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Qualitative Assessment of Windfall Almond (Prunus dulcis) in California

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Qualitative Assessment of Windfall Almonds (Prunus dulcis) in California.

By
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Abstract

This thesis assesses the quality of windfall almonds (Prunus dulcis (Mill.) D. A. Webb) in alignment with the goal of the California almond community to halve dust emissions during almond harvest by 2025. Windfall is the premature fall of almonds before harvest, usually due to varietal characteristics or weather conditions and mechanical knocking by machines passing through the orchard. One option is to transition to alternative off-ground harvest systems like catch-frames. The transition poses 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. Additionally, the 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.

The first chapter reviews the literature regarding current and future trends of almond production in California and almond quality parameters. The second chapter describes the quality of windfallen Nonpareil almond fruits as determined in the 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). T4 fruits had overall poor quality with higher moisture (from 9% to 20%) than T2 and T0 (6% and 5%, respectively), a higher percentage of insect-damaged fruits (17.5 % for Bakersfield and 13.3% for Chico), a higher count of very molded fruits which was associated with a darker kernel skin reading on the Minolta colorimeter. Fresh kernel weight slightly decreased from T4 (1.4 to 1.1 g) and stabilized at harvest T0 (~1.0 g). For reasons that remain unclear, free fatty acids (FFA) values were significantly higher than the industry standard and the other reported

percentage values for the fruits incubated for 2 weeks in Bakersfield than at T4 or T0. Generally, FFA values remained greater than the minimum industry standard of 1.5%. Peroxide Values (P.V.) were below the industry maximum standards (< 5.0 meq/kg) across the treatments. In general, T4 nuts had higher moisture, darker kernel skin, more significant insect damage, and greater mold formation than T2 and T0 while T2 fruits were comparable in quality to regularly harvested fruits (T0). Hence, a slightly early harvest (T2) to optimize off-ground practices does not represent a loss of fruit quality. T4 fruits at harvest were of lower quality; further T4 fruits that remain on the ground for an extended time are of low quality with more significant insect damage and inferior quality than those harvested two weeks from traditional harvest. In traditional harvest T4 and older nuts will be collected, windrowed, and processed with newly shaken nuts, further study is needed to understand how the mixing of T4 with the newly shaken nuts would affect the overall quality of harvested nuts during post-harvest handling phases.

Collectively, the results suggest that windfallen nuts that remain on the orchard floor for greater than two weeks have lower quality and are more susceptible to insects and fungal damage.

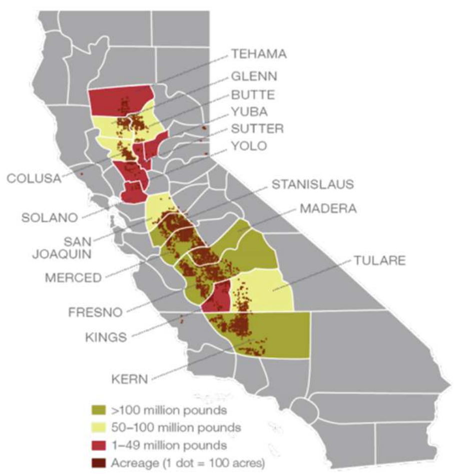
Chapter 1: Literature Review

Overview of Almond Production in California

California has one of the most productive agricultural sectors in the entire world. The variety of crops includes more than 400 commodities, which account for over a third of the country's vegetable production and nearly two-thirds of its fruits and nuts. (Pathak et al., 2018) Almonds [Prunus dulcis (Mill.) D. A. Webb], represents the most widely planted tree crop in California. Almonds are almost entirely grown in the Central Valley, stretching 400 miles between Bakersfield and Red Bluff. In 2016, the agricultural establishments employed 405,400 people and paid a total wage of 13.7 billion(Philip et al.,2019). The mild climate, rich soil, abundant sunshine, and water supply make for ideal growing conditions (Micke & Kester, 1998). However, the California almond industry is faced with sustainability challenges in water use efficiency, optimization of orchard outputs, integrated pest management (IPM), and air quality pollution during harvest operations. In the current on-ground harvesting approach, 75% of dust associated with the harvest is generated primarily during the sweeping and pickup stages. (*California Almonds: 4 Goals to Improve Sustainability by 2025 – AgFax*, n.d.). Fine particles, called $PM_{2.5}$, are more dangerous because they can get into the deep parts of your lungs-or even into your blood (CDC,2019). For these reasons, the California almond community aims to halve dust emissions during almond harvest by 2025 by introducing new equipment and an off-ground approach with a catch frame, a method used in other almond-producing countries such as Australia, Spain, and Israel (Almond Board of California, 2019). One issue associated with the off-ground harvest is windfall - premature fruits that fall to the ground before harvest time.

Windfall fruits would typically be incorporated into on-ground harvest, but almond growers would forego this portion of yield during off-ground harvest the marketability and quality of windfall fruits is however unknown. This study was initiated to uncover the effects of windfall duration on almond fruit quality.

Our overarching hypothesis is that almond fruit quality, as determined by the chemical attributes (kernel moisture content, Free Fatty Acids (FFA) and Peroxide Value (PV) content, Aflatoxin content) and physical attributes (mold formation, insect damage, kernel color) will be diminished with the increasing duration of windfall. The longer the windfall duration, the more significant the exposure period of moisture from irrigation, insects, and mold, resulting in poorer quality characteristics than almond fruits at harvest.



Note. Fresno, Kern, Madera, Merced, and Stanislaus counties accounted for 73% of the total bearing acreage. (*California Almond Production Counties - Google Search*, n.d.)

Figure 1.1: CA Almond production by county

The almond tree was introduced to California from Spain in the mid-1700s by the Franciscan Padres. The initial phase of almond dissemination to the "New World" followed early colonization by European and Asian settlers. Successful cultivation typically occurred only after a series of failures as early settlers, not recognizing the almond's tolerance of winter cold, spring frost, and summer rains, tested different growing regions and germplasm until a suitable combination was found (Wood, 1925). The moist, cool weather of the coastal missions did not provide optimum growing conditions in the coastal zones. It was not until the following century that almond trees were successfully planted inland. By the 1870s, research and crossbreeding had developed several of today's prominent almond varieties. By the turn of the 20th century, the almond industry was firmly established in the Sacramento and San Joaquin areas of California's great Central Valley. California Almond production grew from 370 million pounds in 1995 to a record 3.1 billion pounds in 2020 (Figure 1.1), consistently accounting for nearly 80% of the global output (USDA/NASS,2020). The exponential growth is attributable to the steady increase in almond acreage and the per-acre yield gains. California's 2020 almond acreage is estimated at 1,600,000 acres, 5.3% higher than the 2019 acreage of 1,520,000. Of the total acreage for 2020, 1,250,000 acres were bearing, 5.9% above 2019, and 350,000 acres were non-bearing, up 2.9% from 2019. Preliminary bearing acreage for 2021 is estimated at 1,330,000 acres (USDA/NASS, 2020).

The continuous expansion of the almond industry raises sustainability challenges for almond growers. The Almond Board of California addressed these pressing challenges through its California Almond Sustainability Program (CASP) and outlined the strategic sustainability goals in a document known as the Almond Orchards 2025 Goals, articulated around four priority areas: water efficiency, zero waste, pest management, and air quality (Almond Board of California, 2019). This study will focus on the challenges of current harvest practices in connection with almond quality.

Almond harvest changed significantly in the 1960s and 70s with the advent and extensive adoption of mechanized harvest equipment. Before that, almonds were harvested by hand, with employees using mallets, poles, rakes, and tarps to bring in the crop. Manual harvesting required many workers during a short period, an increasing problem due to difficulty finding part-time seasonal workers. Hand harvesting in an irrigated almond orchard represents 30-35% of direct production costs. (Gradziel, T. M. (Ed.). (2017). *Almonds: botany, production and uses*. Cabi.) In contrast, harvest costs for the in-field mechanized operations are 18% of the total production cost. Therefore, harvest mechanization is a time and cost-effective strategy in almond production necessary for its sustainability.

Commercial harvesting in almond (Prunus dulcis (Mill.) D.A. Webb cv. Nonpareil) orchards in California is a highly mechanized and sequential process usually occurring during August for early ripening cultivars through September-October. Before describing the harvest operations, it is essential to review some critical phenological stages of the almond tree upstream of the harvest.

Almond fruit development and maturation

The annual growth cycle of almonds (Figure1.2) is initiated with a dormancy period spanning from October to November or January, depending on the cultivars' chill requirement (Kester et al., 1996). Nonpareil almonds meet their chilling requirements in November and then enter a 'paradormancy' period through mid-December. Spring is marked by an active vegetative growth following vegetative bud bursting, further shoot elongation, and trunk expansion, causing an increase in tree volume. Shoots make up most of the structure of the tree canopy and give rise to future spurs. Spurs are shorter vegetative growth components that arise from shoots or other spurs. They are responsible for most of the almond yield yearly (Kester et al., 1996). However, they only produce vegetative growth for the first 1-2 years (Goldhamer & Viveros, n.d.).

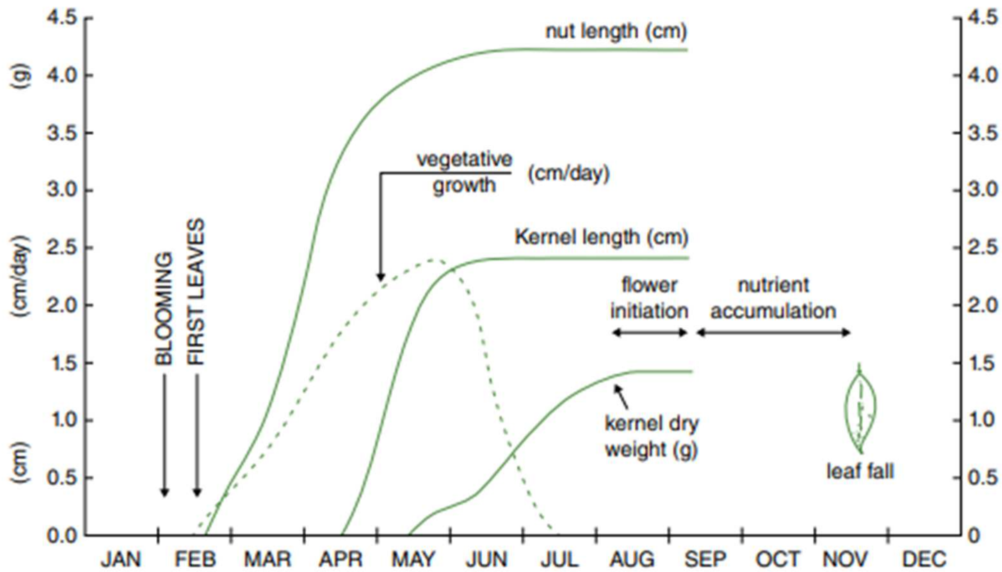


Figure 1.2. The annual growth cycle of Almond. (Modified from Ross and Catlin 1978; Grasselly and Crossa-Raynaud,1980; Felipe, 2000)

After successful vernalization and accumulation of chilling during winter, bud break occurs in mid-February and mid-March. (Martínez-Gómez et al., 2017) . Subsequent warmer temperatures in January and February favor the development of vegetative buds into leaves through March and April (Kester et al., 1996). The vegetative shoot growth and spur elongation initiated at bud break continue throughout the season, and spur extension ends around April or May. The following year's vegetative bud set is complete by April or early May.

