Quantitative and Qualitative Impacts of Windfall on Almond Yield and Quality

Project No.: **HORT40.Brown**

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A. Summary

By 2025, the California almond community commits to reduce dust during almond harvest by 50%. One option is to transition to alternative off-ground harvest systems like catch-frames. Even though a transition to catch-frames would reduce harvest passes and subsequently dust, there is a potential unknown loss of marketable yield in the form of windfall that would not be picked up if the on-ground harvest is abandoned. Windfall is the premature fall of almonds before harvest, usually due to varietal characteristics or weather conditions and mechanical knocking by machine passes through the orchard. Windfall is a relevant concern for alternative off-ground harvesting systems that mitigate dust because windfallen nuts may never be harvested. Additionally, windfall is a concern for current harvest systems since windfallen nuts that lie on the orchard floor for extended periods might disproportionately affect crop quality, food quality, and food safety of the resultant harvested nuts. Therefore, the research was undertaken to 1) quantify the magnitude of windfall and 2) determine the impact of windfall on nut quality.

Our quantitative data comes from 26 and 24 orchards surveyed in 2019 and 2020, respectively. In both years, we observed the factors that impact windfall of almonds are excessive fruit drying and machine knockdown, especially in later varieties. The majority of sites showed less than 1% fruit drop at harvest. Nonpareil orchards had the lowest fruit drop of all cultivars surveyed in both years, typically less than 0.8%. Wood Colony and Monterrey had the highest fruit drop in both years, but Monterrey had the most consistent drop while Wood Colony was more sporadic. In 2020, several orchards delayed harvest of late-maturing fruit until well after 100% hull split, this resulted in the increased windfall from both mechanical practices in the orchard, normal fruit

drop, and storm wind events occurred all of which increased windfall observed in 2020. Overall, these results indicate that windfall is most commonly an insignificant problem; however, large windfall events can occur under specific conditions. The greatest threat for windfall is seen with late harvest cultivars especially if nuts are held on the tree for an extended period post full hull split or exposed to prolonged periods of low soil moisture.

The quality of windfallen almond fruits was determined in 2019 and 2020 seasons by incubating them on the ground at three maturity levels corresponding to 5% hull split (mid-July or T4 = 4 weeks pre-harvest until T0), 50% hull split (early-August or T2=2 weeks pre-harvest until T0) and harvest at 95% hull split (mid-August or T0 = nuts at regular grower harvest date). Results of nut incubation in Bakersfield and Chico indicate that T4 nuts had higher moisture from 9% to 20% compared to T2 and T0 at 6% and 5%. Free fatty acids (FFA) values were higher following T2 incubation; all FFA values remained greater than minimum industry standards of 1.5%. Peroxide Values (PV) were below the industry standards of 5.0 meq/kg. In general, T4 nuts had higher moisture, darker kernel skin, more severe insect damage from NOW and ants, and greater mold formation compared to T2 and T0. Overall, these results demonstrate that early harvest up to 2 weeks in advance of traditional harvest has no adverse effects on yield or quality, while nuts that remain on the ground for more prolonged periods show more damage and inferior quality compared to those harvested 2 or less weeks before from traditional harvest.

Collectively, the results suggest that windfallen nuts that remain on the orchard floor for greater than three weeks will have lower quality and be more susceptible to insect and fungal damage. Further, results confirm that windfall depends on fruit maturity, with windfall potential increasing significantly once the fruit is fully dry on the tree (100% stage E or greater). Windfall is greater in late-harvested cultivars, likely due to greater fruit maturity, greater knocking by equipment passes, late-season wind events, and/or prolonged water stress.

B. Objectives

This project seeks to identify quantitative and qualitative impacts of windfall and to evaluate the opportunities and challenges of transitioning to off-ground harvest. The overall question is how to estimate both the amount and quality of nuts that prematurely fall prior to harvest. This project was divided into two separate yet integrated sets of objectives, milestones, and deliverables. The first project aims to estimate the quantitative impact of windfall, and the second project aims to estimate the qualitative impact of windfall.

Quantitative objectives

- Characterize the windfall dynamic and estimate its relative importance in relation to environmental, biological, and management factors

Quantitative milestones

- Observe orchard management factors that may influence windfall
- Estimate significant windfall factors

Quantitative deliverables

- Identify factors that can influence windfall
- Obtain a statewide average of windfall nuts to determine possible yield loss
- Estimate significant regional windfall factors for the Central Valley

Qualitative objectives

- Assess the quality of the windfallen nuts collected from two regions of the Central Valley
- Determine environmental conditions that affect nut quality of windfallen nuts

Qualitative milestones

- Analyze windfallen nuts for quality characteristics
- Estimate the loss of yield and quality from windfall
- Determine the potential yield and value loss due to windfall

Qualitative deliverables

- A nut quality comparison frame of windfallen nuts
- Estimate an incubation time by variety and region under specific management practices.

