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EFFECT OF HARVEST TIME AND STORAGE DURATION ON PHYSICO-CHEMICAL PROPERTIES OF CITRUS (*CITRUS SINESIS VAR. LATE VALENCIA)*

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Abstract
Citrus fruits are mostly consumed as fresh fruit and as processed natural fruit juice which is rich in vitamin C and other important nutritional food supplements. However, the nutritional content of citrus fruits depend on the physico-chemical content of the fruit at maturity and in holding. This paper investigated the effect of harvesting time and storage duration on the physico-chemical properties of the citrus fruits (Citrus sinensis var. late Valencia) and its likely impact on quality natural fruit juice processing in Ghana. The study used experimental method, (2 ×2) factorial design with three replications. A total of 450 fruits with the same maturity periods were harvested from the same farm for three different months (December 2011, January and February 2012), harvesting 150 fruits each month. A sample of 50 fruits physico-chemical properties were analyzed in their fresh state on day one of harvest while the remaining 100 fruits were stored at ambient temperature for five and ten days before analysis. The major findings of the study were that Vitamin C content of fruits increased with duration of storage, early harvested fruits contained high TSS and TTA and did not depend on storage duration. Also, TSS content in full ripe fruits increase as sugar content increases and acid content decreases. The study therefore concluded that vitamin C content of citrus fruits depends on duration of storage before processing while that of TSS and TTA did not depend on duration of storage before processing.

Keywords: Time of harvest, Physico-chemical properties, Duration of storage, Citrus processing quality.

Introduction

Fruit is an integral part of human diet serving as an important source of fiber, vitamins, minerals, and many other compounds that are essential for healthy living. Fruit crops also have an agricultural and commercial impact worldwide and are a considerable source of income for both the developed and the developing countries. Citrus is one of the four (including bananas, grapes and apples) most important fruit crops which dominates the world export trade, accounting for over 15 billion U.S. dollars in 2002, indicating the growing economic importance of fruit crops (Rodrigo & Zacarias, 2006). The citrus fruits are fragrant and have good flavour and juice. Currently, ten species of edible citrus are known of which eight are commercially cultivated and five are considered to be of great economic importance (Salunkhe & Desani, 1984). In the citrus fruit market, there are clearly two different sectors: fresh fruit consumption dominated by oranges, tangerines, and mandarins; and processed citrus products in which orange juice ranks first (Rodrigo & Zacarias, 2006). Sweet oranges are usually the most consumed as either fresh fruits or juice and are a good source of vitamin C with high antioxidant potential (Codd *et al*, 1972). The orange juice is the world most

popular fruit juice constituting a major portion of the food industry (TetraPak, 2004; Kimball, 1999). In 2005, about 59 million tons of oranges were produced worldwide. This represented 45 percent increase in orange production since 1970 (FAO, 2006). As of 2005, 21.8 million tons of orange fruits were processed into orange juice with Brazil leading (11.9 million tons) and followed by the United States (6 million tons). In Florida alone about 92 percent of all oranges produced are processed into single strength orange juice while 72 percent of all the oranges are sold as fresh fruits in California (USDA, 2007). The same cannot be said for Ghana where most of the fruits are consumed as fresh fruits with minimum household level processing. Over the last two decades, some food industries in Ghana have started commercial level processing of citrus fruits, among other fruits, into juice. However, the supply of orange fruits to the plants of these processing industries could have serious implications on the quality of juice chains out as the final product. The time (month) at which the fruits are harvested and the duration of storage could have direct or indirect impact on the physico-chemical properties which serve as precursors for synthesizing the nutritional compounds contained in the fruit. Hence, the quality of these precursors in the fruit determine the quality of the final processed product (orange juice) that is consumed. The aim of this paper therefore is to investigate the influence that time (months) of harvest as well as the duration (days) at which the fruits are stored after harvest have on the physico-chemical properties of sweet oranges, the dominant citrus variety in Ghana. This will provide processors with information on the most appropriate time to procure fruits for processing especially in the major season which spans from October to February for most countries in the tropics, south of the Sahara.

