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# Entire Whitening of Apple Trees to Increase Chill Units in Regions of Warm Temperatures during the Fall-Winter Seasons

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## Abstract

Different studies have shown that global warming and climate change have increased the planet's temperature in different locations. For the apple-growing farmers, this may have a negative impact on the accumulations of chill units when the air temperature during the fall-winter season increases. When the entire trees are covered with a reflective material, the wood temperature may decrease. Therefore, the objective of this study was to evaluate the effect of whitening (with calcium hydroxide) the entire apple trees (*Malus domestica* Borkh) after defoliation, on the branches and trunks' internal temperature (under the bark), the accumulation of chill units (CU), its effects on fruit yield and quality and the relation with the use of thidiazuron (TDZ) (inducer of budbreak). The study was conducted during the fall-winter seasons of 2019-2020 and 2020-2021. The results of this study showed that at the hours of the highest incidence of solar radiation, the internal temperature of the whitened trunks and leaves decreases up to 9˚C and 6˚C respectively. The accumulated CU during the time of the study, of the whitened branches were up to 81% higher than the ones recorded on the branches with no whitening; while the CU was lost at the hours of highest solar radiation (due to a high temperature) were up to 37.2% smaller. Entire tree whitening increased up to 26% of the yield per tree compared to the application of TDZ. No statistical difference in fruit quality was observed between whitened trees and those with no whitening but with the application of thidiazuron.

## Keywords

*Malus domestica* Borkh, Chill Units, Whitening, Calcium Hydroxide, Budbreak

## 1. Introduction

The apple is a deciduous tree that requires low temperatures during the fall-winter season to accumulate sufficient chill units (CU) to get an adequate and uniform blossom budbreak and to obtain a uniform harvest with high fruit yields [1] [2] [3].

One chill unit can be defined as one hour when the air temperature is between 0 and 7.2˚C [4] [5] [6]. Deciduous trees need to store chill units to break the tree dormancy [7]. The Golden Delicious cv requires approximately 850 CU to get a good and uniform budbreak [8] [9], although the CU requirements depend not only on the cultivars but also on the interactions between the cultivars and the environmental factors [10] [11].

A deficient accumulation of CU results in a longer period of tree rest, irregular and deficient flowering, inhibition of vegetative and floral buds, detachment of vegetative and floral buds and abortion of embryos [12] [13] [14] [15]. A consequence of this can be an unseasonable harvest, lack of maturity and fruits of small size.

Different studies have shown that due to the increase of greenhouse gases originating from the burning of fossil fuels, deforestation and agricultural activities, the global planet temperature has risen [16] [17] [18]. Due to the increment of air temperature during the winter season in the regions of apple production, the trees may not accumulate enough CU for an adequate bud break. When the air temperature fluctuates considerably between day and night, it reduces the adding of CU, while continuity of low temperatures favors its accumulation [19] [20]. In the regions of warm winters, cold nights usually occur but warm and sunny days cause a warming of the trees and as a consequence, a negative effect on the accumulation of CU. The highest warming of the trees occurs from 12 to 17 hrs due to a greater incidence of solar radiation. These conditions may result in a deficient and irregular budbreak and blooming, causing irregular harvest and low yields.

To attenuate this problem, the growers usually apply chemists such as cyanamide and thidiazuron (TDZ) to induce budbreak. The applications are done by the last part of the winter season (approximately 20 days before blooming). However, the results of these applications are not always favorable because they depend on several factors such as the CU accumulated before the applications, the date of the applications and the doses applied [21] [22] [23].

Another approach to mitigate this problem is to apply white substances on the trunk and branches such as calcium hydroxide and white paint, in order to reflect the solar radiation from the surfaces of the trees and reduce the internal heating. The whitening with calcium hydroxide or white paint is a well-known practice that has been done for decades in many countries to delay the budbreak and reduce trunk cracking [24]. For instance, Durner and Gianfagna [25] observed that the budbreak of floral buds on peach trees was delayed two days when the trees were painted with white paint, before the winter season. Gar-

cia-Perez *et al.* [26]) indicated that the trunks' temperature of pecans limed or white painted was smaller with a higher number of floral budbreak than those with no whitening.

Another white substance as Kaolin, which has a high reflectivity, has been applied to reduce the leaf temperature and transpiration, and to improve the photosynthesis rate of apple trees [27] and grapefruits [28] that gave higher fruit yields.

Under the hypothesis that the whitening of the entire apple trees increases the CU and yield, the objective of this study was to evaluate the effect of liming complete apple trees on the internal temperature of the branches and trunks; the CU accumulated during the winter season, its effects on yield and quality of fruits and the relation to yield obtained by applying thidiazuron as a bud break inducer.

## 2. Materials and Methods

### 2.1. Study Site Description

The study was conducted on an apple orchard located in Jame, municipality of Arteaga, Coahuila, Mexico, during the fall-winter seasons of 2019-2020 and 2020-2021. The orchard is located at 25˚22'N and 100˚37'W at an elevation of 2280 m. The rain occurs basically from May to October, the yearly average rainfall is between 400 and 500 mm and the annual mean higher and lower air temperatures are 31˚C and 10˚C respectively [29].

The study was carried out on an orchard of apple trees cultivars Golden delicious of nine years old, 3.5 m height grafted over rootstock M 111. The trees are aligned on lines (east-west) separated by 4 m and 3 m between trees. The trees are drip irrigated every other day to maintain adequate soil moisture content. The pest control was made by the owner of the orchard according to the recommendations established for the region.

### 2.2. Treatments Evaluated and Experimental Design

To evaluate the effect of the entire whitening of apple trees on fruit yield and quality, and the relation with the use of TDZ to induce budbreak, a complete randomized block design with four treatments and six replications (**Figure 1**) was used, and the experimental unit was one tree.

The evaluated treatments were: No whitening nor application of TDZ (T1, control), entire whitening of apple trees at the end of the fall season (T2), application of TDZ before spring (T3) and entire whitening of apple trees at the end of the fall season and application of TDZ before spring (T4).

