**AGREEMENT INIFAP-NATIONAL MANGO BOARD**

# VALIDATION OF THE HEAT UNITS TECHNIQUE TO DETERMINE THE OPTIMUM HARVEST TIME ON MAIN EXPORTING MANGO VARIETIES

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## SUMMARY

The determination of optimum harvest time is perhaps one of the main factors that affects the postharvest life of mango fruit. Fruit harvest immature never reach the degree of required maturity, while fruit that ripe on the tree have the best flavor, color, and aroma, but they are very susceptible to pathogen attack and less resistant to shipping. When fruit are harvested at physiologically ripe stage their characteristics of color, flavor, aroma, firmness, and shipping resistance are much better. It is evident that the determination of optimum harvest time and the maintenance of sensorial properties after harvest (handling, packing, trading, and distribution) is essential to satisfy the consumers' needs, which allow us to offer they fruit with more colorful, scented, and appropriate texture.

The objectives of this assay were to validate the use of the Accumulated Heat Units technology in 'Ataulfo', 'Tommy Atkins', 'Kent', and 'Keitt' mango varieties; to increase the fruit caliber comparing to traditional harvest; to increase the fruit yield at least in 2 ton/ha, and to get higher total soluble solid content (°Bx) at consumption stage.

During 2017-2018 trials were established in commercial orchards of the varieties Tommy Atkins and Kent (2017) as well as Ataulfo, Tommy Atkins, Kent and Keitt (2018) in the counties of San Blas and Santiago Ixcuintla, Nayarit and the counties of Rosario and Escuinapa in the South of Sinaloa. To quantify the accumulation of Heat Units (HU), Hobos were installed at the beginning of each year to follow flowering, set fruit and fruit development from full flower to optimum harvest stage. The Hobos were programmed to record temperature and relative humidity (RH) every 30 min. In each orchard 10 representative trees were selected, in which at least 40 panicles were marked (10 in each cardinal point) when they were in full bloom of the main flowering flow and once the fruit was big enough, they were individually labeled to monitor growth and development of fruit every three weeks until reaching the optimum harvesting time. The variables analyzed were dry matter, weight loss, external color, firmness and pulp color, total soluble solids (° Bx) and ° Bx / acidity ratio. The fruit were measured for length, diameter, weight and size, as well as initial quality at harvest time, at the end of refrigerated transfer simulation (seven days at 12 ± 1 ° C, 90 ± 5% RH) and at consumption ( after 7-12 days of marketing simulation at 22 ± 2 ° C, 75 ± 10% RH). Data was analyzed using the SAS statistical program.

It was corroborated that the HU required for the optimum harvest time of the Ataulfo and Tommy Atkins mango varieties was 1,600 HU, for Kent 1,800 HU and for Keitt from 2,100 to 2,200 HU. If there is no early harvest and the varieties are allowed to reach their optimum harvest time, fruit size caliber will increase, as well as yield volume. In addition, greater satisfaction is achieved to the buyer since the fruit reach consumption stage with higher content of total soluble solids and better ratio Bx / Acidity.

## BACKGROUND

The determination of optimum harvest time is perhaps one of the main factors that affects the postharvest life of mango fruit. Fruit harvest immature never reach the degree of required maturity, while fruit that ripe on the tree have the best flavor, color, and aroma, but they are very susceptible to pathogen attack and less resistant to shipping. When fruit are harvested at physiologically ripe stage their characteristics of color, flavor, aroma, firmness, and shipping resistance are much better (Osuna-García, 2006). It is evident that the determination of optimum harvest time and the maintenance of sensorial properties after harvest (handling, packing, trading, and distribution) is essential to satisfy the consumers' needs, which allow us to offer they fruit with more colorful, scented, and appropriate texture (Medlicott et al., 1988).

There are maturity indexes that are based on the sugar content, acidity, color of the skin or pulp, specific gravity, days of flowering to harvest and accumulation of Heat Units, among others. The Heat Units (HU) or degrees-day are defined as the time required to complete a particular phenological phase based on the accumulation of heat units from a base temperature (Muñoz et al., 1986; Ruiz-Corral et al. 1992, Pérez de Azkue and Puche, 2003). The accuracy of the prediction of HU required is a function of the determination of the base temperature (Higley et al., 1986), or the use of cardinal temperatures that in mango are reported between 10 and 35 °C (Benachio and Avilán, 1982). In addition, some authors indicate that the success of the degrees-day depend on a close relationship between radiation and temperature; photoperiod and temperature and cultivars adapted to local photoperiods (Hodges and Doraiswamy, 1979). The mango grows and develops between 10 and 43 °C with an optimum of 25 to 28° C. When the temperature drops below 10 °C, the growth of the tree is very slow and its flowering is very low (Mederos, 1998), so by definition it is deduced as a base temperature of 10 °C, which was used by Guzmán-Estrada et al. (1996) in Manila mango, although some authors report 12 °C (Ometto, 1981) or even 17.9 °C (Burondkar et al., 2000). Mosqueda-Vázquez et al. (1993) determined the degree-day and base temperature required for elongation of inflorescence and fruit development in Manila mango, concluding that 434.7 degree-days were required with a base temperature of 12 °C for inflorescence elongation and 2292.7 degree-days to complete fruit development.

In Venezuela, preliminary mango studies report differences in the heat units required by the Haden variety compared to other varieties (Cumare and Avilán, 1994) as well as different requirements for Springfels, Haden and Edward varieties under high density management conditions (Azkue et al., 2000).

In Mexico, this technology was generated in 2005, year in which three orchards were selected in the strata of 0-150 masl, 151-300 masl and 301-450 masl. For 2006, the information was validated in two orchards located in Santiago Ixcuintla (19 masl) and La Cofradía (137 masl). In 2007, the technology was demonstrated in two commercial orchards of 'Ataulfo' located at 22 masl (Crucero de Estación Nanchi, Santiago Ixcuintla County) and 137 masl (La Cofradía, San Blas County).

The greatest impact of the HU accumulation until the time of harvest was in the caliber of the fruit. It was observed that the greater the HU accumulation, the greater the caliber of fruit, especially in those harvested around 1,600 HU, which reached in 'Ataulfo' more than 50% of fruits greater than size 18 with unit weights of 251 to 420 g. It is important to highlight the harvesting of larger calibers. For the 2006 season, the sale price per box of 10 pounds to the broker was $ 1.98 for the 18-caliber, while the sizes 16, 14 and 12 reached a price of 2.97, 4.12 and 5.03 dollars, respectively. In addition, it was observed that fruits harvested at 1,600 HU weighed 30 to 50 g more than those harvested around 1,250 UC, which allows an increase in yield of 1.2 to 2.0 ton / ha. On the other hand, it was noticeable that at the time of harvest, as the AHU increased, the pulp color increased, which, with the highest amount of AHU, varied from 2.3 to 3.0.According to the maturity table of EMEX, AC (1998), these values indicate a maturity stage from minimum acceptable to ripe, which implies a lower risk of rejection in packing for unripe fruit and that finally this was also reflected in better quality since it was observed that the higher the quantity of AHU, the higher the content of total soluble solids (° Bx) at consumption stage.

According to the experiences obtained, the optimum harvest time for mango 'Ataulfo' and 'Tommy Atkins' in Nayarit is between 1,500 and 1,600 UCA, while for 'Kent' it is 1,800 UCA and in 'Keitt' it is estimated to be 2,000 UCA. To know this moment, the temperature information that is being captured by the Hobos can be monitored at weekly intervals from 100-110 days when the "zero" moment was determined and when it

reaches at least 1,500 AAUs it is the time to schedule the harvest in 'Ataulfo' and 'Tommy Atkins', in 'Kent' when it reaches 1,700 UCA and in 'Keitt' when it reaches 1,800 UC.

## OBJECTIVES

- To validate the use of the Accumulated Heat Units technology in ‘Ataulfo’, ‘Tommy Atkins’, ‘Kent’, and ‘Keitt’ mango varieties.
- To increase the fruit caliper comparing to traditional harvest.
- To increase the fruit yield at least in 2 ton/ha.
- To get higher total soluble solid content (°Bx) at consumption stage.

## METHODOLOGY

- **Varieties**: ‘Tommy Atkins’ and ‘Kent’ (2017). ‘Ataulfo’ ‘Tommy Atkins’, ‘Kent’, and ‘Keitt’ (2018).
- **Location**: Commercial orchards of the four varieties in San Blas and Santiago Ixcuintla counties in Nayarit, as well as, in Rosario and Escuinapa in southern Sinaloa.
- **HU Accumulation**: HOBOS were installed at the beginning of January of each year to follow flowering, fruit set and fruit development from full flower (panicles with at least 50% of flowers in anthesis and it is considered the 'zero moment' or the beginning of accumulation of HU), until optimum harvest stage. HOBOS were programmed to record temperature and RH every 30 min. The accumulation of HU was calculated considering base temperature 10 °C (Guzmán-Estrada et al., 1996, Ruiz-Corral et al., 1999). In each orchard, 10 representative trees were selected, in which at least 40 panicles were marked (10 in each cardinal point) when they were in full bloom of the main flowering flow (the one that occurs in the second half of January and normally covers 60 -70% of the tree canopy) and once the fruit is set, they are individually labeled to continue growth and fruit development every three weeks until reaching the optimum harvest stage.
- **Variables to measure**: At harvest time the diameter, length, weight and caliber of 50 fruit was registered, as well as initial quality, then a shipping simulation period

(seven days at 12 ± 1 °C; 90 ± 5 % RH) + Market simulation (22 ± 2 °C; 75 ± 10 % RH) until consumption stage. The variables to measure were: dry matter, weight loss, external appearance, skin color, firmness, pulp color, total soluble solids (ºBx), tritatable acidity, and ratio ºBx/acidity. Sampling was done at Initial, at the end of refrigerated period and then at consumption stage. Data were independently analyzed for each variety by ANOVA using the SAS program. A Completely Randomized design with 20 replications for weight loss and six for all the other variables was used.

**Description of analyzed variables**

- **Dry matter**. Using a microwave oven according to Brecht et al. (2011). Five g of the pulp were got with a slicer and they were put in a Petri dish to dry for 4 to 7 min until constant weight. Values were expressed in percentage.
- **Weight loss.** Weight loss. Using a digital portable scale with a capacity of 2,200 g and approximation of 0.01 g (Ohaus corp Florham Park, NJ). Twenty fruit were weighed periodically from the beginning to the end of the experiment. The difference in weight with respect to the initial weight was expressed as a percentage of weight loss.
- **Skin color**. With a portable colorimeter CR-400 (Konica Minolta) with standard lighting C, the color space parameters 'L' 'a' & 'b' were measured. The data were expressed with the 'a' value, which in Ataulfo was the best color descriptor from deep green to yellow-orange.
- **Firmness.** Data were taken with a Model DFE-050 Chatillon penetrometer (Ametek Instruments, Largo, FL), adapted with cylindrical tip of 8 mm diameter and expressed in pound force (Lbs-f).
- **Pulp color.** A Konica Minolta CR-400 portable colorimeter was used, using the C illuminant and reporting the hue angle (hue).
- **Total soluble solids (TSS).** A digital ATAGO refractometer with temperature compensator model PAL-1 calibrated with distilled water was used (AOAC, 1990).

- **Ratio °Bx/Acidity.** It is obtained by dividing the TSS value over the acidity. The minimum value must be ≥ 35.0.

**RESULTS 2017**

Validations of 'Kent' and 'Tommy Atkins' were established in both Nayarit and southern Sinaloa. In each orchard at the beginning of March, six trees were marked in full bloom. In each tree, 40 panicles were marked. Later, when the fruit had a size of 3-5 cm in length they were labeled individually to follow growth and development. Harvest was done at 1,650 and 1,800 HU for 'Kent' and 1,450 and 1,600 HU for 'Tommy Atkins'.

**Results in 'Kent'**

Figure 1 shows the growth and development of fruit grown in Nayarit and harvested at 1,650 HU on June 14, while the ripe fruit were harvested at 1,800 HU. It was observed that the fruits in the first stage of maturity reached a maximum of 116.5 mm in length and 84.1 mm in diameter, while the ripe ones reached 115.2 mm in length and 85.5 mm in diameter, observing that practically no differences were detected in both HU. This trend was also corroborated for the fruit harvested in Sinaloa, although the final sizes were lower since they had more limited conditions of water availability. The fruits harvested at 1,650 HU, reached a maximum of 105.5 mm in length and 72.8.3 mm in diameter, while those harvested at 1,800 HU reached 105.4 mm in length and 72.6 mm in diameter (Figure 2).

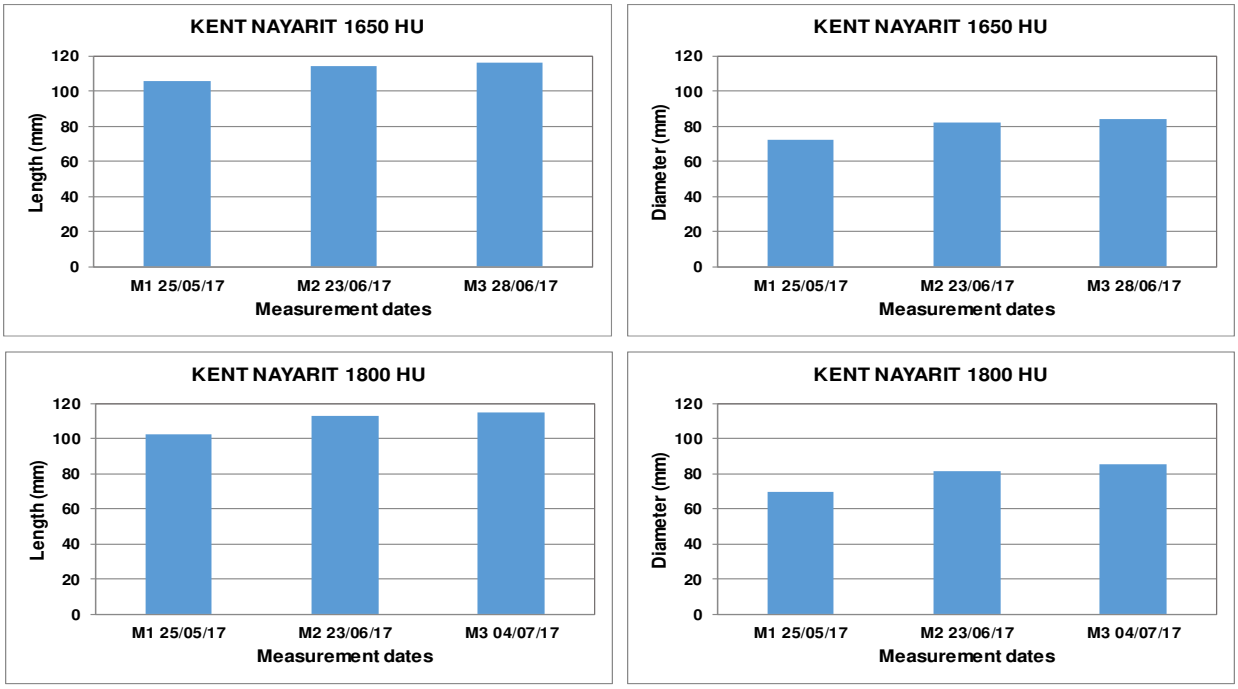


**Figure 1. Length and diameter of fruit (mm) from 'Kent' at 1,650 and 1,800 HU in Nayarit. Season 2017.**

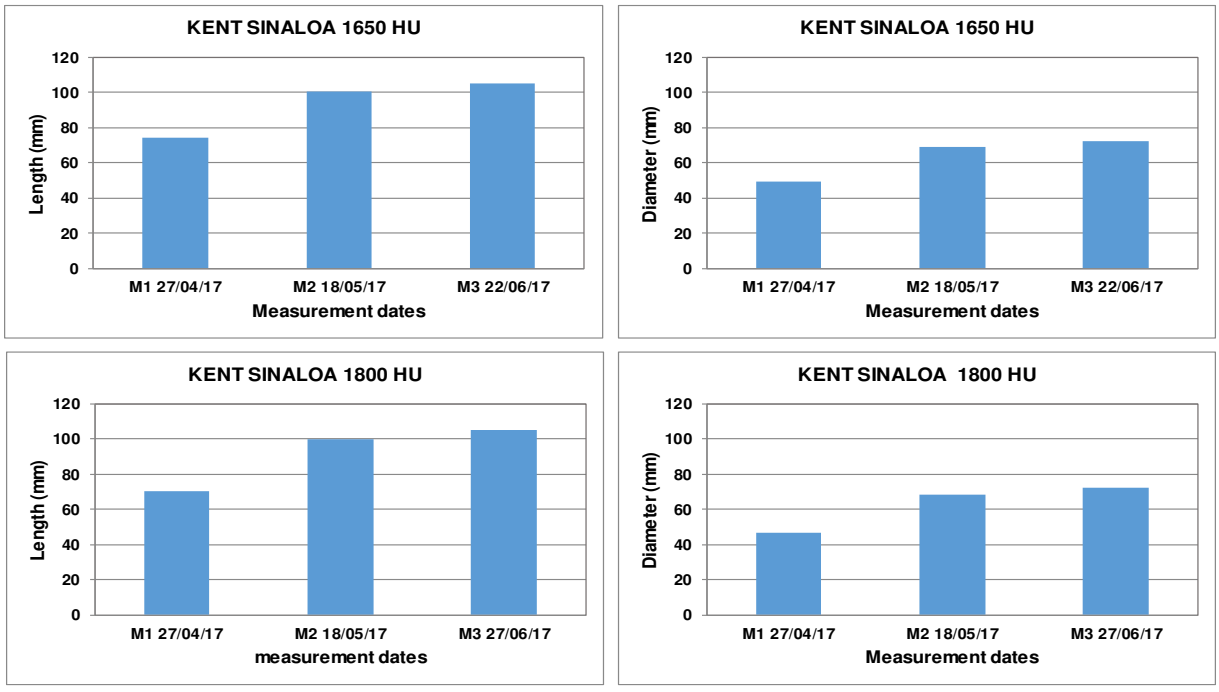


**Figure 2. Length and diameter of fruit (mm) from 'Kent' at 1,650 and 1,800 HU in Sinaloa. Season 2017.**

The harvest results describe perfectly how the weight and the size (number of fruit that fit in a box of 10 pounds) are affected by HU accumulation. Figure 3A illustrates the average weight of the fruit at harvest in Nayarit; those harvested at 1,650 HU averaged 500 g, while those harvested at 1,800 UC averaged 600 g. The 100 g difference represents 3 ton / ha additional to the yield. This same trend was observed in 'Kent' fruit harvested in Sinaloa (Figure 3B). Those at 1,650 HU averaged 390 g and those harvested at 1,800 HU averaged 480 g, which represents an additional 2.7 tons / ha. On the other hand, the effect of HU accumulation is more evident and significant in the sizes of the fruit (larger numbers mean small fruit and the opposite, smaller numbers mean larger fruit). In Nayarit (Figure 3C), fruit harvested at 1,650 HU presented 85% of fruit with calibers 9 and 10, while those harvested at 1,800 HU presented 95% of grades 7 and 8. Something similar happened in the fruit harvested in Sinaloa, although these were smaller because the availability of irrigation water was not enough. In Figure 3D it is observed that the harvested fruit at 1,650 HU had 85% of calibers 12 and 14's, while those harvested at 1,800 HU showed 95% of fruit with calibers 9, 10 and 12's. Here the importance of harvesting the fruit with a greater accumulation of HU is demonstrated, only 150 HU of difference (7 to 10 days), made spectacular differences in weight, caliber, yield volume, shelf life and flavor at consumption stage.