Bud differentiation carries on through summer until flower buds' induction in mid-August in California almonds (Kester et al., 1991). Stress during the differentiation and induction process is a crucial determinant of reproductive to vegetative bud expression (Goldhamer & Viveros, n.d.; Esparza et al., 2001). Bud development occurs once flower initiation has been established in the meristem and leads to flower organ formation. This process begins relatively quickly with the differentiation of the different primordia of sepals, petals, stamens, and pistils. This process is prolonged during winter but does not entirely stop and suddenly accelerates at the end of winter, some weeks before blooming ("Almonds: Botany, Production, and Uses," 2017) . Blooming takes place when the petals appear, showing the different elements of the flower, and takes place when the chilling and heat requirements are fulfilled. During this time, bees are brought into orchards to facilitate pollination and ensure a good fruit set (Kester et al., 1991).

Almond fruits consist of a kernel (seed), shell (endocarp), and hull (mesocarp) (Awker & Buttrose, 1980). The almond kernel is the marketable component of the almond fruit, while the shells and hulls are often used as bedding livestock or fed to cows. Fruits are attached to the almond tree by a peduncle. Figure 1.3 shows these different components.

Almond Fruit Anatomy

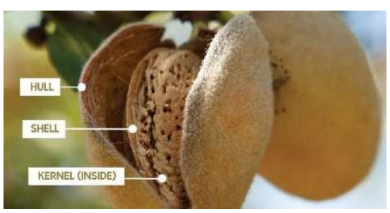
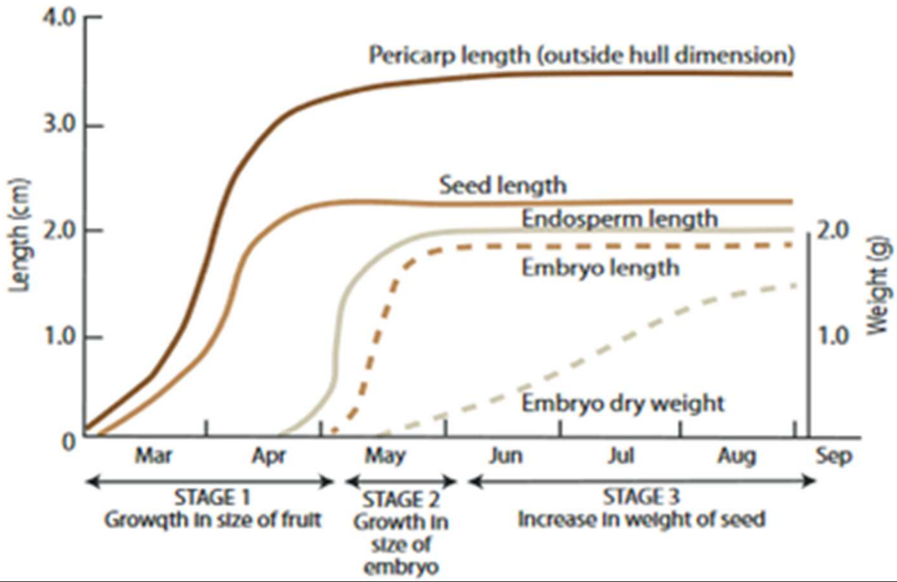


Figure 1.3 Almond Fruit Anatomy

There are three stages of almond fruit growth, as shown in Figure 1.4 (Felipe, 2000.) After pollination, stage 1 of fruit growth begins in the spring and takes approximately 12 weeks from flowering. At the beginning of the endocarp lignification, the embryo occupies a lower position in the tegument and takes up limited space; the endosperm fills the remaining space Gradziel, T. M. (Ed.). (2017). *Almonds: botany, production and uses*. Cabi). Three flower and fruit drop waves occur as the tree sheds unfertilized or otherwise damaged reproductive material (Kester et al., 1996). During the first week of the second stage, without any variable sign of the fruit size, the embryo completes growth until it occupies all the inside the tegument, whereas the endosperm disappears. Stage 2 of fruit growth occurs in early summer and is marked by embryo growth, a rapid kernel filling, and shell hardening. At this stage, water stress negatively affects kernel development and the nutrient status of the tree, mainly if there is nutrient competition among fruits after a high fruit set. An excessive crop reduces the size of the almond kernel (Felipe, 2000). Therefore, adequate irrigation and nutrition are required at this stage to meet the crop developmental demands (Doll & Shackel, 2015). One to two months leading up to harvest, the fruit enters Stage 3 of development, also known as the preharvest stage. At maturity, the mesocarp or hull dries out, provoking the rupture of the suture line, thus leaving the endocarp or shell partially visible. Fruits lose moisture throughout July and August, with the hull split widening and the hull pulling away from the almond shell (Connell et al., n.d.) Some factors, such as excessive drought or diseases, may prevent the mesocarp split despite its dryness. Sticking hulls are a problem for harvest processing as they are challenging to dehull. Fruits ripen first at the top of the tree, then slowly work their way down. Simultaneous ripening is a favorable trait for harvest management. It may be variable among trees of the same cultivar depending on age, nutrient and water status, and crop level ("Almonds: Botany, Production and Uses," 2017) . As the fruits continue to dry, an abscission zone forms between the fruit and the peduncle, weakening the connection between the fruit and the tree, which is beneficial for harvest. Irrigation is essential for hull split induction and abscission layer formation, although moderate levels of water stress during this period do not negatively impact kernel weights (Shackel, 2011; Goldhamer & Viveros, 2000). During this period, the activity of auxin decreases, and that of abscisic acid and ethylene increases. The cementation layer becomes friable at the peduncle, and some cells' cell wall is degraded. Abscission layer forms, spreading to the bordering until reaching the xylem vessels, thus leading to nut drop ("Almonds: Botany, Production, and Uses," 2017). Nut fall before harvest, which is the primary focus of this study, depends on the cultivar and may be a problem when the crop is delayed. Harvest is scheduled as soon as possible to avoid quality losses and minimize fungal attacks and insect infestation (Kester et al., 2003).



Note. The first stage of almond fruit development involves a rapid lengthening of the hull, shell, and seed. In the second stage, the embryo strengthens rapidly. Finally, in the third stage the seed weight increases (Doll & Shackel, 2015)

Fig. 1.4 Growth of the different almond nut components (Felipe, 2000)

Depending on varietal maturity, mechanical harvesting begins in mid-August and lasts through October, following a step-by-step process that must be optimized to ensure ideal fruit quality. The first step is initiated when fruits are knocked on the ground with mechanical shakers, which clamp on individual tree trunks and shake the trees (Reil et al., 1996). In the past, the step was immediately followed by hand polling to knock off fruits not removed by the shakers. Currently, hand polling is less practiced due to labor shortages and the sheer magnitude of harvest operations. Once on the ground, the fruits are allowed to dry for 5-10 days until their moisture content is below 10%. Subsequently, the fruits are swept into windrows, picked up by machines into nut trailers, and transported to the hulling and shelling processing facilities. (Micke & Kester, 1998).

Orchard floor preparation

In California, orchards are grown in valley soils with nearly level terrain, which is amenable to mechanical harvest. Modern harvest practice shakes fruits to the orchard floor, thereby bringing them into intimate contact with the orchard soil surface; this poses the risk of physical contaminants and microbial contamination. The management of the orchard floor is thus of prime importance to ensure optimum quality, minimize contamination, and prevent loss of fruits to weeds or uneven soil surface, which can compromise pick-up. The desired goal is to have a firm, weed-free, smooth orchard floor by the time harvest is scheduled. The most common approach is a no-tillage system with strip weed control in the tree rows. Near harvest, all weeds in both tree row and alleyway are eliminated with a contact herbicide application to accommodate nut drying and mechanical sweeping and pickup of the crop (Gradziel, 2017) Gradziel, T. M. (Ed.). (2017). *Almonds: botany, production and uses*. Cabi)). A study that analyzed nine orchard floor management practices concluded that grass mulch followed by a single glyphosate application was most effective in controlling the weed population and enhancing crop yield and quality (Khokhar et al., 2000).

In rare events, rain may fall during the later harvest months, causing significant rehydration of almonds on the ground. In addition, some almonds that drop prematurely from the trees are wetted with irrigation water. Moisture on fruits can increase disease incidence by creating a favorable environment for the growth of bacteria and fungi, including *Aspergillus flavus* and *Aspergillus parasiticus*, which can produce aflatoxin(Harris & Ferguson, 2013). In addition to the microbiological contamination from bacteria, yeasts, and molds, including Salmonella and E. coli, the presence of fruits on the orchard floor can result in physical contamination that could cause illness or injury with items such as stones, glass, and metal found in food products. Finally, contamination from chemicals used for crop protection or other food allergens and aflatoxin is likely to occur if good agricultural practices are not followed (*Introduction: Why We Need GAPs*, n.d.).

To allow for the dry down of the orchard to enable shaker harvest and a dry surface for nut dehydration, many growers have adopted Regulated Deficit Irrigation (RDI). The RDI comprises terminating preharvest irrigation to allow for soil drying and preparation of the orchard floor for harvest (Goldhamer & Viveros, n.d.). Because of the harvest operations and the interplanting of pollinizers that mature later than cv. Nonpareil, resumption of irrigation after the harvest period is often delayed, resulting in tree water stress (Esparza et al., 2001). The management of irrigation is a strategy used for improved Water Use Efficiency (WUE). The RDI reduces annual orchard water use by 15% without significant yield damages (Stewart et al., 2001). Yield reduction in response to water stress during harvest appears to be a compound, multiyear effect associated with reduced annual growth and renewal of fruiting positions (Esparza et al., 2001). This drying period before harvest helps increase orchard longevity by reducing the time and force required to shake almond trees at harvest (Naor, 2006; Connell et al., 1996). It also contributes to reductions in hull rot (Teviotdale et al., 2007). The effect of irrigation and harvest time was studied concerning almond kernel quality with two almond cultivars. Irrigation delayed almond maturation did not affect oil and sugar content but improved oil composition with higher oleic acid content and sugar composition with higher sucrose content compared to dry-grown almonds. Late harvested almonds contained more dry matter per kernel, higher oil content but lower quality, based on the UV absorption coefficients and oil composition, and higher sugar content mainly due to further sucrose accumulation than early harvested almonds (Nanos et al., 2002). Another study comparing regulated deficit irrigation (RDI) in moderate and severe levels and sustained deficit irrigation (SDI) in almonds concluded that irrigation strategies do not affect almond fruit quality. Instead, it is possible to increase the final quality of fruits when moderate RDI is applied (Lipan et al., 2019)

Mechanical shaking

Determining the optimal harvesting time has been a central preoccupation for growers and scientists alike. The complexity of this concern is further increased by the differential maturity of two to four different cultivars in the same orchards. The Nonpareil cultivar, early ripening and soft-shelled represent 40% of almond production (Sideli et al., 2020).

Almonds are considered ready for harvest when 100% of the hulls have begun dehiscing. By this time, kernel components are fully accumulated even if the hulls of different fruits on the same tree are in various stages of hydration. Although not fully dehydrated, "Nonpareil," the first Californian cultivar to mature, reaches maximum nut removal with mechanical shaking at this stage. Another approach for evaluating the ripening rate of each cultivar is the hull-split prediction model of the Department of Plant Sciences, University of California Davis (Tombesi et al., 2010). The model predicts a date for initiation of hull-split at a location, based on user input of the full bloom and temperature reading during the first 90 days after full color is collected by a local Californian irrigation management information system (CIMIS) weather station, also designated by use (Gradziel, T. M. (Ed.). (2017). *Almonds: botany, production and uses*. Cabi). Also, different stages of hull split in almond production correspond with the extent of fruit development and are used by growers to harvest time (Fig. 1.6). These stages are critical management periods because as hull split progresses there is an increased risk of pest pressure that can compromise almond yield and quality (Smith et al., 2022).