The entire whitening of the apple trees was done on December 3 of 2019 and December 7 of 2020, when the trees were totally defoliated, using a sprinkler backpack. The solution to whitening the trees was made by dissolving 1.5 kg of calcium hydroxide (for agricultural use), 15 mL of Bionex as adherent on 10 L of water, for whitening the six trees of the corresponding treatment. A second

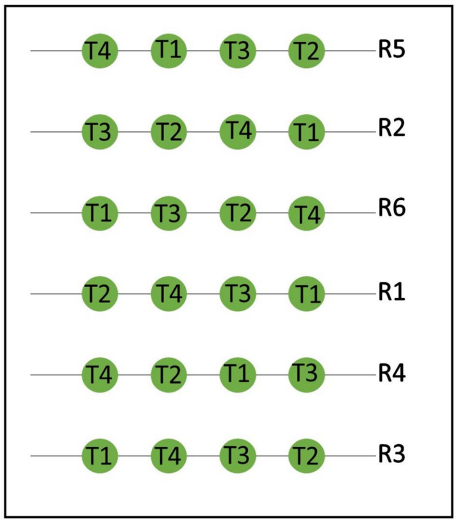


**Figure 1.** Diagram of the field study in a randomized complete block design of four treatments and six replications.

application of the suspension was applied on the first week of January 2019 and 2020.

The solution of TDZ was prepared by dissolving 3 g of TDZ (Thidiazuron) and 15 mL of Bionex as adherent in 10 L of water to shower the six trees with the corresponding treatment. The applications were made before the spring of each year, March 2 of 2020 and March 7 of 2021.

## 2.3. Temperature measurements

To evaluate the effect of the entire whitening in the internal temperature of the trees and the accumulation of CU, we inserted thermocouples of cupper-constantan (0.6 mm of diameter) under the bark of four branches of one tree of the treatment two (entire whitening at the beginning of winter season and in another tree of treatment one (no whitening, no application of TDZ). We also inserted two thermocouples in the north and south faces of the trunks of the same trees. The air temperature was measured with a sensor of temperature and relative humidity (Vaisala, Logan, Utah, USA). The measurements were made at a frequency of 1 s, and average values of 30 min were stored in a datalogger CR1000 (Campbell Sci, Inc, Logan, Utah) during the time of the study (December to March of each year).

To calculate the accumulated chill units (ACU), we defined five temperature intervals with the corresponding weighting factors [6] [30] (**Table 1**). A chill unit is added or reduced by multiplying the weighting factor for the average one-hour temperature. We obtained the ACU using the air temperature and the internal temperature of the branches with and without whitening.

In this study, a climatic potential index (CPI) was established to evaluate if the climatic conditions of the fall-winter season were ideal for the accumulation of chill units. The CPI was the relation of the ACU using the air temperature and the highest possible ACU during a day (24) (**Table 1**). The higher the value of

**Table 1.** Temperature intervals and weighting factor (Wf) to calculate the accumulated chill units (ACU).

| Temperature (˚C): | Wf |
|---|---|
| <1 | 0 |
| 1 - 10 | 1 |
| 10 - 15 | 0.5 |
| 15 - 20 | 0 |
| >20 | -1 |

the CPI, the better the fall-winter season for the accumulation of CU. When the CPI is one for the fall-winter season the trees will have the highest ACU.

### 2.4. Fruits Yield and Quality

The effect of the treatments on the fruits yield and quality was evaluated by harvesting all fruits of the six trees of each treatment. The yield parameters were the weight and the total number of fruits while, of the quality were brix grades (manual refractometer Atago ATC-1E with automatic compensation of temperature), firmness (manual penetrometer Effegi FT-327 with points of 11.3 mm of diameter), quality index of fruits of the first and second category.

Brix grades and fruit firmness were evaluated in four fruits for each experimental unit. The index of first quality fruits was obtained by dividing the number of fruits with an equatorial diameter bigger than 70 mm by the total fruits of the corresponding tree. The fruits second quality index was the relation between the number of fruits with an equatorial diameter bigger than 66 mm and less than 70 mm and the total number of fruits. The ANOVA of the treatments was done using R-studio version 3.0 and the multiple mean comparisons of treatments, the Tukey test ($\alpha \leq 0.05$) was used.

## 3. Results and Discussion

### 3.1. Branches and Trunks Internal Temperatures

During both fall-winter seasons, from 9:00 to 19:00, the air temperature was smaller than the internal temperature (under the bark) of the branches with and without whitening. The highest difference occurs at the time of the highest incidence of solar radiation (12:00 to 17:00) (**Figure 2** and **Figure 3**). The internal temperature of the branches without whitening was up to 10˚C higher than the air temperature, whereas the internal temperature of the whitened branches was up to 5.2˚C above air temperature. In addition, the internal temperature of the control branches (without whitening) was up to 6.0˚C higher than the whitened branches. Hernandez-Herrera *et al.* [31] reported a difference of up to 5˚C between the branches with and without whitening. These differences in temperature among the air and the branches with and without whitening are reflected in different values of ACU during the fall-winter season. For many days, from

