccators in which 6 kg (approximately 50 fruits) of guava fruits were placed. The fruits were removed after 18 hrs of exposure and packed in CFB boxes. All boxes were stored at ambient temperature (25.4-32.2°C and 42% average RH) and various parameters were studied at specified intervals of storage. The respiration and ethylene production rates of treated and untreated fruits were measured during their storage at room temperature in five replicates, and $CO_2$ evolution was measured using an automatic gas analyzer and expressed in mg $kg^{-1}$ $hr^{-1}$. Headspace ethylene concentration was also measured using an ethylene analyser. Evolution of ethylene was calculated and expressed in µl $kg^{-1}$ $hr^{-1}$ (Rao and Rao 2008).

Each ripening stage of the fruit was given a score as mentioned below to calculate the ripening rate based on the visual colour of the fruit. Unripe-1, quarter ripe -2, semi ripe -3, 3/4th ripe -4, full ripe-5. Co-efficient of ripening was calculated using the formula. Co-efficient of ripening = Σ (Number of fruits at a particular ripening stage x its score) / Total number of fruits. Weight of 30 individual fruits in all the treatments were recorded periodically using an electronic balance (Model: Sartorius, BSA 320 2S d=0.01g) and the cumulative physiological loss in weight (CPLW) was calculated and expressed in percentage. The surface colour of the fruits was measured using colorimeter (Model: Colour Reader, CR-10, Konica Minolta, Japan) in terms of Lightness (L*) and Hue (H*) values (Rao and Shivashankara 2018). The readings were taken at three different places on the surface of fruits with five fruits per replications in each treatment. The firmness of fruits was measured using Instron-Universal testing machine (Model 4201, USA), with 8 mm diameter probe, and expressed in kg $cm^{-2}$.

Five fruits were selected randomly from each treatment at different intervals of storage and cut into small pieces. The, samples were then homogenised using a homogenizer (IKA T25 digital ultra Turrax) before analysis. Fruit juice was extracted manually by squeezing the pulp to record TSS in $^0$Brix using hand refractometer calibrated to 25°C (Erma Inc., Tokyo, Japan). All other quality parameters like titratable acidity (TA %), Ascorbic

acid (vitamin C) (mg $100^{-1}$g) and total sugar (TS %) were estimated using standard methods of analysis (AOAC, 1995). The observations recorded under each parameter were statistically analysed using factorial completely randomized design (factor 1 (storage period), factor 2 (treatment). The treatment means were compared using Duncan's new multiple range test and the analysis was carried out using R-software (version-4.0.1) with Agricole package. Principal component analysis (PCA) and Pearson's correlation analysis was carried out using XL-STAT software (version 2019.4.2).

## Results and Discussion

Respiration rate and ethylene evolution rate of guava cv Arka Mridula were measured during storage at room temperature (Fig.1a, 1b). Respiration rate and ethylene production rate gradually increased during storage period in all samples. Exposure to ethylene inhibitors reduced the respiratory and ethylene production rates of guava compared to untreated control. Among all treatments applied, 1-MCP ranked first, followed by SNP 1.5 mM and SA 3 mM in reducing the respiration and ethylene production.