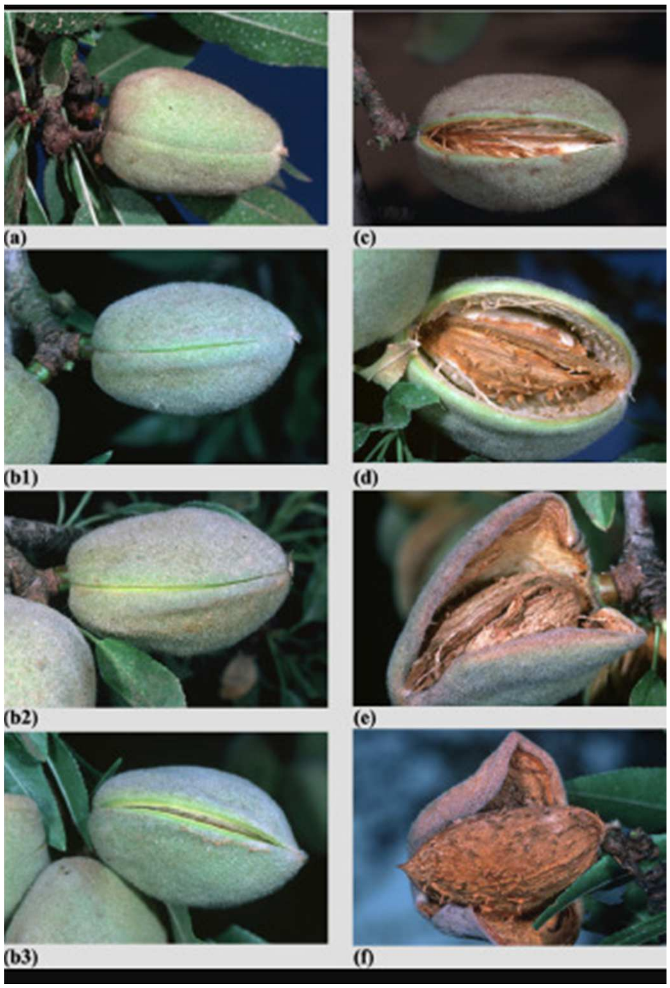


Fig. 1.5 Standard almond hull split stages from (a) to (f) (Flint, 2002). A typical 'Nonpareil' almond fruit is approximately 4.0 cm long and 2.5 cm wide. It is reprinted with permission. Photo credit: Jack Kelly Clark.

Another recent study on sustainable orchards management compared the incidence of Hull Rot (HR) and Navel Orangeworm (NOW) in 2 to 3 weeks early harvest (EH) versus Standard Harvest (SH) with stem water potential (SWP) maintained at -14 to -18 bars (Smith et al., 2022). The result showed a significantly lower HR strike in EH trees than SH and significant reductions in the percentage of kernels infested with NOW when EH is applied. The study concluded that early harvest (EH) might be a strategy for improved water use and pest and disease control in the context of complementary harvest and processing systems (Smith et al., 2022)

Mechanical harvesting with multidirectional shakers has shown a 95% efficiency of fruit removal with homogeneous trees and optimal conditions for shaking. Maintaining all harvesting and hulling equipment is essential to ensure cleanliness routinely. A study investigating four levels of oscillating frequency (10, 12, 14, and 16 Hz) and three levels of shaking amplitude (20, 32.5, and 45 mm) showed that the shaking amplitude and vibrating frequency had a significant effect on fruit detachment (Loghavi et al.,2011). The percent of fruit detachment increased at higher shaking amplitude and frequency levels. Complete fruit detachment (100%) was observed at a shaking amplitude of 45 mm and frequency of 16 Hz, but bark injury and leaf shattering were high. The study recommended a shaking amplitude of 20 mm and shaking frequency of 16 Hz with fruit detachment of high (94.8%) with no bark damage and low leaf shattering (Loghavi et al., 2011).

Although shakers are practical and economical, they can potentially damage almond bark and reduce tree health and productivity (Abdel–Fattah et al., 2003). Bark damage wounds can be infected by Ceratocystis fimbriata causing canker stain; the margin of the fungal abscess produces gumming and is visible when the bark is removed.

Harvest efficiency remains a critical concern for growers since stick-tight fruits, also called "mummies," from the previous season, constitute an overwintering shelter where NOW females lay eggs in the fall through early summer and hence represent a significant infection source for the subsequent fruit ripening period. NOW females do not usually lay eggs on immature fruits of the current season crop until those fruits mature at hull split in August through early October (Barnes & Curtis, 1979). However, NOW females will lay eggs on a current crop before hull-splitting if fruits are already damaged by feeding other insects (e.g., CM in walnuts and PTB in almonds) (Campbell et al., 2003). The Almond Board of California (ABC) strongly recommends orchard sanitation to remove mummy nuts from trees by February 1 and destroy all the fruits on the floor by March 1 (*Orchard Sanitation Is Key to a Quality Crop*, n.d.).

Drying phase

Once fruits with hulls in various stages of dehydration are shaken from trees, they are allowed to dry on the ground for several days before collection. This is important because the hulls must be dry when the fruits are delivered to the hulling and shelling station. Almond hulls have a significant value as part of the feed ration for dairy cattle. Also, given that the hulls of the almond (Prunus dulcis (Miller) D.A. Webb) have a high content of fermentable sugars (glucose, fructose, sucrose), they are a potential feedstock for biofuels and other uses (Offeman et al., 2014) . Almonds are moved considerably on the orchard floor by harvesting equipment during the shaking, raking, and windrowing process. They are mixed repeatedly, which increases the points of contact with the orchard floor and other fruits. The harvested almonds are also in the direct path of significant dust generated by the shaker-harvesters and windrowing and collecting machines (Harris & Ferguson, 2013). The drying times on the ground are determined by the initial moisture content of the fruits in the orchard environment. They may vary from 1 to 2 weeks for the early-harvested crop or 4 to 7 days for the later-harvested harvest, where drying may have progressed while fruits remained in the trees (Reil et al., 1996). Optimal hull moisture of 8 to 12% ensures efficient hulling (Thompson et al., 1996). The target water activity for stored almonds is below 0.65 (approximately 6% moisture)(Kader, 2013) .

The dust generated during harvest also spreads contamination around the orchard and throughout the harvested crop. The trend of planting soft-shell varieties, which have thin and often open shells allowing for exposure of the kernel, provides the additional potential for contamination (Harris & Ferguson, 2013).

Sweeping and pick-up phase

In the Mediterranean, fruits may be collected from the tree in various ways, including falling onto a mesh, into inverted umbrellas onto trays, or onto catching frames in harvesters. Once collected, fruits and the accompanying impurities could be dumped from the mesh into trailers and transported to the farm headquarters prior to drying and storage. In California, once the almonds have reached the desired moisture content of 6%, after drying on the ground for 5-10 days, they are swept into windrows in a separate mechanical sweeping operation followed shortly by an automatic pickup operation. Fruits are removed from the field by a shuttle wagon for further processing ("Almonds: Botany, Production, and Uses," 2017). Almond harvest accounts for a substantial particulate matter of less than 10 μm in aerodynamic diameter (PM_{10}) emissions in California each harvest season (Faulkner et al., 2009). The current emission factor applied to all almond harvesting operations is 4570 kg $PM_{10}/km^{-2}yr^{-1}$, accounting for 11 Gg of PM_{10} each year. The almond harvest emission factor is composed of the emission factors for the three different harvest operations: shaking, sweeping, and pickup. First, the trees are shaken to remove the product from the tree, allowing it to air-dry sitting on the ground; this accounts for 41.5 kg $PM_{10}/km^{-2}yr^{-1}$r of the emission factor. The almonds are then swept into windrows, accounting for 415 kg $PM_{10}/km^{-2}yr^{-1}$. Finally, pick-up machines remove the product from the field, accounting for 4120 kg $PM_{10}/ km^{-2}yr^{-1}$(Faulkner et al., 2009).

The efforts to mitigate PM and total PM_{10} emissions during harvest are geared towards properly adjusting the harvester to minimize the amount of soil picked. Moreover, the adoption of modern sweepers with optimized speed can lower emission factors (Faulkner & Capareda, 2012). Emissions from four low-dust harvesters (Flory 850, Exact E3800, Weiss-McNair 9800 and Jack Rabbit) were compared to those from a conventional harvester (Flory 480) in two orchards, located in the Fresno County. Emissions of $PM_{2.5}$, PM_{10} and total suspended particles were observed to be lower for all new harvesters compared to the conventional harvester. The range of reductions varies from about 40% to 77% in $PM_{2.5}$emissions based on emission factors generated. This research concluded that almond low-dust harvesters could reduce PM emissions over traditional harvesters without adversely affecting product quality (Baticados et al., 2019).

Our research feeds into a new effort to understand the tradeoffs of switching to off-ground harvesting, which will drastically reduce total PM_{10} emissions and enhance nut quality.

Almond quality attributes

Almonds are an excellent dietary source of vitamin E, sterols, and flavonoids, each of which has been suggested to play a role in promoting health. Increased consumption of flavonoids has been associated with an anti-obesity effect in women and reduced risk of stroke, cardiovascular disease, and some forms of cancer (Yochum et al., 1999). Fresh almonds are living organs where respiration and other biochemical processes occur before they are processed or consumed. Respiration is the predominant process through which almonds fruits acquire energy to maintain their metabolic activities after being separated from their parent plants (Gama et al., 2018). The eating quality of almonds is influenced by several factors, including the physiological development of the almond kernel in the field, the harvest and shelling conditions of the almond, and the processing and storage conditions (Franklin & Mitchell, 2019). The USA, Spain, and Australia are the major exporters of almonds globally and must adhere to stringent regulations (Panda et al., 2022). The quality of almond fruits can be broken down into the following three major components. In the first place, there are the chemical composition and nutritional profiles: sugars, organic acids, antioxidant activity, total phenolic content (TPC), and volatile compounds (Lipan et al., 2019; Nanos et al., 2002) . In the second position comes the physical properties of the fruits related to their integrity and appearance. And finally, the textural and sensory attributes are responsible for the almond flavor. This section will examine each quality component's interaction with harvest operations and industry standards.

Chemical quality attributes:

The almond kernel, which constitutes the edible part, is a seed formed by two large cotyledons covered by brown skin and protected by an external hull with an intermediate shell. The hull opens once maturity is reached, and the seed separates easily. Almonds contain lipids (around 50%), proteins (about 25%), and carbohydrates (approximately 20%) and have a low moisture content and diverse minor bioactive compounds ideally. The beneficial effects of almond consumption are associated with its composition of macro-and micronutrients. Among the compounds with beneficial properties for health, the lipid profile, predominantly monounsaturated fatty acids (MUFA, 60%), followed by polyunsaturated fatty acids (PUFA, 30%), fiber, vitamins, minerals, phytosterols, and polyphenols, can be highlighted (Barreca et al., 2020).

Lipid oxidation and rancidity

One of the significant quality concerns associated with the almond industry is rancidity caused due to lipid oxidation within the fruits (Canneddu et al., 2016). Lipid oxidation is a complex series of undesirable reactions that cause the breakdown of fats and oils. In oil-containing foods like almonds, the oxidation reactions lead to a loss of quality as the fruits develop "rancid" flavors and odors. During lipid oxidation, oxygen reacts spontaneously with the fatty acids in fats to form primary breakdown products (e.g., peroxides, conjugated dienes) and, as oxidation progresses, secondary outcomes (e.g., volatile aldehydes, ketones) are created that give rise to off-flavors and off-odors. There are multiple extrinsic and intrinsic factors causing rancidity, such as high moisture content, temperature, relative humidity, insect damage, and fungal growth (Moscetti et al., 2013). However, high moisture in fruits during harvest is reportedly one of the prime reasons behind initiating hydrolytic rancidity (Canneddu et al., 2016; Ghirardello et al., 2013). High moisture levels encourage microbial growth, which produces enzymes responsible for hydrolyzing the fat to form free fatty acids (FFAs) (Panda et al., 2022). Water activity (aw) level affects lipid oxidation rates; lipid oxidation is typically lowest when almond aw is ~0.25 to 0.35 (~3–4% moisture content) and increases above or below that water activity range (Altan et al., 2011)

Rancidity development can occur through hydrothermal or enzymatic hydrolysis of triglycerides (i.e., hydrolytic rancidity) and the direct oxidation of fatty acids and triglycerides (i.e., oxidative rancidity). Both processes produce a range of primary lipid oxidation products (e.g., free fatty acids, lipid hydroperoxides, and conjugated dienes and trienes) and secondary lipid breakdown products (e.g., aldehydes, ketones, alcohols, hydrocarbons, oxiranes, and lactones (Franklin et al., 2017). Oxidation can be measured by testing for the presence or accumulation of one or more of these primary and secondary products. For example, almonds can be tested for peroxide value (PV) and free fatty acids (FFA)(Altan et al., 2011).