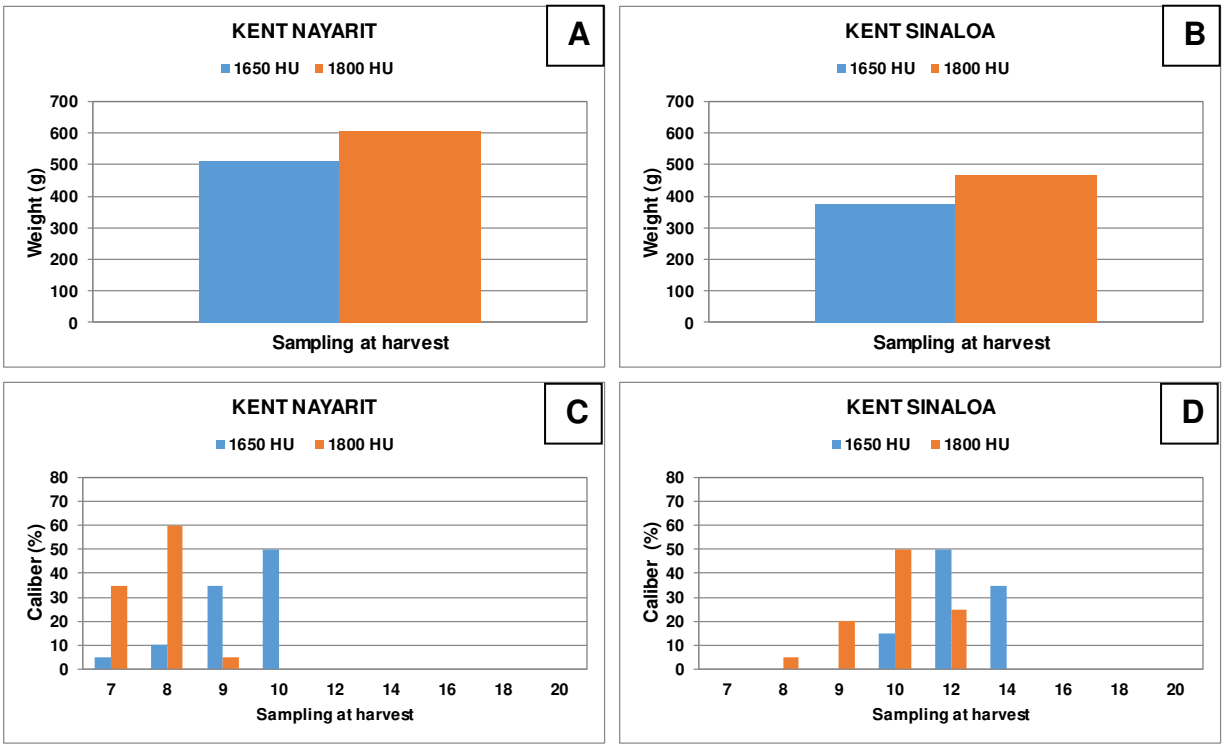


**Figure 3. Average weight (g) and caliber of 'Kent' fruit harvested at 1,650 and 1,800 HU in Nayarit and Sinaloa. Season 2017.**

The external and internal appearance of 'Kent' fruit at harvest and at consumption are presented in Figures 4 and 5. The fruit of Nayarit looked like as with the minimum maturity to harvest at 1,650 HU, while those of 1,800 HU looked as ripe fruit with good external and internal appearance. On the other hand, the fruit of Sinaloa harvested at 1,650 HU showed themselves as unripe since they did not ripen properly, while those at 1,800 HU behaved like fruit with the minimum maturity at harvest since they developed good external and internal appearance.


**Figure 4. Illustration of the external and internal appearance of 'Kent' fruit harvested at 1,650 HU (A) or at 1,800 HU (B). Las Palmas, Nayarit. Season 2017.**

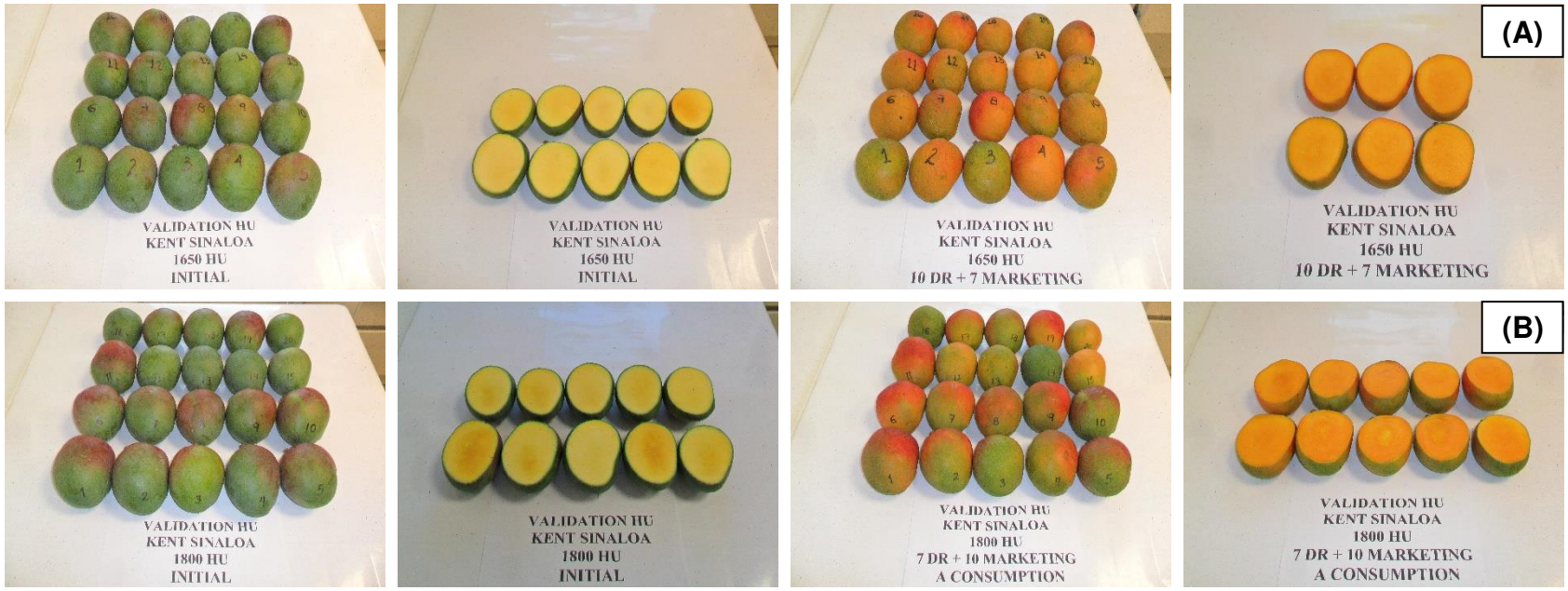


**Figure 5. Illustration of the external and internal appearance of 'Kent' fruit harvested at 1,650 HU (A) or at 1,800 HU (B). Escuinapa, Sinaloa. Season 2017.**

**Results in 'Tommy Atkins'**

Unfortunately, the cooperating growers harvested the marked trees and fruit labeled in this variety, in both locations, in advance without having previously warned us. The argument they stated was because of a lot of demand in the market, the packers asked for sizes that looked like ripe fruit and everything that seemed to fulfill it was harvested.

In the 2018 season, the validation lots of the four varieties (Ataulfo, Kent, Keitt and Tommy Atkins) were established, both in Nayarit and in the south of Sinaloa.

**RESULTS 2018**

Validations of the four varieties (Ataulfo, Tommy Atkins, Kent and Keitt) were established in both, Nayarit and southern Sinaloa (Table 1). The key stages of Hobos placement, zero moments and the dates for HU accumulation to harvest1 (minimum maturity) and harvest2 (ripe) are noted.

**Table 1. Location of Hobos in Ataulfo, Tommy Atkins, Kent and Keitt orchards from Nayarit and southern Sinaloa with their respective accumulated HU.**

| State | Variety | Location | Dates | | | |
|---|---|---|---|---|---|---|
| | | | Installation | Zero Moment | AHU1 | AHU2 |
| Nayarit | Ataulfo | Las Palmas | Dec, 2017 | 4 March, 18 | 1,460 (060618)* | 1,594 (130618)* |
| | Tommy A. | El zopilote | Feb, 2018 | 05 Feb, 18 | 1,470 (210518) | 1,612 (290518) |
| | Kent | Rigoberto | Dec, 2017 | 27 Feb, 18 | 1,563 (140618) | 1,901 (030718) |
| | Keitt | Las Palmas | Dec, 2017 | 03 Feb, 18 | 1,881 (140618) | 2,225 (030718) |
| Sinaloa | Ataulfo | Diazteca | Dec, 2017 | 03 Feb, 18 | 1,496 (110618) | 1,627 (180618) |
| | Tommy A. | Tasajal | Dec, 2017 | 21 Feb, 18 | 1,400 (020618) | 1,581 (110618) |
| | Kent | Tasajal | Dec, 2017 | 02 Feb, 18 | 1,661 (041618) | 1,805 (110618) |
| | Keitt | Tasajal | Dec, 2017 | 02 Feb, 18 | 1,843 (110618) | 2,259 (040718) |

***Day/Month/Year**

Next, the process from the installation of Hobos in December, 2017 is illustrated, going through identification of trees, marking of panicles in full bloom, fruit labeling and measuring growth and development of fruit every three weeks.

1. **Hobos installation**



2. **Identification of trees**



3. **Marking panicles in ‘full bloom’ and ‘zero moment’ (extreme right).**



## 4. Labelling and initial fruit measurement



## 5. Second measurement of growth and development



## 6. Third measurement of growth and development



## I. Results on growth and development of the fruit

### a. Ataulfo

Figure 6 shows the growth and development of 'Ataulfo' fruit grown in Nayarit and harvested at minimum maturity stage at 1,460 HU on June 6, while the ripe fruit were harvested at 1,594 HU on June 13. It was observed that the fruit at the first stage of maturity reached a maximum of 118.5 mm in length and 65.1 mm in diameter, while the ripe ones reached 119.7 mm in length and 67.1 mm in diameter, manifesting the trend that a greater HU accumulation, larger size. This trend was corroborated also for 'Ataulfo' fruit harvested in Sinaloa, although the final sizes were smaller since they had more limited conditions of water availability. Fruit harvested at the minimum maturity at 1,496 HU, reached a maximum of 95.4 mm in length and 52.4 mm in diameter, while the ripe ones harvested at 1,627 HU reached 101.3 mm in length and 56.9 mm in diameter (Figure 7) .

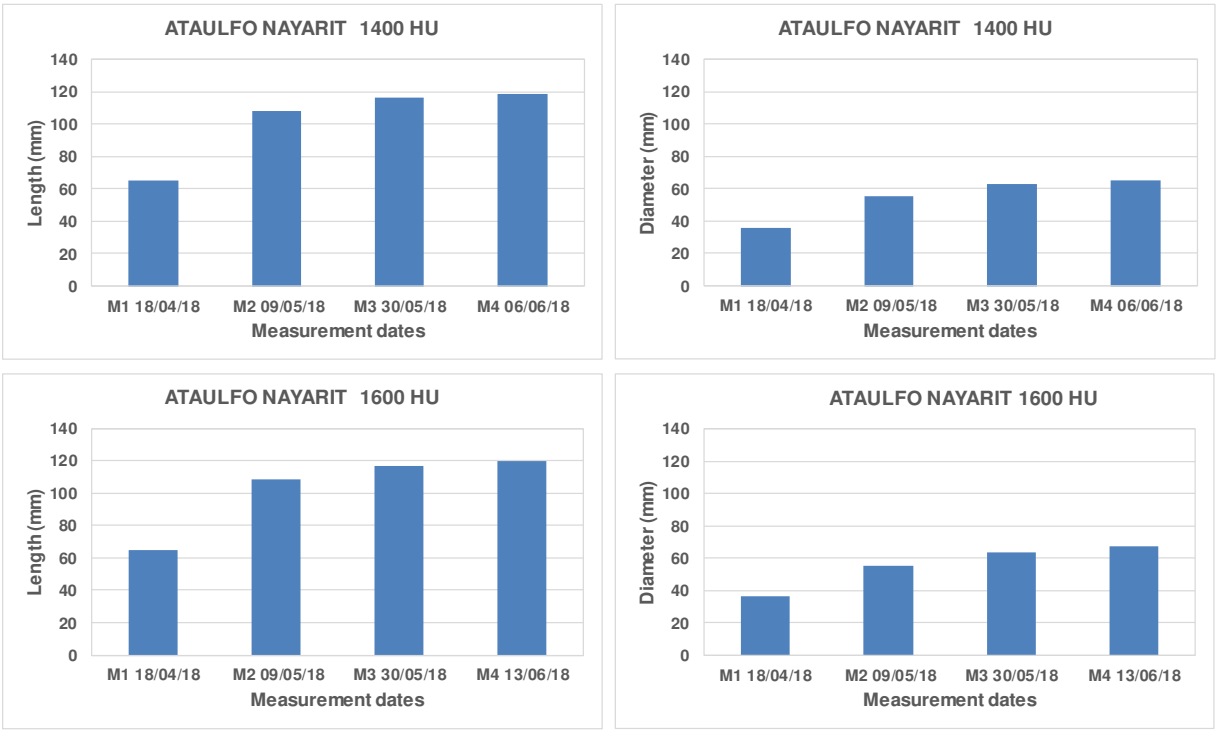


**Figure 6. Growth and development of 'Ataulfo' fruit harvested in Nayarit at two maturity stages and different HU accumulation.**

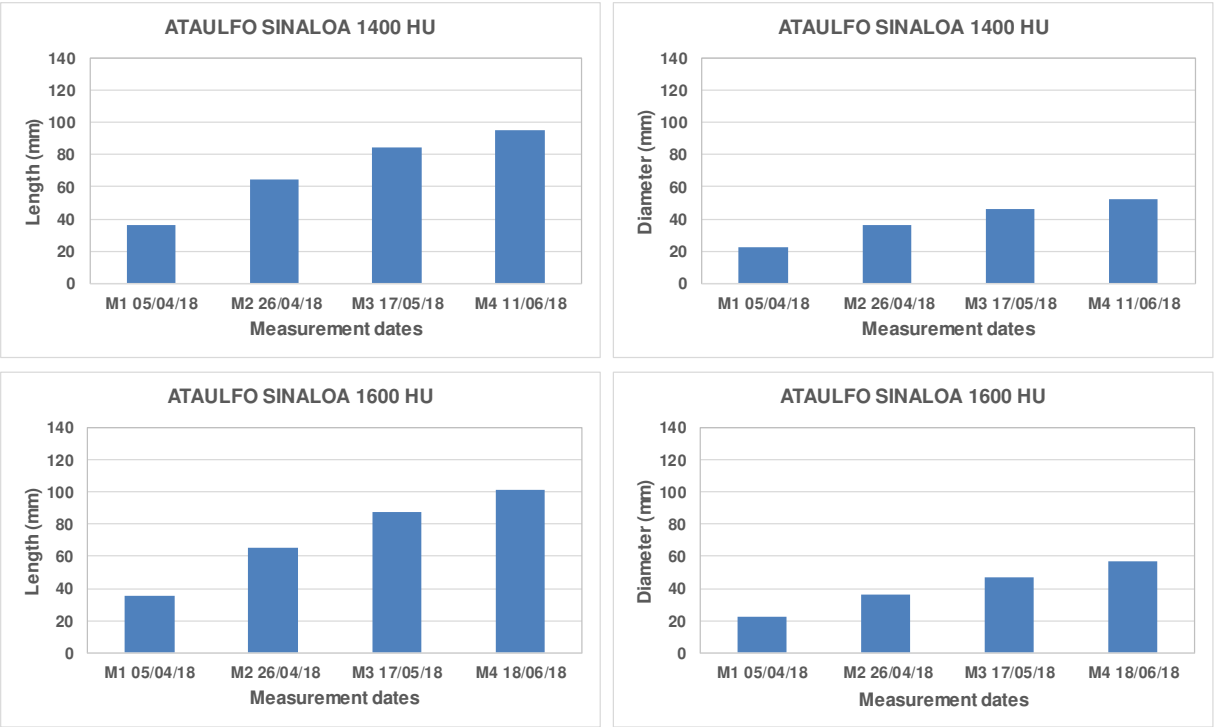


**Figure 7. Growth and development of 'Ataulfo' fruit harvested in Sinaloa at two maturity stages and different HU accumulation.**

Harvest results describe how weight and caliber are affected by HU accumulation. Figure 8A illustrates the average weight of 'Ataulfo' fruit at harvest in Nayarit; those harvested at 1,400 HU averaged 317.0 g, while those harvested at 1,600 HU averaged 355.8 g. The 38.8 g difference represents 1.55 ton / ha in addition to the yield. This same trend was observed in 'Ataulfo' fruit harvested in Sinaloa. Those at 1,400 HU averaged 176.3 g and those harvested at 1,600 HU averaged 212.9 g, which represents an additional 1.46 tons / ha. On the other hand, the effect of HU accumulation is more impact and significant in the sizes of the fruit (larger numbers mean small fruit and the opposite, smaller numbers mean larger fruit). Nayarit (Figure 8C), fruit harvested at 1,400 HU showed 84% of fruit with calibers 12, 14 and 16's, whereas the harvested at 1.600 HU showed 80% of calibers 10, 12 and 14's. Something similar, but more marked, happened in fruit harvested in Sinaloa. They were smaller because the availability of irrigation water was not enough. Figure 8D shows that fruit harvested 1.400 at HU had 88% of calibers 22, 24 and 26's, whereas the harvested at

1.600 HU showed 86% fruit with sizes 18, 20, 22 and 24's. Here the importance of harvesting fruit with a greater HU accumulation is demonstrated, only 200 HU of difference (7 to 10 days) mean spectacular differences in weight, caliber, yield volume, shelf life and flavor at consumption stage.

