The effects of pre-harvest treatments with hexanal formulation on selected post-harvest quality parameters of limequat (*Citrofortunella floridana* J.W.Ingram & H.E.Moore) fruits

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Generally, limequat (*Citrofortunella floridana* J.W.Ingram & H.E.Moore) fruits have a relatively short shelf life at supermarket display temperatures (17-22ºC). In some cases, shelf life can be as short as four days, after which surface discolouration becomes evident, along with shrivelling, and in many instances, the development of post-harvest diseases. Therefore, for maintenance of marketable quality, these three factors must be controlled. Pre-harvest treatments are known to positively affect the post-harvest quality of many commodities. Among these, treatment with hexanal has resulted in improved post-harvest quality maintenance because of its retarding effect on enzyme-driven cellular degradation. This study was conducted to observe the effect of pre-harvest treatments with hexanal on the length of the shelf life and the post-harvest quality of limequat fruits. Pre-harvest spray applications of 2% and 4% EFF (Enhanced Freshness Formulation), containing hexanal as the active ingredient, were made at weekly and biweekly intervals 30-days before the expected date of harvest. Pre-harvest spray treatments of EFF at 2% and 4% to trees of limequat resulted in the delay in the rate of colour change from green to yellow by an average of 7 days and 14 days, respectively, in harvested mature fruit. Senescent changes and other signs of deterioration including surface discolouration as brown patches, appeared on the fruit only after full colour change from green to yellow had occurred. Pre-harvest treatment also resulted in a reduction in the incidence of post-harvest diseases by up to 21 days during storage at 17-19ºC / 90-95% RH. Thus, pre-harvest spray application had a marked effect on appearance by delaying both yellowing and shrivelling of the fruit, and consequently on marketability since appearance is one of the main factors determining acceptability in the marketplace.

Keywords: Enhanced freshness formulation, EFF, hexanal, limequat, pre-harvest

The establishment of sustainable market opportunities for fresh fruits is heavily dependent on the length of fruit shelf life. Limequat (*Citrofortunella floridana* J.W.Ingram and H.E.Moore) has the potential to provide sustainable livelihoods for farmers in Trinidad and Tobago because of its economic importance in both local and export markets. However, this lucrative opportunity can be realized if the fruits have a suitably long shelf life to allow for successful marketing. Generally, limequat fruits have a shelf life of no more than four days at supermarket display temperatures (17-22ºC). After four days, surface discolouration becomes evident, along with shrivelling, and in many instances, the development of post-harvest diseases. Therefore, for maintenance of marketable quality, these three factors: surface discolouration, shrivelling and development of post-harvest diseases, must be controlled. Normally, the major factor affecting the length of the shelf life is postharvest handling. Given the tender nature of the fruit surface, regimes that minimize postharvest handling are desirable to extend marketing time. Previous studies showed that pre-harvest treatments such as gibberellic acid can reduce pre- and post-harvest losses of limequats (Shah et al. 2017).

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many commodities. Among these, treatment with hexanal has resulted in improved post-harvest quality maintenance because of its retarding effect on enzyme-driven cellular degradation. Studies conducted on cherries and other stone fruits showed that pre-harvest treatments using Enhanced Freshness Formulation (EFF) with hexanal as the active ingredient, enhanced shelf life properties of the respective fruits for up to thirty days after harvest (Sharma et al. 2010). Other studies showed that the application of hexanal as a combination pre-harvest and post-harvest dip enhanced firmness, ascorbic acid content, and brightness in greenhouse tomatoes (Cheema et al. 2014). The objective of this study was to observe the effect of EFF spray containing hexanal at 2% and 4% concentration, on the shelf life of limequats when applied as a pre-harvest treatment only.