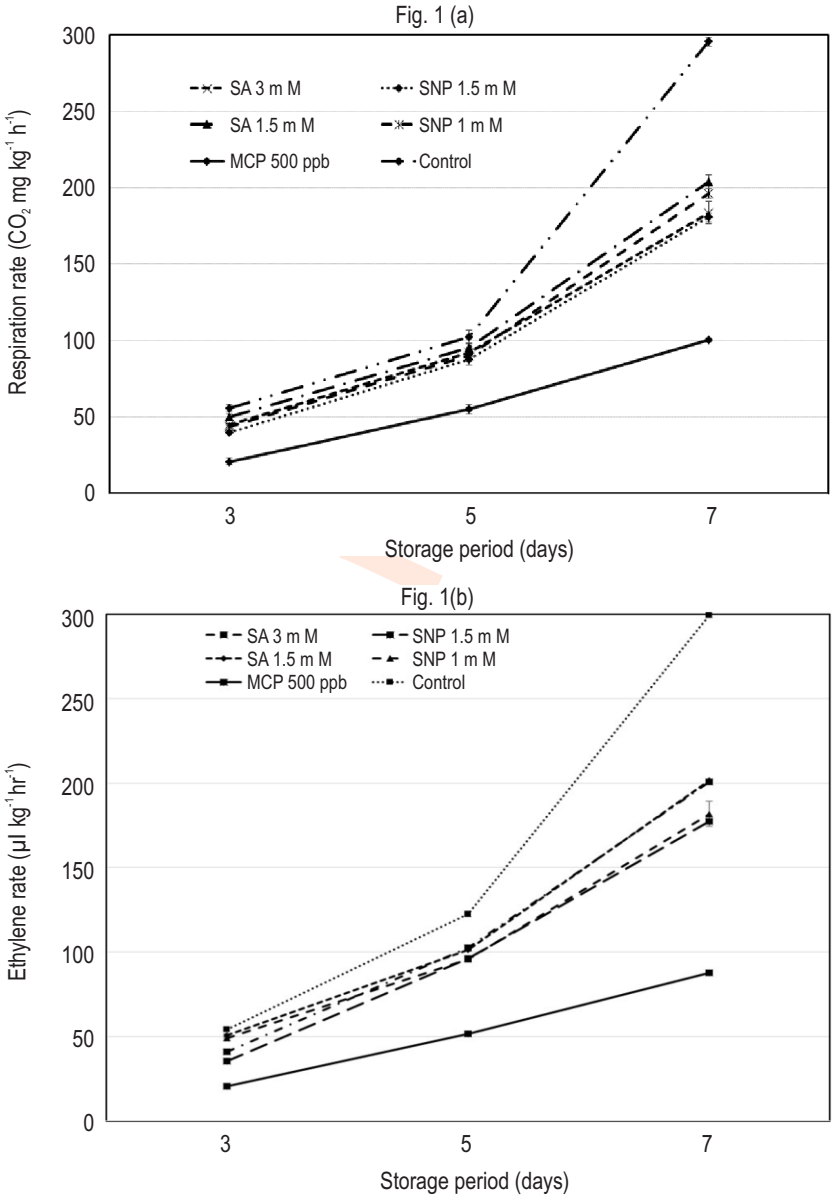


**Fig. 1:** Effect of ethylene inhibitors on respiration rate (1a) and ethylene rate (1b) of guava cv. Arka Mridula at room temperature. Error bar represents ±SE.

Fig. 2(a)

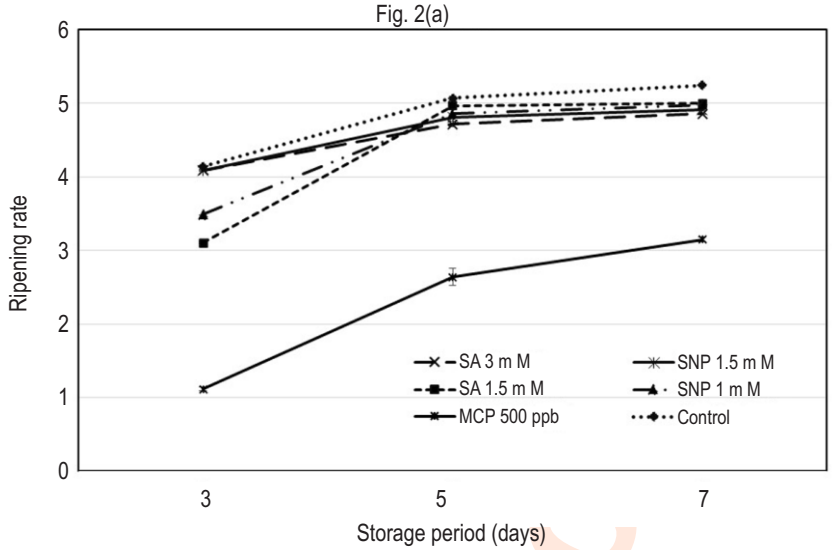


Fig. 2(b)