Peroxide Value (PV)

The Primary oxidation assessment method often includes measuring PV and conjugated dienes (CD). PV measures the concentration of lipid peroxide. This measurement is commonly used in the industry to indicate almond quality. In general, almonds are considered not to have undergone significant lipid oxidation if values < 5 meq peroxide/kg oil (Franklin, 2017)

Free Fatty Acids (FFA)

FFA is an indirect estimate of lipid oxidation often used in conjunction with PV to indicate the degree of hydrolytic rancidity. The industry rejection standard is FFA <1.5%. Several wet lab analytical techniques are recommended to estimate fat quality (Association of Official Agricultural Chemists and Horwitz, 1975; Möller, 2010; ISO, 17059)(Franklin, 2017).

Physical quality attributes:

Almonds can be classified based on their shell characteristics, from soft to hard shell varieties. Most Australian and Californian types have softshell properties. Most Spanish almond varieties have hard shells. Although having a hard sealed body protects the kernel from insect damage, it affects its processability (Shirmohammadi & Fielke, 2017). There are over 30 different almond varieties in production across California. Nonpareil is the number one variety in

California with a soft shell and a medium to large size nut. The average length, width, thickness, geometric mean diameter, unit mass, and fruits are variety specific.

A study found that water stress treatments adversely impact the final kernel dry weight. The allocation of water to the different components of the fruit, characterized by the fresh weight ratio of the kernel to fruit, appeared to be the process most clearly affected by deficit irrigation (Egea et al., 2009).

The target moisture content of the fruit after the harvest and drying on the farm ground is less than 7 %, making the kernel brittle and susceptible to mechanical damage (Shirmohammadi & Fielke, 2017). The average force needed to fracture almond nuts and seeds decreases with increasing moisture content (Aydin, 2003). A study compared physical and mechanical property changes under different compression axes of two almond cultivars with varying hard and soft shells, with variable moisture content levels. The result confirms that force to fracture, absorbed energy, toughness, power requirement, and firmness decreased with increased moisture content (Aktas et al., 2007).

Mold

Excessive moisture at any harvest phase creates conditions favorable for mold formation. *Rhizopus stolonifer*, also known as the bread mold fungi, is a ubiquitous fungus causing Hull Rot (HR) within almonds, which compromises fruit quality and can result in death of spurs and branches through the movement of a produced toxin. Also, irrigation water can increase the moisture of windfallen fruits moisture causing fungal growth. When the kernel dries to a suitable percentage for storage (~6% moisture), the fungal growth usually declines and is no longer a food safety issue (*Rhizopus and Kernel Issues - The Almond Doctor*, n.d.). A study of almonds' fungal population and flora indicates that late harvest almonds had lower counts than early or mid-season (King & Schade, 1986)

Navel Orange Worm Damage (NOW).

Navel Orangeworm (NOW), *Amyalois transitella* (Walker), is a primary pest of almonds, pistachios, and walnuts in California and poses a high risk to an almond crop because the larvae of *A. transitella* cause direct damage to the nut, burrowing into the kernel to feed on the nutmeat and contaminating it with frass and webbing. During oviposition, the adults can introduce *Aspergillus* spp. Fungus, which can produce aflatoxins, is a known human carcinogen heavily regulated both domestically and in key foreign markets (Campbell, Molyneux, & Schatzki, 2003, Aguilar et al., 1993; Fujimoto et al., 1994; Hosono et al., 1993).) As such, there is little tolerance for *A. transitella* infestation, and most operations aim for <2% crop damage from this pest. NOW damage rates as high as 30% have been observed in some almond orchards in California (Higbee & Siegel, 2009). This damage reduces the marketability of the kernels, causing significant negative economic impacts for almond producers (Campbell et al., 2003); Phillips et al., 1980). Figure 1.6 below shows the reproductive cycle and damage of the NOW(Higbee & Siegel, 2009).

Figure 1.6: Clockwise from top left: a navel orange worm adult; a fertile navel orange worm egg laid on a mummy almond; a hatched egg; and an almond mummy infested with navel orange worm larvae.

Aflatoxin

Aflatoxin prevention remains one of the priorities of the almond industry because of its far-reaching cost in terms of health and trade issues. Aflatoxin occurs naturally following the production by specific molds, especially *Aspergillus flavus* and *A. parasiticus*. The primary health concern of aflatoxin is its potential carcinogenicity. Chronic exposure to aflatoxins can increase the risk of developing liver cancer (*Aflatoxin Prevention | Almond Processing Safety*, n.d; Palmgren and Hayes, 1987). Aflatoxin-producing molds are common in nature, affecting several crops. In almonds, the source of the contamination is from the soil, previously infested almonds (mummy fruits), Navel Orangeworm (NOW), or other pests.

Spores of the molds can be transferred by NOW and grow on nutmeats that have been damaged. Favorable conditions for mold growth include high moisture content and high temperatures. Because they are a carcinogen, tolerances for aflatoxin have been established by certain countries to reduce the risk of exposure. When almonds are tested in the lab for aflatoxin and are found to have levels above the allowable limits by the government, the consignment will have to be reconditioned or rejected, with significant monetary losses to the grower and handler.

The difficulty surrounding accurate detection continues to be an issue for California packers and European importers. An increasingly high number of shipment rejections relative to previous years - there were a total of 42 rejections in 2018, 81% of which were from the U.S. - has forced growers to find a solution that ensures a high-quality output to meet business, consumer, and food safety requirements (*Aflatoxin, The Invisible Threat for Almond Processors*, n.d.)

The U.S. Food and Drug Administration (FDA) monitors domestic and imported foods and feeds for this toxin and maintains a 20 ng/g total aflatoxin limit (Wood, 1989). Similarly, foreign governments test imported foods, and demand generally at even lower levels, 4 ng/g being typical (Schatzki, n.d.). However, the lack of an enforced uniform global standard as to what constitutes an 'acceptable' level, coupled with varying testing methods from country to country, only serves to compound the uncertainty facing international shipments. For example, in the European Union, the limit is 10PPB (EU), and less than one milligram of the toxin in one ton (106 grams) of almonds can lead to the rejection of large shipments.(*Aflatoxin, The Invisible Threat for Almond Processors*, n.d.)

Due to low Aspergillus thresholds for almond sales, annual economic damage from aflatoxin contamination is as high as $47 million in the US (Robens & Cardwell 2003).

Chapter 2: Quality assessment of windfallen almond fruits

Introduction

California has one of the most productive agricultural sectors in the entire world. The variety of crops includes more than 400 commodities, which account for over a third of the country's vegetable production and nearly two-thirds of its fruits and fruits (Pathak et al., 2018) Almonds [Prunus dulcis (Mill.) D. A. Webb], represents the most widely planted tree crop in California. Almonds are almost entirely grown in the Central Valley, stretching 400 miles between Bakersfield and Red Bluff. The mild climate, rich soil, abundant sunshine, and water supply make for ideal growing conditions(Micke & Kester, 1998). However, the California almond industry is faced with sustainability challenges in the following areas of water use efficiency, optimization of orchard outputs, integrated pest management (IPM), and air quality pollution during harvest operations. In the current on-ground harvesting approach, 75% of dust associated with the harvest is generated primarily during the sweeping and pickup stages (*California Almonds: 4 Goals to Improve Sustainability by 2025 – AgFax*, n.d.) For these reasons, the California almond community aims to halve dust emissions during almond harvest by 2025 by introducing new equipment and an off-ground approach with a catch frame, a method used in other almond-producing countries such as Australia, Spain, and Israel (Almond Board of California, 2019). One issue associated with the off-ground harvest is windfall - premature fruit that falls to the ground before the harvest time. Windfall would normally be incorporated into on-ground harvest, but almond growers would forego this yield during off-ground harvest. The marketability and quality of windfall fruits are, however, unknown.

Almond harvest happens from August through October in California, depending on the type of almond tree and climate in the specific location where the trees are being grown. Almond hull split begins in the top of the tree and progresses downward with harvest generally scheduled at 95% hull split contributing to the potential for the early maturing nuts to fall to the floor before shaking the tree. The distribution of windfall of almonds across the Central Valley is relatively unknown. It is also unknown if the windall nuts are of equivalent maturity and quality as shaken nuts. To assess the impact of windfall nuts that would not be recovered in an off-ground process requires determination of both the 1) quantity of windfallen nuts which was conducted in a separate study, and the 2) quality attributes of windfall nuts including a determination of the effect of the timing.

Windfall is a concern for the current harvest method (Gradziel, 2017). Windfallen fruits have an extended stay on the orchard floor, where the conditions of moisture, temperature, and pathogens could adversely impact crop quality, food quality, and food safety of the resultant harvested fruits.

This study was initiated to uncover the effects of windfall duration on almond fruit quality. Our overarching hypothesis is almond fruit quality will be diminished with increasing duration of windfall. The longer the windfall duration the greater the exposure period of moisture from irrigation, insects and mold, resulting in poorer quality characteristics compared to almond fruits at harvest.

Materials and Methods

This experiment aimed to assess the quality of windfall nuts versus the regularly harvested ones in two regions of California's Central Valley. This was achieved by closely monitoring the almond Nonpareil fruits maturation process (Mid-March-Mid July), then at specific time points prior to normal harvest date we manually dropped nuts from the tree to simulate windfall, nuts were then left to incubate on the orchard floor (Mid July- Mid August) until harvest during the 2019 and 2020 growing seasons. We used the University of California Davis "hull-split" (HS) predictive model based on the accumulated degree days of warm Spring temperatures between full bloom and the beginning of H.S (Tombesi, Scalia, Connell, Lampinen, & Dejong, 2015) to determine when to impose each treatment. It was essential to have an adequate supply of fully mature almonds with split hulls to incubate for two different periods before harvest (4 weeks T4 and 2 weeks T2) to assess their quality relative to regularly harvested fruits (0 weeks T0). The incubated nuts were separated from those that fell subsequently by a translucent mesh supported by 4 garden staples in each corner. The three groups of nuts were incubated following an RCBD model with two blocks (Bakersfield and Chico) and 6 repetitions. A prior review of the literature suggested a direct relation between orchards management practices (irrigation, sanitation, floor preparation, harvest timing, and harvest methods) with the ultimate quality of almond fruits (Muhammad et al., 2018; Nanos et al., 2002; Smith et al., 2022a, 2022b). Both orchards in Bakersfield and Chico had similar management practices as described in the sections below. On harvest day we collected all the treatment nuts and stored them in the 5 degrees Celsius cold room in the post-Harvest lab in the Wickson building at UC Davis campus. We measured the nuts weight, mold formation, kernel color, insect damage. Additionally, because of their high oil content, almonds are susceptible to lipid oxidation reactions that lead to loss of quality as fruits develop “rancid” flavors and odors(Abdallah, Ahumada, & Gradziel, 1998) . Fruit samples were sent to the JL Analytical lab in Modesto for in-depth chemical analysis of Free Fatty acids, Peroxide Value, Aflatoxins, and moisture content.

