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Low 3,6-dichloro-o-anisic acid concentration application inhibits calyx senescence and maintains Valencia Late oranges' postharvest quality during ambient storage in Ghana

Nasiru Alhassan[1,*]

1, School of Engineering, Department of Agricultural Engineering, Dr. Hilla Limann Technical University, Wa, Upper West Region, Ghana

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***Corresponding author:**
School of Engineering, Department of Agricultural Engineering, Dr. Hilla Limann Technical University, Wa, Upper West Region, Ghana.
Email: nashfreecent@yahoo.com

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ABSTRACT

Purpose: This study determined whether postharvest application with low 3,6-dichloro-o-anisic acid concentration could inhibit calyx senescence and preserve internal and external qualities of Valencia Late oranges during extended storage. **Research method:** The experiments were conducted using a completely randomized design with three replicates of 50 fruits for each treatment. The oranges fruits were dipped in four treatment concentrations; control (0), 0.01, 0.03, or 0.05 mmol L^{-1} in experiment 1, and control (0), 0.003, and 0.01 mmol L^{-1} in experiment 2 for one minute. Post-treatment, the oranges were kept in solid cardboard boxes as individual treatment units (n = 50 fruits) with three units comprising a treatment and held at an ambient temperature (25 ± 2°C) and a 60%–65% RH. Oranges were evaluated every seven days for four weeks. **Findings:** The results showed that fruit dipped at 0.01 mmol L-1 for both experiments resulted in lower calyx browning and drop, weight loss, and fruit firmness compared to control and higher dicamba concentrations. Moreover, the treatment delayed the increase in total soluble solids and the decrease in titratable acidity, slowing the maturation rate. **Research limitation:** This study could not evaluate fruit carbon dioxide and ethylene production during storage to understand their impact on other quality changes due to lack of Gas Chromatography machines in the resident laboratory. **Originality/Value:** The results demonstrate the effects of dicamba treatments in delaying detrimental calyx changes and retaining fruit integrity during storage.

INTRODUCTION

Calyx browning and drops of citrus fruit are major external quality parameters that consumers often consider during the purchase. Consumers usually relate these external quality parameters to fruit's internal qualities, although these quality factors may not relate in some situations after harvest. This effect can significantly influence the commercialization of citrus fruit for the fresh market (Carvalho et al., 2008). Calyx senescence in citrus fruit mostly influences fungal attachment on the abscission zone of the citrus fruit which can result in fruit decay. Several plant growth regulators have been applied to citrus fruit to prevent calyx deterioration. The auxin, 2,4-Dichlorophenoxyacetic acid (2,4-D) is a synthetic plant growth regulator, which is often used in the citrus postharvest industry to prevent calyx senescence and maintain quality. However, the use of 2,4-D is now prohibited in the citrus industry in many countries for human safety and environmental concerns (Peterson et al., 2016). Therefore, there is a need to find an alternative to 2,4-D, to preserve the postharvest quality of citrus fruit calyxes.

Pre-harvest use of synthetic auxins, such as 3,5,6-trichloro-2-pyri-dyloxyacetic acid (3,5,6-TPA) increases fruit size, peel, pulp, juice, and acid contents and prevents fruit abscission (Agustí et al., 2002). Some researchers have found that 3,5,6-TPA and 2,4-dichlorophenxoyacetic acid isopropyl ester, reduce calyx changes of Clementine cultivars caused by ethylene degreening (Carvalho et al., 2008), but are less effective than 2,4-d. A previous study reports that fluroxypyr, which has lower toxicity than 2,4-d, significantly reduced calyx senescence rates in mandarins and orange fruits compared with control and 2,4-D treatment (Ma et al., 2015). The authors did not find a significant effect of the treatment on TA, TSS, and TSS/TA ratio in the juice of Satsuma mandarin, Newhall navel orange, and Olinda Valencia orange fruit.

A selective herbicide (3,6-dichloro-o-anisic acid) used to control a wide spectrum of broadleaf weeds and woody plants is registered for use in agriculture and other applications (EPA, 2009). In agricultural applications, dicamba is registered for use on rye, asparagus, barley, corn, oats, soybeans, sugarcane, and wheat. Dicamba is also registered for use on golf courses, residential lawns, and rights-of-way along utility lines, roadsides, and railways. At low doses, dicamba has similar hormonal properties to natural auxins (Kelley & Riechers, 2007). Reports have shown that high concentrations of dicamba in plant tissues induce abnormal and uncontrollable growth, disrupting normal plant functions, and resulting in death (Caux et al., 1993). This auxin is a class of phytohormones that are involved in plant developmental processes that occur at the cellular level, affecting cellular elongation and turgor, as well as cellular differentiation and division (Kelley & Riechers, 2007).

