

Harvest Maturity Affects Postharvest Quality of Lime Fruits (*Citrus aurantifolia* Swingle)

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ABSTRACT: Postharvest storage of lime fruits, harvested at 119, 133, 147 and 161 days after fruit set (DAFS) was evaluated based on changes in physiological weight loss (PWL), peel lightness (L^*), hue (h°), Chroma (C^*) values and overall visual quality rating (VQR) along with juice pH, titratable acidity (TA) and total soluble solids (TSS) under ambient condition (30-34 °C, 70-75% RH). The results showed that stage of maturity had significant effect on changes in PWL, VQR, L^* and h° values with no significant effect on juice quality parameters during the storage. The maximum storage life of nine days was observed in fruits harvested at 133 DAFS with significantly higher VQR (3.71 ± 0.18) and h° (116.44 ± 2.18). Both colour and PWL % influenced the visual quality of fruits. Thus, lime fruits harvested at 133 DAFS had the longest shelf life of 9 days while stages of 119, 147 and 161 DAFS had shelf life of 6, 7 and 3 days, respectively under ambient storage. This study concludes that the most suitable time for harvesting lime fruits is 133 days after fruit set.

Keywords: Hue angle, lightness, maturity, peel colour, quality

INTRODUCTION

Fresh acid lime (*Citrus aurantifolia* Swingle) fruits have a constant year round demand nationally and internationally, as its multi-disciplinary uses in domestic culinary, food processing industry, indigenous medicine, cosmetics and health care products. Globally, limes are largely consumed in fresh form which occupied 85.7% of the world lemon and lime (as there is no data on lime alone) production (13,172.3 MT) in 2016 (FAO, 2016). In Sri Lanka, lime second only to oranges, in terms of area and production where the total export reported in 2016 was 138 tons which valued USD 126,000. However, potential for further expansion of the industry is enormous and hence, lime has been identified as one of the high priority crop by the national committee of postharvest technology and value addition.

The postharvest qualities of lime fruits deteriorate quickly after harvest limiting long distance marketing and hence, it is worthy to extend the postharvest life through preservation of their natural quality. Application of post-harvest treatments has been reported to delay senescence, reduce physiological disorders and decay of lime during storage (Kaewsuksaeng *et al.*, 2015; Win *et al.*, 2006b). However, as in many other non-climacteric fruits, the quality of limes cannot be improved but only be maintained once they are detached from the tree. This

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highlights the importance of the stage of maturity at harvest that highly determines the post-harvest life and fruit quality of lime.

The careless harvesting is a severe problem in Sri Lankan lime industry, creating huge post-harvest losses and in general, too immature fruits are highly prone to be shrivelled, mechanically damaged, under nourished and are poor in quality. On the other hand, over-mature fruits easily become soft, mealy, lose acceptable colour and more often have insipid flavour during ambient storage. Thus, identification of proper harvest maturity, suit for either short distance or long distance marketing of fresh limes, is timely important. Keeping in view of these, the present study was aimed to identify the effect of harvest maturity on the postharvest life of lime under ambient storage