Orchard selection and management practices

1. Two comparable twelve-year-old mature orchards were selected based in the central valley to represent the most prevalent management practices across the almond growing region of California.

The furthest south site of Shafter in Bakersfield-Kern County (Elevation 302 ft, Latitude:35.5°N, Longitude:119.27°W) has an average annual temperature of 78/52 °F (Max./Min.). The hottest months of the year range from June to September and overlap with the Nonpareil cultivar’s maturing and harvest phases with average temperature of 94/66 °F (Max./Min.). The annual average soil temperature is 79.8°F and Bakersfield gets only 7 inches of rain, on average per year with an average relative humidity of 44.

The furthest northern site of Chico in Butte County (Latitude: 39° N, Longitude: -121° W) has an average annual temperature of 75.5/47 °F(Max./Min.). Just as observed in Bakersfield, the hottest period of the year spans form June to September with average temperatures of 92/57.7 °F(Max./Min.). The annual average soil temperature is 75.9°F and Chico gets 28 inches of rain, on average per year with an average relative humidity of 66.

Climate

California’s Central Valley has the ideal climatic conditions for almond production including a long, rainless spring, summer, and fall. Rain occurring during these times can hinder pollination (at bloom), increase disease pressure, and/or interfere with harvest when occurring in late summer and fall. Depending on the cultivar, almond need between 300 and 600 hours of chilling below 45^{0}F during dormant period to adequately break dormancy, and this normally occurs in the San Joaquin and Sacramento Valleys. Most almond growing areas in California do not have a serous frost problem. In areas where frost is likely to occur, water, usually applied by under tree sprinklers, has become the primary means of frost protection in recent years. (Micke & Kester, 1998).

Tables 1 and 2 below extracted from the CIMIS monthly reports summarize the detailed weather information for our experimental sites in Bakersfield (Shafter- Station 5) and Chico (Durham-Station 12). The period highlighted spans from June 15 to September 15 of the years 2019 and 2020 which correspond to the peak of maturation phases and harvest of the almond Nonpareil fruits. On average, the Bakersfield site had higher soil temperatures (79.8°F vs 75.9°F); higher average air temperatures (78.8°F vs 73.1°F) , but lower average Relative humidity (44 vs 62).

CIMIS Monthly Report (June 2019 - September 2019)
Shafter_ San Joaquin Valley- Station 5

Month Year	**Total Precip (in)**	**Avg Air Temp (°F)**	**Avg Rel Hum (%)**	**Avg Soil Temp (°F)**	**Avg Wind Speed (mph)**
June 2019	0.00	62.4 K	47 K	78.7 K	4.7 K
Jul 2019	0.00	65.2 K	42 K	81.9	4.2 K
Aug 2019	0.00	65.8 K	43 K	81.6	4.2 K
Sep 2019	0.00	58.5 K	45	77.1	4.3 K
Tots/Avgs	0.0	63.0	44	79.8	4.4 K

Durham - Sacramento Valley- Station 12

Month Year	Total Precip (in)	Avg Air Temp (°F)	Avg Rel Hum (%)	Avg Soil Temp (°F)	Avg Wind Speed (mph)
June 2019	0.00	73.9	53 L	75.8	2.8
Jul 2019	0.01	75.4	66	77.8	2.1
Aug 2019	0.02	75.0	66	77.8	2.1
Sep 2019	0.39	68.2 K	63 K	72.2	2.8
Tots/Avgs	0.4	73.1	62	75.9	2.5

Flag Legend	
M- All Daily Values Missing	K- One or More Dail Values Flagged
J- One or More daily Values Missing	L- Missing and Flagged Daily Values
Conversion Factors	
Inches * 25.4= mm	(°F-32) *5/9= °C

Table 1a. 2019 CIMIS Monthly Report for Shafter (Station 5) and Durham (Station 12)

CIMIS Monthly Report (June 2020 - September 2020)

Shafter_ San Joaquin Valley- Station 5

Month Year	Total Precip (in)	Avg Air Temp (°F)	Avg Rel Hum (%)	Avg Soil Temp (°F)	Avg Wind Speed (mph)
June 2020	0.00	79.0 K	44 K	77.0	5.0 K
Jul 2020	0.00	82.8	39	79.8	4.6 K
Aug 2020	0.00	83.5 K	40 L	84.5 K	4.2 K
Sep 2020	0.00	76.9 K	49 K	81.5 K	3.5 K
Tots/Avgs	0.0	0.6	43	80.7	4.3

Durham - Sacramento Valley- Station 12

Month Year	Total Precip (in)	Avg Air Temp (°F)	Avg Rel Hum (%)	Avg Soil Temp (°F)	Avg Wind Speed (mph)
June 2020	0.00	72.9 K	59 L	74.4	3.2
Jul 2020	0.00	75.3	62	79.1	2.4
Aug 2020	0.00	75.6 K	69 L	79.5	2.1
Sep 2020	0.01	71.0 K	63 K	73.2	2.4
Tots/Avgs	0.1	73.7	63	76.6	2.5

Flag Legend	
M- All Daily Values Missing	K- One or More Dail Values Flagged
J- One or More daily Values Missing	L- Missing and Flagged Daily Values
Conversion Factors	
Inches * 25.4= mm	(°F-32) *5/9= °C

Table 1b. 2020 CIMIS Monthly Report for Shafter (Station 5) and Durham (Station 12)

Soil and Irrigation

Bakerfield soils are on flood plains. They classified as coarse-loamy, mixed superactive, themic Torrifluventic Haploxerolls.(“Official Series Description - BAKERSFIELD Series,” n.d.). The second site was in Chico /Butte County. The soils in Chico are classified as Fine-loamy, siliceous,semiactive, thermic,Typic Hapludults.Tehy were formed in residuum weathered from acid crystalline rocks, chiefly granite and gneiss (“Official Series Description - DURHAM Series,” n.d.). Both orchards were in their 12th leaf of total production, with Nonpareil as the predominant and Aldrich, Peerless, Winters and Sonora cultivars as pollinizers. Both used single full-circle pattern micro-irrigation systems with micro-sprinklers at the operating pressure of 118 psi, discharging 10 gph, with a diameter of approximately 14 feet wet zone on the orchard floor under the tree canopy.

Plant Material

Fruits were collected at 4 weeks (T4), two weeks (T2) and immediately prior to normal shaking (T0) by manually shaking the limbs and collecting fallen nuts, in the instances when only a little amount of fruits fell as the effect of manually shaking the limbs, we handpicked fruits at the same level of maturity to maintain the uniformity of maturity at phase "e" of the hull-split stages, also called the "initial drying stage" (hull split > 1cm). The manual picking of fruits to supplement the number of nuts needed in our incubation experiment was justified by the absence of strong windfall events in both sites during the two years of study. Additionally, we chose only full-size fruit as the predominantly aborted smaller fruits that were shed on the orchard floor would be screened during harvest and processing and hence would not contribute to final weights. The T4 nuts still pose a higher contamination risk to the windrow as they are more likely to develop higher percentage fungal infestation given their extended stay on the orchard floor. Finally, these T4 nuts while of poor quality and unlikely to be marketed, could contribute to potential Aflatoxin contamination for which even single infected fruit can affect entire batches of processed nuts. Fruits of the 3 harvest dates were incubated under the tree canopy and on the orchard floor for four, two, and zero weeks before harvest.

Experimental design

Block I			**Block II**			**Block III**			**Block IV**			**Block V**			**Block VI**		
T0	T2	T4	T4	T0	T2	T4	T2	T0	T4	T0	T2	T0	T4	T2	T0	T2	T4
T0	T2	T4	T4	T0	T2	T4	T2	T0	T4	T0	T2	T0	T4	T2	T0	T2	T4
T0	T2	T4	T4	T0	T2	T4	T2	T0	T4	T0	T2	T0	T4	T2	T0	T2	T4
T0	T2	T4	T4	T0	T2	T4	T2	T0	T4	T0	T2	T0	T4	T2	T0	T2	T4

Table 1.2, plot map of the Randomized complete bock design inside the selected orchards in Bakersfield and Chico. The treatments T4 , T2 and T0 represent incubation times of 4 ,2 and 0 weeks respectively.

The design and implementation of our experiment happened in three major steps:

2. Orchards survey: during this initial phase we travelled across the almond growing regions in the state of California to identify candidate orchards that were representative of the most prevalent cultivars mix (Nonpareil +pollinizers- Aldrich, Peerless, Winters and Sonora) and management practices (micro sprinkler irrigation and on-ground harvest) .
3. Blooming and Hull split monitoring: We monitored the maturation process from full bloom in early March to the beginning of hull split in early July. During that period, we also studied the orchard layout and used ribbons to tag the rows and trees that will receive our treatments later. Once the early fruits' hulls were visibly dehisced toward Mid-July, experiments were commenced.
4. Treatments application: fruits were collected by shaking the limbs and if necessary, supplementing the fallen nuts with handpicked ones to meet the required 20 nuts per selected tree. The nuts collected were incubated on the orchard floor following a Randomized Complete Block Design (RCBD) design repeated over two harvest seasons in 2019 and 2020 in Bakersfield and Chico. We had six blocks per orchard. Inside each block three random rows received individual incubation time treatment (T4= 4 Weeks in Mid-July, T2= 2 weeks in Early-August, and T0= regular Harvest or control in Mid-August). For each row receiving the individual treatment, we randomly selected and tagged 4 trees as our pseudo-replication. Each tagged tree received 20 almond fruits during the 2019 season, that number was increased to 30

fruits for the 2020 season to increase the statistical power of the experimental design. In all we had 6 blocks x 3 rows x 4 trees x 20 or 30 fruits. The harvest dates in Bakerfield were August 14,2019 and August 12, 2020. In Chico the harvest was conducted on August 14 ,2019 and August 13,2020

The fruits were exposed to the full moisture and light conditions under the canopy.

Upon harvest, the fruits samples were conditioned in tight paper and plastic bags and immediately stored in a cold room at 32° Fahrenheit (5° Celsius) located in the Post-Harvest Lab in the Wickson building at UC Davis. The purpose is to prevent almonds from picking or losing moisture (moisture migration) depending on their initial moisture content and the humidity of the surrounding environment. The cold room environment and packaging also prevented lipid oxidation under high storage temperature, increased moisture, and light.

We conducted several tests and measurements on the same fruits samples to determine the quality parameters:

Kernel Weight

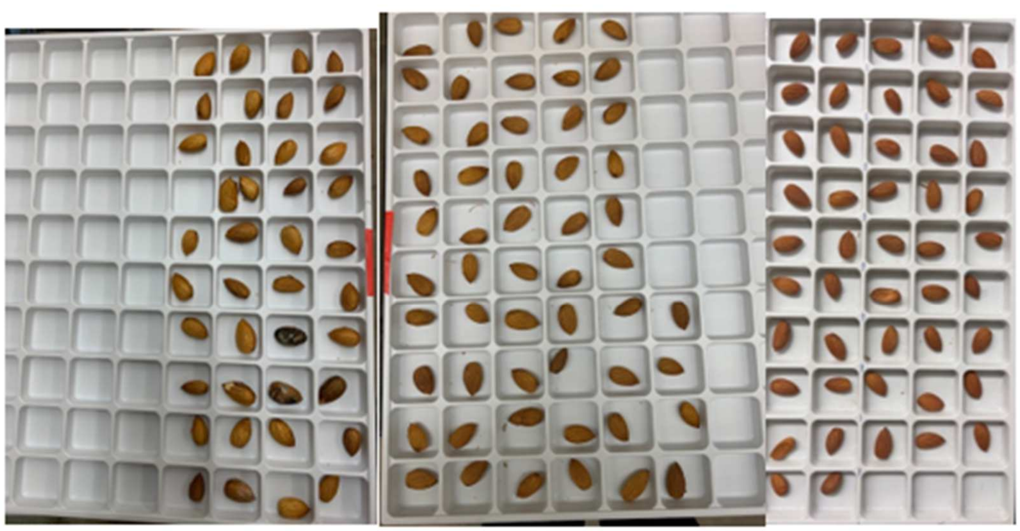
By October of 2019, we had measured the fresh weight of 720 almond whole fruits in Bakersfield and Chico respectively. In the 2020 season that number was increased to 1080 fruits for each site. One hundred and twenty almond fruits were randomly collected from 6 trees in 2019. Two trees for each individual treatment T4, T2, and T0 inside each block. In 2020 we analyzed 180 almond fruits since we increased the number of fruits incubated per tree from 20 to 30. After weighing the whole fruit, the hull and the shell were removed to obtain the kernel weight.