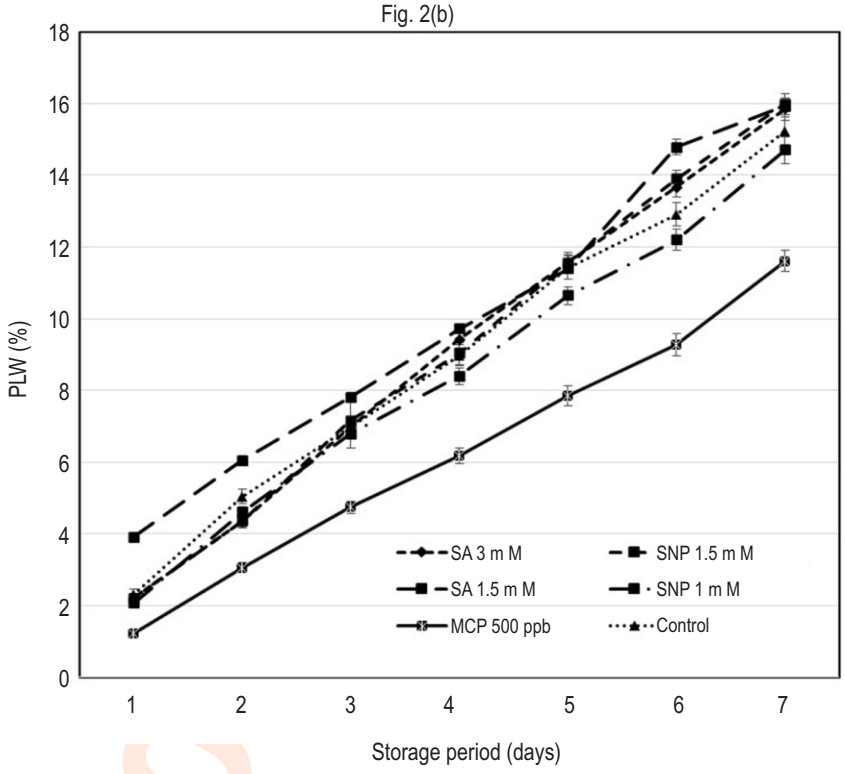


**Fig. 2:** Effect of ethylene inhibitors on ripening rate (2a) and PLW (%) (2b) of guava cv. Arka Mridula at room temperature. Error bar represents ±SE.

SA 3 mM and SNP 1.5 mM treated fruits had lesser amount of ethylene production and respiration rates compared to untreated control and lower concentrations of these compounds. However, fruit colour change (green to yellow) was noticed in these treatments and was almost similar to other concentrations of synthesis inhibitors. However, fruits treated with 1-MCP was different from all other treatments, showing significantly lowest ripening rates. This could be directly attributed to the lower respiration and ethylene production rates (Fig 1a, b). Reduced ethylene synthesis enzymes are reported due to 1-MCP application in several climacteric fruits as a result of absence in autocatalytic ethylene synthesis in fruits (Bassetto *et al.,* 2005).