METHODOLOGY

The field experiment was conducted in a commercial orchard consisting of cultivar 'local', located in low country dry zone (DL1b; 30-35 °C, <1750 mm/y, 120 above meters sea level) and laboratory experiments were conducted at the Institute of Postharvest Technology (IPHT), Anuradhapura. During the peak blooming period (2016/2017 *Maha*), lime fruitlets at 4-5 mm diameter were tagged with polythene strips assuming the fruit set and considered as the reference point. Succeeding days were termed as the days after fruit set (DAFS). Fruits at 119, 133, 147 and 161 DAFS were harvested to evaluate postharvest life which identified as the best maturity stages to harvest (Samaradiwakara *et al.*, 2017). Fruits of uniform size that are free from defects and blemishes were selected from each maturity stage and stored under ambient conditions (30-34 °C, 70-75% RH) in medium size (600 x 300 x 320 mm) surface sterilized plastic crates with Bleach (NaOH). The physical, physiological and biochemical quality attributes were evaluated at harvest (day 0) and were proceeded at 3 day intervals until the produce indicated the limit of the marketability, according to visual quality rating (VQR) chart developed by Seehanam *et al.* (2010). Peel colour was measured by hunter lab colour difference meter (CR 400 – Konica, Minolta) in terms of lightness (L*), a* and b* values and thereby hue angle ($(h^{\circ}: \arctan(b^*/a^*))$) and Chroma ($C: [(a^*)^2 + (b^*)^2]^{1/2}$) were calculated. Fruit weight was measured by top loading balance (OHAUS; model ARA 520) and per cent weight loss ($[(\text{initial weight} - \text{final weight})/\text{initial weight}]$). VQR was carried out according to the VQR chart (Seehanam *et al.*, 2010) on a scale of 1 to 5 where 5= excellent and 1= unusable. Juice from limes was filtered through muslin cloth and used for chemical analysis. Juice pH was measured by the pH meter (420A+, Thermo Orion, USA) calibrated with standard buffer solutions held at pH 2.0 and 7.0. The titrable acidity (TA) % was determined by titrimetric method (AOAC, 2005) and expressed as grams of citric acid equivalents per 100 mL of juice $[(\text{mL NaOH} \times 0.1 \times \text{acid meq. factor}) \times 100/\text{mL juice titrated}]$. TSS was measured by temperature-compensated digital hand-held pocket refractometer (Atago PAL-1, Tokyo, Japan). Each sample contained juice from 10 fruits and all determinations were performed as triplicates.

The experiment was arranged as complete randomized design (CRD) with three replicates consisting 10 fruits per replicate, where parametric data were analyzed using ANOVA, followed by Duncan's multiple range test. The nonparametric data were analyzed using Kruskal-wallis ranking method and Chi-square test respectively. The analysis was done using SAS 9.1 and MINITAB 17 software.

RESULTS AND DISCUSSION

The present study elucidates the physical, physiological and biochemical changes of lime fruits harvested at 119, 133, 147 and 161 DAFS which identified as best maturity (Figure 1) under ambient storage. The results showed that maturity at harvest create a significant effect on the postharvest life.

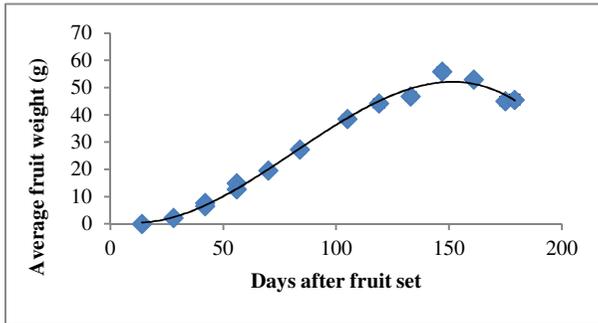


Figure 1. Changes of average fruit weight of lime with the time. Vertical bars represent the standard error. Equation of the growth curve: $y = -4E-05x^3 + 0.0091x^2 - 0.1874x + 1.4558$, $R^2 = 0.9932$.

In all tested maturity stages, h° of fruits harvested at 161 DAFS abruptly declined from 116.02 ± 1.39 to 106.15 ± 1.55 (Figure 2A) within 3 days concurrent with the fading of peel greenness and became full yellow (100.34 ± 1.75) by the 6 days after storage (DAS). Meanwhile, increment of L^* value was comparatively fast in this stage starting from 60.12 ± 1.60 at harvest to 71.97 ± 1.07 at 6 DAS (Figure 2B). However, both stages of 119 and 133 DAFS exhibited the lowest decline in h° (by 4.33 and 5.51 respectively) with lowest increment in L^* (by 4.16 and 6.52 respectively) and C^* (by 3.37 and 6.47 respectively) with an acceptable peel greenness even by 9 DAS. In comparison, h° , L^* and C^* of fruits harvested at 147 DAFS exhibited intermediary trends and acceptable greenness existed for 6 DAS, but rapidly diminished by 9 DAS, limiting the marketability. Changes in peel colour may be a consequence of alterations in the physiological and biochemical processes in the flavedo tissue (Win *et al.*, 2006b), particularly degradation of chlorophyll, which was shown to be highly positively correlated with changes in peel colour and h° of lime under ambient storage (Win *et al.*, 2006a). The differences in peel colour changes observed among maturity stages may be attributed to the different contents of chlorophyll present at harvest and different concentrations of chlorophyll degrading enzymes such as chlorophyllase and peroxidase existed at the harvest as well as even after harvest (Win *et al.*, 2006a). The slowest colour change observed in fruits harvested at 119 and 133 DAFS could be due to higher chlorophyllase activity at harvest which is responsible for the early steps of chlorophyll degradation rather than peroxidase which is responsible for the later steps in chlorophyll degradation and rapid yellowing (Win *et al.*, 2006a). Conversely, it can be speculated that the stage of 161 DAFS might be entered to the senescence phase at the harvest that having higher peroxidase activity which results very fast colour change (Win *et al.*, 2006a).