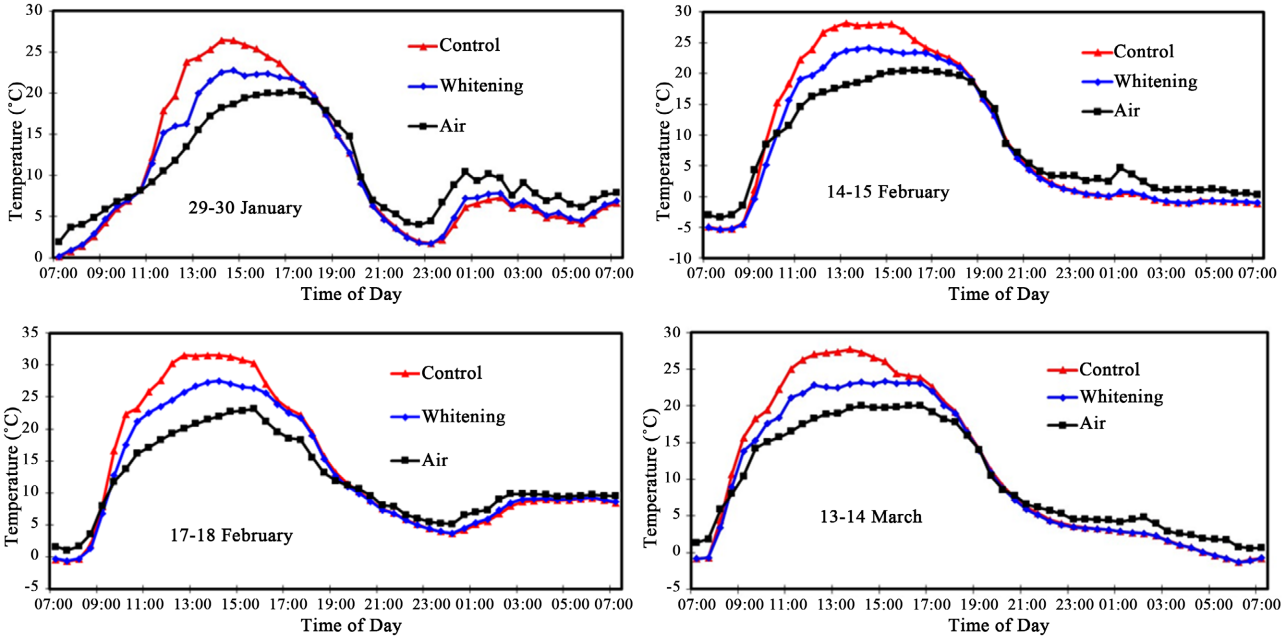


**Figure 2.** Temperature of the air and the branches with and without whitening observed at different dates during the winter of the year 2020, at Arteaga, Coahuila, Mexico.

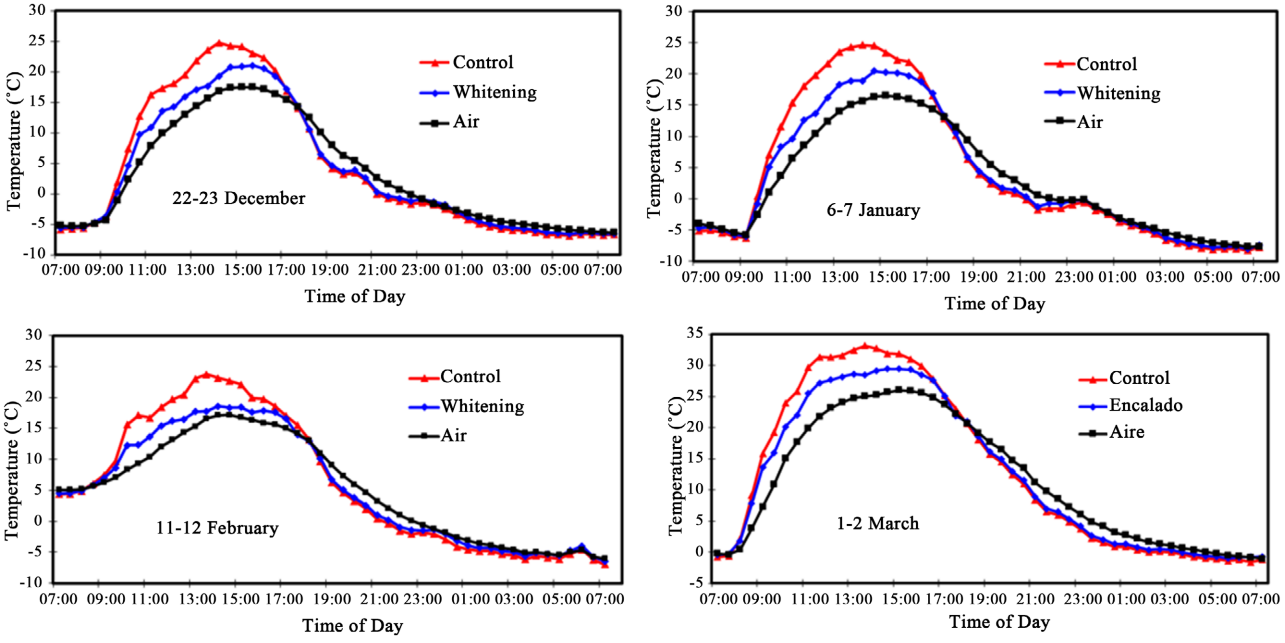


**Figure 3.** Temperature of the air and the branches with and without whitening observed at different dates during the winter of 2020-2021, at Arteaga, Coahuila, Mexico.

approximately 11:00 to 18:00, the air and branches' temperature is higher than 15˚C (**Figure 2** and **Figure 3**) which indicates that the ACU of the trees will be zero or negative (**Table 1**). The high temperatures during the warm days of the winter season may have a negative effect on the accumulation of chill units [14] [15]. From **Figure 2** and **Figure 3** it is possible to see that the effect of reducing the branches' internal temperature, by the whitening of the entire tree that in-

creases the solar reflectivity, is possible to reduce the loss of ACU during the days of a high incidence of solar radiation.

During the night, the temperature of the branches with and without whitewashing was very similar, and both were smaller than the air temperature (**Figure 2** and **Figure 3**). Similar patterns were observed during the course of the two winters. Always the internal temperature of the whitened branches at the time of the highest incidence of solar radiation was smaller than the internal temperature of the control branches.

The effect of entire whitening in the reduction of the internal temperature was higher in the south face of the trunks because this side receives direct solar radiation most of the day (**Figure 4** and **Figure 5**). During the time of the highest incidence of solar radiation (12:00 to 17:00) the internal temperature of the south face of the whitened trunks was up to 9˚C smaller than the internal temperature of the control trunks of the same orientation. Hernández-Herrera *et al.* [31] reported that the internal temperature of the whitened trunks (south face) was up to 15˚C smaller than the internal temperature of the control trunks on the same side. Similarly, Hellmuth *et al.* [32] found that the internal temperature of apple trunks with white vinyl paint was significantly smaller than control trunks. The whitening of the trees reduces the big difference of the trunk internal temperature between day and night, this, in turn, may reduce the trunk cracking [33] [34].