C. Annual Results and Discussion

This project seeks to identify windfall impacts in order to evaluate the opportunities and challenges of off-ground harvest. In 2019, quantitative windfall assessments were conducted on 30 orchards in all prominent almond growing regions with data collection of two or more varieties at 20 of the orchards. Preliminary analysis shows windfall from zero to 1% of total yield, with most sites showing less than 0.8%. Windfall at four or more weeks before harvest showed very poor quality characteristics. The quality and size of kernels were not compromised at two to four weeks before harvest. Qualitative and quantitative differences between windfall and nuts at harvest will influence the overall economic impact from the adoption of off-ground harvest.

Quantitative Results

In 2019 fruit drop was almost non-existent for large parts of the season in most of the cultivars. The highest windfall recorded in one location was 13.6% in Wood Colony with the majority showing less than 0.8% drop. Low to no windfall was typical in the Nonpareil cultivar. Harvest in orchards surveyed took place from August 14th to October 5th in 2019. The majority of the Nonpareil orchards were shaken by September 4th. In 2020, the largest windfall drop recorded was 28.4% in a Wood Colony orchard, with most sites showing less than 2% drop. Harvest 2020 took place from August 25th to October 25th with most Nonpareil shaken by September 15th.

Figures 1 and 2 show the total number of orchards that fell into the designated range of percentage windfall out of total harvest. In 2019, there were 18 orchards with a windfall percentage between 0 to 3% with windfall less than 0.8% in majority of orchards. Nonpareil orchards had the lowest windfall in 2019 and 2020, with maximum windfall of 2.3% in 2019 while in 2020 the maximum Nonpareil windfall of 6 to 8% was observed in one orchard. Figure 2 is a breakdown of all the cultivars surveyed, where we can see that Monterrey and Wood Colony are the two varieties with the highest windfall percentage. 2020 was more challenging as many orchards retained fruit in the tree until well after 100% hull split. At the same time, heavier storm wind events occurred with more frequency in 2020 compared to 2019. Excess fruit drying and machine knocking are the two leading causes of fruit drop, especially in later varieties.

Qualitative Results

Aflatoxin

In 2019, the Aflatoxin tests for composite samples of all treatments were ordered at the IEH-JL Analytical lab in Modesto. Using the AOAC 991.31 protocol, the lab measured the Aflatoxin B1, B2, G1, and G2. The total aflatoxin detected was 0.4 ppb for each treatment and was not affected by the time of windfall or nut maturity. Our experiment's total aflatoxin levels were 0.4 ppb, which is lower than the lowest allowable limits for aflatoxin contamination on almonds set currently at 10 ppb by the European Union (EU). The aflatoxin test was not repeated the second year.

Moisture

Moisture analysis in Bakersfield and Chico as summarized in figure 4 shows moisture percentages gradually decreasing from T4 (4 weeks before harvest) compared to T0 (nuts at harvest) within each year 2019 and 2020. The nuts from the Bakersfield had overall higher moisture values than those in Chico, but as we approached harvest, all the values hover around 6%, which is the industry's recommended standard for collecting the nuts from the orchards.

Kernel Weight

The distribution of Kernel weight across all the treatment is summarized in figure 5. We observed that the kernels weighed more at 4 weeks (T4) incubation then gradually decreased to about one gram at harvest (T0). This trend consistently shows that kernel weight decreased as they lose their moisture until they reach 6% near harvest time.

Free Fatty Acids (FFA)

The percentages of free fatty acids (FFA) were measured for each individual repetition of each treatment and summarized in figure 6. Later we will discuss the implications to nut quality. We observed significant FFA differences between both sites and treatments ($p<0.001$). The year-to-year variability was not significant ($p\geq 0.05$). FFA percentages were on average higher than the industry standard (1.5% FFA) in Bakersfield at T4 and particularly T2, while all samples and dates were below that threshold in Chico. This could be due to higher lipase activity under higher moisture and temperature conditions observed in early harvest fruit in Bakersfield. Almond kernels contain about 50% fat, mainly as unsaturated fatty acids. Oleic and linoleic fatty acids represent 91 to 94 % of the total oil content. These fatty acids can react with oxygen, and this could cause quality problems during storage, particularly in processed almonds. Higher FFA values are often associated with lower shelf life during storage. This may suggest that the high moisture conditions in nuts from the Bakersfield site at T4 and T2 could be problematic depending upon ultimate nut use. Further research is needed to determine the cause of this response and its impact on early harvest practices.