Mold Formation

Sampled fruits were stored in the 5°C (39° F) freezer of the Post-Harvest Lab in Wickson Hall before being analyzed in early September for mold formation by visually rating them on a three-level scale with 1 indicating no Mold, 2 =mildly molded, and 3= very moldy Whole fruit (hull-shell-kernel) kernel alone. A panel of 3 students worked in tandem to rate each nut to get an objective estimate.

Ants are principally a problem after almonds are on the ground; nut damage increases in relation to the length of time they are on the ground. The ants can completely hollow out nutmeats leaving only the pellicle ("Ants / Almond / Agriculture: Pest Management Guidelines / UC Statewide IPM Program (UC IPM)," n.d.).

The (Navel Orange Worm) damage on the almond fruits were scored by the scale of presence (1) or absence (0) of insect damage marks as shown in the Figure 2.1 below. Early September 2019, 360 fruits analyzed while the number was increased to 540 in early September 2020 for each site.



T4 T2 T0

Figure 2.1: The Insect damage form NOW and Ants was scored as 1 or 0. T4 subsamples were mostly affect, T2 subsamples were mild and the control fruits T0 were the cleanest.

Kernel color

Nonpareil kernels have a distinctive light brown color. We were interested to know if this color is affected by the pre-harvest incubation periods. Sampled fruits were stored in the 5°C (39° F) freezer of the Post-Harvest Lab in Wickson Hall before being analyzed in early September for Kernel Color. Luminosity, chroma, and hue measurements of kernel pellicles were accomplished using a Minolta Chroma Meter CR-200 equipped with an 8mm aperture (Minolta Corp., Ramsey, NJ). Luminosity measurements provide information on the degree of lightness or darkness associated with pure chromatic colors. Luminosity is representative of the vertical axis (L*) of a color solid with percentage values ranging from 0 (black-no reflectance) to 100 (white-complete reflectance). Chroma and hue values are calculated from solid color axes a* and b*. At any given plane on the color trustworthy representative of an L* value, a* is a positive or negative coordinate perpendicular to L*and representative of the purplish-red to the bluish-green axis. Coordinate b* is expressed as a positive or negative value on the same plane of the color solid representing the yellow to the blue axis. Hence, colors in color solid near the vertical axis L* represent shades of grays, while as a* and b* increase away from L* in absolute value, chromaticity also increases. Chroma (C*) and Hue (H) are calculated from the following formulas:

$C^*=((a^*)^2 + (b^*)^2)^{1/2}$ and $H= \arctan(a^*/b^*)$

Aflatoxin

The measurement of aflatoxin levels was outsourced to the IEH-JL Analytical laboratory in Modesto-CA: Early September, aflatoxin tests were run on composite samples of almond fruits for each treatment. Fruits samples were stored in the 5°C (39° F) freezer of the Post-Harvest Lab in Wickson Hall. The AOAC 991.31 method reference was used for the analysis (Trucksess et al., 1994). The laboratory requested a minimum sample of 120 grams of kernel weight per treatment. We cracked open the whole fruits to extract the kernels. Given that our experimental design for each site consisted of six blocks with 3 treatments. Inside every block an individual treatment (T4,T2 or T0) was applied on 4 trees or pseudo-repetition with 30 fruits each. We had to mix the fruits of 4 random pseudo-repetitions of the same treatment to meet the laboratory's sample standards of 120 grams minimum. On September 16th, 2019, 18 kernel samples were obtained from harvested fruits in each site and shipped for analysis. The AOAC official Method 991.31 is used for the determination of aflatoxins (Afs, Sum of aflatoxins B1, B2, G1 and G2) by using immunoaffinity column cleanup with LC. The extraction solvent is a mixture of methanol and water. Test portions were extracted with methanol-water (84 + 16, v/v), and the extracts were centrifuged, diluted with phosphate-buffered saline, filtered, and applied to an immunoaffinity column containing antibodies specific for AFs. After the column was washed with water, the toxins were eluted from the column with methanol and quantified by HPLC with fluorescence detection (Bao et al., 2013) . The total Aflatoxin values in parts per billion (ppb) were obtained by adding up Aflatoxin B1, Aflatoxin B2, Aflatoxin G1, and Aflatoxin G2.

Moisture content (in %)

Conventionally, almonds fruits are harvested when about 95 percent of nuts have hulls that split open to expose the in-shell almond inside. Almonds harvested at the traditional time usually require additional drying to prevent mold growth during storage. The drying of almonds fruits in the orchard continues until they reach 7% to 6% industry standard and happens on the orchard floor for one to two weeks after shaking before pickup and delivery to the huller. Kernel moisture plays a central role in determining the quality parameter of the almond fruits. Kernel moisture of 18 samples (three treatments x Six repetitions) was measured in September of 2019 and 2020 using a vacuum oven with the AOAC 925.40 method reference(Trabelsi et al., 2016). This method dries test sample representing ca 2 g dry material to constant weight (ca5h) at 95-100^{0}C under pressure ≤ 100 mmHg (13.3 kPa). It reports loss in weight as moisture.

The Peroxide Values (PV)

PV is an indirect measure of lipid oxidation. PV is the primary initial breakdown product formed when fats, especially unsaturated fat, react with oxygen, in meq/kg were determined using the AOCS Cd 8.53[11] method (Torres et al., 2016). The peroxide Value Acetic Acid–Chloroform method determines all substances, in terms of milliequivalents of peroxide per 1000 grams of sample, that oxidize potassium iodide (KI) under the conditions of the test. The substances are generally assumed to be peroxides or other similar products of fat oxidation. The method is applicable to all normal fats and oils, including margarine. This method is highly empirical, and any variation in the test procedure may result in variation of results.("334498064-AOCS-Cd-8-53-Peroxido-Con-Cl.pdf - PDFCOFFEE.COM," n.d.). Thirty-six fruits samples (3 treatments x 6 blocks x 2 sites) were analyzed at JL-Analytical Lab in Modesto in September 2019 and 2020

Free Fatty acids (%)

Hydrolytic rancidity is the hydrolysis of an ester by lipase or moisture. I refer to hydrolysis of fats and oils, producing free fatty acids (FFA) by enzymatic action, present in oil seeded grains. The FFA determination is also intimately linked to the nature and quality of the raw material, quality, and degree of purity of the fat. FFA percentages of each thirty-six sample (3 treatments x 6 blocks x 2 sites were obtained during the harvest seasons of 2019 and 2020 to complement the information on lipid oxidation. FFA was measured with the AOCS Ca 5a-40[10] (*AOCS Ca 5a-40 - Google Scholar*, n.d.) at the IEH-JL Analytical Lab in Modesto. The Official American Oil Chemist' Society (AOCS) Ca 5A-40 method for determination of free fatty acids was performed by combining the soil sample with 5 ml of isopropanol and 5 to 6 drops of phenolphthalein indicator. FFA levels were determined by alkaline titration (0.01 N NaOH) and the were reported as the percentage of oleic acid.

Data Analysis

The data collected from almond fruits quality assessment in the post-harvest lab at UC Davis and JL-IEH Lab in Modesto were entered in excel spreadsheets and later exported for analysis with the R project for statistical computing and graphics generation. The normality of data was checked by frequency distribution plots. The data was normally distributed for Kernel weight, Peroxide Values and Kernel Color. The Free Fatty acids values were not normally distributed and were subjected to square root transformations before statistical analysis (Table 5). Analyses of variance using a random model were done for Kernel weight and color, FFA, PV for the years 2019 and 2020 which were our true repetitions. Site, incubation time treatments (T4, T2 and T0) were tested as main effects. When appropriate, the post hoc Tukey test was used to determine and compare significant differences between treatments (Table 7 and 9). Untransformed mean values for Kernel weight (Table 1), Kernel color (Table 4), kernel moisture (Figure 5) are reported for ease of interpretation.

Based on the analysis of Variance (ANOVA) there were significant differences in moisture content and FFA percentages among sites and between T4 and T0 treatments (Table 4). These differences could partly be due to environmental variation between the site of Bakersfield which has slightly higher average June-July-September soil temperatures (79.8° vs 75.9°) and average air temperature (78.8° vs73.1°F) compared to Chico. The latter site had a higher relative humidity (66 vs 44) than Bakersfield. The original comparisons constructed before the experiments were initiated were designed to consider the effects of incubation periods between different treatment groups within a single orchard. To better estimate, the differences among orchards, separate analyses of variance were conducted for each site where orchard and incubation periods were tested as the main effects.

Results and statistical analysis.

The results of our experimentation can were broken between external quality parameters such as kernel weight, mold formation, insects damage or kernel color on one hand, and on the other hand we had chemical quality parameters such moisture content, free fatty acids, peroxide values and aflatoxins. We observed that the fresh kernel's weight gradually decreased in both sites as harvest neared (Figure 2). The histogram of the frequency distribution of Kernel weight at the Bakersfield and Chico sites reveals that the bulk of kernel weight is clustered around 1 gr $\pm 0.2\ gram$.

To assess if a more extended pre-harvest stay of almonds on the orchard floor increases the likelihood of aflatoxin development, we tested six almond samples, one for each group of nuts incubated on the orchard floor for 4 weeks (T4) and 2 weeks (T2) prior to normal pickup (control- T0) in September 2019. The lab results reported less than 0.01 ppb for each of the four types of Aflatoxins (B1, B2, G1 G2) that Aspergillus flavus and Aspergillus parasiticus mainly produce. The resulting mean value of total aflatoxin levels in our experiment were 0.4 ppb for the treatments. Given that these values were 10 times lower than the industry standard of 4 ppb, we did not repeat the tests the following year (Table 4).

The mean moisture values for each treatment are summarized in Table 10 and Figure 1. Moisture analysis in Bakersfield (Figure 3A) and Chico (Figure 3B) shows percentages gradually decreasing from 20% for T4, 15% for 2, and 6% for T0 (fruits at harvest) within each year 2019 and 2020. The fruit from the Bakersfield had overall higher moisture mean values than those in Chico. Still, as we approached harvest, all the values came close to 6%.

The percentages of Free Fatty Acids (FFA) are an indirect measure of lipid oxidation. Higher FFA indicates that the oil composition is shifting toward deterioration. The results indicated that percentages were, on average higher than the industry standard (1.5% FFA) in Bakersfield while they remained under that threshold in Chico. The ANOVA Table 5 reports a significant difference between treatments in each site. (Table 1) confirms the difference in the Bakersfield site but not in chico. Higher values of FFA are associated with increased oxidative activity of the fruits' oils, leading to a shorter shelf-life for the group of fruits concerned (Fiegure3).

Peroxide values are summarized in Table 1. The low PV values indicate the minimal effect the incubation periods of 4 and two weeks had on the oxidation of the lipids (Figure 4).