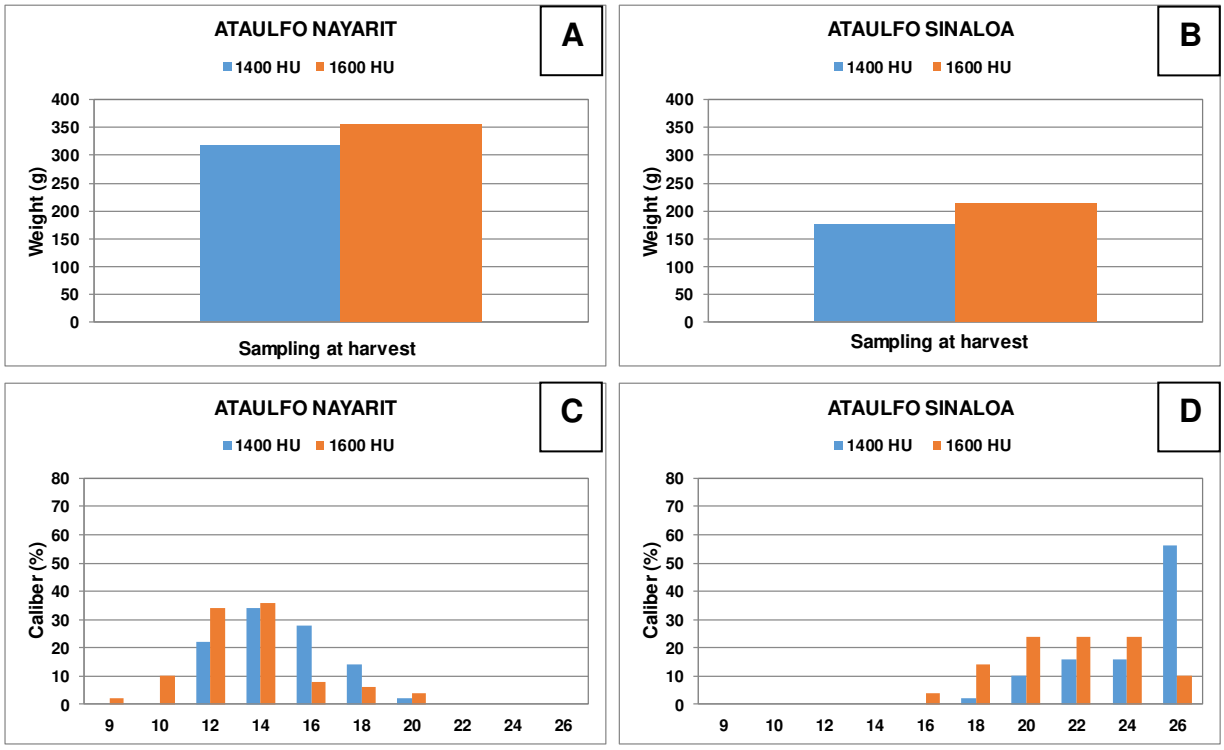


**Figure 8. Average weight (g) and caliber of 'Ataulfo' fruit from Nayarit and Sinaloa.**

### b. Tommy Atkins

Regarding to Tommy Atkins variety, Figure 9 shows the growth and development of fruit grown in Nayarit and harvested at minimum maturity stage at 1,470 HU on May 21, while the ripe fruit were harvested at 1,612 HU on May 29. It was observed that fruit in the first stage of maturity reached a maximum of 94.6 mm in length and 66.9 mm in diameter, while the ripe ones reached 96.1 mm in length and 68.2 mm in diameter, showing the tendency that a greater HU accumulation, larger size. This trend was corroborated also for fruit harvested in Sinaloa, although the final sizes were slightly higher, reaching the least minimum maturity at 1,400 HU, a maximum of 97.7 mm in

length and 72.4 mm in diameter, while the ripe fruit, harvested at 1,581 HU reached 99.9 mm in length and 74.5 mm in diameter (Figure 10).

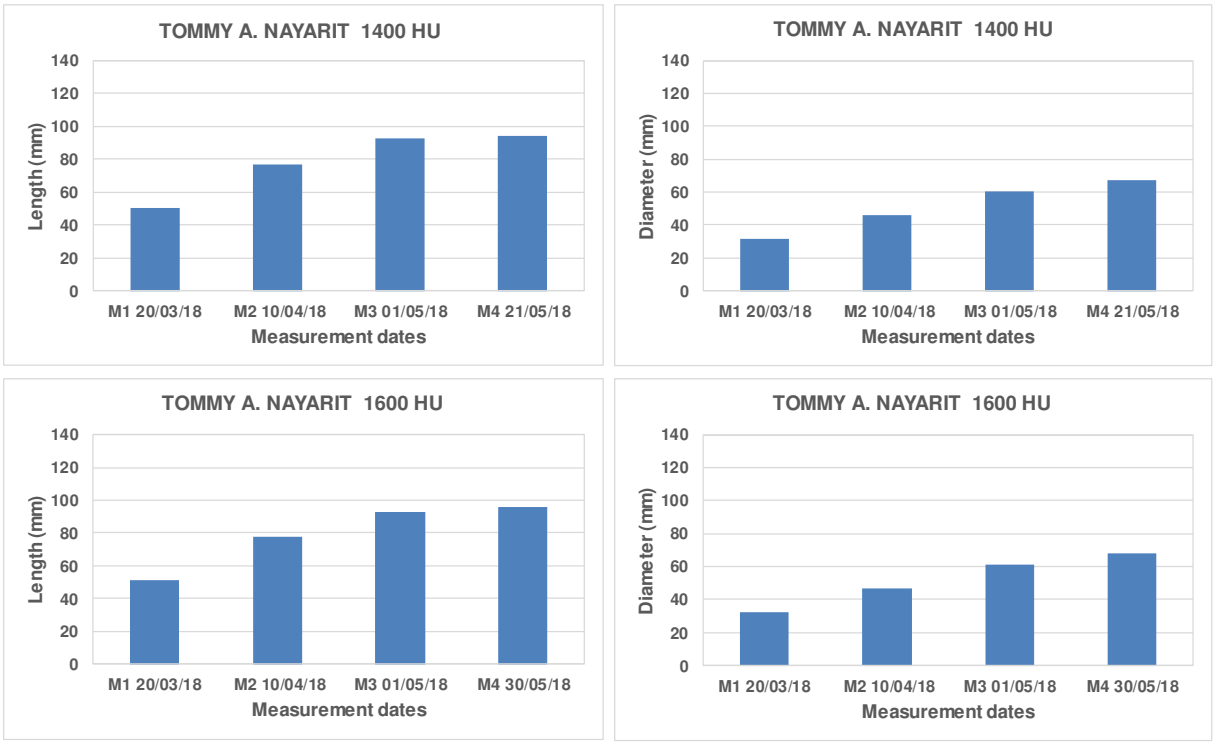


**Figure 9. Growth and development of 'Tommy Atkins' fruit harvested in Nayarit at two maturity stages and different HU accumulation.**

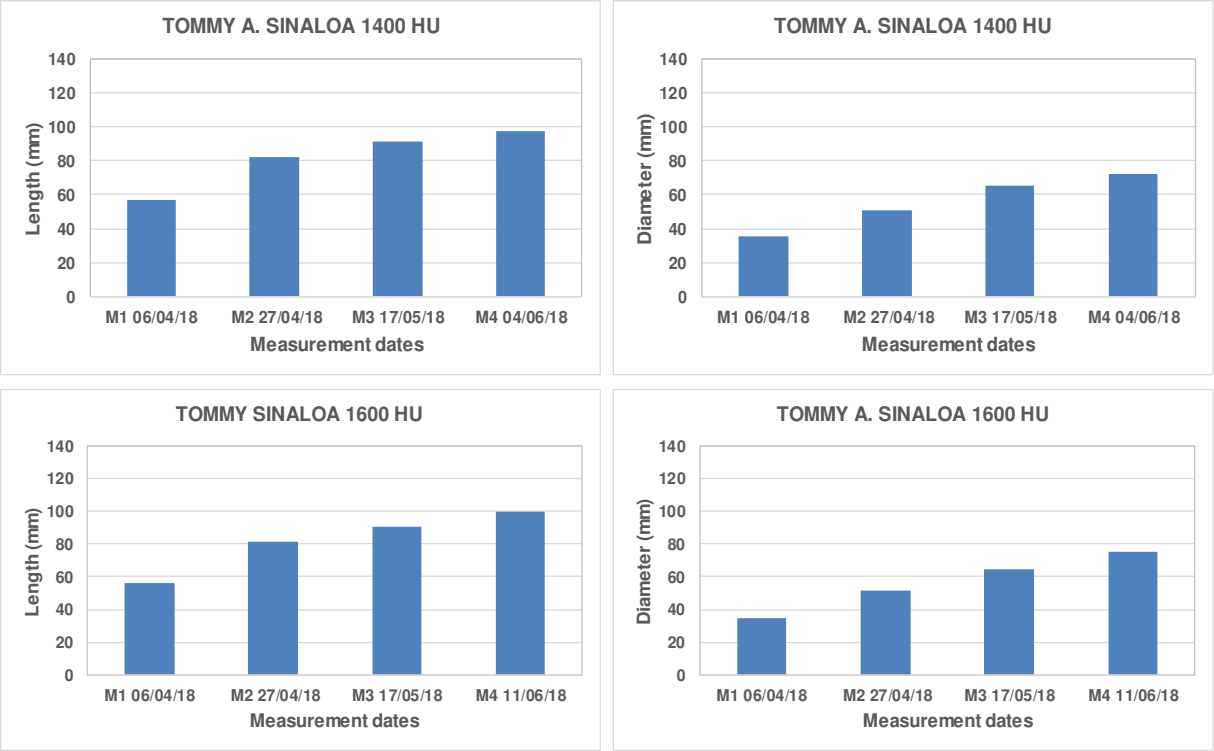


**Figure 10. Growth and development of 'Tommy Atkins' fruit harvested in Sinaloa at two maturity stages and different HU accumulation.**

Harvest results describe how weight and caliber are affected by HU accumulation. Figure 11A illustrates the average weight of 'Tommy Atkins' fruit at harvest in Nayarit; those harvested at 1,400 HU averaged 305.3 g, while those harvested at 1,600 HU averaged 325.6 g. The 20.3 g difference represents 0.81 ton / ha in addition to the yield. This same trend was observed in 'Tommy Atkins' fruit harvested in Sinaloa, although at this time fruit were larger because they had irrigation. Those at 1,400 HU averaged 327.8 g and those harvested at 1,600 HU averaged 358.4 g, which represents an additional 1.22 tons / ha. On the other hand, the effect of HU accumulation is more impact and significant in the sizes of fruit (larger numbers mean small fruit and opposite, smaller numbers mean larger fruit). In Nayarit (Figure 11C), the harvested fruit at 1,400 HU presented 84% of fruit with sizes 14, 16 and 18, while those harvested at 1,600 HU presented 92% of calibers 12, 14 and 16's. Something similar,

but more marked, occurred in fruit harvested in Sinaloa. They were larger because there was availability of irrigation water. Figure 11D shows that fruit harvested at 1.4000 HU had 92% of calibers 12 to 18, while those harvested at 1,600 UC showed 90% of fruit with sizes 12 and 14's. Here the importance of harvesting the fruits with a greater HU accumulation is demonstrated, only 200 UC of difference (7 to 10 days), mean spectacular differences in weight, caliber, yield volume, shelf life and flavor at consumption stage.

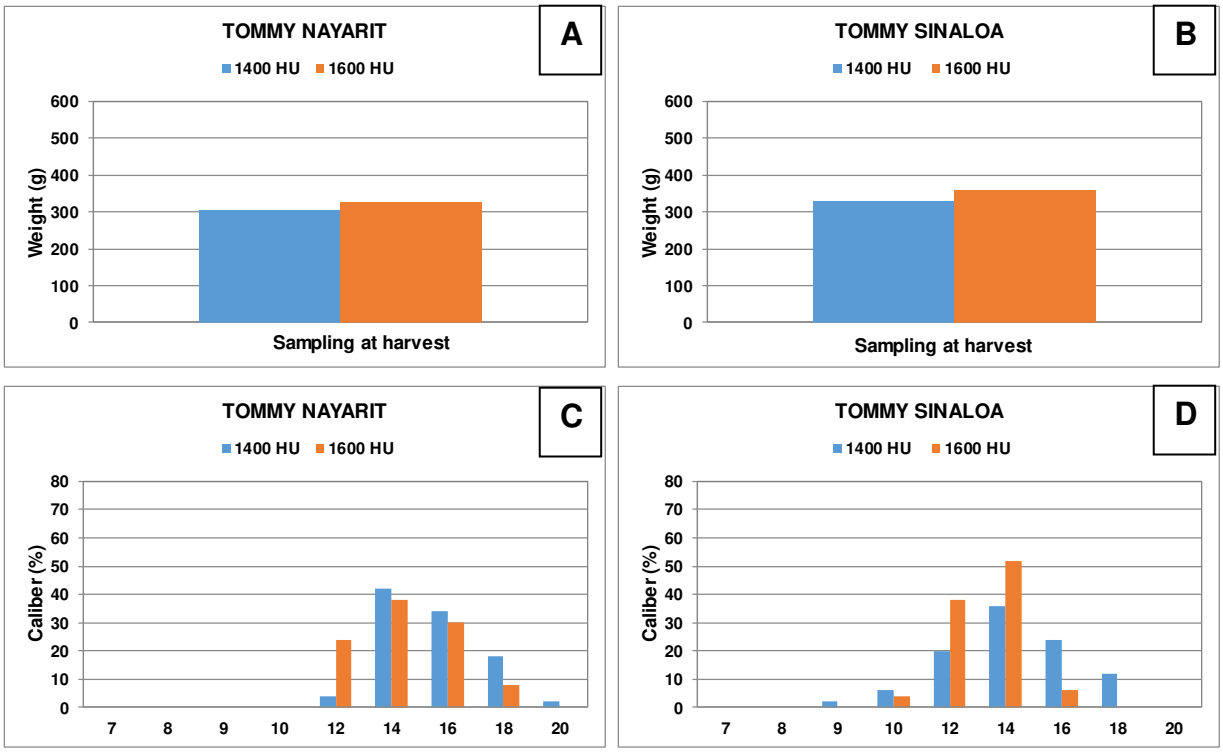


**Figure 11. Average weight (g) and caliber of 'Tommy Atkins' fruit from Nayarit and Sinaloa.**

**c. Kent**

Concerning to Kent variety, Figure 12 shows the growth and development of fruit grown in Nayarit and harvested at the minimum maturity at 1,563 HU on June 14, while ripe fruit were harvested at 1,901 HU July 3. It was observed that fruit in the first stage of maturity reached a maximum of 111.6 mm in length and 77.4 mm in diameter, while the ripe ones reached 113.7 mm in length and 79.7 mm in diameter, showing the tendency that a greater HU accumulation, larger size. This trend was also corroborated for fruit harvested in Sinaloa, although the final sizes were smaller since they had more limited conditions of water availability. Fruit harvested at minimum maturity at 1,661 HU, reached a maximum of 100.9 mm in length and 74.3 mm in diameter, while the ripe fruit, harvested at 1,805 CU reached 107.1 mm in length and 77.3 mm in diameter (Figure 13) .

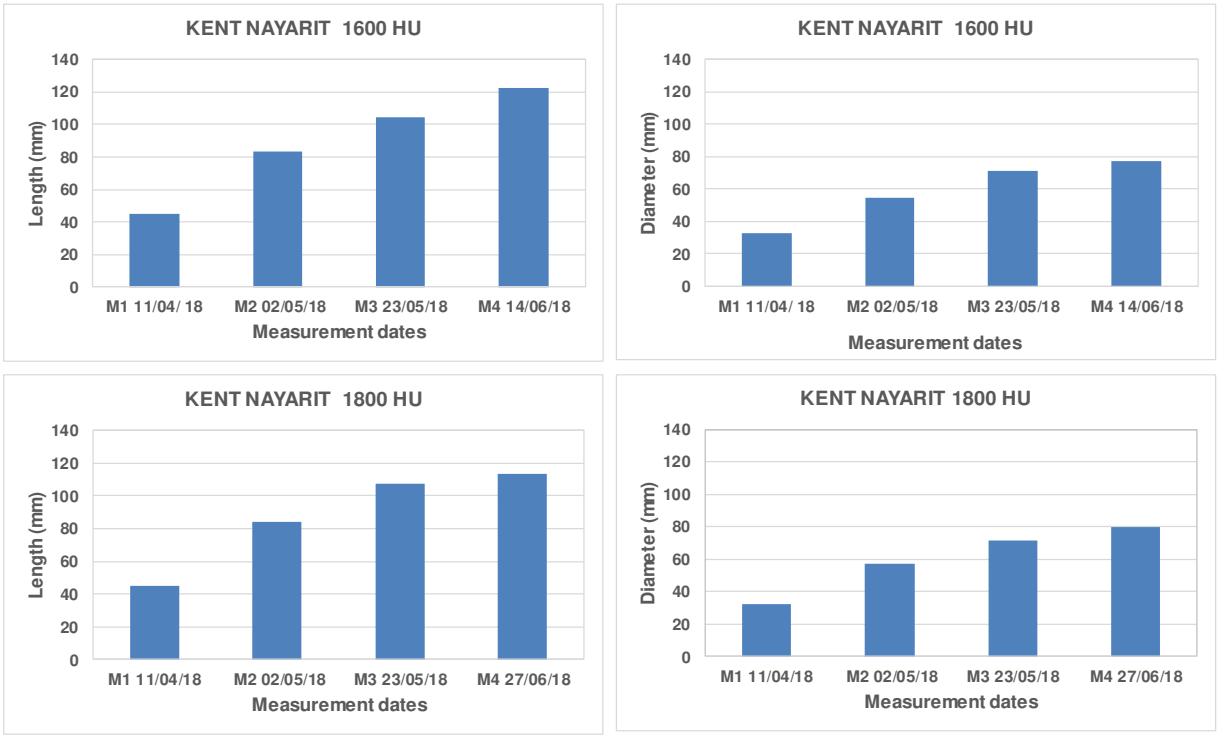


**Figure 12. Growth and development of 'Kent' fruit harvested in Nayarit at two maturity stages and different HU accumulation.**