Data Sources and Methodology

The oranges used for the study were collected from a private farm (Adjei Farms) at Adumasa in the Ejisu-Juaben District of Ashanti Region of Ghana. In all, a total of 450 citrus fruits were harvested from selected citrus trees at three different periods of time (December, 2011 and January and February, 2012). A sub-total of 150 fruits were harvested for each of the periods. In each harvest, fruits were purposively grouped into three in order of maturity (i.e. mature green, half ripe and full ripe). The first batch of 50 fruits were randomly sampled from the three groups and their physico-chemical properties analysed on the day of harvest and the remaining 100 fruits stored at ambient temperature. The second batch of 50 fruits were randomly sampled and their properties analysed at 5days of storage. While the last batch of 50 fruits were analysed at 10 days of storage. The same procedure was followed for all the three harvests periods.

Using experimental method, the study used (3 ×3) factorial design with three replications. A one-way ANOVA set at ($p<0.01$ and $p<0.05$) was used to analyse the data and the mean values of the parametres analysed with their Least Significant Difference (LSD) and Cumulative Variance (CV) values presented in tables and line graphs. The summary of physico-chemical properties assessed in this paper is as shown in Table 1.

Table 1. List of physico-chemical properties assessed

Physico-chemical Property	**Measurement Unit**
Fruit Weight,	Grams (g)
Fruits Firmness	Millimeters (mm)
Juice Yield	Milliliters (ml)
pH	Number
Vitamin C	$mg100ml^{-1}$ juice

Total soluble solids (TSS)	$g100ml^{-1}$ juice
Total Dissolve Solids (TDS)	mgL^{-1} juice
Total Titratable Acidity (TTA)	$g100ml^{-1}$ acid
Electrical Conductivity (EC)	Number

Results and Discussions

Total Titratable Acidity (TTA)

The results showed a general decrease in total titratable acidity content of fruits harvested in December and February except January harvest which recorded the highest TTA content (Table 2). Fruits harvested in January showed fairly constant acid content in storage than those harvested in December and February. Significant differences of ($P<0.05$) existed in the TTA content among all the harvest for all the days of storage. The low TTA content in fruits harvested in February agrees with Anwar *et al.* (1999) that acidity in sweet oranges decrease with time of harvest. This could be due to accumulation of more soluble solids or sugars in the fruit which turns to dilute the acid concentration. This postulation resonates with the findings of Samson (1986) that the longer the fruits remain unharvested on the tree, TSS of the fruit increases which causes decrement in acidity of the fruit until eventually the fruit over ripe. Since lower acid content is known to improve flavour and sweetness oranges harvested late in the season (February) could be palatable and most prefered by consumers than early harvested fruits.

Table 2. Average Titratable Acidity (TTA)

Storage Duration (Days)	**Time of Harvest (Month)**			**LSD**	**CV**
	December	**January**	**February**		
Day1	11.000	9.033	8.333	1.7551	18.57
Day5	7.048	9.411	7.048	1.3157	16.78
Day10	7.044	9.133	7.856	1.2443	15.54

Source: Field Data, 2012

Total Soluble Solids (TSS)

The TSS content of fruits harvested in February was higher than that of fruits harvested in December and January. On the other hand, while the TSS content of fruits harvested in February and January steadily declined in storage that of December increased to the highest, $10.444g100ml^{-1}$, at the same duration of storage (Figure 1). The differences in the TSS content observed in all the months of harvest were significant (at $P<0.05$) across all the days of storage. The high TSS content of fruits harvested late in the season (February) disagrees with Bakshi *et al.* (1967) report that TSS decreases in late Valencia varieties when harvesting is prolonged. This observation however, confirmed Anwar *et al.* (1999) and Ahmad *et al.* (1992) findings that citrus fruits harvested in February have high TSS content. The TSS level of fruits harvested in January and February expectedly declined during prolonged storage as less and less solutes could be synthesized and accumulated. Unlike the late and middle season

harvested fruits, early (December) harvested fruits consistently increased in TSS level during holding which could be due to carry over synthesis and accumulation of solutes by maturing cells during the period of holding. This observation could also be attributed to high amount of water absorbed by the fruit during early season harvest when soil humidity is still high which might carry high amounts of the minerals that constitute the TSS content into the orange fruit. This suggests that middle and late season harvested orange fruits could give good quality processed fruit juice with high solute (sugars) content when processed shortly after harvest. However, in holding for scheduled processing early season harvested fruits will be more appropriate.