A plethora of studies have been conducted on the effectiveness of a range of compounds for their ability to retain the postharvest keeping quality of citrus fruits (Strano et al., 2022). Cronjé et al. (2005) investigated the effects of ethylene antagonists aminoethoxyvinylglycine (AVG) and 1-methylcyclopropene (1-MCP) (Shikwambana et al., 2023) and the synthetic auxin analog 1-naphthalene acetic acid (NAA) on citrus fruits and found that AVG maintained fruit firmness, however, did not have significant effect on calyx quality while NAA application led to an increased in citrus calyx abscission. However, a lower 1-MCP concentration (100 ppb) maintained calyx retention but had a desiccating effect on the calyx whereas higher concentrations (500 ppb) resulted in higher calyx senescence (Ali et al., 2016; Cronjé et al., 2005). In other investigations, Carvalho et al. (2008) applied 3,5,6-TPA on a range of Clementine mandarin cultivars and found a significant reduction in calyx senescence without detrimental effects on internal fruit quality. Sdiri et al. (2013) compared the efficiency of 2,4-D to S-ethyl-4-chloro-O-tolyloxythioacetate (MCPA) and 2-(4-amino-3,5-

dichloro-6-flfluoropyridin-2yl) oxyacetic acid to maintain citrus fruit quality and reported that these treatments did not exceed the performance of 2,4- D, which is consistent with the finding of Alhassan et al. (2020) where 3,56-TPA delayed calyx senescence of citrus. Currently, there is no reported study of dicamba on citrus calyx senescence and internal quality during ambient storage (25 ± 2 °C) in any country, thus knowledge of its efficacy in maintaining fruit quality could garner support for its approval for postharvest application. Therefore, the objective of this study was to investigate the effects of the postharvest application of dicamba on calyx senescence and internal quality factors of Valencia Late oranges during ambient storage.

MATERIALS AND METHODS

Two experiments were conducted to accomplish the objective of this study. The same experimental design was applied for both experiments with the same replications in each case. The treatments were four (4) and three (3) concentrations for the first and second experiments, respectively. The same parameters were experimented on in each case of the two experiments.

Experiment 1

Experimental design, replications, and treatments

The experiment was conducted using a completely randomized design (CRD) applying four (4) treatment concentrations and three (3) replicates of 50 fruits for each treatment. The dicamba concentrations applied were 0 (control), 0.01, 0.03, and 0.05 mmol L^{-1} and the fruits were dipped in the solutions for 1 min each. The zero concentration was only water which was considered a control. The fruits were air-dried and kept in solid cardboard boxes as replicates (n = 50 fruits) with three replicates comprising a treatment. The cardboard boxes were placed on benches in the postharvest laboratory at ambient temperature (25 ± 2 °C) with relative humidity (RH) of 60-65% to stimulate shelf-life. Both external and internal fruit quality was determined on initial fruit condition and every 7 days for 4 weeks.

Source of experimental plant materials

Mature Valencia Late oranges (*Citrus sinensis,* L. Osbeck) were obtained at the commercial maturity stage; when the TSS and TA levels of fruits are greater than 8.5% and 0.4% citric acid respectively (Ritenour, 2015), with calyxes from a farmer from Obuasi in the Ashanti region of Ghana. The fruits were packaged in corrugated cardboard boxes and transported to Dr. Hilla Limann Technical University Postharvest Laboratory in Wa in the Upper Region of Ghana for investigation. Immediately after arriving the fruits were sanitized with commercial sodium hypochlorite solution (25 ppm) then cleaned, sorted, and sized.

Sampling of experimental plant materials

Healthy orange fruit samples (Citrus *sinensis* L., Valencia variety) were used for the experiments. In total, one thousand four hundred (1400) fruits free of undesirable characteristics such as physical damage, mould, and polluting components were used for the experiments to avoid contamination and physiological changes (Tiencheu et al., 2021). The oranges were transported in plastic crates at an ambient temperature (26 ± 1 °C) to the experimental location for the physiochemical analyses and shelf-life studies. The samples were sorted into two groups; intact and defective fruits. Fruit with their calyxes intact were used for the study. The sampling procedure was according to a study with similar purposes on Navel oranges (Alhassan et al., 2022).

Evaluation of calyx changes

One hundred and fifty fruits were visually examined for calyx senescence (browning and abscission) with different treatment concentrations. The Browning index of citrus calyx was scored according to the method of Li et al. (2018) and Alhassan et al. (2022), where; 1, no browning; 2, browning less than 1/4 of the total area of the calyx; 3, browning less than 1/2 of the total area of the calyx; 4, browning less than 3/4 of the total area of the calyx; and 5, browning more than 3/4 of the total area of the calyx. Calyx browning was calculated using the following formula (1); browning level of the calyxes in each replicate divided by the total number of calyxes evaluated. Calyxes that had dropped were counted during each assessment day and were classified as abscised calyx (Sdiri et al., 2013). Calyx abscission was expressed as a percentage.

$$\text{Calyx abscission} = \left(\frac{\text{The number of calyx abscissed}}{\text{Total number of fruits in the sample}}\right) \times 100\% \quad (1)$$