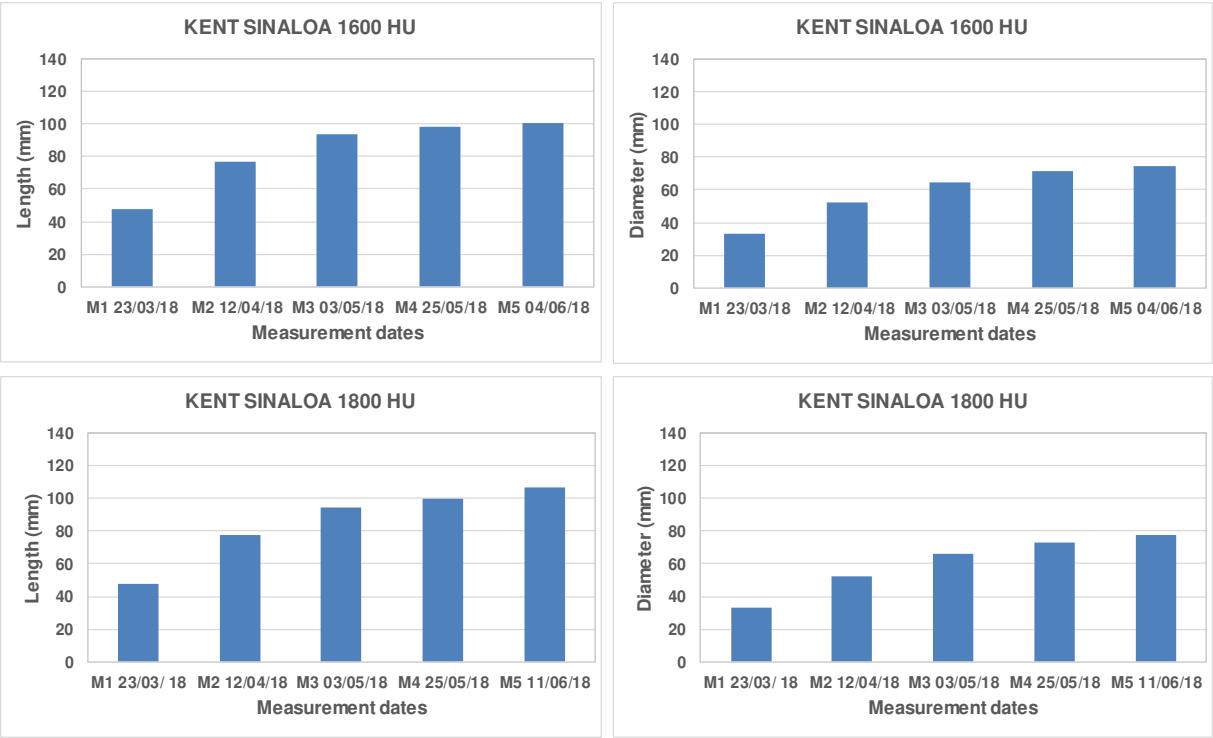


**Figure 13. Growth and development of 'Kent' fruit harvested in Sinaloa at two maturity stages and different HU accumulation.**

Harvest results describe how weight and caliber are affected by HU accumulation. Figure 14A illustrates the average weight of 'Kent' fruit at harvest in Nayarit; those harvested at 1,600 UC averaged 452.6 g, while those harvested at 1,800 HU averaged 508.9 g. The 56.3 g difference represents 1.69 ton / ha in addition to the yield. This same trend was observed in 'Kent' fruit harvested in Sinaloa, although at this time fruit were smaller due to deficiencies with irrigation. Those at 1,600 HU averaged 373.5 g and those harvested at 1,800 HU averaged 407.7 g, representing an additional 1.03 tons / ha. On the other hand, the effect of HU accumulation is more impact and significant in the sizes of fruit (larger numbers mean small fruit and the opposite, smaller numbers mean larger fruit). In Nayarit (Figure 14C), fruit harvested at 1,600 HU presented 96% of fruits with calibers 9, 10 and 12's, while those harvested at 1,800 HU presented 85% of sizes 8, 9 and 10's. Something similar happened in fruit harvested in Sinaloa. They were smaller due to the limitations of irrigation water. Figure 14D shows that fruit harvested at 1.6000 HU had 82% of sizes 12 and 14, while those harvested at

1,800 HU showed 96% of fruit with sizes 10 and 12's. Here the importance of harvesting fruit with a greater HU accumulation is demonstrated, only 200 UC of difference (7 to 10 days) mean spectacular differences in weight, caliber, yield volume, shelf life and flavor at consumption stage.

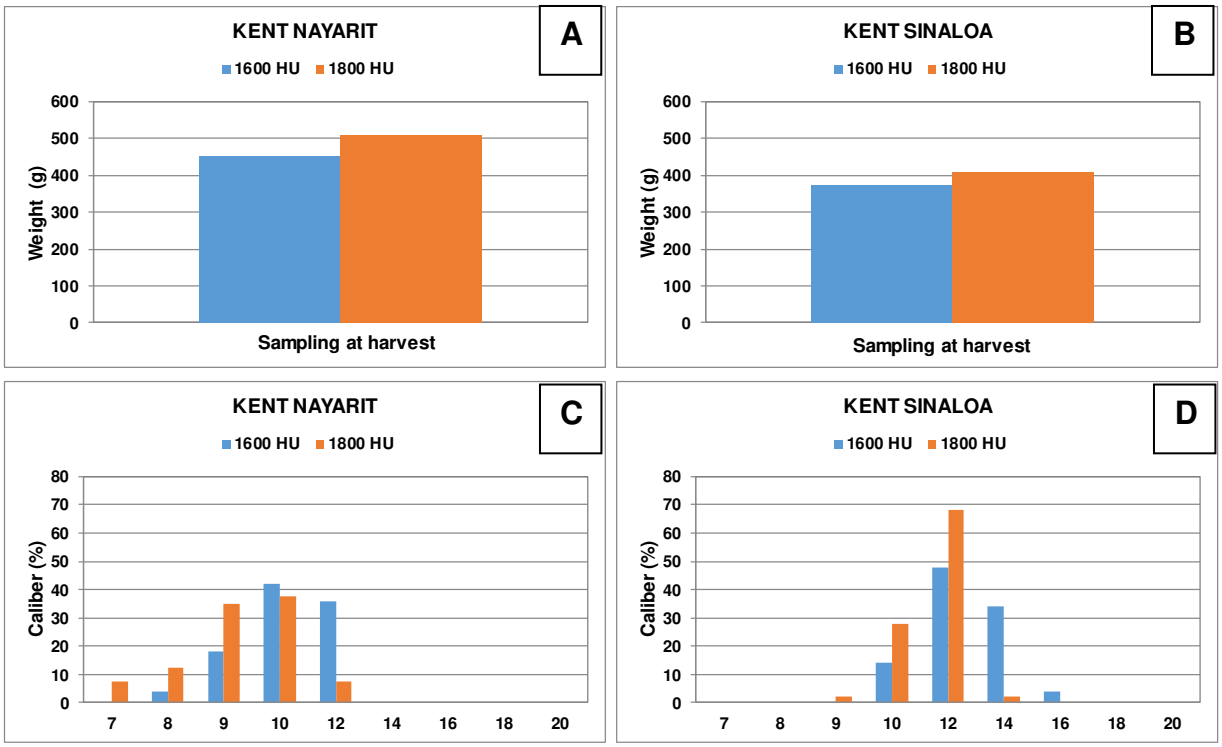


**Figure 14. Average weight (g) and caliber of 'Kent' fruit from Nayarit and Sinaloa.**

## d. Keitt

Regarding to Keitt variety, Figure 15 shows the growth and development of fruit grown in Nayarit and harvested at minimum maturity at 1,881 UC on June 14, while the ripe fruit were harvested at 2,225 HU on July 3. It was observed that fruit in the first stage of maturity reached a maximum of 117.3 mm in length and 76.7 mm in diameter, while the ripe ones reached 122.6 mm in length and 79.7 mm in diameter, showing the trend that a greater HU accumulation, larger size. This trend was also corroborated for fruit harvested in Sinaloa, although the final sizes were smaller since they had more limited conditions of water availability. Fruit harvested at minimum maturity at 1,843 HU, reached a maximum of 100.4 mm in length and 65.1 mm in diameter, while ripe fruit, harvested at 2259 HU reached 105.2 mm in length and 69.2 mm in diameter (Figure 16)

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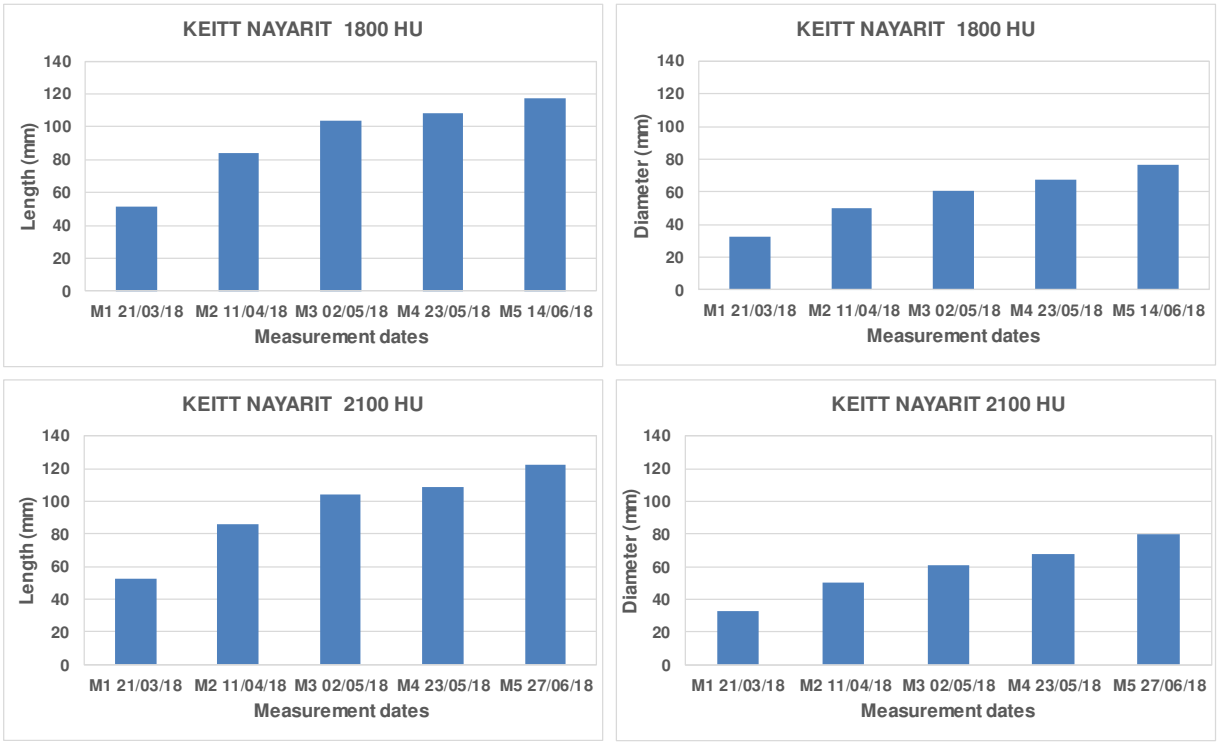


**Figure 15. Growth and development of 'Keitt' fruit harvested in Nayarit at two maturity stages and different HU accumulation.**

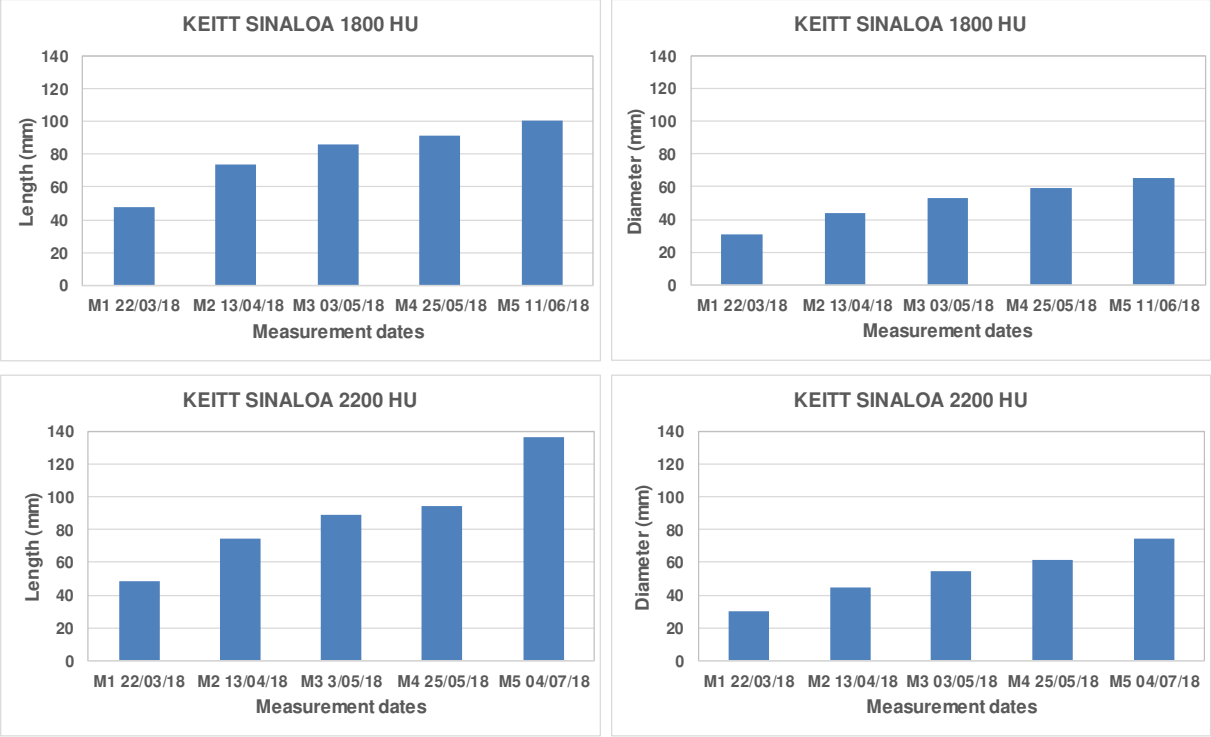


**Figure 16. Growth and development of 'Keitt' fruit harvested in Sinaloa at two maturity stages and different HU accumulation.**

Harvest results describe how weight and caliber are affected by HU accumulation. Figure 17A illustrates the average weight of 'Keitt' fruit at harvest in Nayarit; those harvested at 1,800 HU averaged 467.1 g, while those harvested at 2,100 HU averaged 555.0 g. The 87.9 g difference represents 2.64 ton / ha in addition to the yield. This same trend was observed in 'Keitt' fruit harvested in Sinaloa, although at this time fruit were smaller due to deficiencies with irrigation. Those at 1,800 HU averaged 280.5 g and those harvested at 2,200 HU averaged 343.5 g, which represents an additional 1.89 tons / ha. On the other hand, the effect of HU accumulation is more impact and significant in the sizes of fruit (larger numbers mean small fruit and the opposite, smaller numbers mean larger fruit). In Nayarit (Figure 17C), fruit harvested at 1,800 HU presented 90% of fruit with calibers 9, 10 and 12's, while those harvested at 2,100 HU presented 90% of sizes 8, 9 and 10's. Something similar happened in fruit harvested in Sinaloa. They were smaller due to the limitations of irrigation water. Figure 14D shows that fruit harvested at 1,800 HU had 98% of calibers 14 to 20's, while those

harvested at 2,200 HU showed 92% of fruit with sizes 10 and 12's. Here the importance of harvesting fruit with a greater HU accumulation is demonstrated, only 300 HU of difference (7 to 10 days) mean spectacular differences in weight, caliber, yield volume, shelf life and flavor at consumption stage

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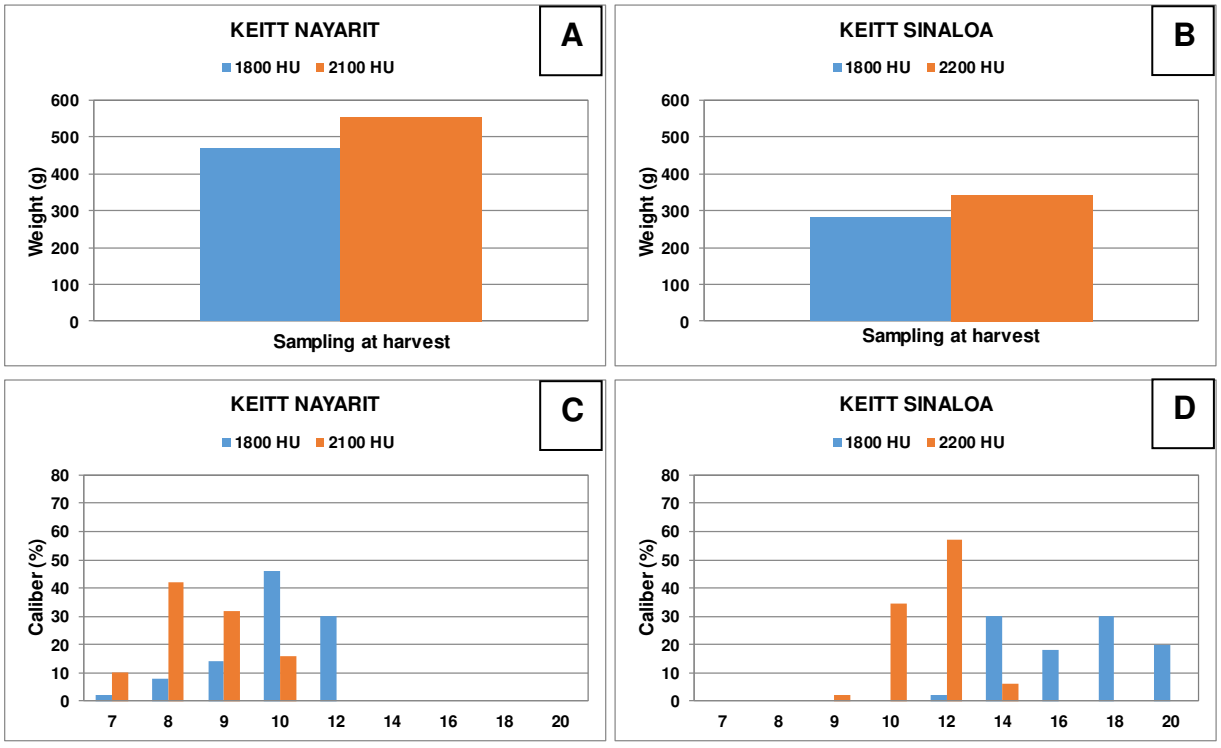



**Figure 17. Average weight (g) and caliber of 'Keitt' fruit from Nayarit and Sinaloa.**

## II. Results of Initial quality, shipping simulation and at consumption stage

### a. Ataulfo

Figure 18 illustrates the dry matter (DM) content of 'Ataulfo' fruit harvested at 1,400 and 1,600 HU, both in Nayarit and Sinaloa. It was observed that the initial DM content and DM content at the end of shipping simulation was greater at 1,600 HU (22.0 and 22.2%, respectively) than at 1,400 HU (20.6 and 21.9%, respectively) and this is according to expected, since fruit accumulate more DM when harvested at an optimum maturity stage. On the other hand, it was observed that DM values of fruit harvested in Sinaloa showed higher DM contents in any of the two accumulated HU. At 1,400 HU they had 26.6 and 29.0% of DM respectively for the beginning and the end of refrigeration, while those harvested at 1,600 HU had 26.8 and 29.2%, respectively. This may be due to the fact that in Sinaloa there were more restrictive conditions of water availability during the crop cycle.