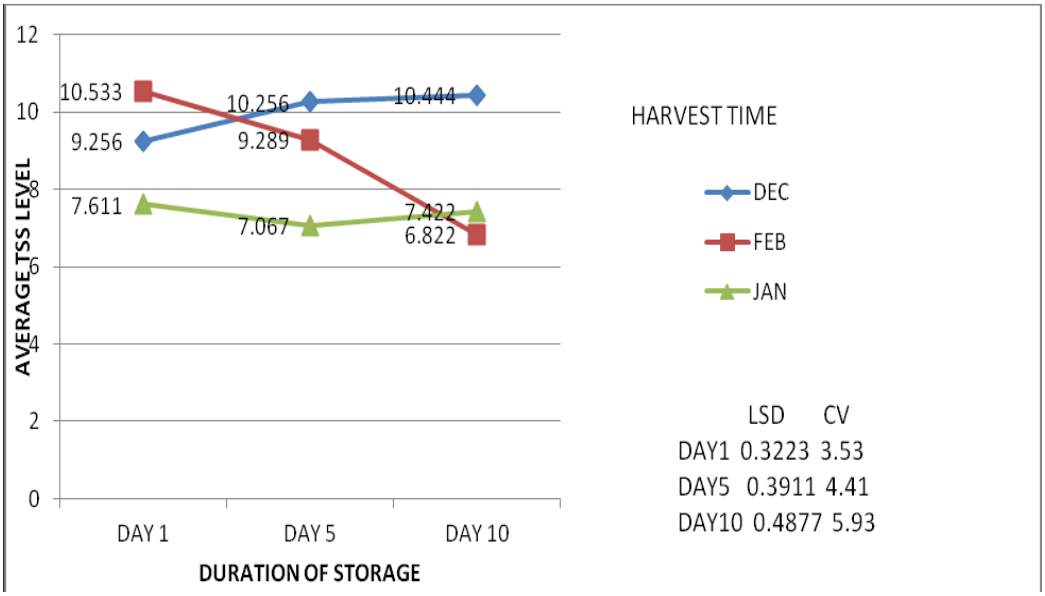

Figure 1. Harvest time and duration of storage on TSS
Source: Field Data, 2012

Total Dissolve Solutes (TDS)

The results (Figure 2) again showed that TDS content of fruits harvested in February was high as compared to TDS content in January and December harvested fruits, indicating that TDS content increase with time of harvest. However, the differences in TDS content of fruits harvested for all the months and days of storage were not significant ($p>0.05$). This observation could be due to the fact that the longer the fruit stayed on the tree before harvest the more TDS may synthesized and accumulated or absorbed into the fruit. This hypothesis is based on WHO (1996) explanation that TDS is made up of inorganic salts found in water as well as organic salts synthesized by plants. However, in storage fruits harvested in December and January increased while that of February declined. This suggests that fruits harvested in December and January for processing could contain high mineral supplements when stored for some time before processing, unlike fruits harvested in February which should be processed shortly after harvest to obtain maximum mineral supplements.