Other studies have reported the effect of reflective films in reducing the internal temperature of other plants. For instance, Rosati *et al.* [35] showed that the temperature of the leaves of almond and walnut trees decreased up to 3˚C by applying a 3% of kaolin film, with no effect on the photosynthesis rate. The effect of the reflective materials on the temperature of the plants depends on the

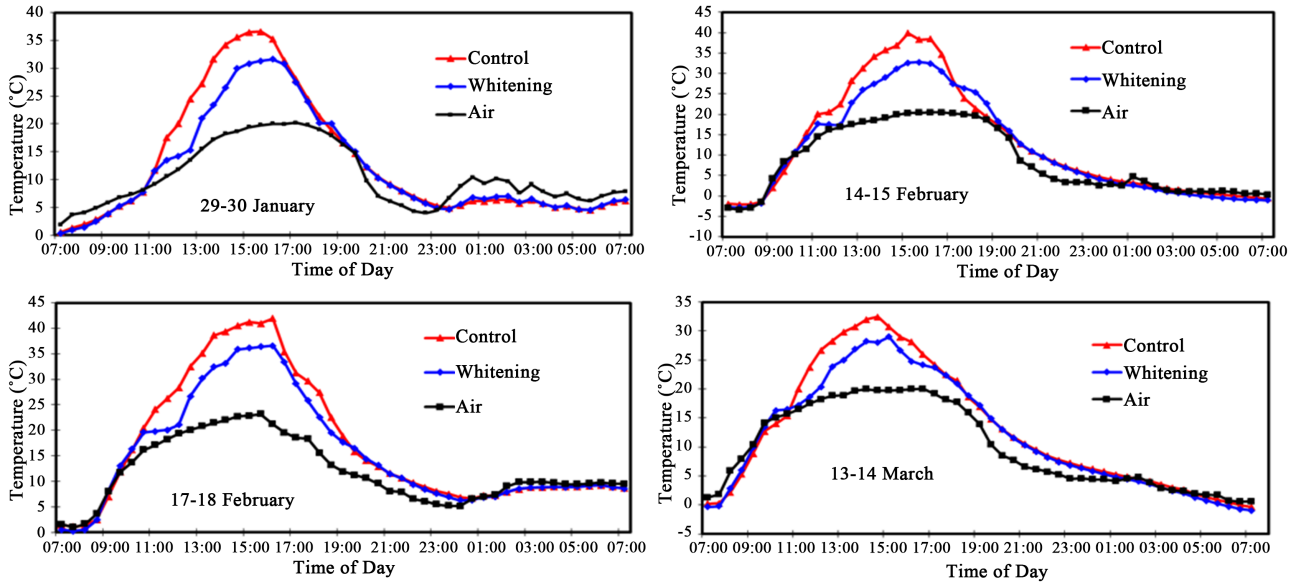


**Figure 4.** Temperature of the air and the trunk (south face) with and without whitening observed at different dates during the winter of the year 2020, at Arteaga, Coahuila, Mexico.

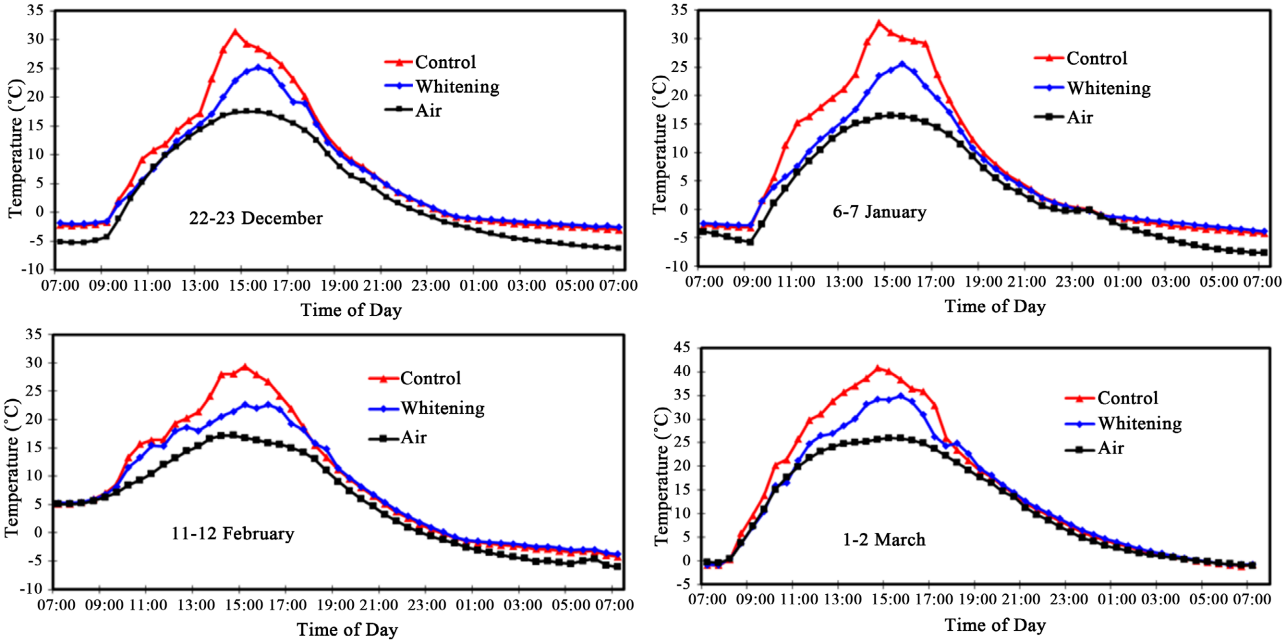


**Figure 5.** Temperature of the air and the trunk (south face) with and without whitening observed at different dates during the winter of 2020-2021, at Arteaga, Coahuila, Mexico.

weather conditions. On clear sky calm days (wind speed < 0.5 $ms^{-1}$) at noon, the internal fruit temperature of the kaolin-treated plants was 4.4˚C lower than the control plants (without kaolin) while, on days with cloudy days no temperature difference was observed [36]. The temperature of mango fruits coated with bentonite was 9˚C lower than the temperature of the control fruits (with no coating), and 13˚C inferior when coated with kaolinite [37]. The temperature under the epidermis of apple fruits covered with a film of calcium hydroxide at the time of the highest incidence of solar radiation was up to 3˚C smaller than the fruits with no liming [38].

### 3.2. Accumulated Chill Units

The air temperature at the hours of the highest incidence of solar radiation was smaller than the internal temperature of the branches with and without whitening (**Figure 2** and **Figure 3**). Consequently, the ACU calculated using the air temperature is higher than those calculated with an internal temperature of the branches with and without whitening, which corresponded to the internal ACU by the trees. As the temperature under the bark of the whitened branches during the daylight was smaller than the internal temperature of the control branches during the two winters, the ACU calculated with the internal temperature of whitened branches were higher than those calculated with the internal temperature of the control branches (**Table 2** and **Table 3**)

From January 7 to March 31 of 2020, the ACU calculated with the air temperature and the branches with and without whitening were 1067.5, 725.25 and 567.00, respectively (**Table 2**). This shows that the ACU using the air temperature are higher than those calculated with the internal temperature of the branches.