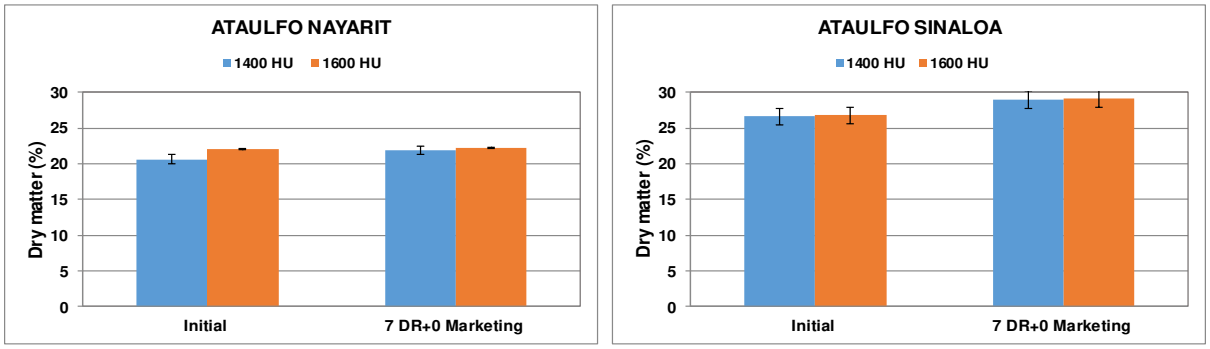



**Figure 18. Dry Matter content of 'Ataulfo' fruit harvested at different HU accumulation in Nayarit and Sinaloa. Vertical bars represent the standard error (if they overlap = NS; if not = *).**

With regard to the skin color (Figure 19), practically no significant differences were detected between harvested fruit at 1,400 or 1,600 HU, except for the sampling at the end of refrigeration where the fruit of Sinaloa harvested at 1,600 HU showed a pale green color, characteristic of a more advanced maturity stage.

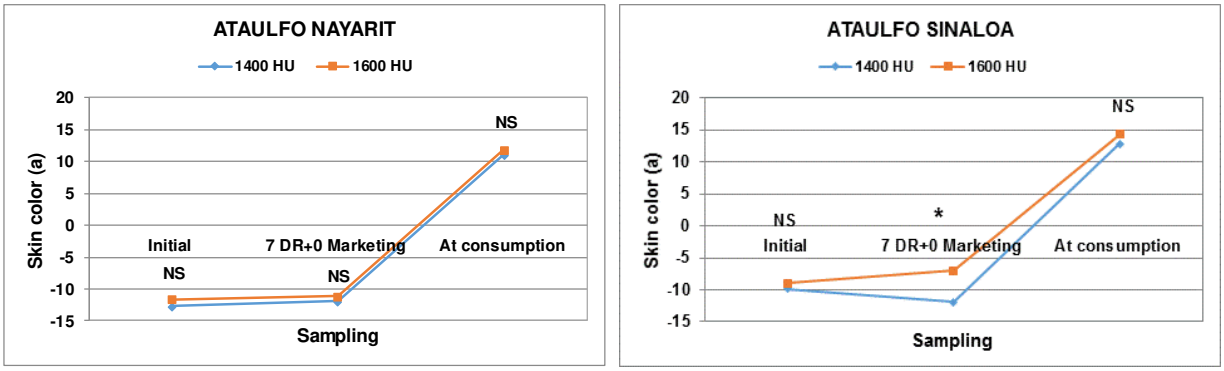



**Figure 19. Skin color of 'Ataulfo' fruit harvested at different HU accumulation in Nayarit and Sinaloa.**

Regarding to weight loss (Figure 20), for fruit harvested in Nayarit, significant differences were observed only for consumption (7DRef + 9 Marketing), being those with the least accumulation of HU that showed the greatest weight loss. Concerning the fruit of Sinaloa, the trend was the same until the end of shipping simulation, but at consumption stage was observed inverse to Nayarit's situation. In this case, the harvested fruit at 1,600 HU showed greater weight loss (13.5%) than those harvested at 1,400 HU (10.3%). The reason was because fruit harvest at 1,600 HU required 10 marketing days to reach the consumption stage, while those at 1,400 HU were ready to eat after six days of marketing.

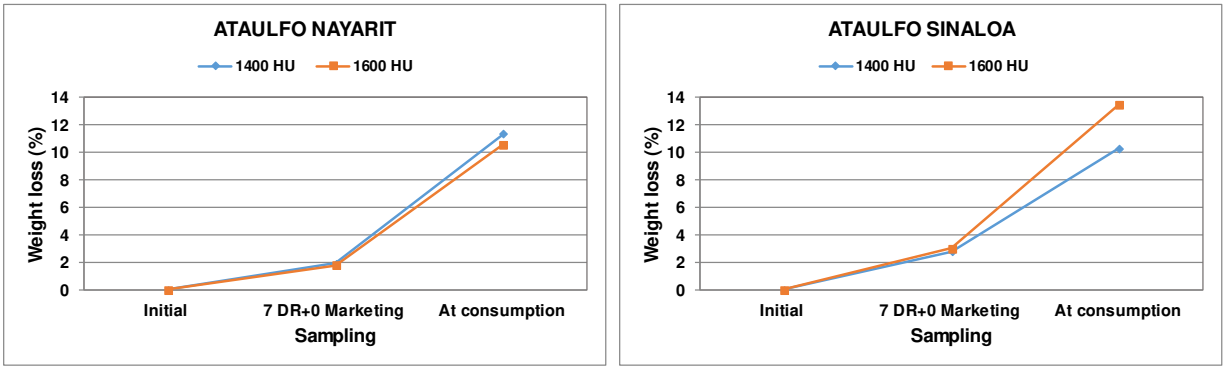
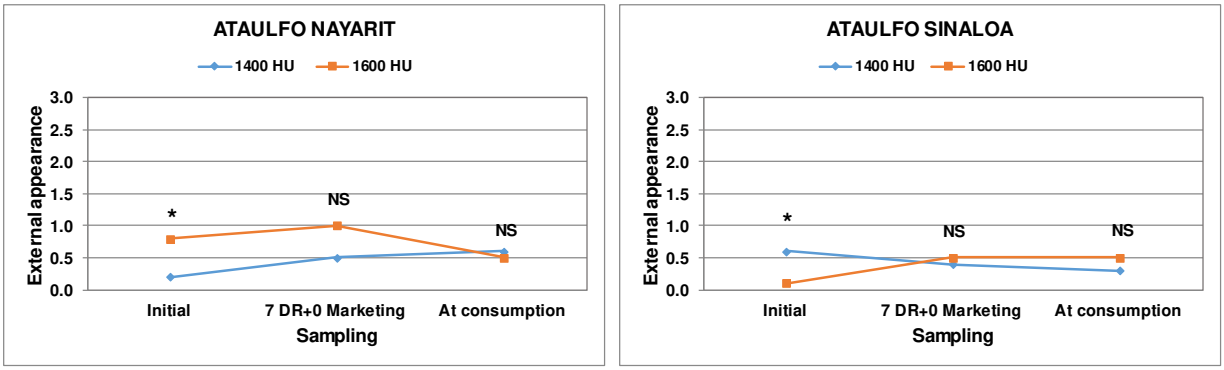



**Figure 20. Weight loss (%) of 'Ataulfo' fruit harvested at different HU accumulation in Nayarit and Sinaloa.**

Regarding to the external appearance (Figure 21), only significant differences were detected at the beginning, being the opposite in Nayarit than in Sinaloa; however, in both cases the values were within the export range with values between 0 and 1, which means external appearance from excellent to good.




**0 = Excellent 1 = Good 2 = Regular 3 = Bad**

**Figure 21. External appearance of 'Ataulfo' fruit harvested at different HU accumulation in Nayarit and Sinaloa.**

Regarding to pulp firmness (Figure 22), no significant differences were observed between HU or between states. This shows that pulp firmness is not a good indicator of maturity at harvest as proposed by other authors.

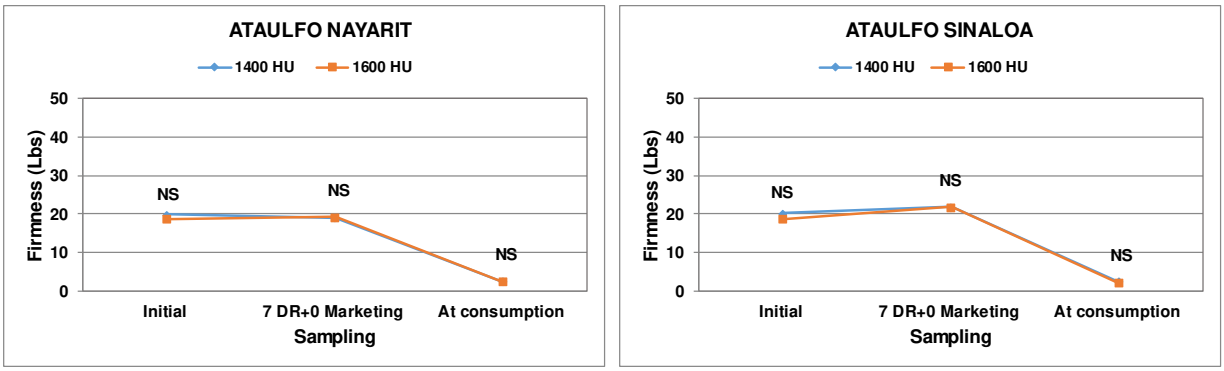



**Figure 22. Pulp firmness (Lbs) of 'Ataulfo' fruit harvested at different HU accumulation in Nayarit and Sinaloa.**

Regarding to pulp color (Figure 23), no significant differences were detected for any of the samplings among the different UC accumulated for Nayarit. In contrast, for Sinaloa the harvested fruit at 1,600 HU showed greater intensity of pulp color, indicating a higher quality of consumption.

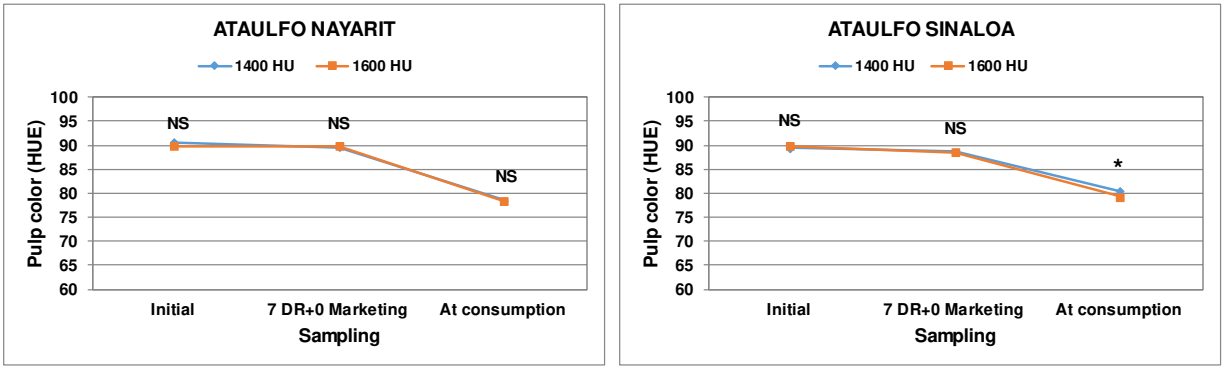



**Figure 23. Pulp color (Hue) of 'Ataulfo' fruit harvested at different HU accumulation in Nayarit and Sinaloa.**

With regard to the content of total soluble solids (°Bx) [Figure 24], a significant difference from the beginning with the harvested fruits at 1,400 HU was expected, showing a lower content in both states; however, this difference was manifested only at consumption stage. However, what gives a better idea of an enjoyable taste to the consumer is the ratio Bx / Acidity at consumption, and here significant differences were detected in favor of fruit harvested at 1,600 HU (Figure 25).

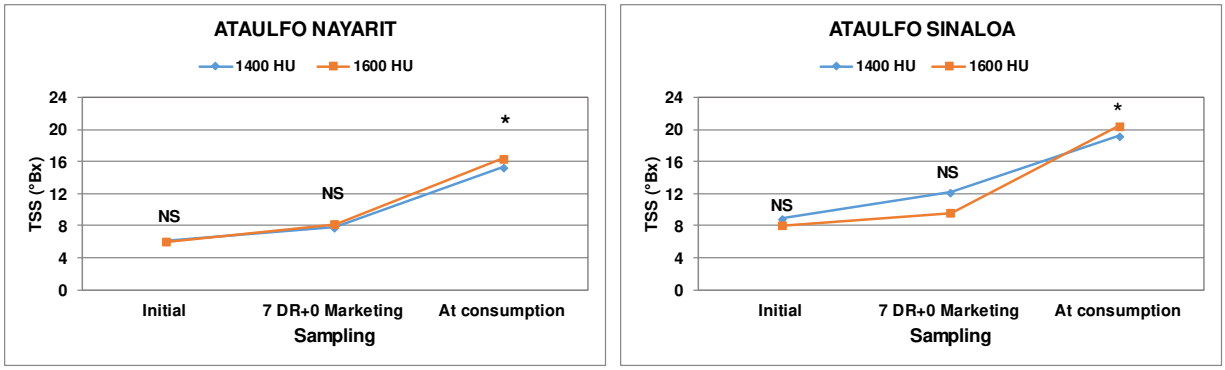



**Figure 24. Total soluble solids content (°Bx) of 'Ataulfo' fruit harvested at different HU accumulation in Nayarit and Sinaloa.**

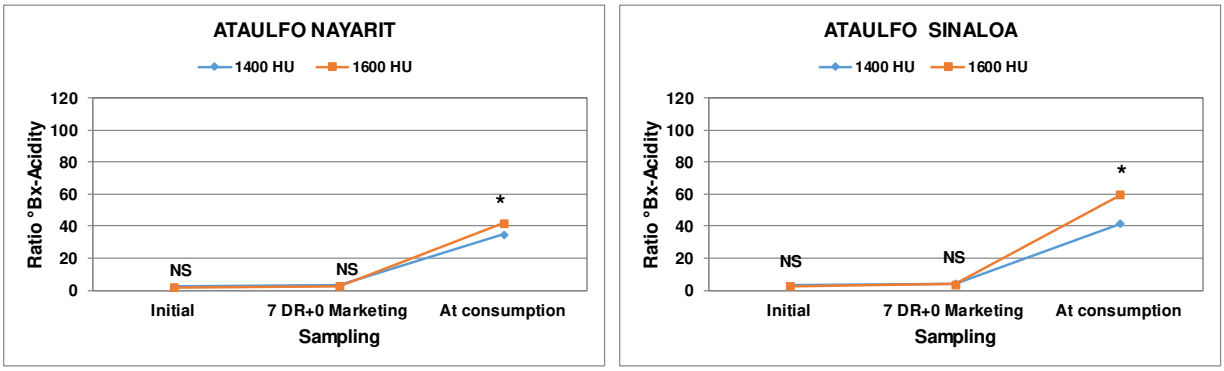



**Figure 25. Ratio Bx/Acidity of 'Ataulfo' fruit harvested at different HU accumulation in Nayarit and Sinaloa.**

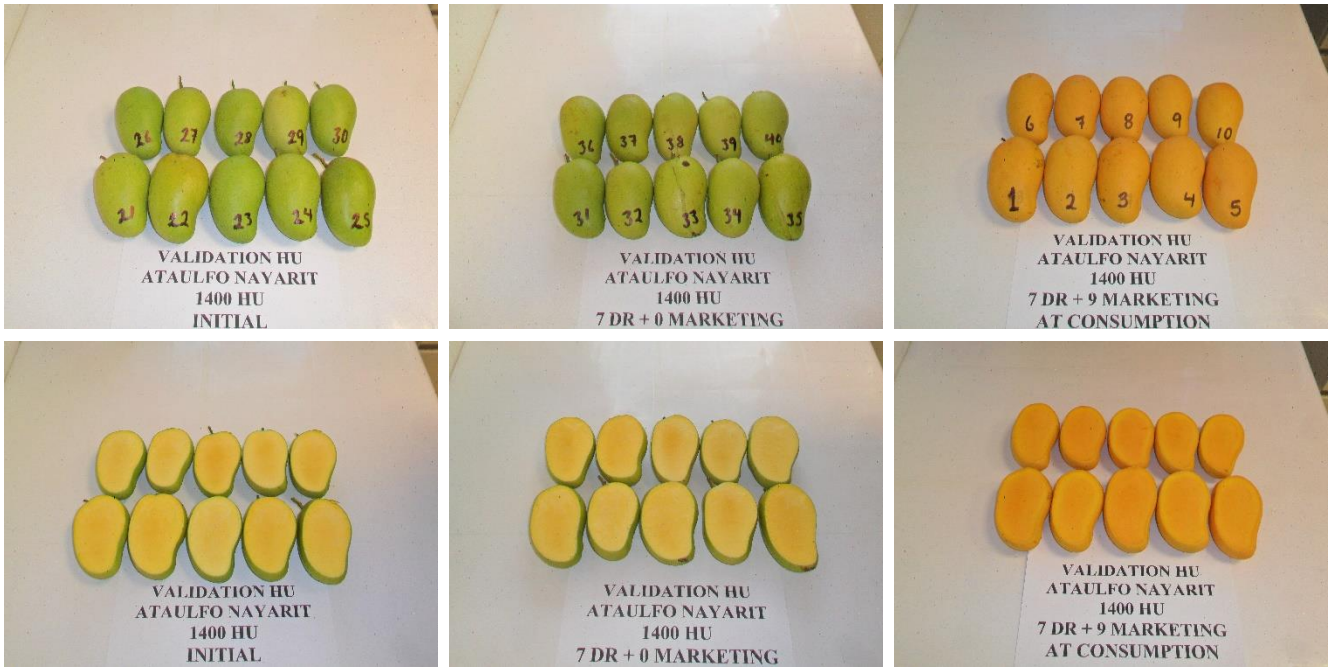



**Figure 26. Illustration of external and internal appearance of 'Ataulfo' fruit harvested in Nayarit at 1,400 HU**


**Figure 27. Illustration of external and internal appearance of 'Ataulfo' fruit harvested in Nayarit at 1,600 HU**


**Figure 28. Illustration of external and internal appearance of 'Ataulfo' fruit harvested in Sinaloa at 1,400 HU**


**Figure 29. Illustration of external and internal appearance of 'Ataulfo' fruit harvested in Sinaloa at 1,600 HU**

For Ataulfo variety, it is concluded that the use of the HU accumulation technique is viable and that the optimum harvesting stage is reached at 1,600 HU.