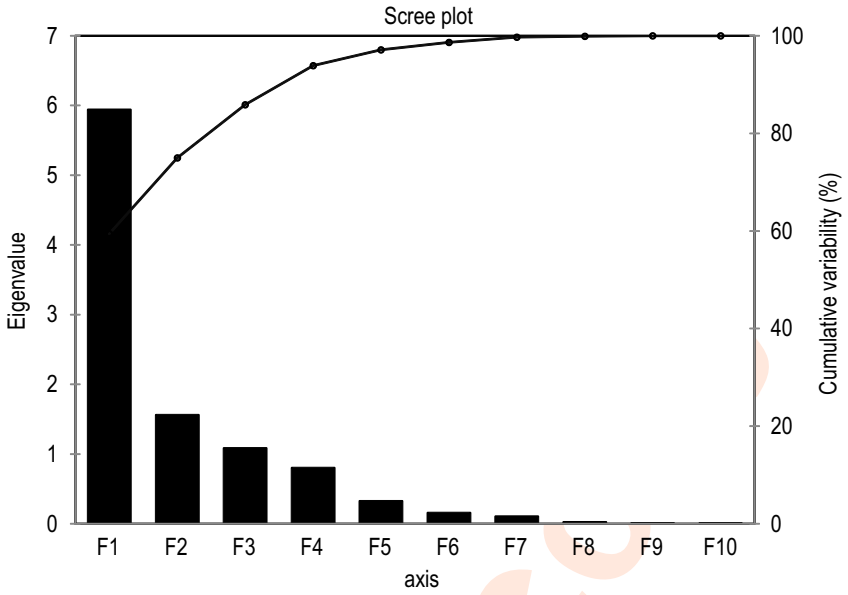


**Fig. 3:** Scree plot explaining the number of principle components to the Principal Component Analysis.

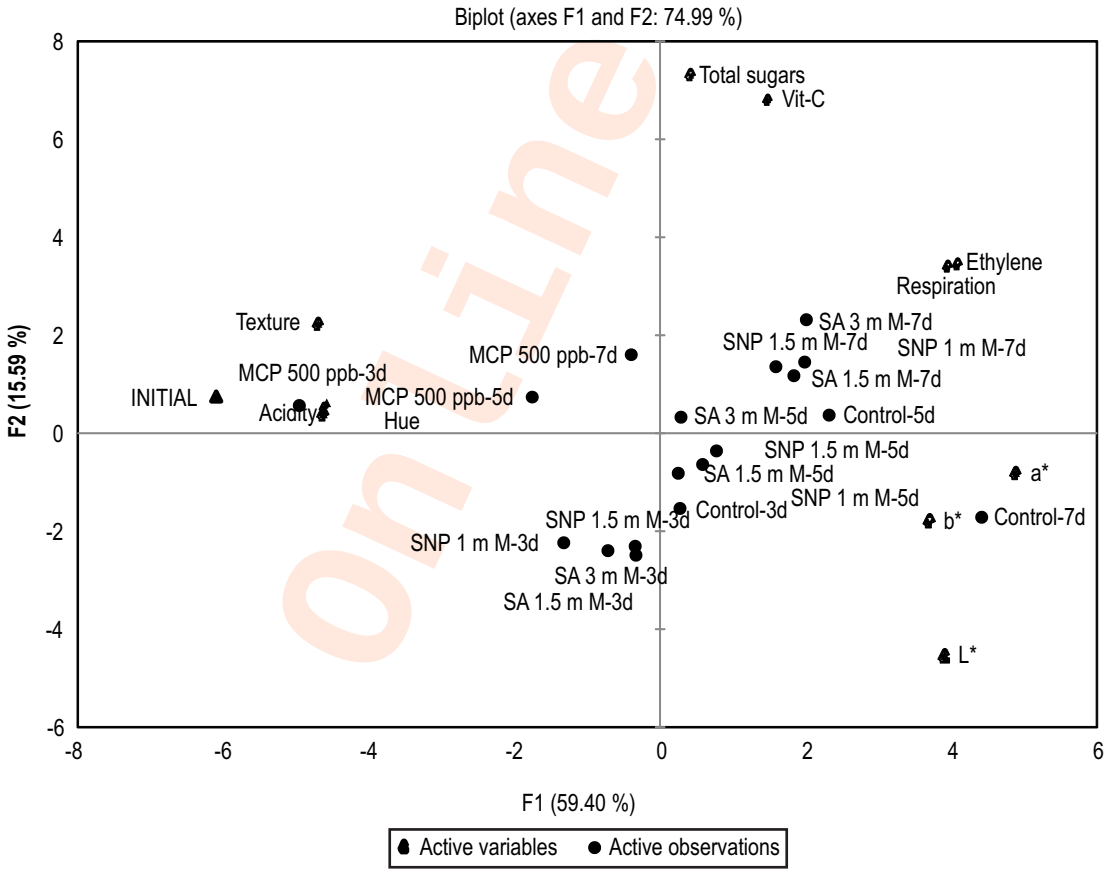


**Fig. 4:** Biplot for different variables of guava treated with ethylene inhibitors stored at room temperature.

**Table 1:** Effect of ethylene inhibitors on surface colour and firmness of guava fruits (cv. Arka Mridula) stored under ambient conditions

| Treatments | Surface colour | | | | | | | | Texture (kg cm$^{-2}$) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | L* values | | | | Hue values | | | | | | | |
| | 3 days | 5 days | 7 days | Mean | 3 days | 5 days | 7 days | Mean | 3 days | 5 days | 7 days | Mean |
| SA 1.5mM | 67.36$^{d}$ | 57.52$^{j}$ | 57.62$^{j}$ | 60.83$^{c}$ | 80.13$^{g}$ | 79.16$^{h}$ | 70.70$^{l}$ | 76.66$^{f}$ | 6.71$^{ij}$ | 6.63$^{ij}$ | 6.50$^{j}$ | 6.61$^{d}$ |
| SA 3 mM | 66.56$^{de}$ | 62.90$^{f}$ | 60.63$^{gh}$ | 63.36$^{b}$ | 82.98$^{e}$ | 79.18$^{h}$ | 77.41$^{ij}$ | 79.86$^{d}$ | 6.25$^{jk}$ | 5.99$^{k}$ | 5.39$^{l}$ | 5.87$^{e}$ |
| SNP 1 mM | 62.97$^{f}$ | 65.85$^{e}$ | 62.80$^{f}$ | 63.87$^{b}$ | 83.16$^{e}$ | 81.93$^{f}$ | 76.55$^{k}$ | 80.54$^{c}$ | 10.40$^{d}$ | 8.25$^{f}$ | 7.04$^{hi}$ | 8.56$^{b}$ |
| SNP1.5 mM | 61.20$^{g}$ | 69.09$^{c}$ | 60.37$^{ghi}$ | 63.55$^{b}$ | 84.69$^{d}$ | 82.01$^{f}$ | 77.90$^{i}$ | 81.53$^{b}$ | 9.39$^{e}$ | 7.59$^{g}$ | 7.21$^{gh}$ | 8.06$^{c}$ |
| MCP 500 ppb | 47.47$^{k}$ | 59.23$^{i}$ | 59.76$^{hi}$ | 55.49$^{d}$ | 111.45$^{a}$ | 103.44$^{b}$ | 88.07$^{c}$ | 100.99$^{a}$ | 25.96$^{a}$ | 15.48$^{b}$ | 14.25$^{c}$ | 18.56$^{a}$ |
| Control | 70.89$^{b}$ | 69.09$^{c}$ | 72.49$^{a}$ | 70.82$^{a}$ | 79.03$^{h}$ | 81.49$^{f}$ | 77.01$^{jk}$ | 79.18$^{e}$ | 4.19$^{m}$ | 2.98$^{n}$ | 1.27$^{o}$ | 2.81$^{f}$ |
| Mean | 62.74$^{b}$ | 63.94$^{a}$ | 62.28$^{b}$ | | 86.91$^{a}$ | 84.54$^{b}$ | 77.94$^{c}$ | | 10.48$^{a}$ | 7.87$^{b}$ | 6.94$^{c}$ | |