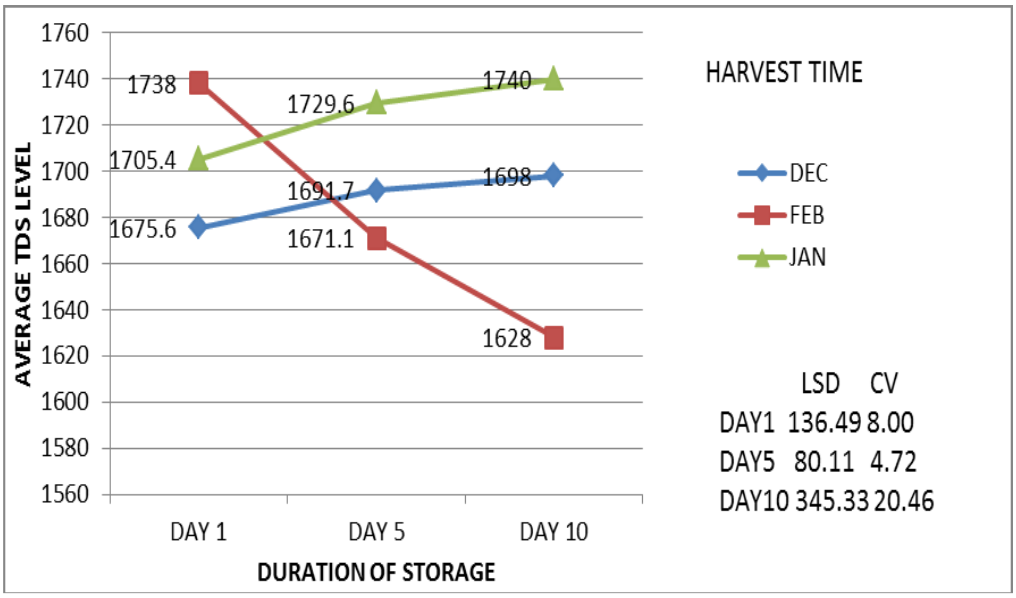

Figure 2. Harvest time and duration of storage on TDS
Source: Field Data, 2012

Juice Yield

The orange fruits harvested in December recorded the highest juice yield compared to fruits harvested in January and February. Also the juice yield of fruits harvested in December and February declined steadily in storage, while that of January increases sharply in storage (Figure 3). However, the differences in the juice yield of fruits in all the months of harvest were not significant ($p>0.05$) irrespective of the duration of storage. The higher amount of juice yield in orange fruits harvested in December observed confirmed the findings made by Anwar *et al*. (1999) that juice content of citrus decreased with harvesting time and that juice content are higher when orange fruits are harvested in December. This observation could be due to the fact that atmospheric humidity is high within this period and hence fruits at the time might absorbed more water thus soaring the juice content of the fruit. However, with the exception of fruits harvested in January, all the fruits harvested in December and February juice content declined in storage. An observation that can be attributed to loss of moisture by the fruits due to storage under ambient temperatures. This suggests that orange fruits no matter the time of harvest could have higher juice yield when process immediately after harvest than when kept in storage for some time before processing.

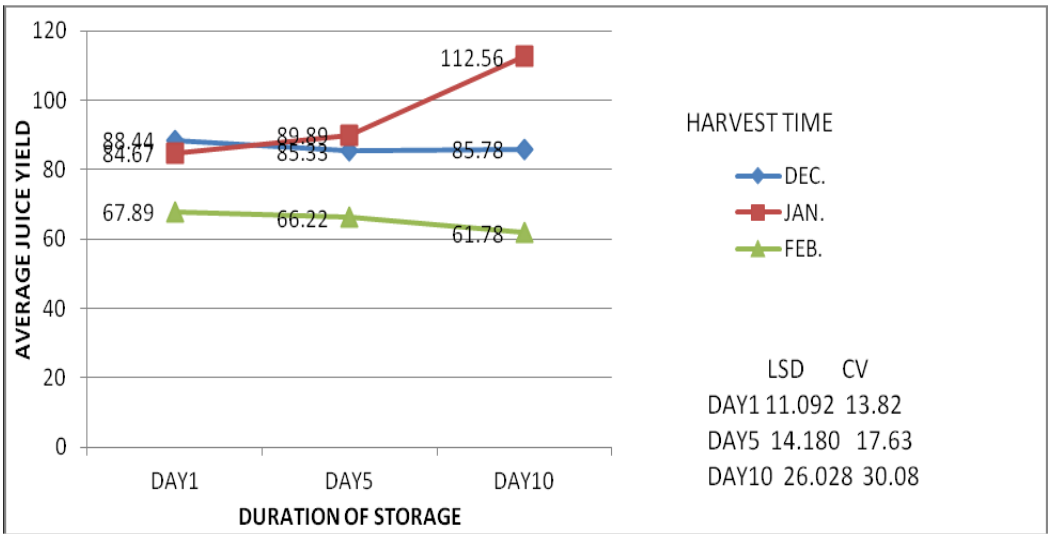

Figure 3. Harvest time and duration of storage on juice yield
Source: Field Data, 2012