**b. Tommy Atkins**

Figure 30 illustrates dry matter (DM) content of 'Tommy Atkins' fruit harvested at 1,400 and 1,600 HU, both in Nayarit and Sinaloa. A trend very similar to what happened with 'Ataulfo' fruit was observed. The initial DM content and DM content at the end of shipping simulation were greater at 1,600 HU (16.2 and 16.8%, respectively) than at 1,400 HU (14.3 and 15.0%, respectively), which is in agreement with was expected, since mango fruit accumulate a greater quantity of DM when harvested in an optimum maturity stage. However, the DM content values of 'Tommy Atkins' were lower (range of 14 to 19%) than those of 'Ataulfo' (range of 20 to 29%), because of varietal differences. On the other hand, it was observed that DM values of fruit harvested in Sinaloa showed higher DM content in any of the two accumulated HU. At 1,400 HU they registered 17.6 and 18.6% of DM respectively for the beginning and end of refrigeration, while those harvested at 1,600 HU had 18.7 and 19.1%, respectively. This may be due to the fact that in Sinaloa there were more restrictive conditions of water availability during the crop cycle.

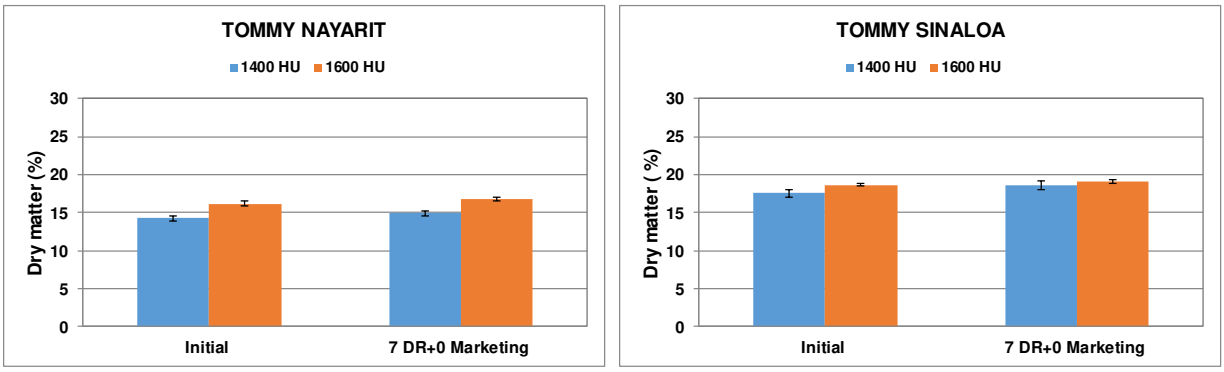



**Figure 30. Dry Matter content of 'Tommy Atkins' fruit harvested at different HU accumulation in Nayarit and Sinaloa. Vertical bars represent the standard error (if they overlap = NS; if not = *).**

Regarding to weight loss (Figure 31), for fruit harvested in Nayarit, significant differences were observed at the end of refrigeration and at consumption stage. Fruit at 1,600 HU lost more weight than those at 1,400 (3.01% vs. 1.59%), but this was because these fruit were maintained one more week in refrigeration. In spite of this, at consumption stage fruit at 1,400 HU showed the greatest weight loss. With regard to the fruit harvested in Sinaloa, the trend was the same until the end of shipping simulation, but at consumption fruit harvested at 1,600 HU showed less weight loss (8.9%) than those harvested at 1,400 HU (10.05 %) even under the same shipping simulation conditions and marketing at the environment.

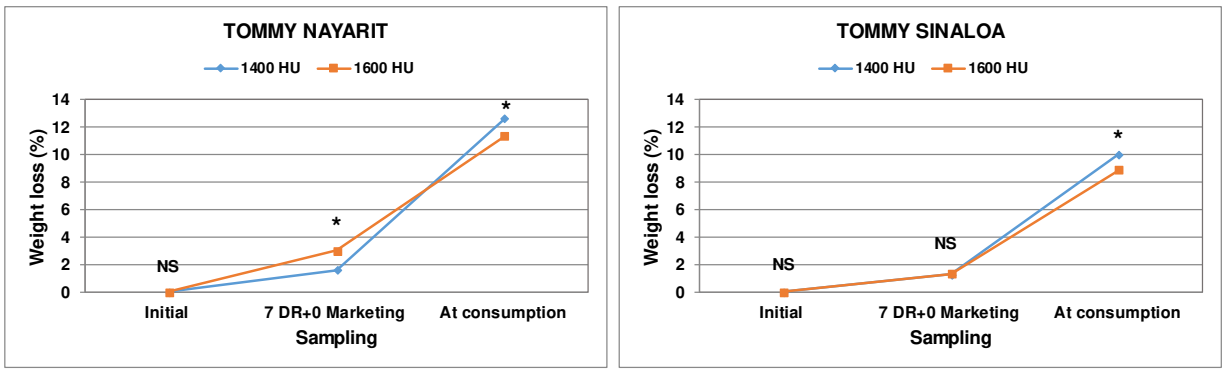
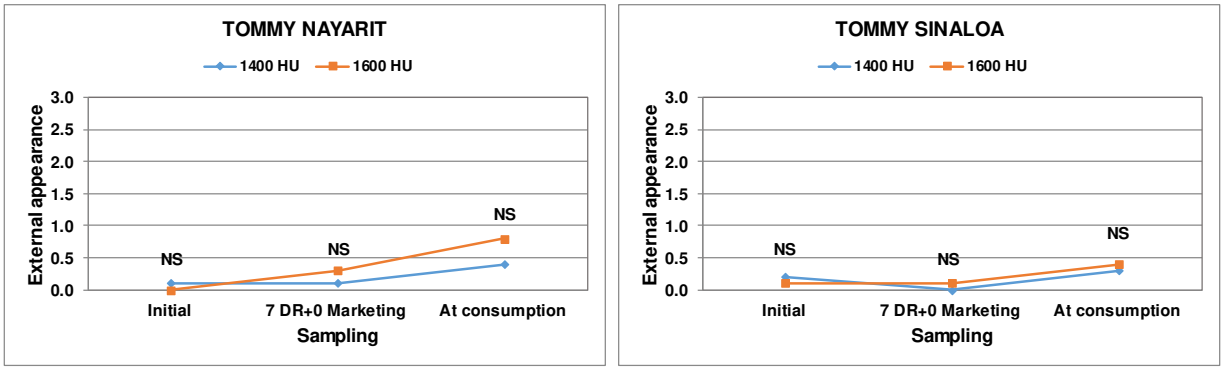



**Figure 31. Weight loss (%) of 'Tommy Atkins' fruit harvested at different HU accumulation in Nayarit and Sinaloa.**

Regarding to external appearance (Figure 32), no significant differences were detected for any of the HU or for the states. In both cases, the values were within the export range with values between 0 and 1, which means external appearance from excellent to good.




**0 = Excellent 1 = Good 2 = Regular 3 = Bad**

**Figure 32. External appearance of 'Tommy Atkins' fruit harvested at different HU accumulation in Nayarit and Sinaloa.**

With regard to pulp firmness (Figure 33), no significant differences were observed between HU or between states. This shows that pulp firmness is not a good indicator of maturity at harvest as proposed by other authors.

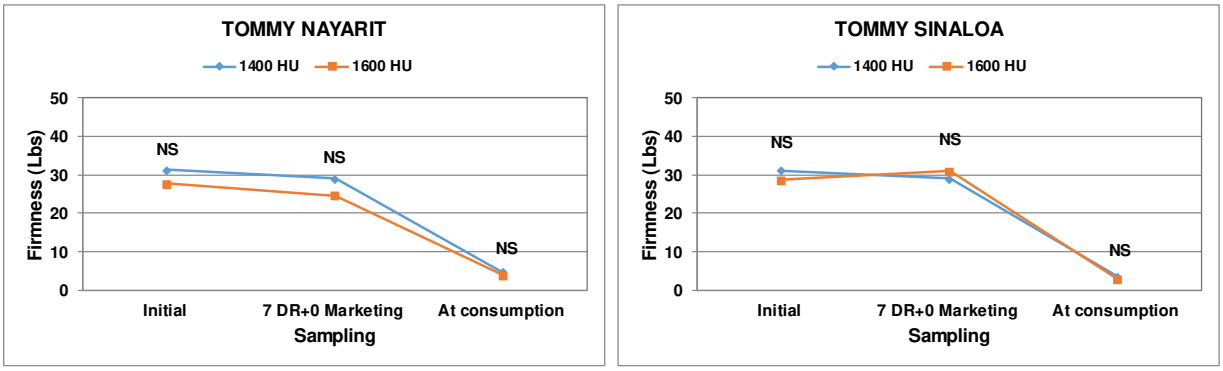



**Figure 33. Pulp firmness (Lbs) of 'Tommy Atkins' fruit harvested at different HU accumulation in Nayarit and Sinaloa.**

With regard to pulp color (Figure 34), although in all the samplings the trend was that harvested fruit at 1,400 HU showed less intensity of color, only for Nayarit the harvested fruit at 1,600 HUC showed greater intensity, indicating a higher quality at consumption stage. On the other hand, although the trend was similar, no significant

differences were detected for any of the samplings among the different UC accumulated for Sinaloa.

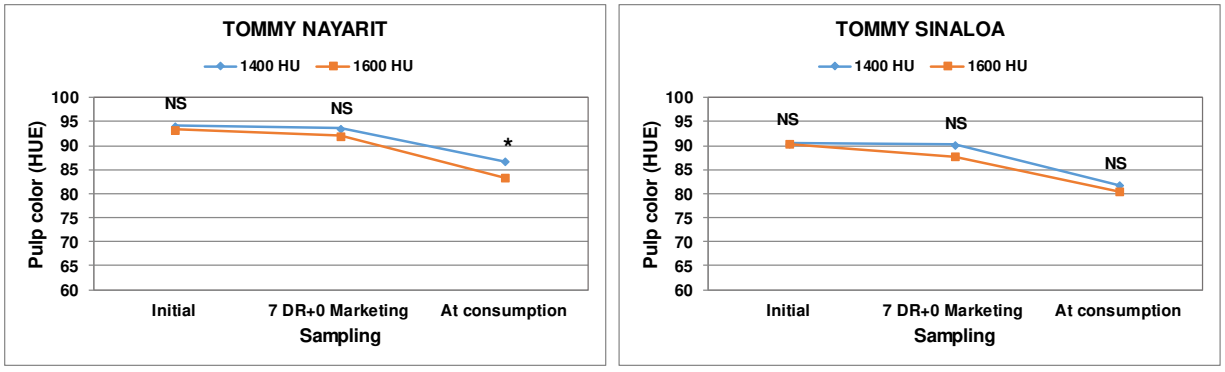



**Figure 34. Pulp color (Hue) of 'Tommy Atkins' fruit harvested at different HU accumulation in Nayarit and Sinaloa.**

With regard to the total soluble solids content (° Bx) [Figure 35], a significant difference from the beginning with the harvested fruit at 1,400 HU was expected, showing a lower content in both states; nevertheless, this difference was manifested only at consumption stage. However, what give a better idea of an enjoyable taste to the consumer is the ratio Bx / Acidity at consumption, and here significant differences were detected in favor of fruit harvested at 1,600 HU (Figure 36).

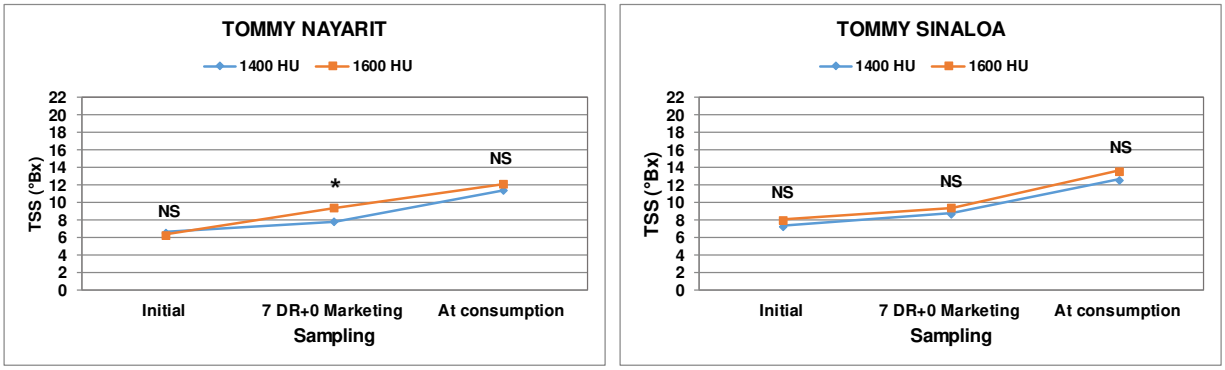



**Figure 35. Total soluble solids content (°Bx) of 'Tommy Atkins' fruit harvested at different HU accumulation in Nayarit and Sinaloa.**

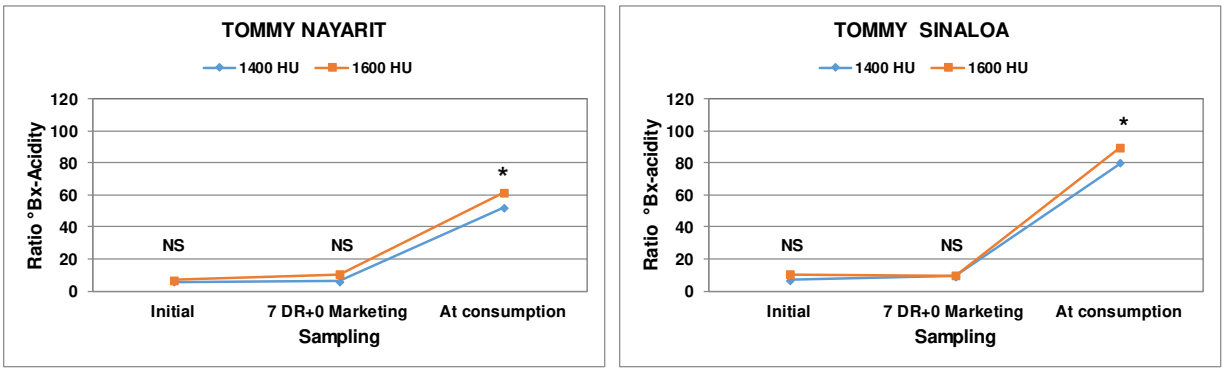



**Figure 36. Ratio Bx/acidity of 'Tommy Atkins' fruit harvested at different HU accumulation in Nayarit and Sinaloa.**

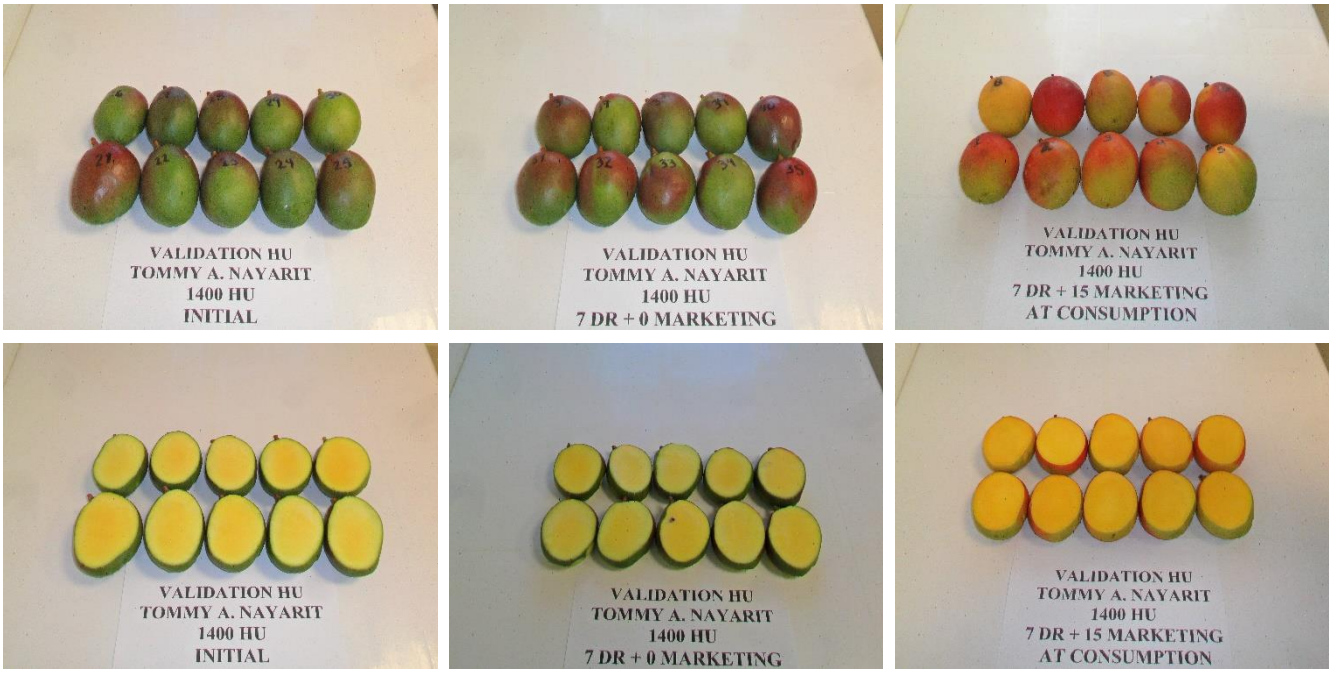



**Figure 37. Illustration of external and internal appearance of 'Tommy Atkins' fruit harvested in Nayarit at 1,400 HU.**


**Figure 38. Illustration of external and internal appearance of 'Tommy Atkins' fruit harvested in Nayarit at 1,600 HU.**


**Figure 39. Illustration of external and internal appearance of 'Tommy Atkins' fruit harvested in Sinaloa at 1,400 HU.**


**Figure 40. Illustration of external and internal appearance of 'Tommy Atkins' fruit harvested in Sinaloa at 1,600 HU.**

For Tommy Atkins variety it is concluded that the use of the HU accumulation technique is viable and that the optimum maturity is reached at 1,600 HU.

**c. Kent**

Figure 41 illustrates dry matter (DM) content of 'Kent' fruit harvested at 1,600 and 1,800 HU, both in Nayarit and Sinaloa. A similar trend was observed to what happened with 'Ataulfo' and 'Tommy Atkins' fruit, since initial DM content and DM content at the end of shipping simulation was greater at 1,800 HU than at 1,600 and this is according to expected, since fruit accumulate a greater quantity of DM when harvested in an optimum ripening stage. For this variety the DM values ranged from 21 to 26% in both locations, without significant difference between locations, but between HU.