**Table 2:** Effect of ethylene inhibitors on TSS and acidity of guava fruits (cv. Arka Mridula) stored under ambient conditions

| Treatments | TSS $^{o}$B | | | | Acidity (%) | | | |
|---|---|---|---|---|---|---|---|---|
| | 3 days | 5 days | 7 days | Mean | 3 days | 5 days | 7 days | Mean |
| SA 1.5 mM | 13.2$^{bcdef}$ | 13.3$^{bcde}$ | 14.9$^{a}$ | 13.8$^{bc}$ | 0.83$^{c}$ | 0.72$^{de}$ | 0.64$^{gh}$ | 0.73$^{b}$ |
| SA 3 mM | 12.0$^{efgh}$ | 13.3$^{bcde}$ | 14.2$^{abc}$ | 13.2$^{cd}$ | 0.75$^{d}$ | 0.69$^{efg}$ | 0.62$^{h}$ | 0.69$^{c}$ |
| SNP 1 mM | 14.5$^{ab}$ | 15.0$^{a}$ | 15.2$^{a}$ | 14.9$^{a}$ | 0.70$^{ef}$ | 0.70$^{ef}$ | 0.57$^{i}$ | 0.66$^{d}$ |
| SNP1.5 mM | 13.7$^{abcd}$ | 14.2$^{abc}$ | 15.2$^{a}$ | 14.4$^{ab}$ | 0.66$^{fgh}$ | 0.63$^{h}$ | 0.35$^{l}$ | 0.55$^{e}$ |
| MCP 500 ppb | 11.0$^{h}$ | 12.5$^{defgh}$ | 14.3$^{abc}$ | 12.6$^{de}$ | 1.0$^{a}$ | 1.00$^{b}$ | 0.99$^{b}$ | 0.99$^{a}$ |
| Control | 12.8$^{cdefg}$ | 11.8$^{fgh}$ | 11.7$^{gh}$ | 12.1$^{e}$ | 0.72$^{de}$ | 0.52$^{j}$ | 0.44$^{k}$ | 0.56$^{e}$ |
| Mean | 12.9$^{b}$ | 13.3$^{b}$ | 14.2$^{a}$ | | 0.77$^{a}$ | 0.71$^{b}$ | 0.60$^{c}$ | |
| At harvest | 13.2 | | | | 1.1 | | | |

A gradual increase in PLW irrespective of the treatments was noticed along the storage period (Fig. 2b). Ethylene synthesis inhibitors did not have a significant impact on PLW during the storage. However, 1–MCP 500 ppb treated fruits showed quite lesser PLW probably due to the lowest respiration observed which in turn contributed to low transpiration rates. Reduced PLW in 1-MCP treated guava fruits were also reported by (Phebe and Ong, 2010). Fruit surface colour is the most important character used by consumers to judge the fruit ripening stage in guava; with dark green, light green and yellow colour indicating the stages viz., less mature, mature and fully ripe stage respectively (Lo'ay and El Khateeb, 2011). Hunter's L* a* b* values and the derived values like Hue angle (Ho) is the measurement of colour in which, 0$^{o}$ is related to red colour, 90$^{o}$ is related to yellow colour, 180$^{o}$ to green and 270$^{o}$ to blue (Abreu *et al.,* 2012). At harvest, the measured L* value was 42.53 and Hue angle was 120.34, which gradually changed at different rates during storage in different treatments (Table 1). The highest L* value was recorded in untreated control fruits all along the storage period, while 1-MCP treated fruits showed lower L* value. Fruits treated with ethylene synthesis inhibitors also had higher L* value showing signs of ripening (Fig 2a). Synthesis inhibitors treated fruits had higher L* value initially which gradually decreased due to uneven browning on fruit surface showing signs of deterioration. Fruit colour mainly depends on the relative concentration of chlorophyll and carotenoids. Loss of green colour is due to catabolism of chloroplasts and increased anabolism of carotenoids (Charoenchongsuk e*t al.,* 2018). Chloropyllase, the major enzyme which degrades chlorophyll is inhibited by 1-MCP (Escribano *et al.,* 2017), clearly evidenced by higher Hue angles in 1-MCP treated fruits, indicating more greenness. The texture of fruits is another major character in guava to decide fruit ripening status (Table 1). At harvest, the texture measured was 27.86 kg cm$^{-2}$ which decreased gradually over the period of storage. Irrespective of the concentrations of ethylene synthesis inhibitors used, the firmness decreased to 5-7 kg cm$^{-2}$ during storage. But, 1-MCP treated fruits maintained higher mean firmness values (18.56 kg cm$^{-2}$) showing lower activity of enzymes responsible for pectin and cell wall degradation. Thus, 1- MCP treated fruits retained better consumer acceptability through maintenance of surface colour and texture till the end of storage period.