**Table 2.** Accumulated chill units (ACU), calculated with the air temperature, the internal temperature of the branches with and without whitening and the ACU (max), that represents the highest chill units accumulated in a day (24). From january 7 to march 31, 2020, at Jame, Arteaga, Coahuila, Mexico.

| Month | days | ACU with whitening | ACU without whitening | ACU with air temperature | ACU (max) |
|---|---|---|---|---|---|
| January | 7 - 10 | 22.50 | 15.50 | 39.50 | 72 |
| | 11 - 20 | 70.75 | 45.00 | 110.50 | 240 |
| | 21 -31 | 93.25 | 71.50 | 160.25 | 264 |
| February | 1 - 10 | 147.75 | 133.75 | 158.00 | 24 |
| | 11 - 20 | 61.50 | 43.75 | 106.00 | 240 |
| | 21 - 28 | 114.5 | 98.00 | 143.5 | 192 |
| March | 1 - 10 | 135.5 | 104.00 | 165.50 | 240 |
| | 11 - 20 | 55.50 | 41.00 | 121.00 | 240 |
| | 21 - 31 | 24.25 | 14.50 | 63.25 | 264 |
| | total | 725.25 | 567.00 | 1067.50 | 1992 |

**Table 3.** Accumulated chill units (ACU), calculated with the air temperature and the internal temperature of the branches with and without whitening and the ACU (max), that represents the highest chill units accumulated in a day (24). From december 17, 2020 to march 10, 2021, at Jame, Arteaga, Coahuila, Mexico.

| Month | days | ACU with whitening | ACU without whitening | ACU with air temperature | ACU (max) |
|---|---|---|---|---|---|
| December | 17 - 31 | 63.5 | 25.25 | 130.75 | 336 |
| January | 1 - 10 | 21.5 | 1.75 | 71.25 | 240 |
| | 11 - 20 | 54.0 | 27.0 | 83.5 | 240 |
| | 21 - 31 | 124 | 101.75 | 161.75 | 264 |
| February | 1 - 10 | 50.25 | 18.75 | 99.50 | 240 |
| | 11 - 20 | 42.75 | 17.75 | 80.75 | 240 |
| | 21 - 28 | 41.50 | 29.75 | 72.00 | 192 |
| March | 1 - 10 | 18.00 | 7.50 | 36.00 | 240 |
| | total | 415.50 | 229.50 | 708.50 | 1992 |

During this time, the whitened branches had an additional accumulation of 158.5 CU in relation to the branches without whitewash, which corresponded to an increment of 27.9%

From December 17, 2020 to March 10, 2021 the ACU of the whitened branches were 415.50 and 229.50 for the control branches, this was a difference of 186 ACU that corresponded to an increase of 81% due to the whitening of the branches (Table 3). These results indicated that a decrease in the internal tem-

perature of the branches by the whitening of the entire trees (Figure 2 and Figure 3), increased the accumulation of CU. A higher accumulation of CU may improve budbreak and fruit yield [1] [2].

The climatic potential index (CPI) calculated for the winter of 2019-2020 was 0.54 (1067.50/1992) (Table 2), while for the winter of 2020-2021 was 0.36 (708.50/1992) (Table 3), indicating that the climatic conditions of 2019-2020 winter in the locality of Jame, Coahuila, Mexico, were better to accumulate chill units for this cultivar. The entire tress whitening has more effect on warmer winters because the lower under bark temperature of branches and trunks (due to major solar reflectivity) reduces the loss of ACU.

### 3.3. Loss of Chill Units

The largest loss of CU occurred at the hours of the highest incidence of solar radiation (12:00 to 17:00) due to higher warming of the branches (Figure 2 and Figure 3). Therefore, the benefit of the entire tree whitening is reached at these hours of the day. It was observed that for the winter of 2019-2020, from January 7 to March 31, for the time interval mentioned, 6 CU were gained considering the air temperature. However, using the internal temperature of the control branches 259.25 CU were lost, while for the internal temperature of whitened branches only 162.75 CU were lost. This represented 37.2% of less CU lost due to the total whitening of the trees (Table 4).

For the winter of 2020-2021, No gain of CU was observed at the time of the highest incidence of solar radiation using the air and branches temperatures (Table 5). 102.75 CU were lost using the air temperature, 246.25 and 344.50 CU were lost using the internal temperature of the branches with and without

Table 4. Accumulated chill units gained or lost (negative numbers), as a function of air temperature and the internal temperature of the branches of apple cv Golden Delicious with and without whitening, from 12:00 to 17:00 for several day intervals of the winter months of 2020, at Jame, Arteaga, Coahuila, Mexico.

| Month | days | ACU with whitening | ACU without whitening | ACU with air temperature |
|---|---|---|---|---|
| January | 7 - 10 | −15.75 | −19.50 | −8.25 |
| | 11 - 20 | −7.50 | −25.00 | 11.50 |
| | 21 -31 | −27.50 | −42.00 | 4.75 |
| February | 1 - 10 | 4.75 | −4.50 | 15.50 |
| | 11 - 20 | −33.00 | −41.00 | −12.50 |
| | 21 - 28 | −3.50 | −12.00 | 17.25 |
| March | 1 - 10 | 6.00 | −19.50 | 23.50 |
| | 11 - 20 | −27.75 | −35.25 | 0.75 |
| | 21 - 31 | −58.50 | −60.50 | −46.25 |
| | total | −162.75 | −259.25 | 6.00 |

Table 5. Accumulated chill units gained or lost (negative numbers), as a function of air temperature and the internal temperature of the branches of apple cv Golden Delicious with and without whitening, from 12:00 to 17:00 for several day intervals of the winter months of 2020-2021, at Jame, Arteaga, Coahuila, Mexico.

| Month | days | ACU with whitening | ACU without whitening | ACU with air temperature |
|---|---|---|---|---|
| December | 17 - 31 | −32.75 | −53.50 | −0.250 |
| January | 1 - 10 | −41.00 | −49.75 | −19.75 |
| | 11 - 20 | −13.50 | −31.75 | −0.50 |
| | 21 - 31 | −2.25 | −17.75 | 16.75 |
| February | 1 - 10 | −27.75 | −47.25 | −3.75 |
| | 11 - 20 | −36.00 | −49.5 | −20.25 |
| | 21 - 28 | −42.50 | −44.00 | −26.50 |
| March | 1 - 10 | −50.50 | −51.00 | −48.50 |
| | total | −246.25 | −344.50 | −102.75 |

whitening respectively. In this winter, the entire whitening of the trees decreased 28.52% the loss of CU in relation to the control trees.