Materials and methods

Limequat trees were selected from a field in Central Trinidad, Trinidad and Tobago, West Indies. Six treatments were applied to selected trees: EFF spray containing hexanal at 2% and 4% concentration and applied as pre-harvest sprays, twice within thirty (30) days from the planned date of commencement of harvest and four times within thirty days from planned date of commencement of harvest. Control trees were sprayed with solutions made up as EFF without the hexanal. Mature green fruits and fruits showing any signs of yellowing were removed from the trees before spray application. Fruits that fell from the trees were disregarded in this study. Fruits were harvested from treated and control trees at full, green, mature stage and placed into storage at 17-19^{o}C and 90-95% RH, for observation on time to change in fruit colour from full green to full yellow, development of surface discolouration, incidence of postharvest diseases, changes in firmness and development of shrivelling. Relative humidity was maintained by inclusion of water-filled trays in the storage area.

Change in fruit colour

Colour change was measured using an indicator of <50% colour change (green to yellow) on the fruit surface or >50% colour change.

Development of surface discolouration and postharvest diseases

Limequat fruits stored at 17-19^{o}C and 90-95% RH, were observed for the development of surface discolouration and visual evidence of microbial rots on the surface of the fruit. The presence of microbial rots was checked for individual fruits to be recorded on a percentage basis. The presence of discolouration was similarly recorded.

Firmness and shrivelling

Observations were made on the nature of the skin surface and time to first signs of development of shrivelling was recorded. Firmness was measured at seven day intervals for up to 21 days. Measurements were read using a manual penetrometer (Koehler Model K19500) using a 10mm tip and the results were recorded in kg-force (Bundit and Udomsak, 2007).

Results and discussion

Effect of EFF treatment on change in fruit colour

Change in colour of limequat fruits from full green to yellow is an indicator of ripening and senescence. For fruits treated pre-harvest with 4% EFF, colour change from full green to full yellow occurred after 21 days of storage at 17-19^{0}C when compared to control fruits which changed to full yellow by seven days storage at

the same temperature regime. Thus, the results of the trial showed that pre-harvest treatments of 4% EFF applied at weekly intervals or biweekly intervals 30 days prior to the expected date of harvest delayed colour change from full green to full yellow by 14 days. For fruits treated pre-harvest with 2% EFF, colour change from full green to full yellow occurred after fourteen (14) days of storage at 17-19C with an average delay of one week compared to control fruit.

The results (Table 1) showed that 54% of the fruits observed in the control group had more than 50% colour change within the observation period. For fruits treated with 2% EFF, 93% of the fruit observed had less than 50% colour change within the observation period. The chi square analysis (*Chi Sq. Value = 44.676; P = 0.000)* showed that there is a mutual dependence between treatment and colour change. The results indicated that the application of 2% EFF sprayed twice within a 21 day observation period will delay postharvest yellowing that indicates senescence.

Effect of EFF treatment on development of surface discolouration and postharvest diseases

Surface discolouration, as brown patches, developed on all fruits during storage but appeared only after full colour change from green to yellow. Thus, while surface discolouration began to develop in control fruit after seven days, in treated fruit, discolouration began to develop after 14 and 21 days storage for treatments at 2% and 4%, respectively. A chi square analysis was used to determine if there is a mutual dependence existing between the treatment and post-harvest disease and between treatment and colour changes. Fifty per cent of fruits from control trees, observed within the 21 day observation period, showed the presence of post-harvest diseases whereas Effect of EFF on fruit shrivelling and firmness 12.5% of fruit from treated trees had evidence of post-harvest disease incidence in the same observation time period. This showed a significant reduction in the incidence of post-harvest diseases as a result of treatment with 2% EFF (Table 2).