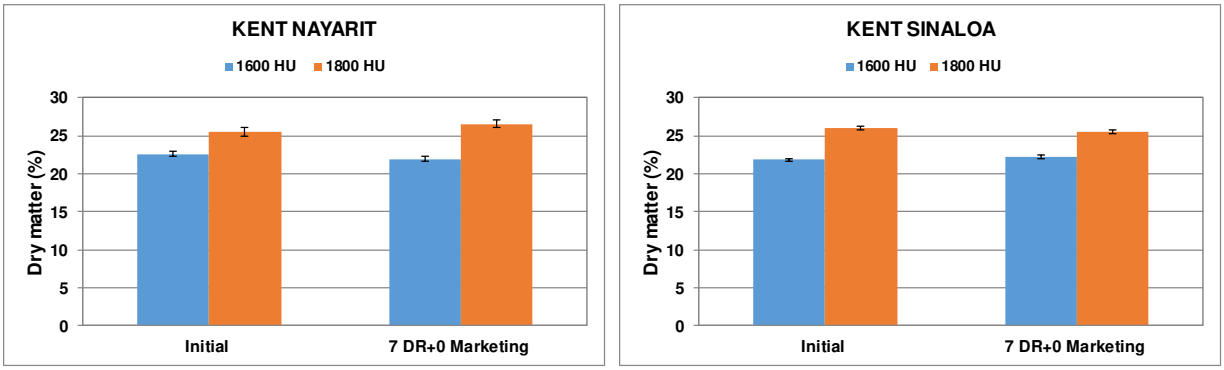



**Figure 41. Dry Matter content of 'Kent' fruit harvested at different HU accumulation in Nayarit and Sinaloa. Vertical bars represent the standard error (if they overlap = NS; if not = *).**

Regarding to weight loss (Figure 42), for fruit harvested in both Nayarit and Sinaloa, only significant differences were observed at consumption stage. Fruit at 1,600 HU lost more weight than those of 1,800 (9.79% vs 4.72%), but this wide difference was due to the fact that fruit at 1,600 HU required 11 marketing days to reach consumption and those at 1,800 HU required only six days. With regard to the fruit of Sinaloa, the trend was the same until shipping simulation, but at consumption it was observed that fruit harvested at 1,600 HU showed greater weight loss (7.26%) than those harvested at 1,800 HU (5.95%) although those at 1,800 HU required one day less of marketing simulation.

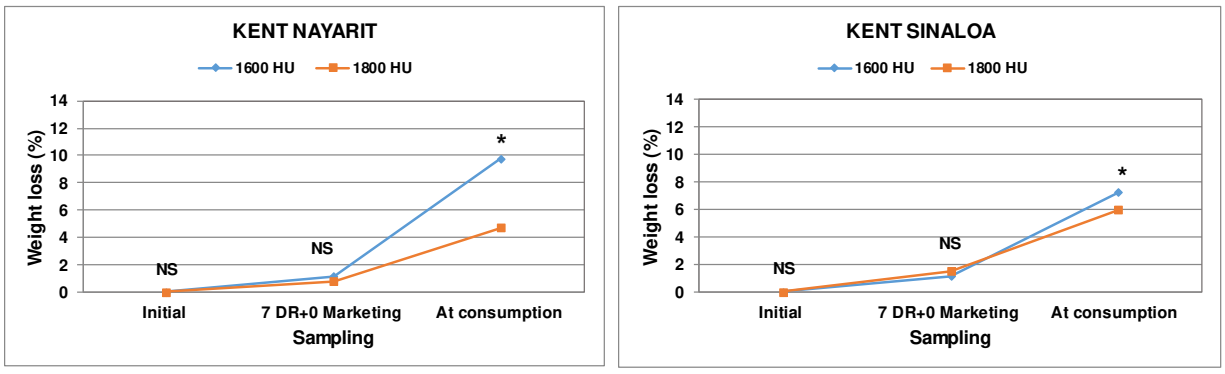
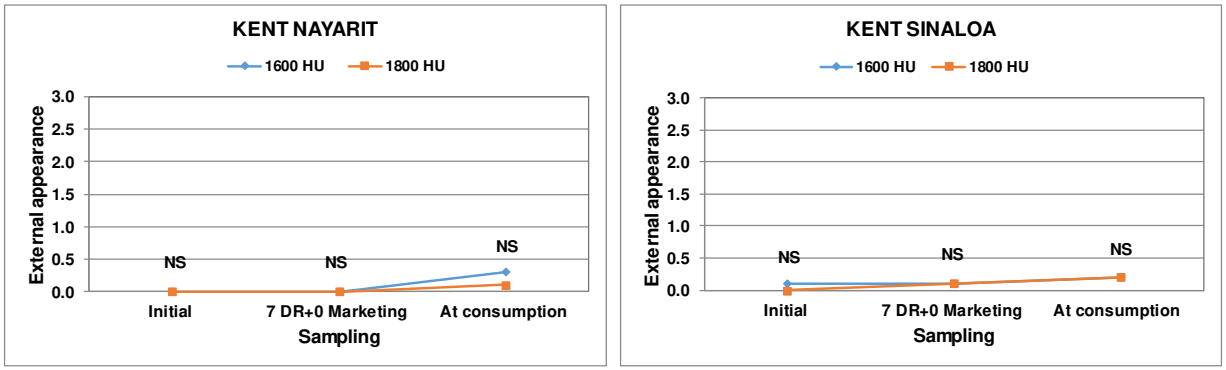



**Figure 42. Weight loss (%) of 'Kent' fruit harvested at different HU accumulation in Nayarit and Sinaloa.**

With regard to external appearance (Figure 43), no significant differences were detected for any of the HU or for the states. In both cases, the values were within the export range with values between 0 and 1, which means external appearance from excellent to good.




**0 = Excellent 1 = Good 2 = Regular 3 = Bad**

**Figure 43. External appearance of 'Kent' fruit harvested at different HU accumulation in Nayarit and Sinaloa.**

Regarding to pulp firmness (Figure 44), no significant differences were observed between HU or between states. This shows that pulp firmness is not a good indicator of maturity to harvest as proposed by other authors.

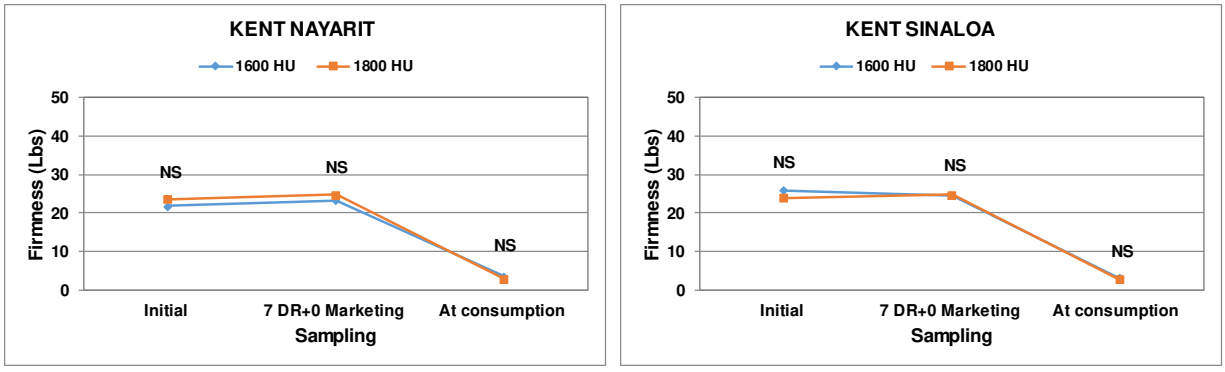



**Figure 44. Pulp firmness (Lbs) of 'Kent' fruit harvested at different HU accumulation in Nayarit and Sinaloa.**

Regarding to pulp color (Figure 45), in the initial sampling and at the end of shipping simulation, significant differences were observed between the two HU in both states. Fruit harvested at 1,800 HU showed greater color intensity than those harvested at 1,600 HU, indicating a more advanced stage of maturity. However, at consumption no significant differences in pulp color intensity were detected neither in the accumulated HU nor in the states.

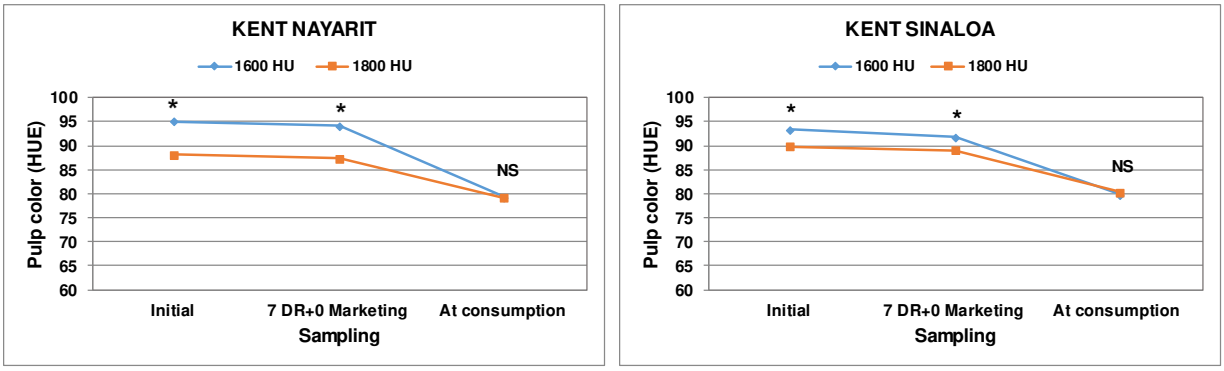



**Figure 45. Pulp color (Hue) of 'Kent' fruit harvested at different HU accumulation in Nayarit and Sinaloa.**

Regarding total soluble solids content (°Bx) [Figure 46], significant differences were observed from the beginning to the ripeness at consumption stage between fruit harvested at 1,600 HU compared to those at 1,800 HU in both states. At consumption, fruit harvested at 1,600 HU had 16.3 °Bx while those harvested at 1,800 HU showed 17.9 °Bx. In Sinaloa the difference was more marked, fruit harvested at 1,600 HU showed 16.1 °Bx, while those at 1,800 HU reached 18.1 °Bx. This variety showed the highest difference at consumption stage. However, this was no longer reflected in the ratio Bx / Acidity where practically no significant differences were detected neither between HU nor in the states (Figure 47).

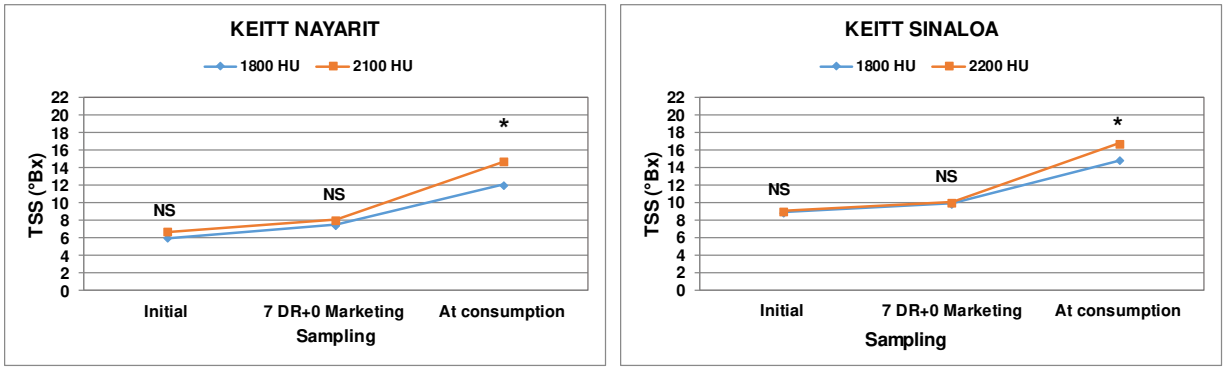



**Figure 46. Total soluble solids content (°Bx) of 'Kent' fruit harvested at different HU accumulation in Nayarit and Sinaloa.**

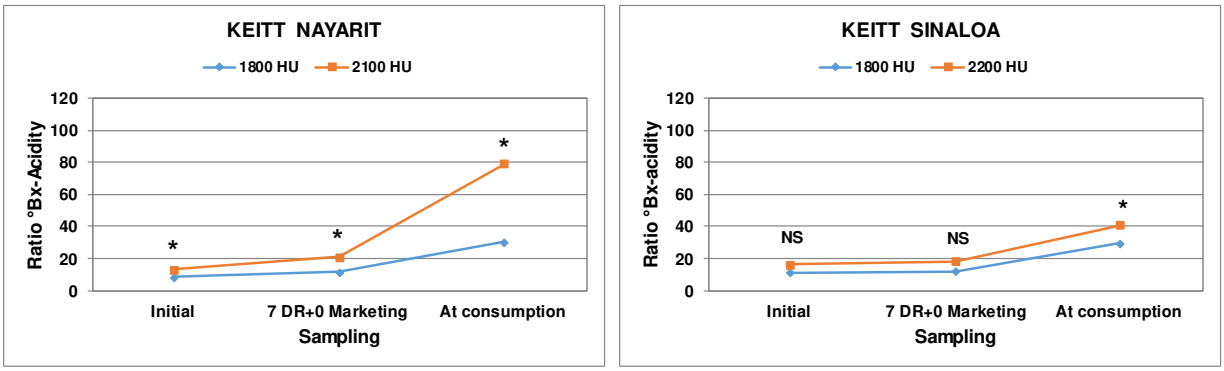



**Figure 47. Ratio Bx/acidity of 'Kent' fruit harvested at different HU accumulation in Nayarit and Sinaloa.**


**Figure 48. Illustration of external and internal appearance of 'Kent' fruit harvested in Nayarit at 1,600 HU.**


**Figure 49. Illustration of external and internal appearance of 'Kent' fruit harvested in Nayarit at 1,800 HU.**

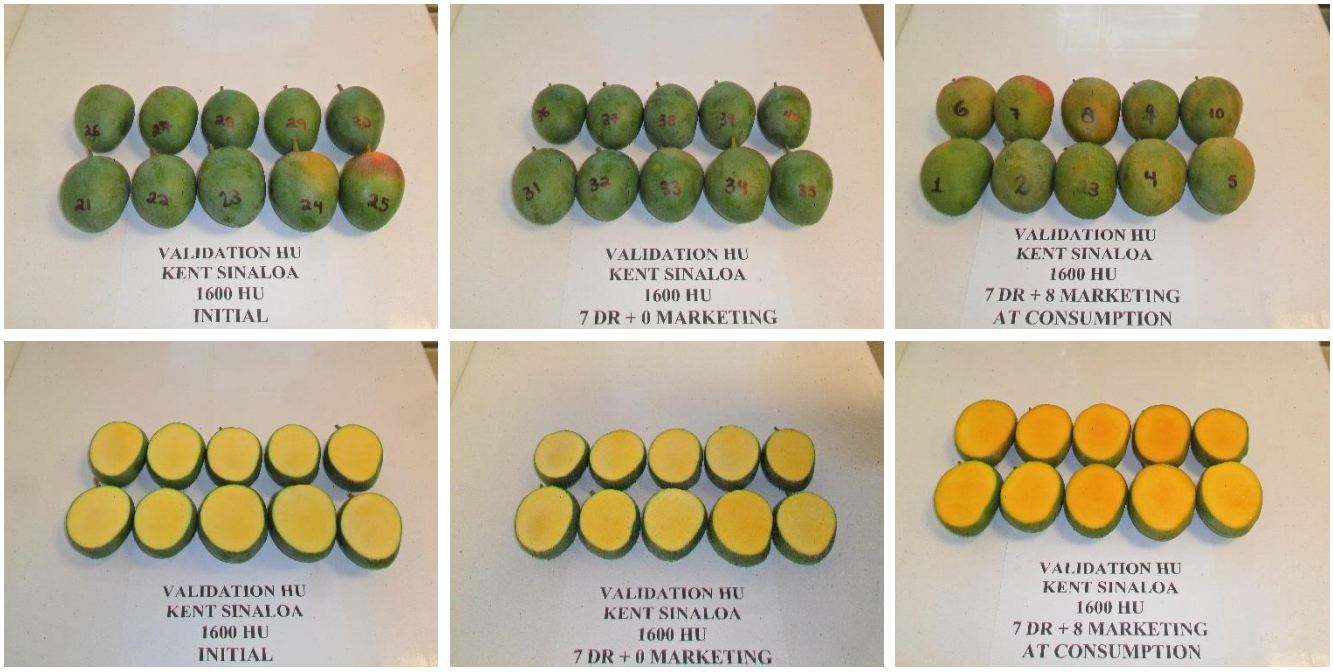



**Figure 50. Illustration of external and internal appearance of 'Kent' fruit harvested in Sinaloa at 1,600 HU.**

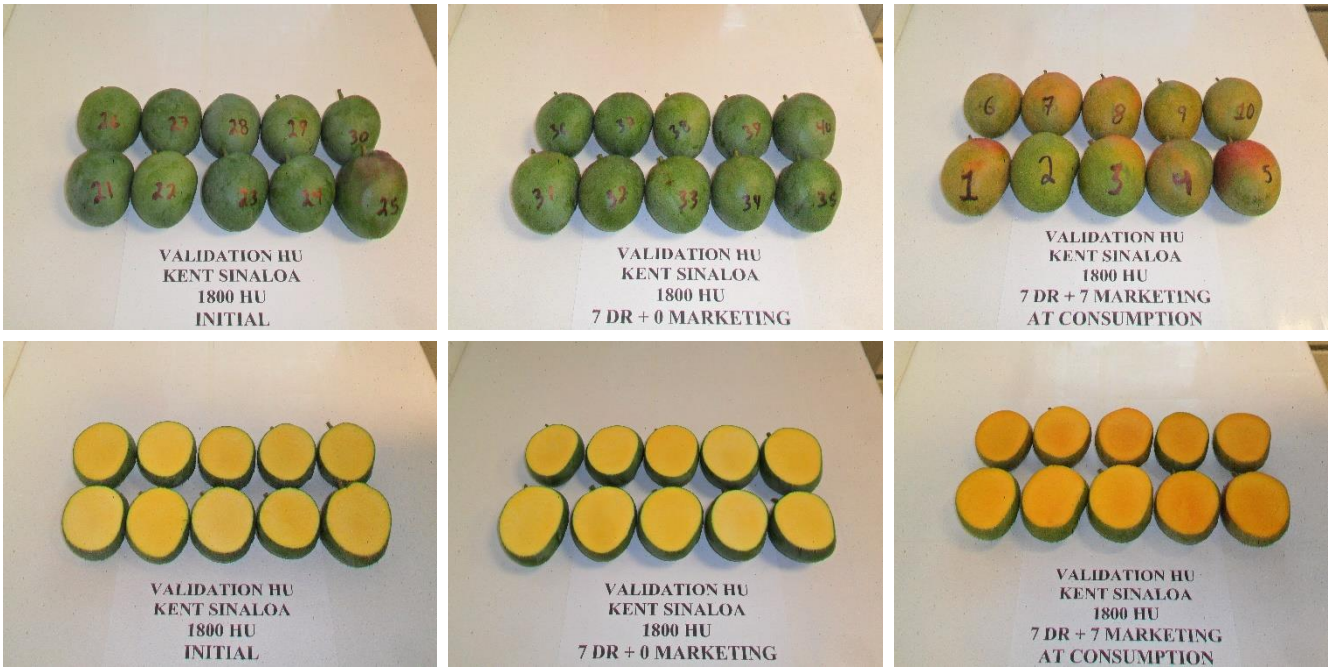



**Figure 51. Illustration of external and internal appearance of 'Kent' fruit harvested in Sinaloa at 1,800 HU.**

For Kent variety it is concluded that the use of the HU accumulation technique is viable and that the optimum maturity is achieved at 1,800 HU.