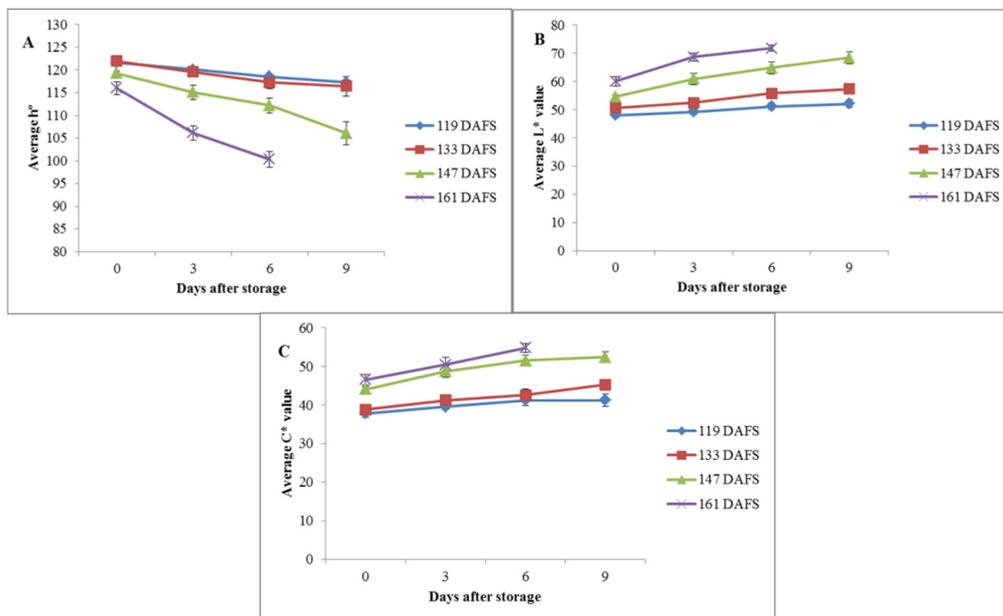


Figure. 2. Changes of h° (A); L^* (B) and C^* (C) values of peels of fruits harvested 119, 133, 147 and 161 days after fruit set (DAFS) under ambient storage (30-34 °C, 70-75% RH).

During the storage phase of 12 days, fruits harvested at 119 DAFS exhibited higher PWL in each sampling point compared to all other tested stages and losses were significant at 9 DAS exhibiting 23.33 ± 0.34 , 19.84 ± 0.73 , 14.66 ± 0.62 and $18.96 \pm 0.59\%$ in stages of 119, 133, 147 and 161 DAFS respectively (Figure 3). The higher PWL observed in the stage of 119 DAFS may be due to the higher metabolism including respiration in less mature non-climacteric fruits compared to mature ones at harvest as well as after harvest.