Biochemical parameters of guava fruits were quite influenced by different treatments (Table 2). The TSS of freshly harvested Arka Mridula guava fruits was 13.2$^{o}$B and an increase in TSS as storage period prolonged indicates ripening. TSS increased in all samples during storage at significantly different levels among the treatments showing change in ripening status. The acidity of freshly harvested guava was 1.1%, and ripening reduced acidity. Untreated (control) fruits showed lower acidity during storage indicating higher ripening, while 1-MCP treated

**Table 3:** Effect of ethylene inhibitors on ascorbic acid and total sugars of guava fruits (cv. Arka Mridula) stored under ambient conditions

| Treatment | Ascorbic Acid (mg 100g$^{-1}$) | | | | Total Sugars (%) | | | |
|---|---|---|---|---|---|---|---|---|
| | 3 days | 5 days | 7 days | Mean | 3 days | 5 days | 7 days | Mean |
| SA 1.5 mM | 90.24$^{i}$ | 105.60$^{c}$ | 121.33$^{a}$ | 105.73$^{a}$ | 6.24$^{i}$ | 7.13$^{g}$ | 7.85$^{e}$ | 7.07$^{d}$ |
| SA 3 mM | 92.95$^{h}$ | 102.39$^{d}$ | 111.30$^{b}$ | 102.22$^{b}$ | 6.18$^{i}$ | 7.02$^{g}$ | 8.01$^{de}$ | 7.07$^{d}$ |
| SNP 1 mM | 83.42$^{j}$ | 90.53$^{i}$ | 95.49$^{g}$ | 89.81$^{e}$ | 6.28$^{i}$ | 8.23$^{cd}$ | 9.32$^{b}$ | 7.94$^{b}$ |
| SNP1.5 mM | 84.28$^{j}$ | 99.66$^{f}$ | 101.55$^{de}$ | 95.16$^{c}$ | 6.51$^{h}$ | 8.28$^{c}$ | 9.11$^{b}$ | 7.97$^{b}$ |
| MCP 500 ppb | 91.24$^{i}$ | 92.49$^{h}$ | 95.31$^{g}$ | 93.01$^{d}$ | 7.20$^{g}$ | 9.30$^{b}$ | 10.50$^{a}$ | 9.00$^{a}$ |
| Control | 100.61$^{ef}$ | 105.33$^{c}$ | 80.27$^{k}$ | 95.40$^{c}$ | 7.59$^{f}$ | 9.31$^{b}$ | 6.05$^{i}$ | 7.65$^{c}$ |
| Mean | 90.46$^{c}$ | 99.33$^{b}$ | 100.87$^{a}$ | | 6.67$^{c}$ | 8.21$^{b}$ | 8.47$^{a}$ | |
| At harvest | 120 | | | | 6.45 | | | |

**Table 4:** Correlation matrix based on Pearson's Correlation Coefficient between different parameters for ripening.

| Variables | L* | a* | b* | Hue | Texture | Acidity | Vit C | Total sugars | Ethylene | Respiration | Ripening rate |
|---|---|---|---|---|---|---|---|---|---|---|---|
| L* | 1 | | | | | | | | | | |
| a* | **0.605**** | 1 | | | | | | | | | |
| b* | **0.589**** | **0.489*** | 1 | | | | | | | | |
| Hue | **-0.550**** | **-0.979**** | -0.322 | 1 | | | | | | | |
| Texture | **-0.789**** | **-0.915**** | **-0.524*** | **0.888**** | 1 | | | | | | |
| Acidity | **-0.513*** | **-0.818**** | **-0.497*** | **0.767**** | **0.783**** | 1 | | | | | |
| Vitamin C | -0.206 | 0.314 | -0.136 | -0.376 | -0.224 | -0.174 | 1 | | | | |
| Total sugars | -0.156 | -0.134 | 0.051 | 0.113 | 0.178 | 0.054 | 0.362 | 1 | | | |
| Ethylene | 0.227 | **0.674**** | **0.553*** | **-0.572**** | **-0.513*** | **-0.706**** | 0.241 | 0.157 | 1 | | |
| Respiration | 0.223 | **0.644*** | **0.533*** | **-0.544*** | **-0.483*** | **-0.684**** | 0.188 | 0.174 | **0.993**** | 1 | |
| Ripening rate | **0.612**** | **0.910*** | **0.484*** | **-0.886**** | **-0.899**** | **-0.829**** | 0.387 | 0.055 | **0.670**** | **0.636**** | 1 |

*, ** means a significance of p = 0.05 and p = 0.01, respectively. **Bold numerical** indicate the significance, Data which are not bold indicates non significance

fruits had higher acidity compared to all other treatments indicating slower ripening. Ripening and storage played a major role in ascorbic acid content of guava fruits (Table 3). Vitamin C increases during ripening and gradually decreases as the fruit over ripens (Bashir and Abu-Goukh 2003). Similar trend was noticed in this study too, as untreated control fruits had highest ascorbic acid content after 5 days, with subsequent reduction during prolonged storage of 7 days, coinciding with over ripening stage. However, Vitamin C content in ethylene inhibitors treated guava fruits was recorded higher after 7 days storage indicating delay in ripening. Ethylene inhibitors treatment has been proposed to reduce the accumulation of active oxygen species in fruit which in turn may help to prevent loss of Vitamin C (Larrigaudiere *et al.,* 2004; Azzolini *et al.,* 2005).