Level of pH

Table 3 showed that orange fruits harvested in January and December have high pH level than fruits harvested in February. Also in storage, fruits harvested in February showed consistently lower pH level than both December and January harvest. The differences in the pH levels of oranges observed for all the days of storage were significant ($P<0.05$) in all the months of harvest. The high pH level observed in fruits harvested in December and January partly supports Anwar *et al.* (1999) findings that in citrus fruits acidity is maximum when fruits are harvested in December as compared to fruits harvested in the other months. The increment in the pH levels observed in the December and January harvested fruits in storage was unexpected because according to Sasson & Monselise (1977), Sinha *et al*. (1962) and Cepeda *et al.* (1993) malic acid and ascorbic acid which are major determinants of pH in citrus decrease in storage which contravenes this finding. Also, the low pH level observed in fruits harvested in February could be attributed to accumulation of more sugar as the fruit stay longer on the tree in late season oranges. This suggests that orange fruits harvested late in the season have low acid content and therefore might be more palatable than early and middle season harvested fruits even under the same condition of holding before processing.

Table 3. Average pH level

Storage Duration (Days)	Time of Harvest (Month)			LSD	CV
	December	January	February		
Day1	3.917	3.807	4.100	0.1332	3.38
Day5	3.964	3.758	4.006	0.1596	4.08
Day10	3.871	3.764	4.187	0.1316	3.34

Source: Field Data, 2012

Fruit Weight

The analysis further indicated (Figure 4) that fruits harvested in January recorded the highest weight 209.56g, while December harvest had the lowest weight 180.22g which was significant (P<0.05). There was however, a general decline in weight levels of orange fruits in prolonged storage (5-10days) for all the months of harvest but the differences were not significant (p>0.05). The highest fruit weight observed in fruits harvested in January disagrees with Anwar *et al.* (1999) report that sweet orange fruits harvested in February weighs more than fruits harvested in December and January. The observation however, partly support Cepeda *et al*., (1993) and Anwar et al. (1999) report that citrus fruits weight increase with time of harvest. The increase could be attributed to accumulation of photosynthates in the fruit as argued by (Khan *et al*, 1992). However, the decline in weight of fruits in storage for all the months of harvest could be attributed to loss of moisture in fruits stored under ambient temperatures. This suggests that farmers who sell their fruits by weight could lose some money as fruits may lose weight during holding.

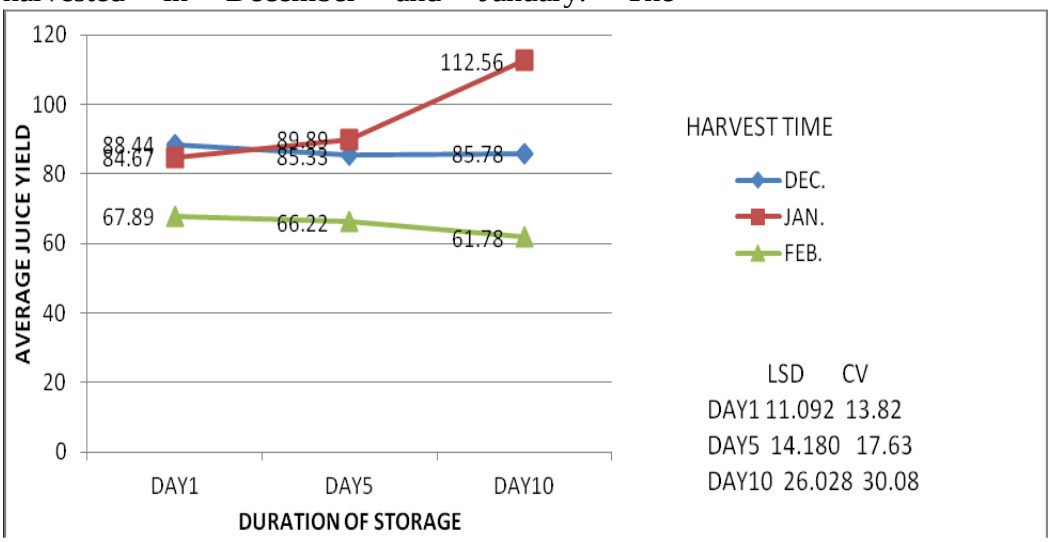

Figure 4. Harvest time and duration of storage on fruit weight
Source: Field Data, 2012