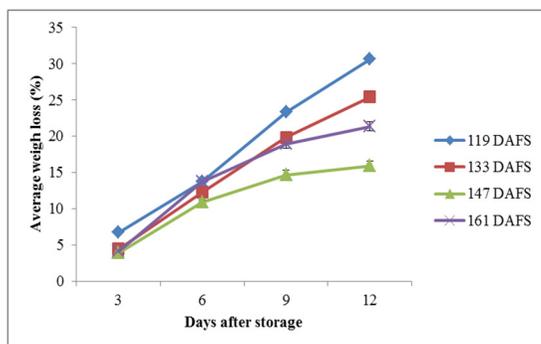


Figure.3. Changes in physiological weigh loss (%) of fruits harvested 119, 133, 147 and 16 days after fruit set (DAFS) under ambient storage (30-34 °C, 70-75% RH).

Conversely, this might be the reason for the lowest PWL exhibited in fruits harvested at 147 DAFS which of physiologically mature stage. Similar observations have been reported in other unripe non-climacteric fruits such as pomegranate (Fawole and Opara, 2013) and Camucamu

fruits (Neves *et al.*, 2015) during the postharvest storage. However, 9 DAS, PWL of 147 and 161 DAFS fruits seemed to be more or less stable and this may be the declined respiration when fruit senesce and become fully yellow (Win *et al.*, 2006a).

As in many other citrus fruits, visual quality largely affects the marketability of limes where firm, mature green limes are highly appreciated by consumers (Rodrigo *et al.*, 2013). According to the VQR scale of Seehanam *et al.* (2010), fruits having a VQR below 3, was considered as unmarketable. VQR of fruits harvested 161 DAFS sharply declined from 4.29 ± 0.18 at 3 DAS to 2.6 ± 0.3 at 6 DAS exhibiting the shortest marketable period of 3 days (Figure 4 and late 1). This appears to be associated with rapid loss of peel greenness and considerable weight loss (13.72 ± 0.55 %) experienced by those fruits compared to other maturity stages. However, fruits harvested at 147 DAFS remained marketable until 6 DAS (VQR 3.86 ± 0.26) and lost marketability by 9 DAS (VQR 2.71 ± 0.36), mainly as they became fully yellow even though the weight loss was significantly lower (14.66 ± 0.66 %) compared to the other stages. Moreover, characteristic shrivelling and wilting observed in fruits harvested at 119 DAFS seemed to be the main reason for the loss of visual quality by 9 DAS in comparison with fruits harvested at 133 DAFS which exhibited non-significant differences with respect to the peel colour changes and this may be related to the higher weight loss (23.33 ± 0.34 %) of the stage of 119 DAFS. Generally, the presence of active stomata and poorly developed cuticular waxes along with accelerated metabolism and high respiratory activity of immature non-climacteric fruits elevates moisture loss through transpiration compared to mature ones (Fawole and Opara, 2013).

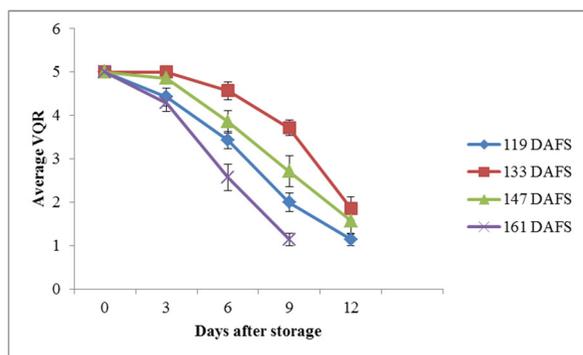


Figure. 4. Changes of visual quality rate (VQR) of fruits harvested 119, 133, 147 and 161 days after fruit set (DAFS) under ambient storage (30-34 °C, 70-75% RH).

Changes in juice pH and TA % were not significantly different 6 DAS and TA % slightly declined in all maturity stages except in 119 DAFS fruits concurrent with the slight increments observed in juice pH (Fig. 05: A and B). Fruits continue to respire using stored compounds such as organic acids, soluble sugars and proteins to sustain its life activities even after harvesting and utilization of citric acid more rapidly than soluble sugars as respiratory substrate during postharvest storage could have resulted the decline of the acidity (Sun *et al.*, 2013). However, increased acidity observed in the stage of 119 DAFS could be due to higher moisture loss associated with harvesting of immature fruits. In all the harvesting maturity except 119 DAFS, juice TSS content reduced within 6 DAS (Fig. 05: C), and this could be due to the decline of juice TA %. It has been reported that in acidic fruits such as lemons citric acid may account for 60–70 % of the juice TSS (Ladaniya, 2010).