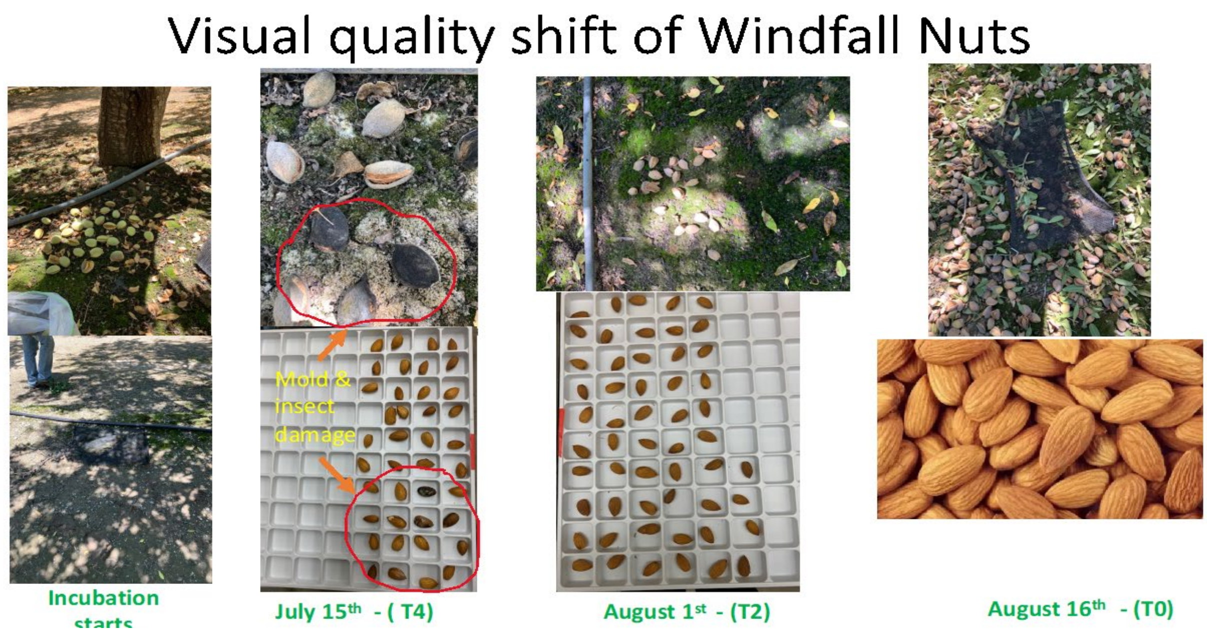
Peroxide Values (PV)

Figure 7 shows the Peroxide values (meq/ kg) were obtained for each repetition of each treatment. There were significant differences between sites and treatment, but the overall PV values were very low compared to the industry standard (<5.0 meq/kg).

Kernel Color

The Nonpareil kernel has a highly desirable distinctive light brown color. To determine if this color is affected by the pre-harvest incubation periods, we measured luminosity, chroma, and hue measurements of kernel pellicles using a Minolta Chroma Meter CR-200 equipped with an 8mm aperture (Minolta Corp., Ramsey, NJ). Luminosity (L) ranges from 0 (black reflectance) to 100 (white reflectance). Chroma (C) and hue (H) are derived from solid color axis a (purplish-red to bluish-green) and b (yellow to blue).

The ANOVA response tables 1-3 indicate significant differences between treatments for all the kernel color parameters analyzed were observed (luminosity, chroma, and hue). The difference between sites (Bakersfield and Chico) was detected for luminosity (L) and hue (H), but not for chroma (C). The interaction plots for L, C, and H show that T4 nuts were on average of darker brown skin since they scored below 50 followed by T2 nuts with a score of 51, and finally, the T0 nuts had a light brown skin with an average score above 55.



External Quality Parameters
A panel of three student assistants was trained before grading external quality parameters and almond nut integrity. The following data were collected and are being analyzed: almond fruit whole weight, presence of mold on the hull, presence of mold on the kernel, and signs of insect damage on the kernel. The result indicates more insect damage (NOW or ants) at T4 and T0 primarily due to injury caused by harvest machinery than at T2.

D. Outreach Activities

In 2019, we presented at the 2019 Almond Conference posters session. We also participated in a UC Davis poster competition as well as the GradSlam presentation. In 2020, we did not conduct outreach activities due to the COVID restrictions.

E. Materials and Methods:

Quantitative project approach
Our research team selected multiple regions in the Central Valley were selected for windfall monitoring by our research team and in cooperation with other UC and industry partners. We selected several orchards across the Central Valley region to maximize the number of cultivars, tree age, and management combinations. We worked at the multiple UCCE farm advisor managed variety trials. We enrolled and surveyed 50 orchards in 2019 and 35 in 2020, but our data is represented from 26 orchards in 2019 and 24 in 2020. Most of the surveyed orchards

had 3 cultivars. Each cultivar had 3 replicates per orchard (trees), which in turn had 6 data collection points totaling 1,404 and 1,296 data collection points in 2019 and 2020, respectively.