Ripening leads to increased sugars in the fruits mainly due to conversion of starch and organic acids into simple sugars. A rise in sugars in all treatments was observed, while in untreated control fruits there was decline in sugars after 5 days of storage (Table 3). This was the reason for loss of sweetness, mealy taste and poor nutritional quality of guava beyond full ripe stage. Untreated control fruits had lower Vitamin C, sugars and acidity making fruits unacceptable beyond 5 days of storage. Interestingly, all quality parameters clearly showed that 1-MCP 500 ppb treated fruits enhanced shelf life by maintaining all freshness attributes including higher sugars till 7 days storage period making them taste good with high acid sugar blend. Further, the 1-MCP 500 ppb treated fruits remained green and firm suitable for table purpose. The results were in conformity with that reported in pear fruits where 1-MCP treatment with different concentrations had minimum weight loss, maintained acceptable firmness and quality attributes for 75 days under 0-1°C (Mahajan *et al.,* 2010). Pearson correlation analysis can be used to find the correlation between two parameters. In this study, parameters responsible for ripening were correlated. Interestingly, there were multiple sets of significant correlations (with p=0.05 or p=0.01) among the parameters (Table 4). There was a significant positive correlation of Hunter L*, b*, a* values with ripening rate.

Ethylene rate was highly significant and positively correlated with respiration rate and ripening rate which clearly indicates that a rise in respiration in turn enhances fruit ripening. A significant negative correlation was noticed between acidity and texture with ethylene production, respiration rate and ripening rate. Texture was positively correlated with acidity and Hue angle indicating mature green stage of fruit. Hue angle was negatively

**Table 5:** Eigen value, variability (%) and cumulative (%) of three principal components

| | F1 | F2 | F3 |
|---|---|---|---|
| Eigen value | 5.940 | 1.559 | 1.085 |
| Variability (%) | 59.397 | 15.591 | 10.845 |
| Cumulative (%) | 59.397 | 74.988 | 85.833 |

correlated with ethylene rate, respiration rate and ripening rate. The results confirmed the increase in respiration rates and ethylene production as fruit ripening enhanced, positive correlations with Vitamin C and total sugars indicated the increase in ascorbic acid content as the fruit ripening enhanced and further the Vitamin C content decreased. Similar results in ponkan mandarins with positive correlations between Vitamin C and sugars were observed (Cai *et al.,* 2019). Principal component analysis helps in condensing multiple variables into few comprehensive variables and it clearly indicates the relation between the variables and observations. All quality parameters mentioned were selected for carrying out multivariate analysis to understand the most significant parameters associated with the acceptability of fruits at mature green stage and to understand the comparative utility of post-harvest application of ethylene inhibitors in maintaining quality for extended period.

Cumulative variance of first three PC's was 85.83% which was quite efficient to reflect the total original data (Table 5). Scree plot (Fig.3) indicates first 3 PCs had Eigen value above 1. Table 6 shows factor loading and contribution of variables in individual PC's. Principal component 1 showed the highest variance contribution rate (59.37%) and variables such as a*, texture, acidity, Hue°, L*, ethylene rate and respiration with highest loading values. Variance contribution rate of PC2 was 15.91% and variables like Vitamin C, total sugars and L*value had higher loading. Similarly, PC 3 had variance contribution rate of 10.84% with Vitamin C, b* and Hue angle had larger loading values. Biplot analysis was carried out to estimate the relationship between the quality parameters and treatments. It is clear from biplot that 1-MCP (3 days, 5 days and 7 days) treated fruits grouped together (fourth quadrant) with freshly harvested ones. This confirms that even after 7 days of storage, 1-MCP treated fruits possessed qualities similar to freshly harvested fruits. Parameters such as texture, Hue angle and acidity also grouped with these fruits indicated that these parameters had the highest use in defining the quality of guava fruits. The untreated control fruits were placed diagonally opposite quadrant (second quadrant) showing the highest level of quality changes happened in them. The untreated control fruits after 7 days was grouped in the second quadrant with Hunter's b* value, showing the higher level of yellowness of the fruits.