Table 4 illustrates the significant differences between treatments for all the kernel color parameters analyzed (luminosity, chroma, and hue). The difference between sites (Bakersfield and Chico) was detected for luminosity (L) and shade (H) but not for chroma (C) (Table 6, Table7, Table 8).

A panel of 3 student assistants was trained prior to grading sub-samples of each treatment with regards to external quality parameters and almond nuts integrity. The presence of mold on the hull was scored using a 3-level scale from 1- "no mold" to 3- "very molded"). Molded nuts' hull presented a dark black color instead of the light brown color for normally dried hulls. The nuts that had been incubated for 4 weeks had the highest count of mold nuts followed by 2weeks nuts while the regular harvest was mold-free (Figure 5). The "insect" damage from NOW and ants was scored on a binary scale with 0 marking the absence of damage while 1 signaled a damaged kernel (Table 2). The treatment effect was not significant for fruit damage. Some harvested fruits came with damage marks, primarily by the Navel Orange worm (NOW) (Entomology & 1977, n.d.).

Discussion

This study aimed at uncovering the effects of windfall duration on almond fruit quality. Windfall is a concern for the current harvest method because windfallen fruits have an extended stay on the orchard floor, where the conditions of moisture, temperature, and pathogens could adversely impact crop quality, food quality, and food safety of the resultant harvested fruits. Our overarching hypothesis is almond fruit quality will be diminished with increasing duration of windfall.

We found that T4 fruits had overall poor quality with higher moisture (from 9% to 20%) than T2 and T0 (6% and 5%, respectively) (Figure 1a,b); a higher percentage of insect-damaged fruits (17.5 % for Bakersfield and 13.3% for Chico)(Table 2); a higher count of very molded fruits (Figure5) which was associated with a darker kernel skin reading on the Minolta colorimeter (Table3). For reasons that remain unclear, free fatty acids (FFA) values were higher than the industry standard and the other reported percentage values for the fruits incubated for 2 weeks in Bakersfield than at T4 or T0. In general, FFA values remained greater than the minimum industry standard of 1.5% (Table 1). Peroxide Values (P.V.) were below the industry maximum standards (< 5.0 me/kg) across the treatments (Table1).

Aflatoxin results from all three treatments (T4, T2, T0) in Bakersfield and Chico were of 0.4 ppb/kg which is significantly lower than the lowest allowable limits for Aflatoxin contamination on almonds set currently at 10 ppb by the European Union (AFLATOXIN, The Invisible Threat for Almond Processors, n.d.) (Table 4). Given this negligible outcome, the aflatoxin test was not repeated in the second year.

We expected that T4 fruits with higher mold formation would test higher in aflatoxin, yet the lab analysis detected equal concentration of 0.4 ppb/kg with the other two treatments groups T2 and T0. Given the importance of continuously monitor aflatoxin content and its associated negative impact on product quality and marketability (Aflatoxin Prevention | Almond Processing Safety, n.d.; Schatzki, n.d.), and also given that mycotoxin can accumulate following the intermingling of fruits mixed with contaminated soils under the current harvest approach (Harris & Ferguson, 2013); further studies are needed to elucidate aflatoxin progression in fruits samples containing a mix of fruits from all three treatments over a six months or more timeframe.

The literature on almond quality highlights the fact that almond kernel moisture is one of the critical parameters in determining quality attributes (Panda et al., 2022; Vickers et al., 2014b). Moisture levels and water activity create conditions favorable to mold formation and microbial activity (Harris & Ferguson, 2013). T4 fruits with a longer windfall duration were exposed to 2 to 2 ½ inches of irrigation water ("How to Water an Almond Tree," n.d.) every other week and thus greater moisture led to higher mold formation in this group of nuts.

Additionally, kernel weight decreased gradually from T4 to T0 is congruent with the maturity indices in California with 100% of dehisced hulls, causing a decline in moisture content in the kernel as the fruit dries down to 6% (Gradziel, 2017).

Oil oxidative stability is essential to determine nut nutritional quality in terms of fatty acid composition over storage (Bai et al., 2019). The high lipid content comprises unsaturated fatty acids (oleic and linoleic represent 91 to 94 % of the total oil content) (Maestri et al., 2015). Our experiment revealed a significant treatment effect on the FFA % (Table 5), but more so between the pairs T0-T2 and T0-T4 than in T2-T4. This could be due to higher lipase activity under higher moisture and temperature conditions that we measured in the previous section on moisture. The fatty acids can react with oxygen and cause quality problems such as rancidity and off-flavors during storage. The higher the FFA value, the lower the shelf life during storage.

Peroxide value (PV) is a chemical parameter commonly used to indicate almond quality. Almonds are generally considered not to have undergone significant lipid oxidation if values are <5 meq peroxide/kg oil (Franklin, 2017). Based on the finding that all PV detected remained below the industry standard (0.5 meq/kg), we reached the conclusion that fruits oils did not undergo significant oxidation.

The kernel skin color was affected by the incidence of mold formation (Figure 5) and the effect of temperature on non-enzymatic browning reaction. T4 windfall nuts had a higher mold formation and overall darker skin. During the hulling and shelling phases of almond processing, discolored fruits are ejected by the color sorters (Schatzki & Ong, 2001). Further study is required to assess the effect of T4 fruits on the overall quality of the almonds harvested fruits.

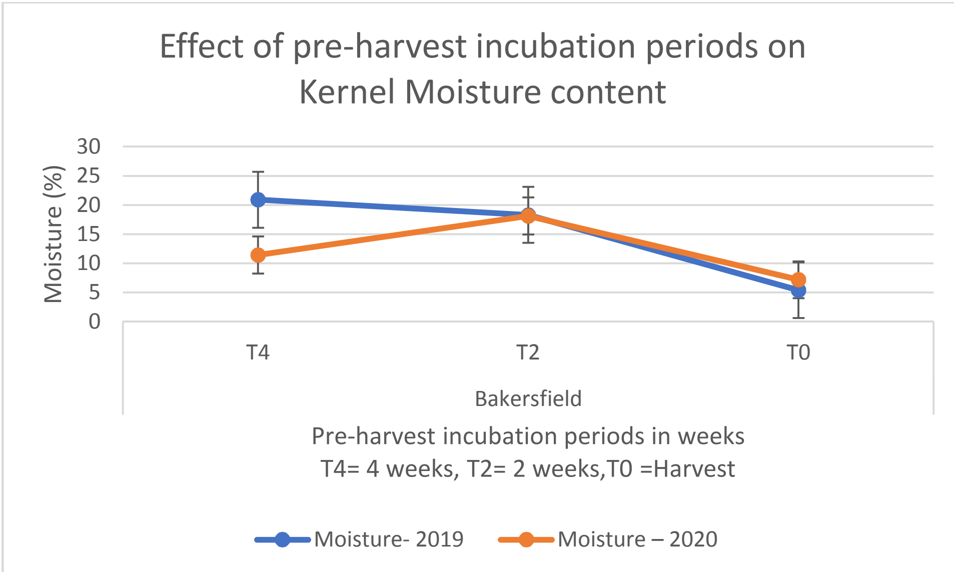
Taken collectively, these findings advocate for a preservation of almond fruits up to two weeks before the conventional harvest date. Windfall fruits at 4 weeks pre -harvest (T4) should not be included in the regular harvest due to their poor quality.

Conclusion.

The results of the qualitative assessment of windfallen almonds indicate that incubation times affects nut quality. There was extreme variation in mold formation, moisture content, insect damage, and kernel discoloration the fruits incubated for four weeks (T4) compared to those incubated for two weeks (T2) pre-harvest or regularly harvested (T0). These poor-quality T4 nuts should preferably be excluded from nut harvest as they are of low quality and may represent a threat to the entire harvest. Windfallen fruits collected two weeks prior to regular harvest were of comparable quality attributes to those collected at standard harvest.

As some of the T4 quality attributes may have been the result of those nuts being wetted from irrigation on damaged during field preparation, further studies might involve the assessment of windfall fruits at intervals preharvest under different irrigation systems and regimes. Since we have demonstrated that windfall occurring within two weeks of harvest remains of suitable quality and could represent a yield loss to a grower, an accurate assessment of the quantity of T2 nuts under a variety of situations is necessary. The insights gained from this qualitative research when combined with annual quantitative estimates of the windfall, is required if we are to determine the overall impact of windfall on yield and quality.

Figures



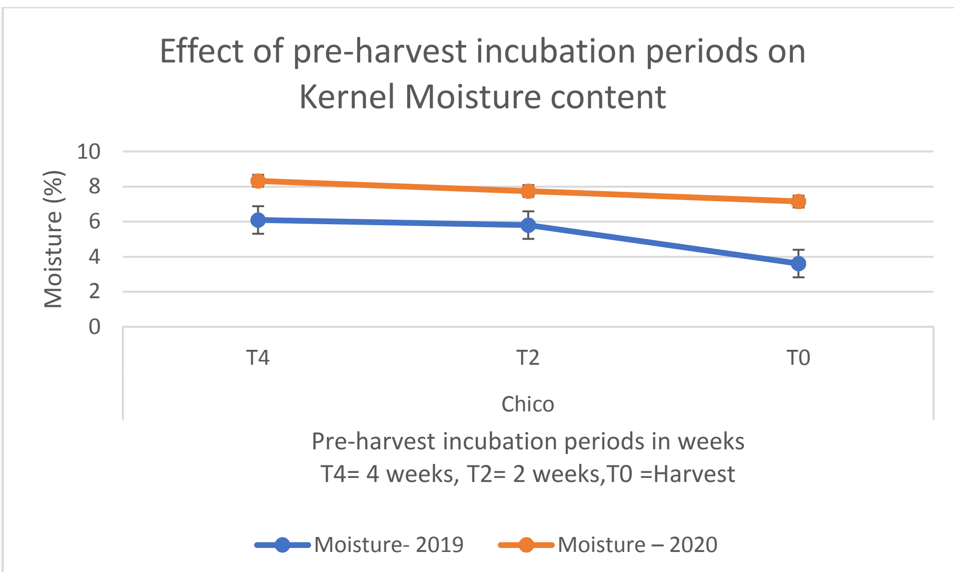


Figure 1. Moisture levels in Bakersfield (A) and Chico (B) orchards. Graphs show decreased moisture levels as fruit approaches harvest (T0). Bakersfield site showed higher moisture levels for T4 and T2 in 2019 as well as 2020.