Determination of fruit weight loss

Weight loss of fruits was measured according to the previous report by Chaudhary et al. (2012). The weight of each sample was recorded on initial weight using an electronic analytic weighing scale (Model Kean &Sohn GmbH, D-72336, Germany) every seven (7) days for four (4) weeks. Weight loss during storage was determined by weighing three groups of the samples in each treatment. The percentage weight loss of the fruits was calculated as (2):

$$\text{Weight loss (WL)} = \left(\frac{\text{Initial weight} - \text{Final weight}}{\text{Final weight}}\right) \times 100\% \quad (2)$$

Fruit firmness determination

A sample of twenty-five (25) fruits from each replicate of every treatment was determined on two opposite sides of the equatorial zone of each fruit with a Digital Fruit Firmness Tester (Bareiss-HPE III Fff, ABQ Industrial, The Woodlands TX, USA) (Dasgan et al., 2024). The evaluation was performed by depressing a test anvil against the skin of the orange fruits to measure the resistance against controlled spring pressure (Singh & Reddy, 2006). The data were expressed as the average firmness of 75 fruits for each treatment and expressed in Newton (N), according to Alhassan et al. (2024).

Measurement of fruits' internal qualities

The TSS of the oranges was determined using a handheld digital refractometer (Atago Co. Ltd., Tokyo Atago, Japan) as described by Alhassan et al. (2024). Six fruits from each treatment (three replicates) were juiced and filtered through two layers of gauze to retain the solid particles (Tiencheu et al., 2021). The juice samples were put in the prism to the refractometer and readings were taken. Data were expressed as average percentage °brix. The titratable acidity level of the oranges was measured according to the method described by Ercisli and Orhan (2007). Five (5) mL of the juice sample was measured into a 10 mL graduated cylinder and was transferred into a clean Erlenmeyer flask—approximately 100 mL of distilled water. Five (5) drops of phenolphthalein were added, followed by titration with 0.1N sodium hydroxide (NaOH) solution until a light pink colour was obtained. The data were expressed as citric acid. The fruit maturity index (MI) was calculated using the TSS/TA ratio (Alhassan et al., 2022).

Experiment 2
To find an optimal treatment concentration to maintain the citrus fruit quality, in experiment 2, the orange fruit was obtained from the same source and a similar was followed as in experiment 1, however, 0.003 mmoL^{-1} was compared with 0.01 mmol L^{-1} dicamba concentration. This lower concentration (0.003 mmol L^{-1}) was applied because in experiment one 0.01 mmol L^{-1} maintained the fruit's internal and external quality, hence it is thought that 0.01 mmol L^{-1} should be compared with a further lower concentration (0.003 mmol L^{-1}). Storage temperature (25 ± 2 °C) and relative humidity (60-65%) were monitored using TinyTag data loggers (TinyTag View 2, Gemini Data Loggers, UK) throughout storage. Both exterior quality (calyx browning and calyx abscission) and internal quality factors of fruit were evaluated on the initial day, then subsequently every seven days' intervals for 4 weeks, as done in experiment one.

Statistical analysis
The data of this experiment were statistically processed using the SPSS version 24.0 software package (SPSS, Chicago, IL, USA). The two-way analysis of variance (ANOVA) was performed, and Fisher's test was used in the analyses to determine the Least Significant Differences (LSD) among treatment means at a significance level of $p \leq 0.05$. Separate analyses were carried out with the data for each of experiments one and two. The errors for these ANOVAS were tested for homogeneity of variances (Snedecor & Cochran, 1980) and found to be statistically ($p > 0.05$) not different, so the results for the different experiments were pooled for analysis.

RESULTS AND DISCUSSION

Fruit calyx browning
Evaluation of Valencia Late oranges calyx browning was based on subjective score criteria. There was a significant effect of the treatment and storage time on the calyx browning of the fruits ($p < 0.05$), with a significant interaction of these factors during storage. Low dicamba concentrations significantly delayed fruit calyx browning compared to control and higher dicamba concentrations. Increasing the concentration of the auxin treatment increased calyx browning of the fruit, but still had a lower rate of browning of fruit compared to control after the twenty-eight (28) days of storage. Orange fruit dipped in 0.01 mmol L^{-1} dicamba concentration was the most effective in reducing calyx senescence to 1.8 compared to the other concentrations. As indicated in Figure 1, almost all calyxes of the fruits under the control treatment were brown (3.6 out of a best score of 1) at the end of storage, and signals of rot around the calyx stalk ends of some fruits. Calyxes of fruits treated with dicamba were still green and fresh, particularly, fruit treated with 0.01 mmol L^{-1}, but there was no significant difference between this concentration and 0.03 mmol L^{-1} which had a score of 2.0 at the end of storage.