Fruits treated with SA 3 mM, SNP 1.5 mM, SNP 1mM, SA 1.5 mM after 7 days storage period grouped together with untreated control of 5 days storage period showed that the qualities of 5 day stored untreated control fruits were equivalent to 7 day stored ethylene synthesis inhibitors treated guava fruits. This indicated that SA and SNP treatment gives an advantage of two days shelf-life extension over untreated control. Parameters *viz.,* respiration rate and ethylene production rate were tightly correlated (Table 6) and distantly placed from the 1-MCP 500 ppb treated fruits in the biplot. Total sugars and vitamin C were tightly grouped together in first quadrant and were located far away from the ethylene inhibitors showing lower association in ripening. But 7 day stored SA 3 mM, SNP 1.5 mM, SNP 1 mM, SA 1.5 mM fruits and 5 day stored untreated control fruits were located in the first quadrant with higher total sugars and higher Vitamin C showing signs of ripening.

This was even confirmed with surface colour and texture (Table 1) values. Fruits stored for 5 days with 1 mM SNP and 1.5 mM SA treatments grouped together with untreated (control) fruits stored for 3 days, thus confirming additional two days enhancement of shelf life with these treatments. Multivariate analysis helps in understanding that surface colour (a* value), ethylene production rate, respiration rate and fruit texture are the major parameters, indicating the suitability of fruits for table purpose. The study shows that most importantly from the seller or buyer point of view,surface

**Table 6:** Factor loading and contribution of variables to principal components

| Variables | F1/PC1 | | F2/PC2 | | F3/PC3 | |
|---|---|---|---|---|---|---|
| | Factor loading | Contribution of variables (%) | Factor loading | Contribution of variables (%) | Factor loading | Contribution of variables (%) |
| L* | 0.766* | 9.867 | -0.463 | 13.722 | 0.073 | 0.491 |
| Hue | -0.917** | 14.166 | 0.054 | 0.184 | -0.328 | 9.932 |
| Texture | -0.932** | 14.636 | 0.209 | 2.812 | -0.247 | 5.614 |
| Acidity | -0.924** | 14.370 | 0.037 | 0.087 | -0.031 | 0.087 |
| Vitamin C | 0.291 | 1.425 | 0.695* | 30.988 | 0.577 | 30.734 |
| Total sugars | 0.084 | 0.118 | 0.739* | 34.984 | -0.093 | 0.791 |
| Ethylene | 0.802* | 10.815 | 0.347 | 7.742 | -0.393 | 14.213 |
| Respiration | 0.778* | 10.201 | 0.343 | 7.564 | -0.434 | 17.400 |
| a* | 0.961** | 15.548 | -0.063 | 0.257 | 0.198 | 3.597 |
| b* | 0.725* | 8.853 | -0.161 | 1.660 | -0.431 | 17.140 |

colour and texture are the best indicators of table guava quality. Grouping of 1-MCP treated fruits throughout the storage period along with freshly harvested fruits (Fig. 4) showed better-quality retention due to this treatment. Physiological reasons for this quality retention have already been discussed in section (Fig. 1, 2) and is clear from the biplot (Fig. 3) as well. Even though literature on Multivariate analysis of fruit quality changes due to ethylene inhibitors, is sparse Galli *et al.* (2019) suggested that surface colour in guava is the major attribute in judging the ripening status of guava fruits in MAP stored fruits. Cai *et al.* (2019) in non climacteric 'Ponkan mandarin' concluded that PCA and correlation studies help in clustering different parameters which makes easier approach in judging the fruit ripening. It is also recommended from this study that Hue angle is the best surface colour measure for judging the quality of table guava, and its acceptable range varies from 120.34 to 88.07.

1-MCP treatment doubled the shelf life of guava fruits (cv. Arka Mridula), by regulating the fruit ripening and maintaining the desirable quality parameters like good surface colour, texture, acidity, sugars. Ethylene synthesis inhibitors were also quite impressive with regard to some parameters like respiration and ethylene rates, but overall fruit acceptability was less when compared to 1-MCP treatment. Principal component analysis indicated that hue, texture and acidity are the major parameters to be considered for judging their suitability for table purpose. Thus, this study provides a baseline for the usage of multivariate analysis to relate the relationship between the variables responsible for ripening in post-harvest shelf-life extension studies.

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## Add-on Information

**Authors' contribution: A.J. Sachin:** Conducted postharvest physiology experiments, biochemical analysis for the experiment; **D.V. Sudhakar Rao:** Conceptualization of the experiment conducted; **K. Ranjitha:** Contributed in analytical work and manuscript preparation; **C. Vasugi:** Contributed in quality analysis, manuscript preparation and original breeder of the variety; **C.K. Narayana:** Contributed in manuscript preparation and first authors advisory council member; **K. Ravishankar:** Contributed in manuscript preparation and first authors advisory council member.

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