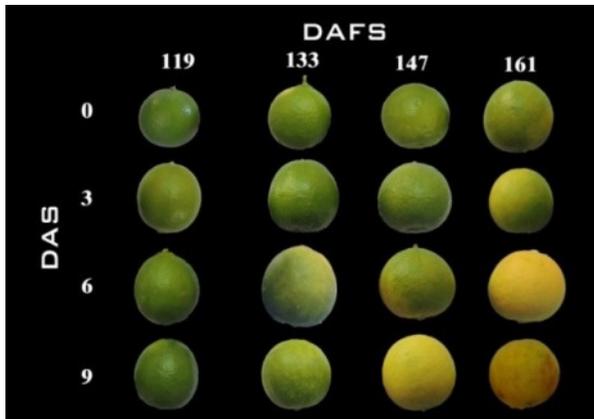


Plate 1. Changes of visual quality of lime fruits harvested at 119, 133, 147 and 161 days after fruit set (DAFS) during 0, 3, 6 and 9 days after storage (DAS).

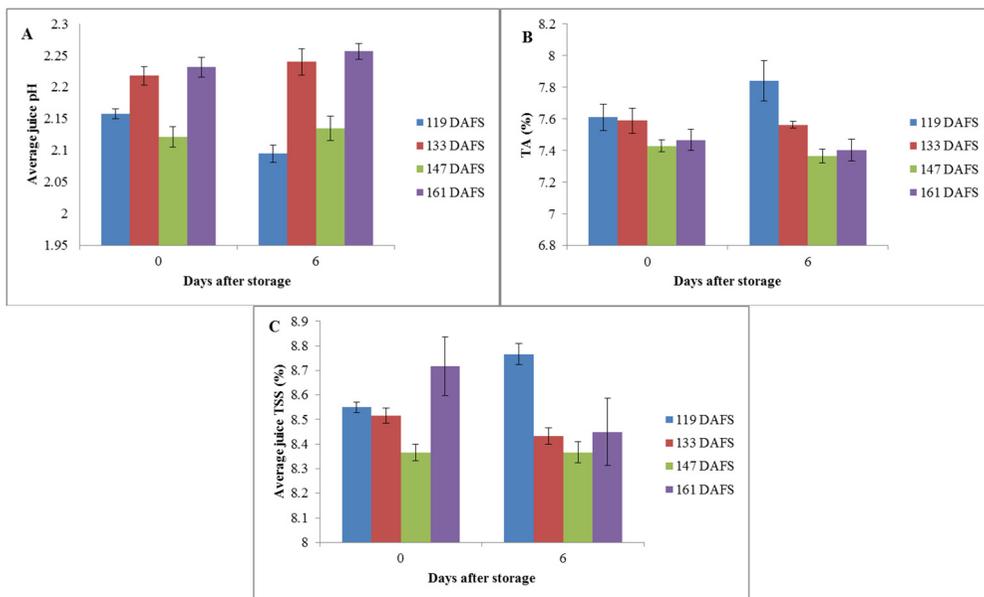


Figure 5. Changes of juice pH (A); titrable acidity (B) and total soluble solids content (C) of fruits harvested at 119, 133, 147 and 161 days after fruit set (DAFS) during 0 and 6 days after storage (DAS).

CONCLUSIONS

It can be concluded that harvest maturity significantly influences the postharvest life of lime. Moreover, both immature (119 DAFS) and over mature (161 DAFS) fruits deteriorate rapidly after harvest. Maturity stages of 133 and 147 DAFS showed shelf life of 9 and 7 days respectively under ambient storage (30-34 °C, 70-75% RH). The findings of this experiment will be useful, with particular reference, to long term storage, quality control, transportation and marketing, and will be beneficial for both lime growers and consumers.

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