In experiment 2, dicamba treatment had a significant effect on Valencia Late oranges calyx browning compared with untreated fruit. Pre-storage dipping (dipping in solution before storage) with 0.01 mmol L^{-1} dicamba treatment was more efficacious in delaying calyx browning score of 2.5 relative to the effect of 0.003 mmol L^{-1} dicamba concentration of 2.1. The results demonstrate that 0.01 mmol L^{-1} dicamba concentration reduced calyx browning better than the control fruit (3.7 score), suggesting that this concentration may be optimal for delaying calyx browning of Valencia Late oranges (Table 1). Previous studies indicate that at low doses, dicamba has similar hormonal properties to natural auxins (Kelley & Riechers, 2007). Other researchers demonstrated that higher dicamba concentrations in plant tissues induce abnormal and uncontrollable growth, disrupting normal plant functions, and resulting in death (Caux et al., 1993). However, orange fruit dipped at 0.05 mmol L^{-1} concentration before storage slightly increased calyx browning but still had better quality than control fruit although not significantly different. This meant that higher dicamba concentration may not have a beneficial effect of inhibiting calyx browning and retaining quality, as this concentration could be more than the amount of auxin the fruit can metabolize during storage. Dipping Valencia Late oranges with lower dicamba concentration (0.01 mmol L^{-1}) before storage inhibited calyx browning and maintained internal quality parameters could be due to low metabolic activities (Alhassan et al., 2022), which is consistent with a report that lower ethylene and respiration reduced calyx senescence of 'Afourer' Mandarins held at 5 and 20 °C for 8 weeks (Li et al., 2018).

Fruit calyx drop

The presence of calyx on citrus fruit is a show of good quality for many consumers to purchase and hence needs to be attached (Alhassan et al., 2020). There was a significant effect of dicamba treatment and storage time on calyx drop citrus varieties ($p < 0.05$) with significant interactions during storage. The results showed that lower dicamba concentrations significantly reduced the rates of calyx drop compared to untreated fruit. Calyx drop increased with an increased browning index in the different auxin treatment concentrations during storage. Treatment with 0.01 mmol L^{-1} dicamba concentration greatly reduced calyx drops to 13.3% compared to control with 55.6% and 0.05 mmol L^{-1} dicamba concentration with 23.3% as shown in Figure 2. There was a significant effect of dicamba treatment on Valencia Late oranges calyx drop compared to control fruit in experiment 2. This study observed that 0.01 mmol L^{-1} dicamba treatment had a 15.7% calyx drop during storage when compared to 0.003 mmol L^{-1} dicamba concentration with 16.2%. Although data between the two concentrations was statistically insignificant ($p > 0.05$), the lower concentration showed more promise in inhibiting calyx in the experiments of this study. The results also indicate 0.01 mmol L^{-1} dicamba treatment delayed calyx drop more relative to control. This difference in efficacy suggests that 0.01 mmol L^{-1} could be the optimal dicamba concentration to delay calyx abscission oranges (Table 1). Ma et al. (2015) in their study inhibited citrus calyx abscission in four varieties with low fluroxypyry treatment concentrations during extended storage. Oranges dipped with 0.05 mmol L^{-1} concentration marginally increased calyx drop but yet gave better calyx retention compared to untreated fruit, which suggests higher concentration may not have a beneficial effect on reducing calyx abscission as this concentration could have provided increased hormonal properties than the amount citrus fruits can metabolize. This effect is consistent with the findings by Kelley and Riechers (2007) that at low doses, dicamba has similar hormonal properties as natural plant auxins. It has been reported that the inductions of abnormal and uncontrollable growth, disrupted normal plant functions, resulting in death due to increased dicamba concentrations (Caux et al., 1993).

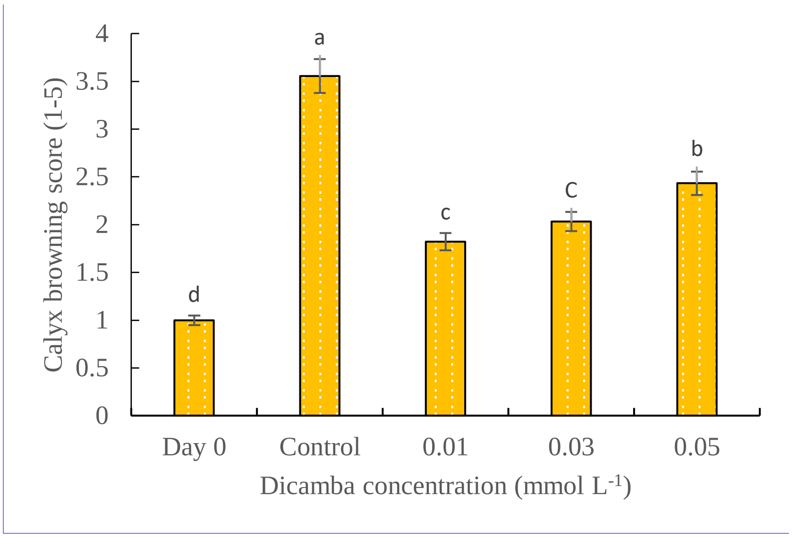

Fig. 1. Effect of postharvest dicamba treatment on Valencia Late orange fruit calyx browning stored at ambient temperature (25 ± 2 ºC) and RH of 60-65% for 4 weeks. Treatments applied: control (no dicamba), 0.01, 0.03 and 0.05 mmol L^{-1} dicamba concentration. Means with different letters are significantly different according to Fisher's LSD test ($p \leq 0.05$).