Each data collection point was marked with GPS, and a unique barcode was assigned to it. This barcode was placed at the center of each data collection point. Commencing at 60% hull split of each variety and using an HD camera, we took an image of an area covering a 1 m^2 using each barcode as the center point of each image (see Figure 3A-C). Each fruit in each of the 6 images per tree was counted by hand and averaged. This average was then multiplied by the area of the tree, which was calculated using the tree spacing of each tree as if they were squares. This resulted in average windfall per tree. We collected about 3,000 fruits from each cultivar and dry-weighted them to calculate each cultivar's average dry fruit weight. This average dry fruit weight was multiplied by the average fruit fallen/tree to calculate the total fruit weight loss per tree.

We then used the tree and row spacing to calculate the trees per acre in each orchard. This number was multiplied by the total fruit weight loss/tree to calculate fruit weight loss per acre, which was then converted into pounds per acre. We calculated grower total fruit yield per acre by multiplying the grower total kernel yield times the industry crackout ratios per variety (0.22-0.27). Percentage windfall was the ratio of fruit weight over grower total fruit yield per acre.

Qualitative project approach
Using a randomized complete block design (RCBD), two sites were selected in Bakersfield and Chico. The orchard age was 12 years and both orchards used a microsprinkler irrigation system, which creates a uniform irrigated zone around the tree where nuts fall before regular harvest. Each 12 year old orchard with predominantly 'Nonpareil' was considered as a fixed effect in the experimental design. Each orchard received three timing treatments, where almond fruit was placed on the ground at 4, 2, and 0 weeks before harvest. In each orchard, we deployed 6 repetitions of the randomized treatments. Inside each treatment raw, we used 4 different trees receiving every 30 nuts as pseudoreplications. Since good windfall did not occur as desired, we simulated windfall by shaking tree branches and collecting uniform split nuts. The 30 nuts collected for each tree were placed under a thin translucent mesh and left on the ground to incubate up until harvest and then picked up to assess for moisture content, peroxide values, kernel weight, and color, insect damage and mold formation, free fatty acid composition, total mass, and changes in USDA grading scale. An ANOVA statistical model was used to explore differences between sites, timing treatments, and potential interactions.

We used the following analysis protocols with the IEH-JL Analytical Lab in Modesto:
- Moisture: AOAC 925.40 protocol in a vacuum oven
- Free Fatty Acids (FFA): AOCS Ca 5a-40 protocol for both 2019 and 2020.
- Peroxide Value (PV): AOCS Cd 8-53 protocol

F. Publications that emerged from this work

Poster presentation for the ABC conference (December of 2019)