Citrus Fruit Firmness

Furthermore, the results (Figure 5) showed that February harvested fruits had the highest fruit firmness 4.244mm, whereas fruits harvested in January recorded the lowest fruit firmness 3.422mm. However, during storage while the firmness level of fruits harvested in February increased at a decreasing rate that of December and January harvest increased at an increasing rate. The differences in firmness of the citrus fruits in prolonged storage were significant (P<0.05) across all the months of harvest. The high firmness level observed in fruits harvested in February is in sync with Anwar *et al.*, (1999) findings that peel thickness or firmness increase with delay in harvest time. The increase could be attributed to increase in fruit size as well as thickening of the peel due to exposure to ambient conditions when harvesting is delayed. The general increased in fruit firmness observed in storage for all the months of harvest confirmed Tu *et al.* (1997) report that some citrus varieties have greater firmness retention during storage than others which may be the case of the late Valencia variety used in this study. The results suggests that good firmness quality of orange fruits is attained when harvesting is delayed.

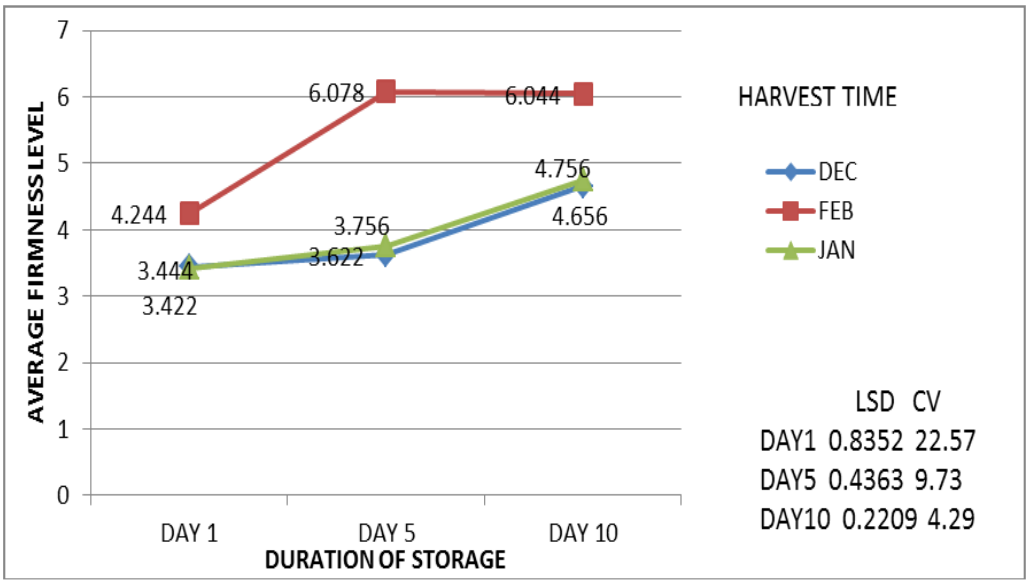

Figure 5. Harvest time and duration of storage on firmness
Source: Field Data, 2012

Electrical Conductivity (EC)

It was also observed (Table 4) that fruits harvested in January had higher EC level as compared to fruits harvested in December and February. The EC levels in citrus fruits harvested fluctuates in storage for all the months of harvest as the EC levels declined shortly after minimum storage and then raised again to maximum in prolonged storage. The differences in the EC levels of fruits in storage were significant ($P< 0.05$) for all the months of harvest. The fluctuations in EC levels observed in this study looked similar to Samson & Monselise (1977) report that during holding of orange fruits internal conductivities declined sharply and then increased very strongly under different storage conditions.