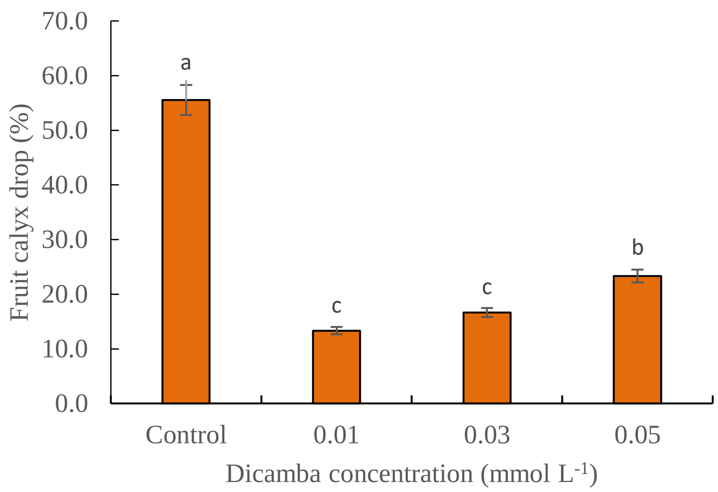

Fig. 2. Effect of postharvest dicamba treatment on Valencia Late oranges fruit calyx drop during storage stored at ambient temperature (25 ± 2 ºC) and RH of 60-65% for 4 weeks. Treatments applied: control (no dicamba), 0.01, 0.03 and 0.05 mmol L^{-1} dicamba concentration. Means with different letters are significantly different according to Fisher's LSD test ($p \leq 0.05$).

Fruit weight loss

There was a significant effect of dicamba treatment on weight loss of Valencia Late oranges ($p < 0.05$) during storage, however, there was also a significant effect of storage time on weight loss of the fruit ($p < 0.05$) but there was no significant ($p > 0.05$) interactions between these factors. As shown in Figure 3, the percentage weight loss of fruit at the end of storage was significantly reduced ($p < 0.05$) to 1.26% and 1.64% by 0.01 and 0.03 mmol L^{-1} dicamba treatments respectively compared to untreated fruit with 32.5% weight loss during storage period. Fruits dipped at 0.05 mmol L^{-1} dicamba concentration had little increase in weight loss but was lower than that of control. Similarly, in experiment 2, low dicamba treatment concentration positively impacted Valencia Late oranges' weight loss during the storage regime. The results demonstrated that 0.01 mmol L^{-1} dicamba application reduced the weight loss of the oranges to 10.6% relative to 0.003 mmol L^{-1} with 11.4% although data for the two treatments was statistically insignificant ($p > 0.05$). However, both treatment concentrations inhibited water loss better than the control fruit with 23.1% as demonstrated in Table 1. Citrus fruit weight loss is an important parameter during the postharvest life of citrus fruit since this can either help maintain quality or adversely affect other quality factors. In the present study, an increase in percentage weight loss of fruit observed altered the commercial quality of the non-treated fruit in Valencia Late oranges during storage, as the majority of fruit that had their calyxes senesced corresponded with an increase in weight loss. Lower dicamba treatment (0.01 mmol L^{-1}) in experiments 1 and 2 significantly reduced weight loss and maintained citrus quality factors. The beneficial role of 0.01 mmol L^{-1} dicamba treatment in reducing weight loss and maintaining other quality factors of Valencia Late oranges, indicating that auxins could reduce metabolism and extend storage life. This result is consistent with Alhassan et al. (2022) where pre-storage dipping of Valencia oranges with a range of plant growth regulators reduced senescence and maintained quality. Although no study has shown the effect of postharvest application of dicamba in minimising weight loss of Valencia Late oranges, a study has demonstrated that dicamba fed to adult rats for 90 days with approximately 500 mg/kg/day showed no effects on weight loss, however, at doses up to 1000 mg/kg/day reduced body weight gain, and changes in the liver's weight, colour, and size (EPA, 2005).