For the two winters, the whitening of the branches reduces the loss of CU in relation to the control branches in the all-time segments analyzed. In addition, for some time segments of the winter of 2019-2020, it was observed a small accumulation of CU when using the internal temperature of the whitened branches. However, when using the internal temperature of the control branches always resulted in a loss of CU. The lower ACU of the control branches may affect the buds break and finally the fruit yield.

### 3.4. Yield and Fruit Quality

The harvest was done the first week of August of the two years (2020 and 2021). The difference in the accumulated chill units among the treatments significantly affected the fruit yield (kg/tree) and fruits per tree. In the fall-winter season of 2019-2020, the trees that were entirely whitened accumulated 158.25 CU more than the no whitened trees (Table 2). For this season, the highest average fruit yield and fruits per tree (Table 6) were obtained when the trees were whitened at the end of the fall season (Treatment 2) and were statistically higher (Tukey, $\alpha \leq 0.05$) than the fruit yield obtained by the trees of the control treatment (no whitening nor application of TDZ) and the application of TDZ as budbreak promoter before spring (Treatment 3). The difference was around 10 kg/tree, corresponding to an increment of 23%. For the number of fruits per tree, the difference was, on average, 116.75 fruits (26.15% higher). No increase in yield (kg/tree) and fruits per tree were observed between treatments two and four; this indicates that applying TDZ is not required before spring if the trees are entirely whitened at the end of the previous fall.

**Table 6.** Average fruit yield (kg/tree), fruits per tree and parameters of fruit quality cv Golden Delicious, observed on the harvest of 2020 and 2021, at Jame, Arteaga, Coahuila, Mexico.

| Year | Treatment | Yield (kg/tree) | Fruits per tree | Firmness (kg/cm²) | Total soluble solids (Bárix) | First quality index fruit | Second quality index fruit |
|---|---|---|---|---|---|---|---|
| 2020 | T1 | 42.12$^{b}$ | 330.5$^{b}$ | 7.75$^{a}$ | 14.57$^{a}$ | 0.482$^{a}$ | 0.189$^{a}$ |
| | T2 | 52.85$^{a}$ | 446.5$^{a}$ | 7.40$^{a}$ | 14.20$^{a}$ | 0.513$^{a}$ | 0.181$^{a}$ |
| | T3 | 42.84$^{b}$ | 329.0$^{b}$ | 7.50$^{a}$ | 14.55$^{a}$ | 0.449$^{a}$ | 0.253$^{a}$ |
| | T4 | 47.48$^{ab}$ | 390.5$^{ab}$ | 7.40$^{a}$ | 14.72$^{a}$ | 0.569$^{a}$ | 0.196$^{a}$ |
| 2021 | T1 | 43.84$^{b}$ | 361.8$^{b}$ | 7.21$^{a}$ | 14.40$^{b}$ | 0.2279$^{a}$ | 0.2588$^{a}$ |
| | T2 | 55.05$^{a}$ | 451.25$^{a}$ | 7.31$^{a}$ | 14.54$^{ab}$ | 0.4026$^{a}$ | 0.2773$^{a}$ |
| | T3 | 43.43$^{b}$ | 354.5$^{b}$ | 7.13$^{a}$ | 15.08$^{a}$ | 0.3308$^{a}$ | 0.2736$^{a}$ |
| | T4 | 51.16$^{ab}$ | 411.3$^{ab}$ | 7.14$^{a}$ | 14.90$^{ab}$ | 0.3259$^{a}$ | 0.3443$^{a}$ |

T1: (control) No whitening neither application of budbreak promoter; T2: entire trees whitening at the end of fall; T3: application of TDZ as budbreak promoter before spring; T4: entire tress whitening at the end of fall and application of TDZ before spring. Means with the same letter inside the columns are statistically equal (Tukey, $\alpha \leq 0.05$).

In the fall-winter season 2020-2021, the whitened trees accumulated 186 more additional chill units than the control trees (Table 3), which also impacted the fruit yield. The average fruit yield (kg/tree) and the number of fruits per tree of the whitened trees (T2) was also statistically superior to treatment one (control) and treatment 3 (application of TDZ as budbreak promoter before spring) (Table 6) (Tukey, $\alpha \leq 0.05$). The difference was above 11 kg/tree and 93 fruits per tree. which corresponded to an average increment of 26% and 20.6% respectively. Similarly, as the previous year, no increase in the yield (kg/tree) and number of fruits per tree was observed between Treatments 2 and 4, confirming that no need for the application of the TDZ before spring, if the trees are entirely whitened at the end of the previous fall. Hernández-Herrera *et al.* [31] also found that the fruit yield under the entire whitening of apple trees is higher than the fruit yield of trees without whitening. Other studies on apple trees have shown that the use of reflective films such as kaolin can increase the fruit yield and improve the reddish of the fruits [27] [39].

Fruit firmness, total soluble solids, and index of the fruit of first and second were not affected by the treatments evaluated in the two years of the study. Only in the year 2021, the total soluble solids of treatment 3 (application of TDZ before spring) were statistically higher than the one observed in the control treatment (T1). Studies performed on orchards of apples by Glenn *et al.* *[39]*, using kaolin as a reflective film reported no effect on total soluble solids and fruit firmness. These results suggest the main effect of the complete whitewashing of the trees is on the fruit yield and has no effect on the parameters of fruit quality.

## 4. Conclusions

The total whitening of apple trees reduced the internal temperature of the branches and trunks. The decrease in temperatures was bigger at the hours of the highest incidence of solar radiation (12:00 to 17:00) and on the south face of the trunks.

The accumulated chill units calculated with the temperature under the bark were higher in the whitened branches than in the branches without whitening and the loss of chill units at the time of the highest incidence of solar radiation was smaller on the whitened branches.