Tables and Figures

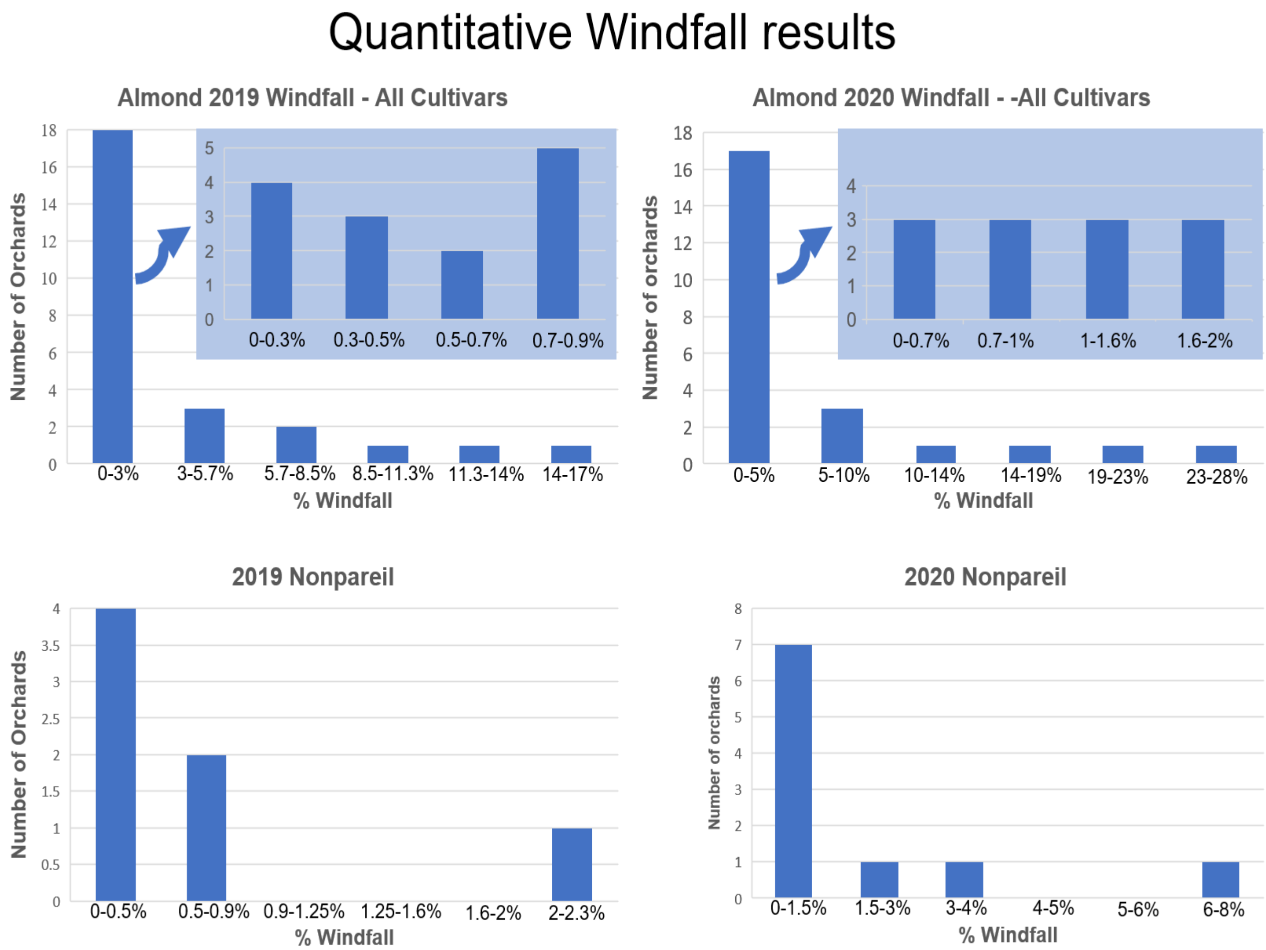


Figure 1. Percent windfall for all cultivars surveyed (top panel) and Nonpareil (bottom panel) in 2019 and 2020. Each bar represents the number of orchards (y-axis) found with corresponding windfall percent (x-axis) in that particular year. Only the first bar in top panels was zoomed out to depict most sites showing less than 1% windfall in 2019 and less than 2% in 2020.