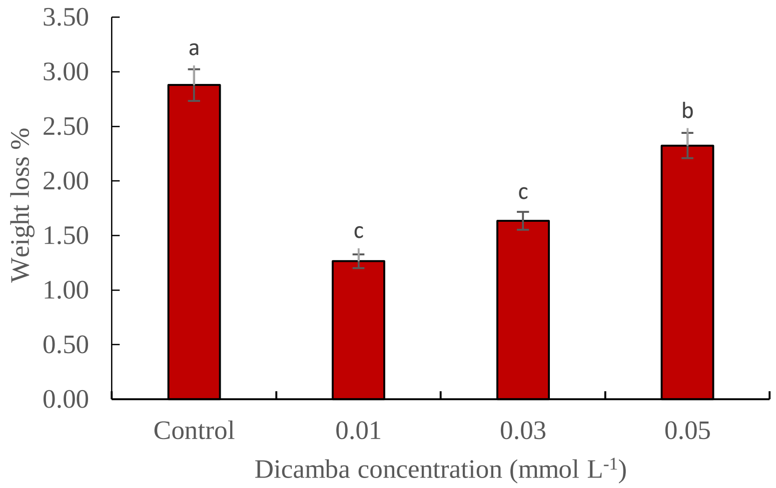

Fig. 3. Effect of postharvest dicamba treatment on Valencia late orange fruits' weight loss stored at ambient temperature (25 ± 2 ºC), and RH of 60-65% for 4 weeks. Treatments applied: control (no dicamba), 0.01, 0.03 and 0.05 mmol L^{-1} dicamba concentration. Means with different letters are significantly different according to Fisher's LSD test ($p \leq 0.05$).

Fruit firmness level

There was a significant effect of dicamba treatment on orange fruit firmness during storage ($p < 0.05$). Pre-storage dipping (dipping before storage) of the orange fruit with 0.01 mmol L^{-1} retained the highest firmness level (38.4N) during storage compared to control fruit (31.8N) and the increased dicamba treatment concentrations. Increasing dicamba treatment concentrations (0.03 or 0.05 mmol L^{-1}) slightly reduces the retention of fruit firmness from 35.4N to 33.6N respectively. However, dicamba-treated fruits showed higher firmness levels than control fruit though control fruit firmness was not significantly different ($p > 0.05$) relative to 0.05 mmol L^{-1} dicamba at the end of storage as indicated in Figure 4. The results in experiment 2, showed dicamba treatment on Valencia Late oranges greatly delayed loss of fruit firmness compared to untreated samples. As expected, pre-storage dipping with 0.01 mmol L^{-1} dicamba inhibited firmness loss (31.2N) of more than no dicamba-treated fruit (24.7N) and 0.003 mmol L^{-1} (30.5N) but there was no significant difference ($p > 0.05$) between oranges treated with 0.003 and 0.01 mmol L^{-1} dicamba concentrations (Table 1). Low dicamba concentration decreased fruit weight loss and delayed firmness loss during the storage regime. As demonstrated in this study, treatment with 0.01 mmol L^{-1} significantly reduced weight loss, and therefore maintained fruit firmness during storage. However, increased auxin concentrations slightly reduced fruit firmness but retained higher firmness than untreated fruit. The result of this study disagrees with the previous findings of Ma et al. (2015), who observed no significant effects of similar auxin such as fluroxypyr treatment on firmness of four citrus varieties during storage at 5 and 20 °C for 12 weeks.

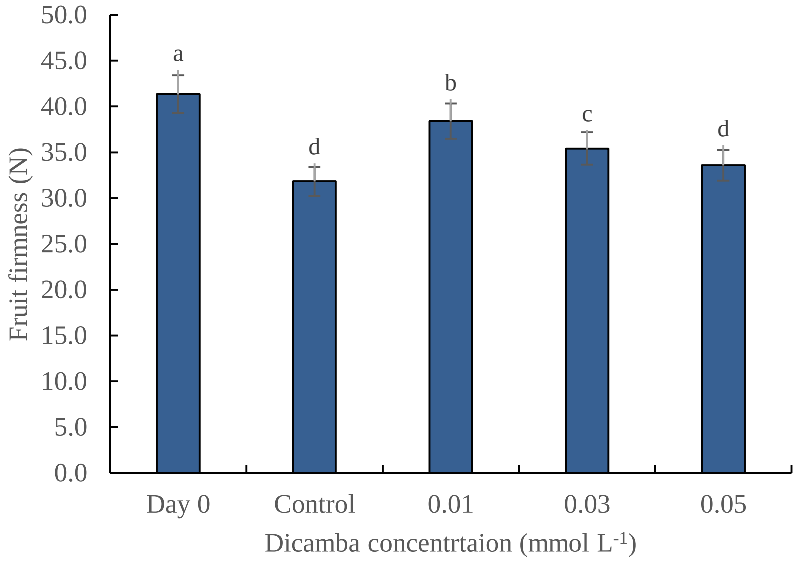

Fig. 4. Effect of postharvest dicamba treatment on Valencia Late oranges' firmness during ambient storage (25 ± 2 ºC), and RH of 60-65% for 4 weeks. Treatments applied: control (no dicamba), 0.01, 0.03 and 0.05 mmol L^{-1} dicamba concentration. Means with different letters are significantly different according to Fisher's LSD test ($p \leq 0.05$).