In the two fall-winter seasons, the fruit yield (kg/tree) and the total number of fruits per tree of the whitened trees were higher than those observed in the control trees (No whitening or application of TDZ) and of the trees with the application of TDZ before spring. Applying TDZ before spring when the trees were previously whitened at the end of fall did not increase the fruit yield. The whitening of the apple trees had no effect on the quality of the fruits.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

## References

[1] Soto-Parra, J.M., Flores-Cordova, M.A., Sánchez-Chávez, E., Pérez-Leal, R. and Piña-Ramírez, F.J. (2020) Cold Compensators in Apple Tree "Golden Glory": Development and Production. *Revista Mexicana de Ciencias Agrícolas*, **11**, 69-82. https://doi.org/10.29312/remexca.v11i1.1744

[2] Seif El-Yazal, M.A., Rady, M.M. and Seif, S.A. (2012) Foliar Applied Dormancy-Breaking Chemicals Change the Content of Nitrogenous Compounds in the Buds of Apple (*Malus sylvestris* Mill. cv. Anna) Trees. *The Journal of Horticultural Science and Biotechnology*, **87**, 299-304. https://doi.org/10.1080/14620316.2012.11512868

[3] Legave, J.M., Guédon, Y., Malagi, G., El Yaacoubi, A. and Bonhomme, M. (2015) Differentiated Responses of Apple Tree Floral Phenology to Global Warming in Contrasting Climatic Regions. *Frontiers in Plant Sciences*, **6**, Article No. 1054. https://doi.org/10.3389/fpls.2015.01054

[4] Maio, S. (2020) Estimación de valores agroclimáticos de horas de frío en San Pedro (Provincia de Buenos Aires, Argentina) y escenario futuro. *Rada Revista Argentina de Agrometeorología*, **11**, 45-53.

[5] Damario, E.A., Pascale, A.J. and Rodriguez, R.O. (2008) Nueva fórmula para la estimación agroclimática de las horas de frío. Rev. *Facultad de Agronomía*, **28**, 139-144.

[6] Shaltout, A.D. and Unrath, C.R. (1983) Rest Completion Prediction Model for Starkrimson Delicious Apples. *Journal of the American Society for Horticultural Science*, **108**, 957-961.

[7] Yang, Q., Gao, Y., Wu, X., Moriguchi, T., Bai, S. and Teng, Y. (2021) Bud Endodormancy in Deciduous Fruit Trees: Advances and Prospects. *Horticulture Research*, **8**, Article No. 139. https://doi.org/10.1038/s41438-021-00575-2

[8] Cornelissen, S., Hefer, C.A., Rees, D.J.G. and Burger, J.T. (2020) Defining the QTL Associated with Chill Requirement during Endodormancy in *Malus* × *domestica*

Borkh. *Euphytica*, **216**, Article No. 122. https://doi.org/10.1007/s10681-020-02645-3

[9] Medina, G.G., Ruiz, C.J.A., Ramírez, L.M.R. and Díaz, P.G. (2011) Effect of Climate Change in the Cold Accumulation in the Apple Producing Region of Chihuahua. *Revista Mexicana de Ciencias Agrícolas*, **2**, 195-207.

[10] Denardi, F., Kvitschal, M.V. and Hawerroth, M.C. (2019) A Brief History of the Forty-Five Years of the Epagri Apple Breeding Program in Brazil. *Crop Breeding and Applied Biotechnology*, **19**, 347-355. https://doi.org/10.1590/1984-70332019v19n3p47

[11] Kwon, J.H., Nam, E.Y., Yun, S.K., Kim, S.J., Song, S.Y., Lee, J.H. and Hwang, K.D. (2020) Chilling and Heat Requirement of Peach Cultivars and Changes in Chilling Accumulation Spectrums Based on 100-Year Records in Republic of Korea. *Agricultural and Forest Meteorology*, **288-289**, Article ID: 108009. https://doi.org/10.1016/j.agrformet.2020.108009

[12] Atkinson, C.J., Brennan, R.M. and Jones, H.G. (2013) Declining Chilling and Its Impact on Temperate Perennial Crops. *Environmental and Experimental Botany*, **91**, 48-62. https://doi.org/10.1016/j.envexpbot.2013.02.004

[13] Malagi, G. (2015) The Comparison of Dormancy Dynamics in Apple Trees Grown under Temperate and Mild Winter Climates Imposes a Renewal of Classical Approaches. *Trees—Structure and Function*, **29**, 1365-1380. https://doi.org/10.1007/s00468-015-1214-3

[14] Diggle, P.K. and Mulder, C.P.H. (2019) Diverse Developmental Responses to Warming Temperatures Underlie Changes in Flowering Phenologies. *Integrative and Comparative Biology*, **59**, 559-570. https://doi.org/10.1093/icb/icz076

[15] Fadón, E., Fernandez, E., Behn, H. and Luedeling, E. (2020) A Conceptual Framework for Winter Dormancy in Deciduous Trees. *Agronomy*, **10**, Article No. 241. https://doi.org/10.3390/agronomy10020241

[16] You, Q.L., Ren, G.Y., Zhang, Y.Q., Ren, Y.Y., Sun, X.B. and Zhan, Y.J. (2017) An Overview of Studies of Observed Climate Change in the Hindu Kush Himalayan (HKH) Region. *Advances in Climate Change Research*, **8**, 141-147. https://doi.org/10.1016/j.accre.2017.04.001

[17] Chand, H., Verma, S.C., Bhardwaj, S.K., Sharma, S.D., Mahajan, P.K. and Sharma, R. (2016) Effect of Changing Climatic Conditions on Chill Units Accumulation and Productivity of Apple in Mid Hill Sub Humid Zone of Western Himalayas, India. *Current World Environment*, **11**, 142-149. https://doi.org/10.12944/CWE.11.1.18

[18] Mahfoud, C. and Adjizian-Gerard, J. (2022) Mapping Apple Trees Future Land Use Potential as a Means of Climate Change Adaptation in East-Mediterranean Mountains: Mount-Lebanon. *Journal of Mountain Area Research*, **7**, 1-13. https://doi.org/10.53874/jmar.v7i0.145