**d. Keitt**

Figure 52 illustrates the dry matter (DM) content of 'Keitt' fruit harvested at 1,800 and 2,100 / 2,200 UC in both Nayarit and Sinaloa. A trend very similar to what happened with the fruit of the other three varieties was observed, since the initial DM content and DM at the end of shipping simulation was greater at 2,100 / 2,200 HU than at 1,800 HU, which is according to expected, since fruit accumulate a greater quantity of DM when harvested in an optimum ripening stage. However, the results for Sinaloa were higher than those for Nayarit, which is attributed to more restrictive conditions of humidity during crop development. For 1,800 HU fruit of Nayarit showed values of 15.4 to 17.1%, while those of Sinaloa ranged between 19.3 and 21.0%. For 2,100 HU, the fruit of Nayarit presented values of 17.2 to 17.8%, while those of Sinaloa varied from 21.2 to 22.2%.

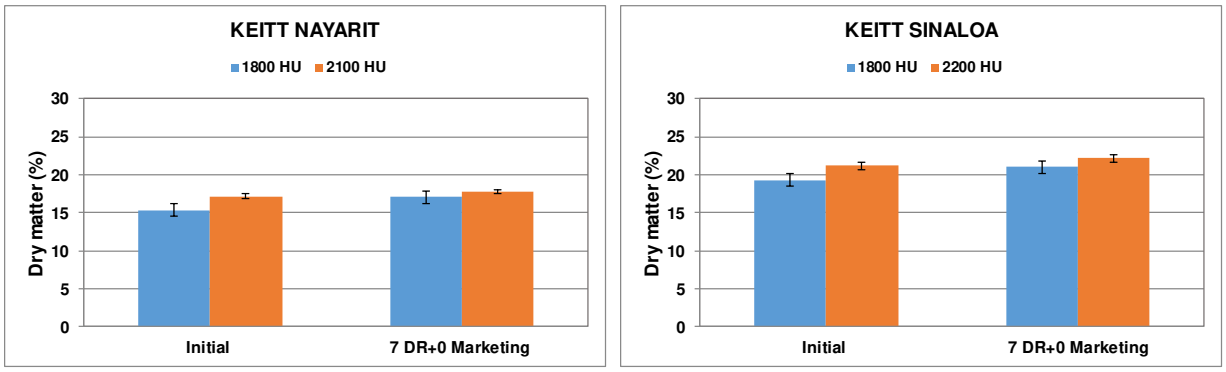



**Figure 52. Dry Matter content of 'Keitt' fruit harvested at different HU accumulation in Nayarit and Sinaloa. Vertical bars represent the standard error (if they overlap = NS; if not = *).**

Regarding to weight loss (Figure 53), for fruit harvested in both Nayarit and Sinaloa, only significant differences were observed at consumption. Fruit of Nayarit at 1,800 HU lost more weight than those of 2,100 (12.7% vs 8.9%), but this difference was because fruit at 1,800 HU required 12 days of marketing to reach consumption stage

and those at 2,100 UC required only 10 days. Regarding to fruit of Sinaloa, the trend was the same until the end of shipping simulation, but at consumption stage fruit harvested at 1,800 HU showed greater weight loss (6.5%) than those harvested at 2,200 HU (5.8 %) although those of 2,200 HU required one less day of marketing simulation.

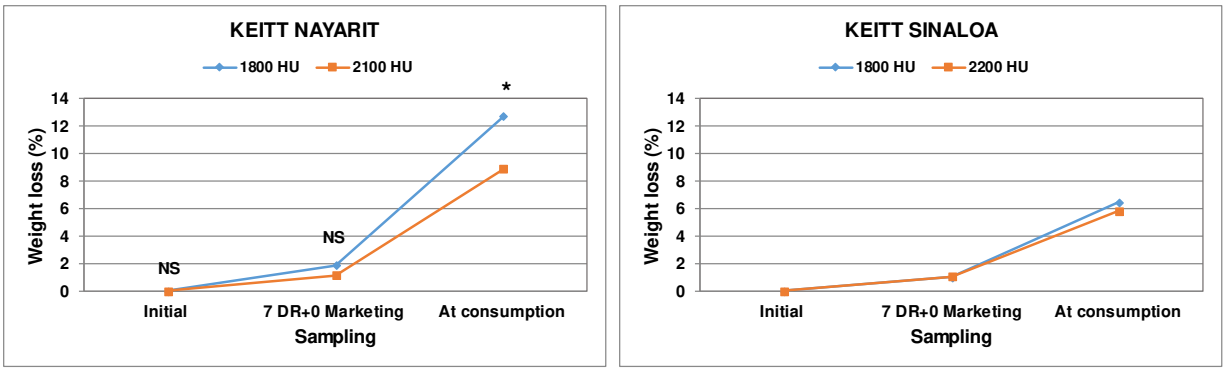
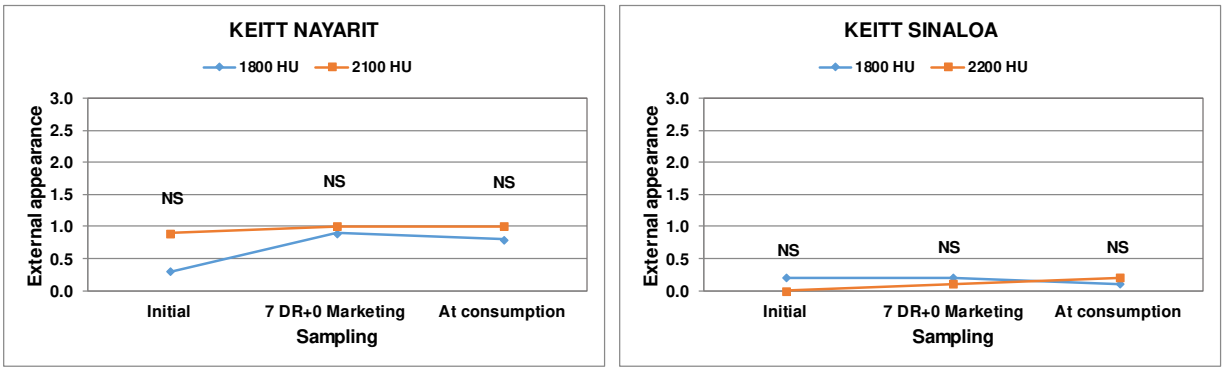



**Figure 53. Weight loss (%) of 'Keitt' fruit harvested at different HU accumulation in Nayarit and Sinaloa.**

Regarding the external appearance (Figure 54), no significant differences were detected for any of the UC or for the states. In both cases, the values were within the export range with values between 0 and 1, which means external appearance from excellent to good.




**0 = Excellent 1 = Good 2 = Regular 3 = Bad**

**Figure 54. External appearance of 'Keitt' fruit harvested at different HU accumulation in Nayarit and Sinaloa.**

Regarding to pulp firmness (Figure 55), no significant differences were observed between HU or between states. This shows that pulp firmness is not a good indicator of maturity at harvest as proposed by other authors.

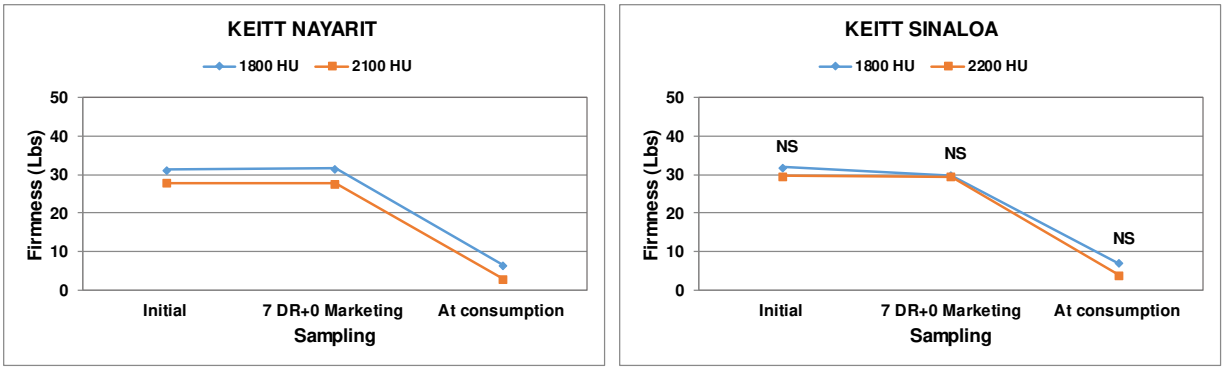



**Figure 55. Pulp firmness (Lbs) of 'Keitt' fruit harvested at different HU accumulation in Nayarit and Sinaloa.**

Regarding to pulp color (Figure 56), in all the samplings significant differences were observed between both HU in the two states. Fruit harvested at 2,100 / 2,200 HU showed greater color intensity than those harvested at 1,800 HU, indicating a more advanced ripening stage.

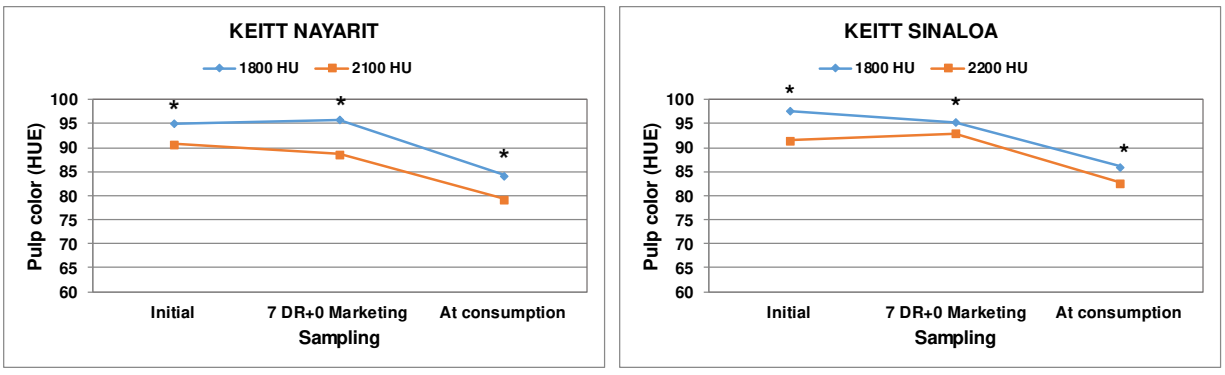



**Figure 56. Pulp color (Hue) of 'Keitt' fruit harvested at different HU accumulation in Nayarit and Sinaloa.**

Regarding to total soluble solids content (°Bx) [Figure 57], only significant differences were detected at consumption stage between fruit harvested at 1,800 HU compared to those at 2,100 / 2,200 HU in both states. At consumption, fruit harvested in Nayarit at 1,800 HU had 12.1 °Bx while those harvested at 2,100 HU showed 14.7 °Bx. In Sinaloa it was a very similar situation, fruit harvested at 1,800 HU showed 14.8 °Bx, while those at 2,200 UC reached 16.8 °Bx. The above-mentioned was reflected in the Bx / Acidity ratio, where the same trend was observed in both states, showing significant differences only at consumption stage in favor of fruit with greater HU accumulation (Figure 58).

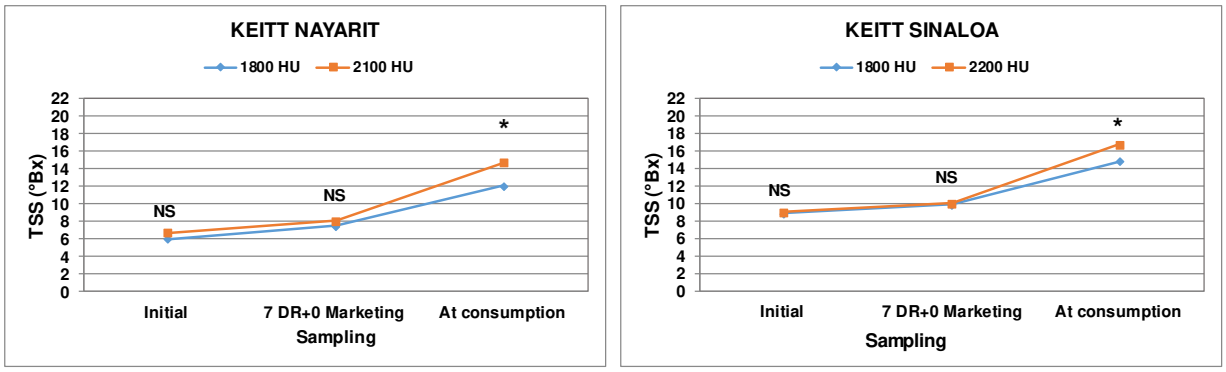



**Figure 57. Total soluble solids content (°Bx) of 'Keitt' fruit harvested at different HU accumulation in Nayarit and Sinaloa.**

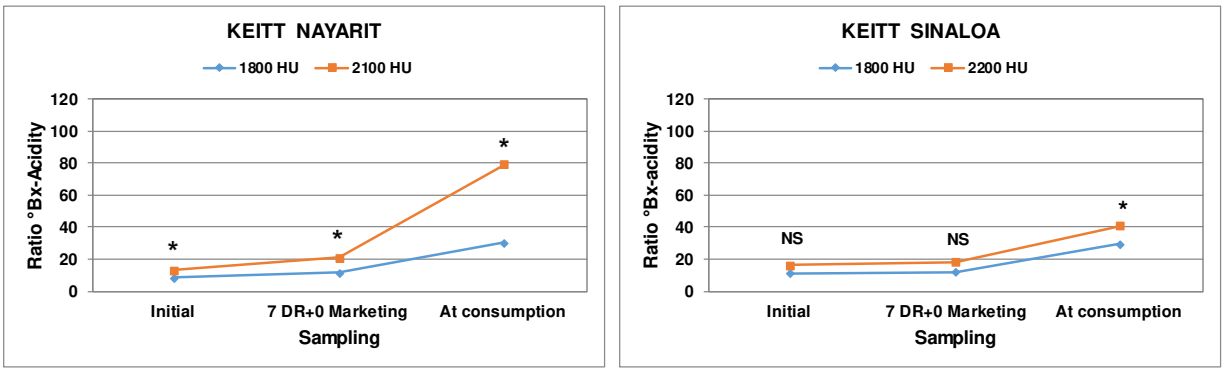



**Figure 58. Ratio Bx/Acidity of 'Keitt' fruit harvested at different HU HU accumulation in Nayarit and Sinaloa.**


**Figure 59. Illustration of external and internal appearance of 'Keitt' fruit harvested in Nayarit at 1,800 HU.**


**Figure 60. Illustration of external and internal appearance of 'Keitt' fruit harvested in Nayarit at 2,100 HU.**


**Figure 61. Illustration of external and internal appearance of 'Keitt' fruit harvested in Sinaloa at 1,800 HU.**

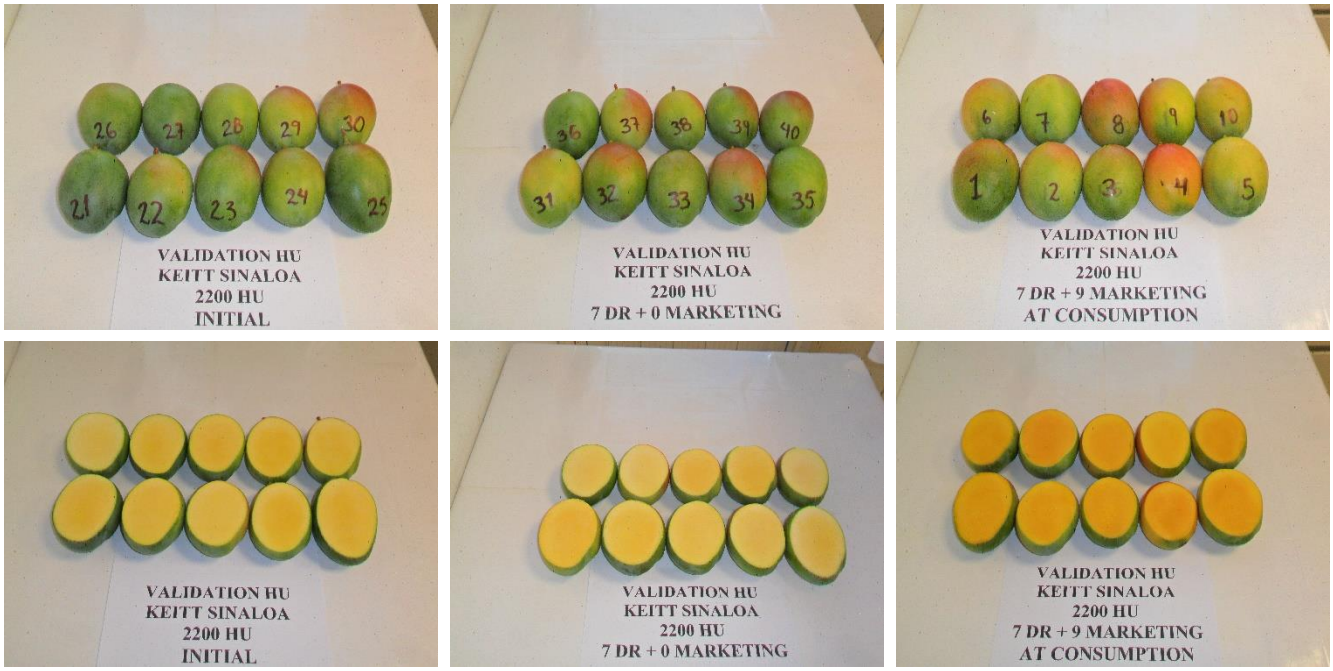



**Figure 62. Illustration of external and internal appearance of 'Keitt' fruit harvested in Sinaloa at 2,200 HU.**

For the Keitt variety it is concluded that the use of the HU accumulation technique is viable and that the optimum harvesting stage is achieved between 2,100 and 2,200 HU.

## CONCLUSIONS

- It was corroborated that HUC required for the optimal harvesting time of Ataulfo and Tommy Atkins mango varieties was 1,600 HU, for Kent 1,800 HU and for Keitt from 2,100 to 2,200 UC.
- If there is no early harvest and the varieties are allowed to reach their optimum harvest time, they will increase the size and caliber of the fruit, as well as the yield volume.
- In addition, greater satisfaction is achieved to the buyer since fruit reach consumption with a higher total soluble solids content and a better Bx / acidity ratio.

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