Effect of dicamba application on internal fruit qualities

There was a significant effect of dicamba treatment and storage time on the total soluble solids (TSS) of Valencia late oranges ($p < 0.05$), however, there was no significant ($p > 0.05$) interaction between the auxin treatments and storage time. Results from this study indicate that Valencia late oranges can be treated with 0.01, or 0.03 mmol L^{-1} dicamba treatments at 25 ± 2 °C and RH of 60-65% for up to 28 days without detrimental effect on their internal quality as expressed by the fruit TSS level (11.2 to 11.5 °brix). The TSS of oranges slightly increased with an increased dicamba treatment concentration but increased at a decreased rate (11.1 to 11.2 °brix) at a low dicamba concentration (0.01 mmol L^{-1}) compared to the other dicamba concentrations of this investigation. However, the TSS content of the control fruit was the highest (11.1 and 10.4 °brix for the two experiments) among all the treatments, which showed a loss of fruit quality. When the experiment was repeated with control, 0.003 and 0.01 mmol L^{-1} as treatment concentrations, 0.01 mmol L^{-1} showed 11.3 °brix compared to 0.003 mmol L^{-1} with 11.7 °brix at the end of storage. Despite this, the two treatments were statistically insignificant ($p > 0.05$), but there was a significant difference ($p < 0.05$) between fruit treated with dicamba and untreated fruit (Table 1). Control fruit showed an increase in TSS from 10.4 to 14.6 °brix at the end of storage, which led to a rise in maturity index and reduced the fruit's internal quality and external appearance (Fig. 5). The result of this study disagrees with the finding of Ma et al. (2015), who reported that auxins such as fluroxypyr have no significant effect on TSS of Satsuma mandarin and Olinda Valencia oranges stored at 5 and 20 °C for 12 weeks.

There was also a significant effect of dicamba treatment and storage time on titratable acidity (TA) of the citrus fruit ($p < 0.05$), however, there was also an interaction between dicamba treatment and storage time on TA of Valencia Late oranges dipped at low dicamba treatment concentrations. As expected, there was a general decline in the TA level across all fruits during storage under the different treatments. The TA of fruit dipped in 0.01 mmol L^{-1} dicamba before storage was significantly higher (1.30 citric acid) than control fruit with 1.02 citric acid, 0.03 with 1.17 citric acid and 0.05 mmol L^{-1} with 1.11 citric acid (Fig. 6). When the experiment was repeated using control (0), 0.003, and 0.01 mmol L^{-1} dicamba concentrations the 0.01 mmol L^{-1} treatment showed similar trends to experiment 1 with TA of 6.1 citric acid at the end of storage compared to control fruit with 4.3 citric acid and 0.003 mmol L^{-1} with 5.9 citric acid. This shows the TA decline in untreated oranges was more pronounced during storage than in fruits dipped with dicamba prior to storage. This effect contributes to an increase in the TSS content. In a similar study, fluroxypyr was found to have low toxicity similar to dicamba, however, it did not have a significant effect on the TA level of fruit during storage (Ma et al., 2015). However, there was a significant effect of dicamba treatment and storage time on the maturity index of the oranges ($p < 0.05$) at the end of storage.

The TSS/TA ratio of citrus fruit is an important quality factor affecting sensory qualities (Barros et al., 2012). Comparing the treatment concentrations in this study, there was a gradual increase in maturity index due to the decrease in the juice acidity with a corresponding TSS increase of the Valencia Late fruit during ambient storage. The effects of pre-storage dipping of dicamba auxin at different concentrations on TSS, TA, and their ratio consistently relate to corresponding increases or decreases in calyx senescence and the other quality parameters of the orange fruit held for 4 weeks during ambient storage in the present investigation.

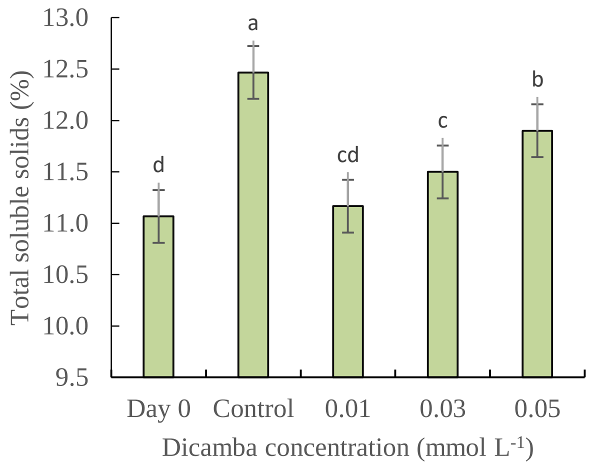

Fig. 5. Effect of postharvest dicamba treatment on Valencia Late oranges TSS content during ambient storage (25 ± 2 ºC), and RH of 60-65% for 4 weeks. Treatments applied: control (no dicamba), 0.01, 0.03 and 0.05 mmol L^{-1} dicamba concentration. Means with different letters are significantly different according to Fisher's LSD test ($p \leq 0.05$).