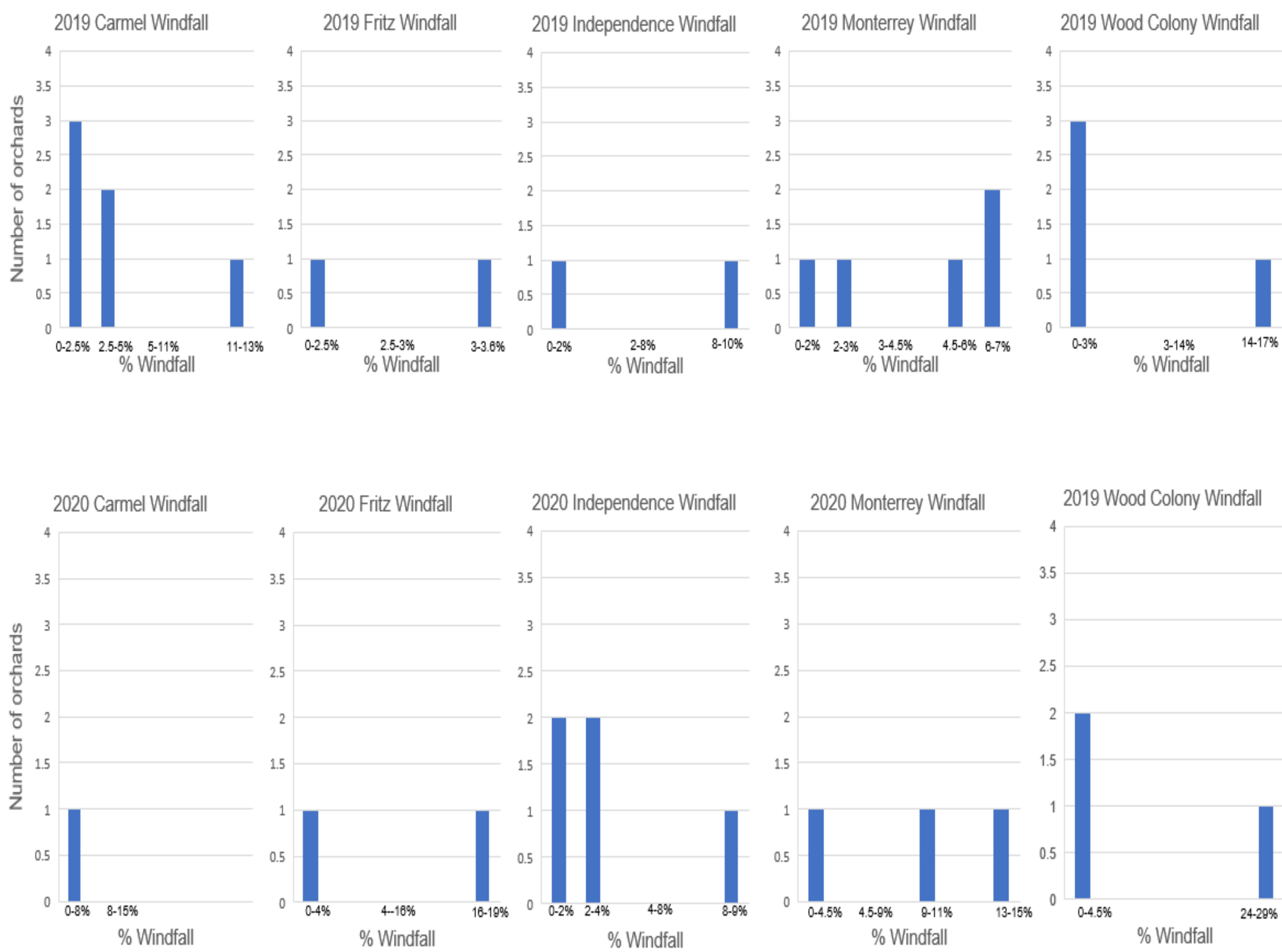


Figure 2. Percent windfall by cultivar in 2019 (top panel) and 2020 (bottom panel). Each bar represents the number of orchards (y-axis) found with corresponding windfall percent (x-axis) in that particular year.

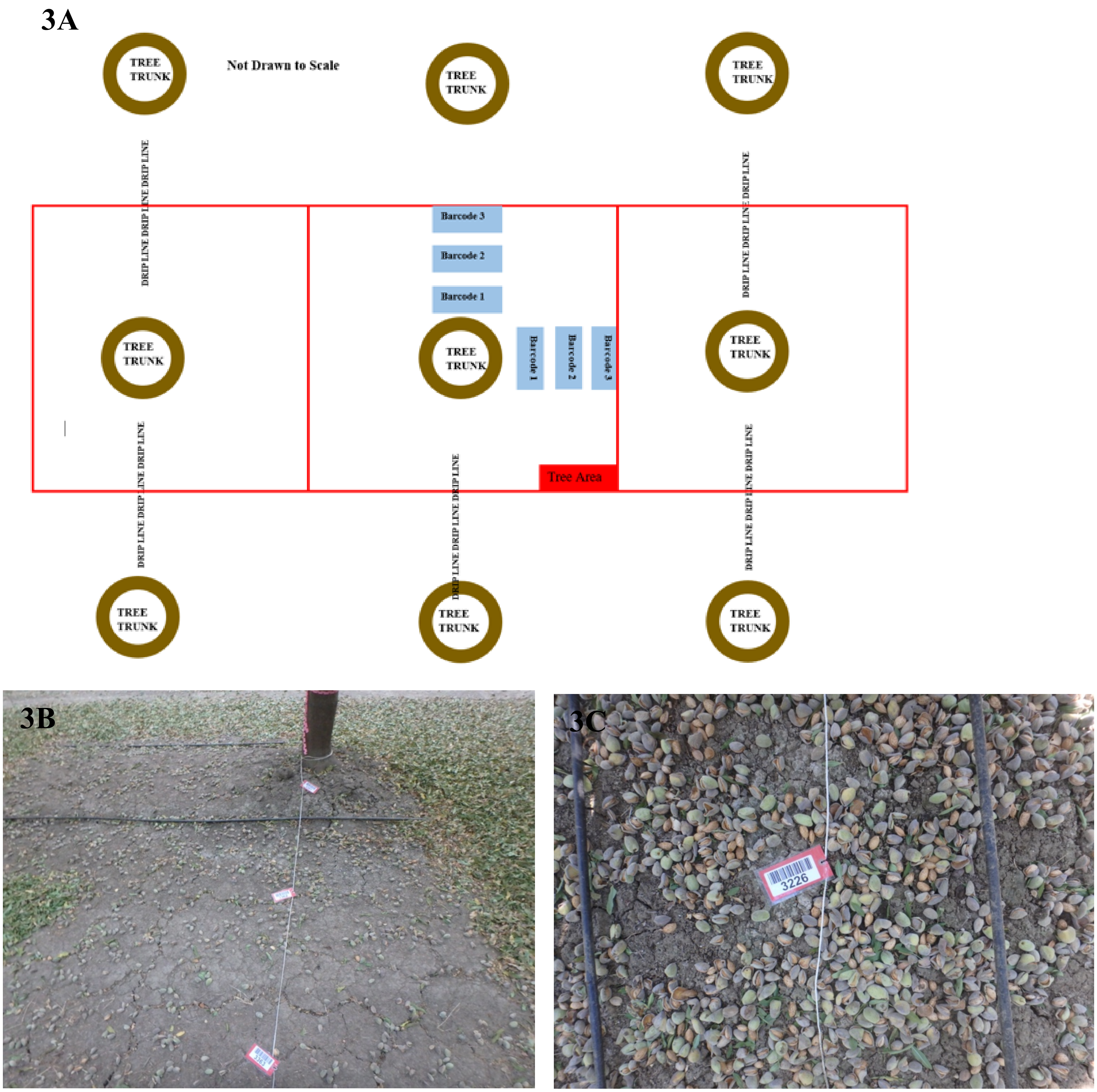
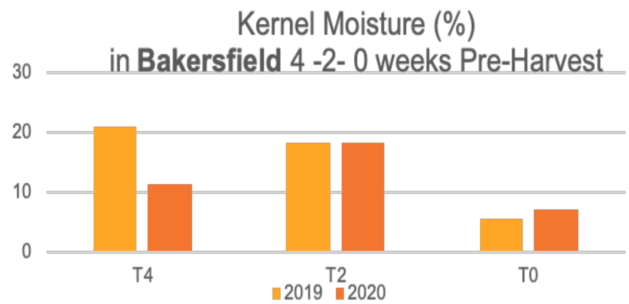