Table 1: Test of mutual dependence between treatment and colour change

	Colour Change		
Treatment	**<50%**	**>50%**	**N**
Control	37	43	80
2% EFF	82	6	88
Chi Sq. Value = 44.676; P = 0.000			

*** p-value indicating less than 1% significance

Table 2: Test of mutual dependence between treatment and the presence of postharvest disease

	Postharvest disease		
Treatment	**Observed**	**None Observed**	**N**
Control	40	40	80
2% EFF	11	77	88
*Chi Sq. Value = 27.873; P = 0.000****			

*** p-value indicating less than 1% significance

For fruit treated with 4% EFF, fungal rotting was observed in about 5% of fruit. Based on the results observed, the 2% EFF treatment effectively reduced the incidence of postharvest diseases in limequat fruit. The chi square analysis (*Chi Sq. Value = 27.873; P = 0.000*) showed that a mutual dependence exists between the treatment used and the presence of a postharvest disease. After storage for 21-days at 17-19ºC / 90-95% RH postharvest microbial rotting was evident in 12.5% of the pre-harvest treated fruits and 50% of the control fruits (Table 2).

Shrivelling of the skin in limequats reduces marketability of the fruit. It was observed that the incidence of shrivelling was concomitant with the development of full yellow colour change in EFF pre-treated fruits as well as in control fruits. Fruits pre-treated with 4% EFF at both weekly and bi-weekly intervals 30 days prior to harvest showed no visible shrivelling for up to 21 days storage at 17-19ºC. Similarly, fruits pre-treated with 2% EFF at the same times, showed no signs of shrivelling for up to 14 days storage at 17-19ºC. Shrivelling started in control fruit after seven days.

Fruits treated with 4% and 2% EFF remained firm during storage for up to 21 days and 14 days respectively, after harvest. Control fruits maintained firmness up to seven days after harvest when stored at 17-19ºC. One-way analysis of variance was used to test if a statistical difference exists between the average fruit firmness for the treated fruits and control fruits. The average firmness for the fruit treated with 2% EFF sprayed twice for a two week period was 1.5194 kg-force whereas control fruits had an average firmness of 1.2855 kg-force (Table 3).

Table 3: Firmness of fruits treated with 2% EFF and control fruits

Independent Variable	Sub Categories	N	Mean Score	Std. Dev.
Treatment	Control	38	1.2855	0.267
	2% EFF	36	1.5194	0.296
	*F = 12.764; P = 0.001******			

***p-value indicating less than 1% significance

The one way ANOVA model showed that a statistical difference was observed at a 1% significance level (*F = 12.764; P = 0.001).* Essentially, the results showed that pre-harvest spray application of 2% EFF will yield firmer fruit than untreated control fruits.

Conclusion

Application of pre-harvest spray treatment of EFF at 2% and 4% to trees of limequat resulted in the delay in the rate of colour change from green to yellow by an average of seven days and 14 days, respectively in harvested fruit. Surface discolouration, as brown patches, appeared on the fruit surface only after full colour change from green to yellow had occurred. Shrivelling also became evident after yellowing of the fruit surface. Senescent changes and other signs of deterioration appeared on the fruit only after full colour change from green to yellow. Thus, pre-harvest spray application had a marked effect on appearance by delaying both shrivelling and yellowing in the fruit, and consequently on marketability since appearance is the main factor determining acceptability in the marketplace. Pre-harvest applications of 2% and 4% EFF resulted in a reduction in the incidence of postharvest diseases by up to 21 days during storage at 17ºC / 90-95% RH. The effects observed suggest that fruit yellowing occurred as a result of senescent changes in the fruits. This would most likely be associated with tissue breakdown and possible water loss.

Hence, visible shrivelling was evident as fruits turned full yellow. Measurable loss of firmness, also associated with tissue breakdown, was also apparent after development of full yellow colour. The skin of fruits stored at high relative humidity, remained soft and pliable indicating advance of senescence as demonstrated by browning discolouration of the skin; further softening and incidence of postharvest rotting were also likely associated with tissue breakdown. Under conditions of the experiment, where fruit were handled carefully and mechanical injury was not allowed to occur, fruits developed postharvest diseases only after senescence was ongoing. In normal commercial practice, rotting was more common because the thin-skinned fruit is susceptible to easy bruising.

Therefore, pre-harvest spray treatment with EFF offers a viable option for farmers to increase their earning and must be coupled with careful post-harvest handling to avoid bruising, water loss and postharvest disease incidence in order to maximise the positive effects of the treatment.

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