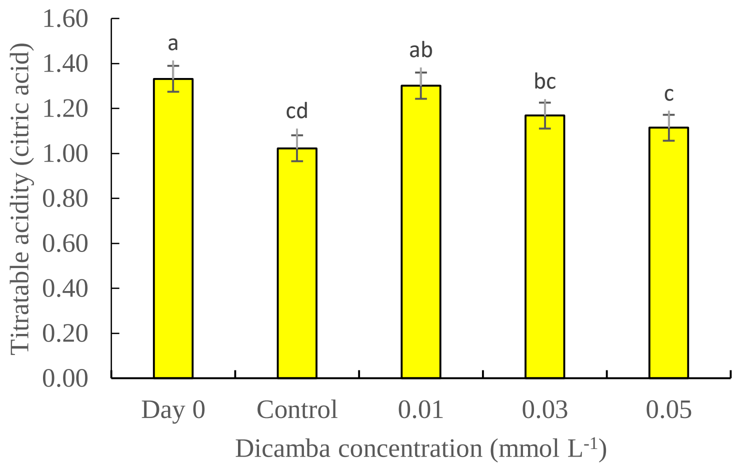

Fig. 6. Effect of postharvest dicamba treatment on Valencia Late oranges TA stored at ambient temperature (25 ± 2 ºC) and RH of 60-65% for 4 weeks. Treatments applied: control (no dicamba), 0.01, 0.03 and 0.05 mmol L^{-1} dicamba concentration. Means with different letters are significantly different according to Fisher's LSD test ($p \leq 0.05$).

Table 1: Effect of postharvest dicamba treatment on quality factors of Valencia Late oranges during ambient storage.

Dicamba Conc. (mmol L^{-1})	External and internal quality factors evaluated						
	Calyx browning (score)	Calyx drop (%)	Weight loss (%)	Fruit Firmness (N)	TSS (%)	TA (Citric acid)	TSS: TA
Day 0	1.0^{c}	0.0^{c}	0.0^{c}	35.4^{c}	10.4^{c}	8.1^{c}	1.3^{c}
Control	3.7^{a}	32.5^{a}	23.1^{a}	24.7^{b}	14.6^{a}	4.3^{b}	3.4^{a}
0.003	2.5^{b}	16.2^{b}	11.4^{b}	30.5^{a}	11.7^{b}	5.9^{a}	2.0^{b}
0.01	2.1^{b}	15.7^{b}	10.6^{b}	31.2^{a}	11.3^{b}	6.1^{a}	1.9^{b}
P < 0.05							

Internal and external quality assessment under control (no dicamba) and dicamba concentrations (0.003 and 0.01 mmol L^{-1}) at a temperature of 25 ± 2 °C and 60-65% RH.

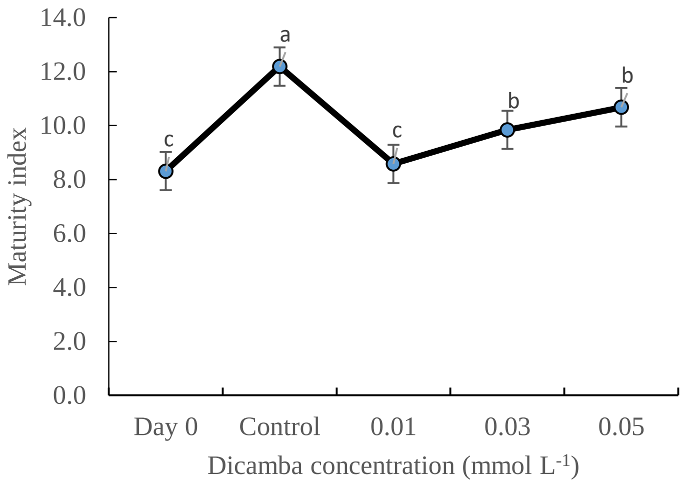

Fig. 7. Effect of postharvest dicamba treatment on Valencia Late oranges maturity index stored at ambient temperature (25 ± 2 °C), and RH of 60-65% for 4 weeks. Treatments applied: control (no dicamba), 0.01, 0.03, and 0.05 mmol L^{-1} dicamba concentration. Means with different letters are significantly different according to Fisher's LSD test ($p \leq 0.05$

CONCLUSION

This study investigated the effects of the postharvest application of dicamba on calyx senescence and internal quality factors of Valencia Late oranges during ambient storage. Low dicamba concentration applications were more effective in retaining calyx quality and ameliorating adverse changes in fruit internal quality parameters. The auxins reduced weight loss, and delayed firmness loss. Pre-storage dipping with low dicamba treatment delayed TSS increase and inhibited the TA decline and fruit maturity; extending the Valencia Late oranges' postharvest storage. This beneficial effect is associated with a decrease in fruit senescence. The results demonstrate the impact of dicamba treatments in delaying detrimental calyx changes and retaining fruit integrity during storage. Dicamba application effectively delays orange fruit calyx disorders and maintains good internal quality parameters. This positive result could contribute to shaping the decision to approve dicamba for postharvest utilisation in the citrus industry. However, further study is required to confirm the impact of dicamba treatment on a broader range of citrus types and storage conditions during extended storage.

Conflict of interest

The author declares no conflict of interest regarding the publication of this work.

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