Figure 3. A) Aerial view of our 6 data collection points diagram for each selected tree. Three images were taken along the row (0°), and three were taken across the row (90°). B) View of some of the actual barcodes used under the tree canopy to be pictured across the row (90°). Each barcode is 1 meter apart from the other, and each barcode has a unique number for data tracking purposes. C) Aerial view of one data collection point after the shake. Each data collection point had an assigned barcode that served as the center of each image collected. Each image represents about 1 meter square under the tree canopy.



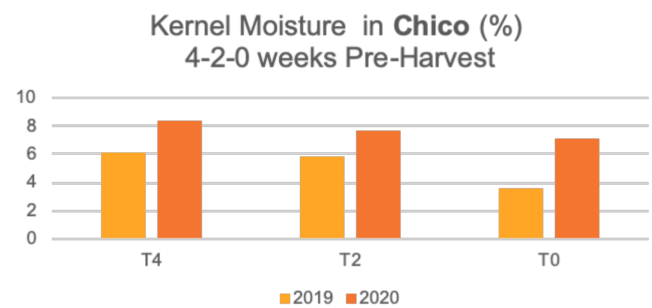


Figure 4. Kernel Moisture of windfall nuts was measured for Bakersfield (left graph) and Chico (graph on the right) for the harvest seasons of 2019-2020. We observed that nuts with more extended residence on the orchard floor (T4 and T2) had higher moisture than the regularly harvested nuts (T0).

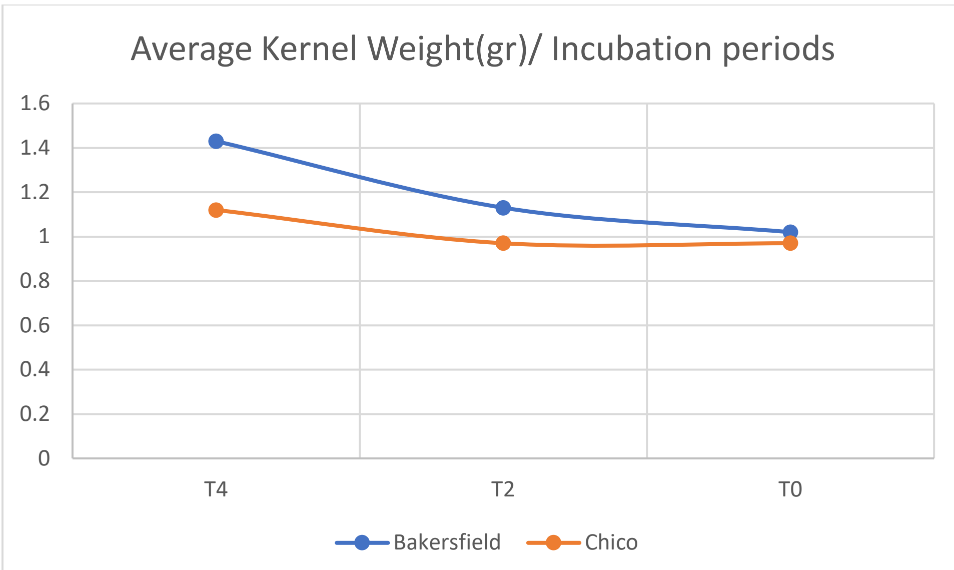


Figure 5. Average Kernel weight was averaged across the incubation experiment without pre-drying the nuts. The results indicate that T4 weighted higher than T2, which weighed more than regularly harvested nuts T0. This result is congruent with the loss of moisture.