Table 4. Average Electrical Conductivity (EC) level

Storage Duration (Days)	Time of Harvest (Month)			LSD	CV
	December	January	February		
Day1	3234.4	3644.3	3457.1	342.09	9.94
Day5	3361.1	3516.9	3359.0	164.53	4.82
Day10	3042.3	3413.0	3591.8	546.59	16.33

Source: Field Data, 2012

Vitamin C Content

The analysis of vitamin C content showed (Figure 6) that fruits harvested in December had the highest vitamin C content, 2.3mg100ml^{-1} when compared to February and January. There was however a general increased in vitamin C content in prolonged storage for all the months of harvest. The differences in vitamin C levels of fruits observed in storage for all the months of harvest were significant at ($P<0.01$) for all the days of storage. The maximum vitamin C content observed in fruits harvested in December is contrary to Sinha *et al.* (1962) and Anwar *et al.* (1999) earlier report that vitamin C content of most sweet orange varieties is maximum in February or increase as harvesting time increases. This observation could be attributed to differences in intensity of light at various times of harvest. A postulation that is pedestaled on Lee & Kader (2000) argument

that higher light intensity during the growing season of the citrus tree could increase the vitamin C content in the plant tissues.

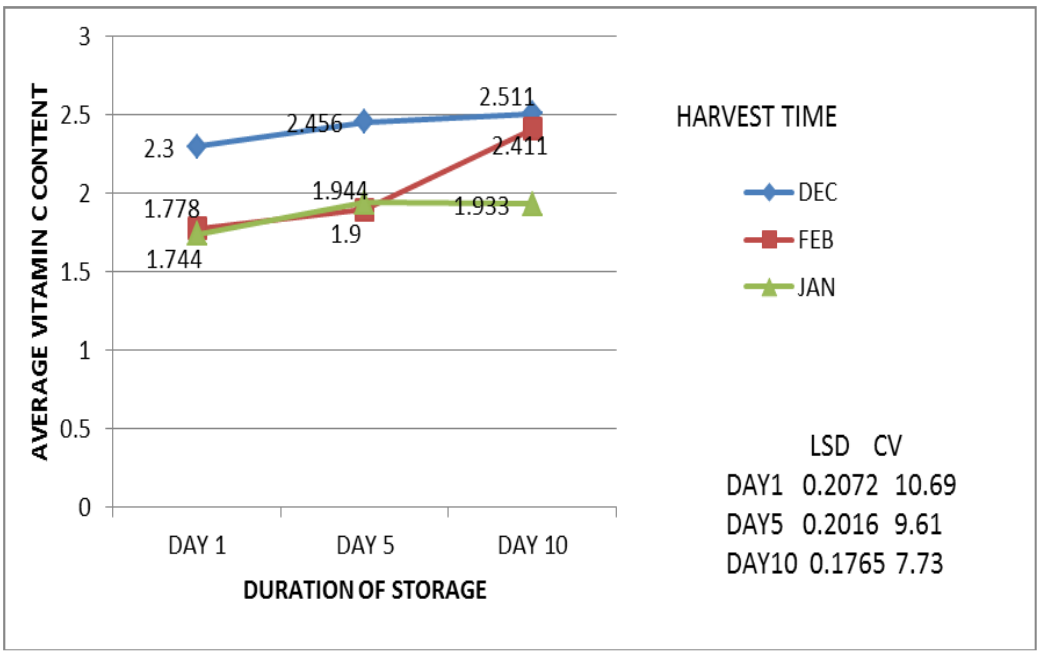

Figure 6. Harvest time and duration of storage on vitamin C
Source: Field Data, 2012

However, the increase in vitamin C content of orange fruits in storage was unexpected because according to Sinha *et al.* (1962) and Cepeda *et al.* (1993) vitamin C (determined by ascorbic acid in citrus) content of late Valencia citrus fruit decrease in storage. Probably, the increase in vitamin C content in prolonged storage observed in this study could be due to residual synthesis of vitamin C by vitamin C precursors which was carried over into storage hence the increment observed. This suggests that orange fruits harvested early in the season is rich in vitamin C content than middle and late harvest fruits. However, the vitamin C content of the middle and late harvest fruits can be enhanced before processing by prolonged period of storage at ambient temperatures.

Conclusion

The level of physico-chemical properties of sweet oranges which are either nutritional supplements on their own or serve as precursors for synthesizing important nutrients required by the human body are determined by the duration of storage and the time at which the fruits are harvested for processing or consumption. Therefore orange fruits harvested late in the season should be processed shortly after harvest to take full advantage of the high physico-chemical properties associated with fruits at this time. While fruits harvested early and middle of the season should be held in storage for a minimum of five days and maximum of ten days to concentrate the physico-chemical elements in them for quality juice production.

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