[19] Medina-García, G., Grageda-Grageda, J., Ruiz-Corral, J.A., Casas-Flores, J.I., Rodríguez-Moreno, V.M. and De la Mora-Orozco, C. (2019) Cold Hours Decrease as a Result of Climate Change in Mexico. *Revista Mexicana de Ciencias Agrícolas*, **10**, 1325-1337. https://doi.org/10.29312/remexca.v10i6.1688

[20] Kishore, D.K., Pramanick, K.K., Singh, A.K., Singh, R. and Verma, J.K. (2015) Chilling Unit Accumulation at Shimla, Himachal Pradesh, India—A Predominantly Apple (*Malus* × *domestica* Borkh) Growing Region. *International Journal of Fruit Science*, **15**, 117-128. https://doi.org/10.1080/15538362.2014.931171

[21] North, M.S., K. De Kock, K. and Booyse, M. (2014) Rest Breaking Agents and Application Date Affect Bud Break but Not Yield of Granny Smith and Royal Gala Apple. *Acta Horticulturae*, **1058**, 639-644.

https://doi.org/10.17660/ActaHortic.2014.1058.83

[22] Duarte-Marques, L.O., Mello-Farias, P., Dos Santos, R.F., Martins, C.R., Konzen, L.H. and Malgarim, M.B. (2021) Alternative Budburst Inducers for Kiwifruit Vines Grown in an Organic System. *Revista Brasileira de Fruticultura*, **43**, 1-8. https://doi.org/10.1590/0100-29452021313

[23] Rimpika, S. and Ajender, D.P. (2021) Vulnerability of Temperate Fruit Production to Climate Change: Adaptation and Mitigation Measures: A Review. *Agricultural Reviews*, **42**, 190-196. https://doi.org/10.18805/ag.R-2016

[24] Glenn, D.M. (2012) The Mechanisms of Plant Stress Mitigation by Kaolin-Based Particle Films and Applications in Horticultural and Agricultural Crops. *HortScience*, **47**, 710-711. https://doi.org/10.21273/HORTSCI.47.6.710

[25] Durner, E.F. and Gianfagna, T.J. (1990) Peach Pistil Growth Inhibition and Subsequent Bloom Delay by Midwinter Bud Whitewashing. *HortScience*, **25**, 1222-1224. https://doi.org/10.21273/HORTSCI.25.10.1222

[26] García-Pérez, E.R., Nieto, A. and Boris, M.W. (1989) Efecto de la radiación solar en la temperatura de árboles de nogal pecanero y su relación con la brotación. *Revista Chapingo*, **62-63**, 137-143.

[27] Glenn, D.M., Puterka, G.J., Drake, S., Unruh, T.R., Knigth, A.L., Baherle, P., Prado, E. and Baugher, T. (2001) Particle Film Application Influences Apple Leaf Physiology, Fruit Yield, and Fruit Quality. *Journal of the American Society for Horticultural Science*, **126**, 175-181. https://doi.org/10.21273/JASHS.126.2.175

[28] Jifon, J.L. and Syvertsen, J.P. (2003) Kaolin Particle Film Applications Can Increase Photosynthesis and Water Use Efficiency of "Ruby Red" Grapefruit Leaves. *Journal of the American Society for Horticultural Science*, **128**, 107-112. https://doi.org/10.21273/JASHS.128.1.0107

[29] Comision Nacional Del Agua (CNA) (2015) Subdireccion General Técnica. Gerencia de Aguas Subterráneas. Subgerencia de Evaluación y Ordenamiento de Acuíferos. México. 30 p.

[30] Erez, A. and Lavee, S. (1971) The Effect of Climatic Conditions on Dormancy Development of Peach Buds Temperature. *Journal of the American Society for Horticultural Science*, **96**, 711-714.

[31] Hernández-Herrera, A., Zermeño-González, A., Rodríguez-García, R. and Jasso-Cantú, D. (2006) Benefits of Total Whitewashing of Apple (*Malus domestica* borkh) Trees in the Sierra de Arteaga, Coahuila, México. *Agrociencia*, **40**, 577-584.

[32] Hellmuth, M., Ferree, D.C. and Schupp, J.R. (1988) Effects of White Paint on Trunks of Greenhouse-Grown Apple Trees. Research Circular, Ohio Agricultural Research and Development Center, Wooster, No. 295, 17-19.

[33] Coutanceaou, M. (1971) Fruticultura técnica y económica de los cultivos de rosáceas leñosas productoras de fruta. Edit. Oikos-taw, Barcelona, 139-140.

[34] Grokhol-Skill, V.V. and Solov-Eva, M.A. (1992) Protection of Trunks of Fruit Trees from Damage by Sunscald and Frost. *Sadovodstvo-I-Vinogradarstvo*, **11-12**, 5-7.

[35] Rosati, A., Metcalf, S., Buchner, R., Fulton, A. and Lampinen, B. (2006) Physiological Effects of Kaolin Applications in Well Irrigated and Water Stressed Walnut and Almond Trees. *Annals of Botany*, **98**, 267-275. https://doi.org/10.1093/aob/mcl100

[36] Cantore, V., Pace, B. and Albriziob, R. (2009) Kaolin-Based Particle Film Technology Affects Tomato Physiology, Yield and Quality. *Environmental and Experimental Botany*, **66**, 279-288. https://doi.org/10.1016/j.envexpbot.2009.03.008

[37] Feitosa Araújo, A.L. and De Britto, D. (2020) Rapid Protocol to Evaluate the

Photoprotective Effect of Film-Forming Formulations on Mangoes. *Revista Brasileira de Fruticultura*, **43**, Article ID: 118. https://doi.org/10.1590/0100-29452021118

[38] Zermeño-Gonzalez, A., Gil-Marín, J.A., Ramirez-Rodriguez, H., Hernandez-Herrera, A., Rodríguez-Garcia, A., Benavides-Mendoza, A., Jasso-Cantú, D. and Murgia-Lopez, J. (2008) Whitewashed of the Fruit in the Organic Production of Apple: Impact on the Russeting of the Fruit. *Tropical and Subtropical Agroecosystems*, **8**, 171-179.

[39] Glenn, D.M., Erez, A., Puterka, G.J. and Gundrum, P. (2003) Particle Film Affect Carbon Assimilation and Yield in "Empire" Apple. *Journal of the American Society for Horticultural Science*, **128**, 356-362. https://doi.org/10.21273/JASHS.128.3.0356