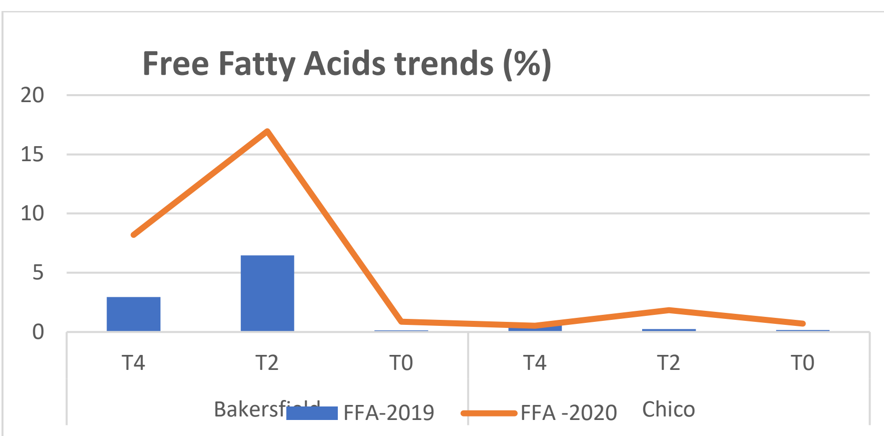


Figure 6. Free Fatty Acids percentage averages were obtained for each treatment in 2019 and 2020, both in Bakersfield and Chico. T2 nuts showed a bump across the board.

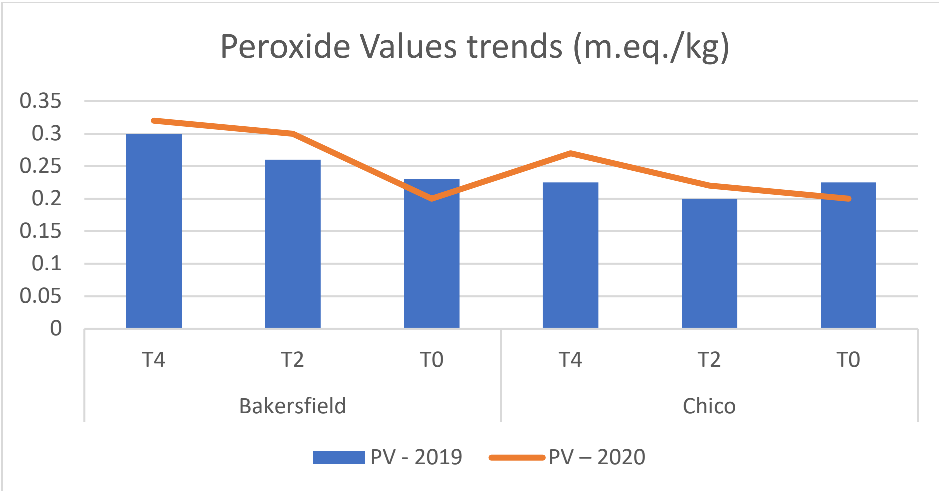


Figure 7. Average peroxide values by treatment in Bakersfield and Chico in 2019 and 2020. The trend showed a slight decrease as we approached regular harvest (T0).

Table 1. ANOVA response for Kernel Color Luminosity (L), Chroma (C) and Hue (H).

Luminosity(L)	Df	Sum Sq	Mean Sq	F Value	Pr(>F)
Site	1	903.4	903.36	52.9851	1.064e-12***
Treatment	2	1964.5	982.25	57.612	< 2.2e-16 ***
Residuals	597	10178.4	17.05		
Sig. codes	0 '***'	0.001'**'	0.01'*'	0.05 '.'	0.1 ' ' 1

Chroma (C*)	Df	Sum Sq	Mean Sq	F Value	Pr(>F)
Site	1	0.9	0.92	0.0607	0.8055
Treatment	2	1793.5	896.74	59.0829	< 2.2e-16 ***
Residuals	597	9061.1	15.18		
Sig. codes	0 '***'	0.001'**'	0.01'*'	0.05 '.'	0.1 ' ' 1

Hue (H)	Df	Sum Sq	Mean Sq	F Value	Pr(>F)
Site	1	1852.7	1852.65	116.304	< 2.2e-16 ***
Treatment	2	881.1	440.54	27.655	3.263e-12 ***
Residuals	597	10178.4	17.05		
Sig. codes	0 '***'	0.001'**'	0.01'*'	0.05 '.'	0.1 ' ' 1