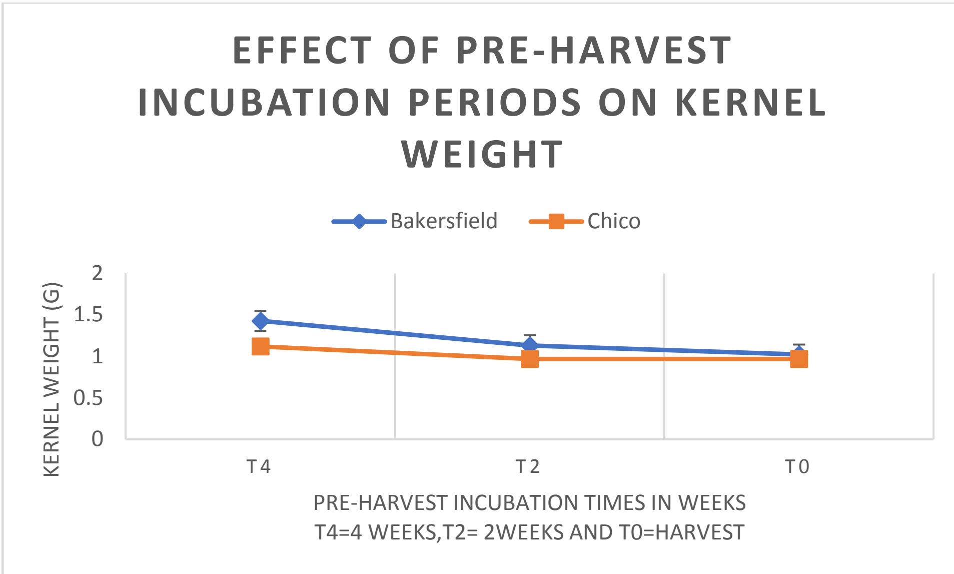
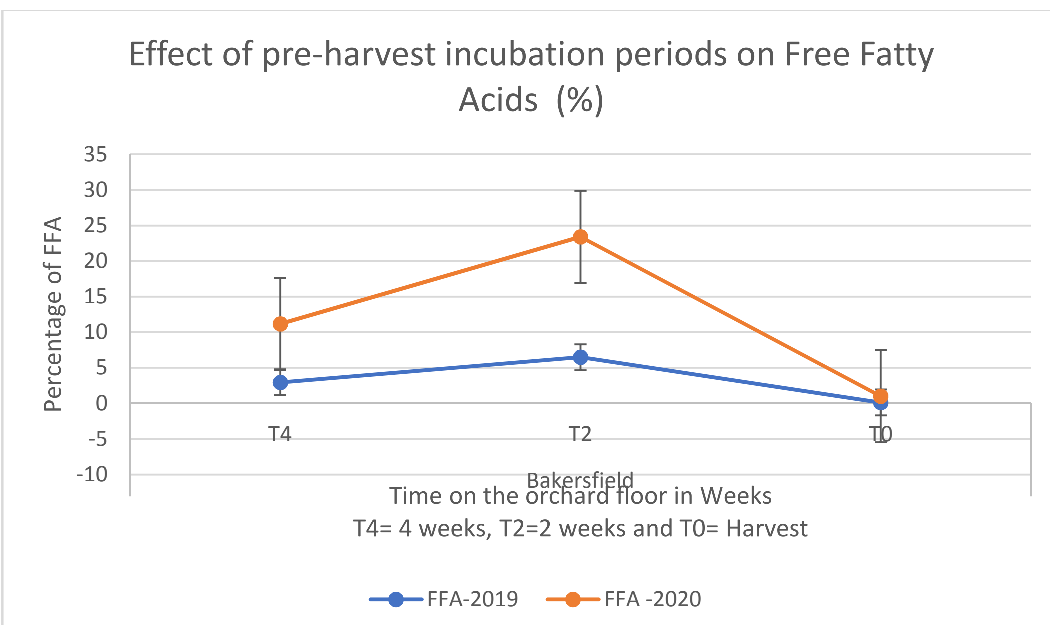


Figure 2. Fresh Kernel weight at Bakersfield and Chico show a gradual decrease and stabilizes at harvest



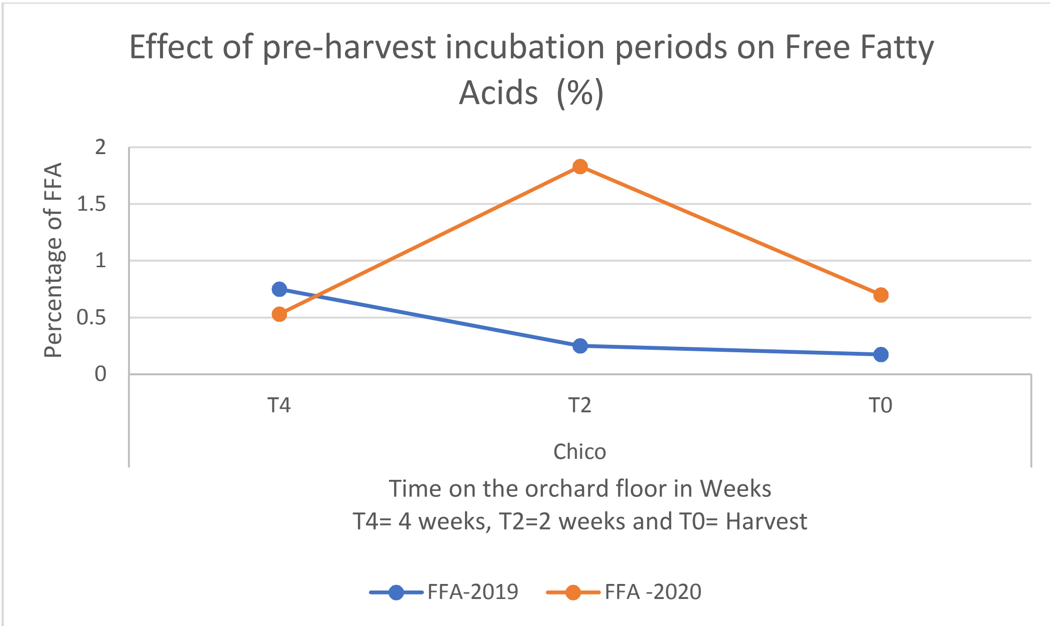
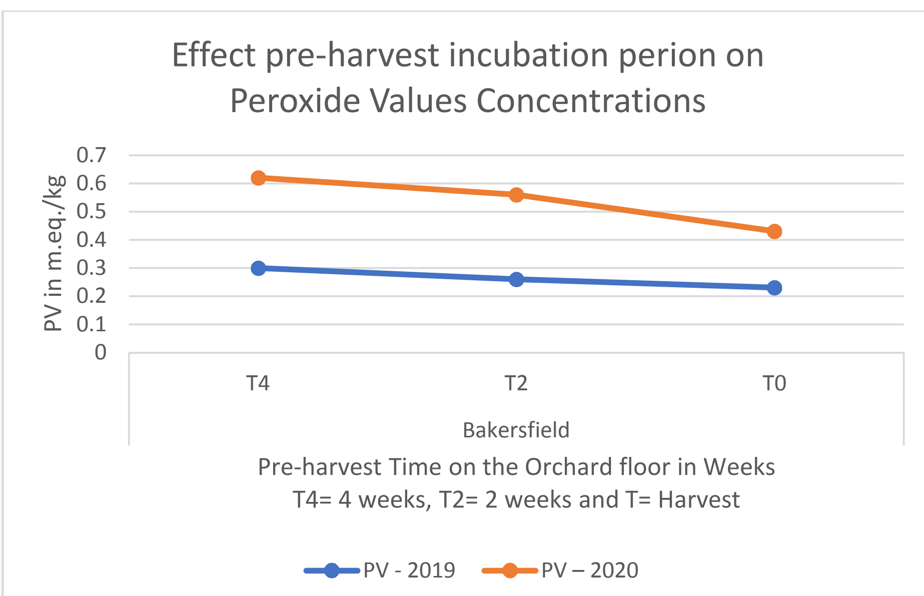


Figure 3(A, B). Free Fatty Acid percentages (FFA) in 2019 and 2020, mostly under the industry threshold of < 1.5%, except for T4 and T2 in Bakersfield (A) and T2 in Chico (B).



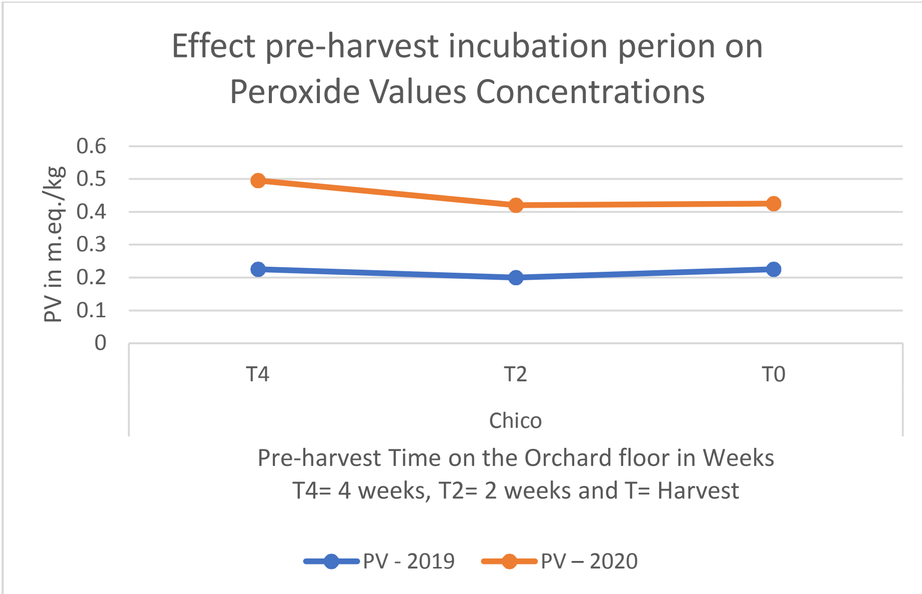


Figure 4(A, B). Peroxide Values (P.V.) in 2019 and 2020, all under the threshold of 0.5 meq/kg.

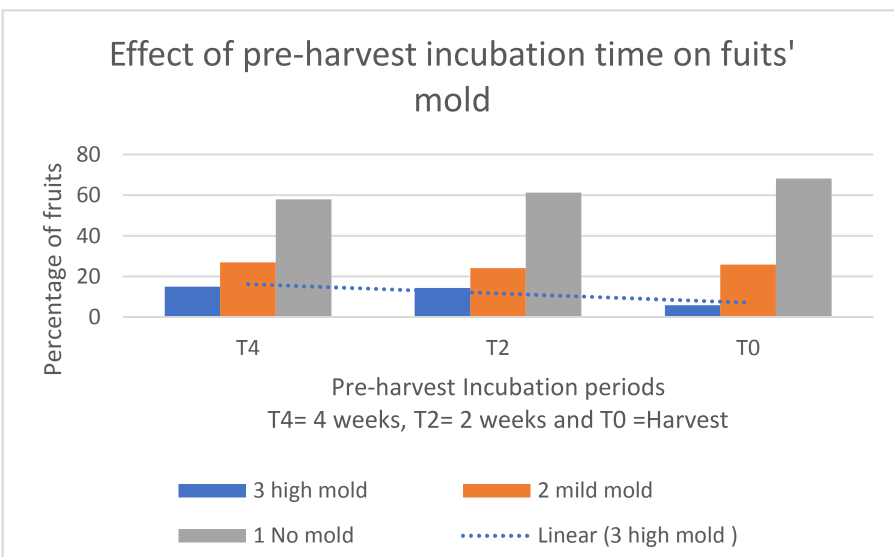


Figure 5: Mold Formation in Chico and Bakersfield (scale= 1-No mold, 2- mildly moldy, 3=Very moldy) after 3 weeks post-harvest in at 5°C. The trendline shows less incidence of high mold fruits as we approach harvest.

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Appendices

Table 1: Effect of pre-harvest incubation times (T4, T2, T0) on fruits oils oxidation measured in Free Fatty Acids (%) and Peroxide Value (in meq. /Kg) in 2019. and 2020

Site	Treatments	FFA (%)		SD	PV (meq/Kg)		SD
		2019	2020		2019	2020	
Bakersfield	T4	2.96	8.2	2.75	0.3	0.32	0.08
	T2	6.475	16.95	4.73	0.28	0.3	0.05
	T0	0.13	0.867	0.05	0.23	0.2	0.05
Chico	T4	0.75	0.53	0.79	0.225	0.27	0.05
	T2	0.25	1.83	0.10	0.2	0.22	0.00
	T0	0.175	0.7	0.05	0.225	0.2	0.05

Table 2: Insect Damage count on windfall Effect of pre-harvest incubation times (4 weeks (T4), 2 weeks (T2) and zero week (T0- Control)) on fruits insect Damage. A binary scale was used (0= no damage, 1= presence of damage) on samples of 120 fruits from each treatment in Bakersfield and Chico.

Site	Treatments	% Insect Damaged fruits	
		0	1
Bakersfield	T0	96.6	3.4
	T2	86.6	13.4
	T4	82.5	17.5
Chico	T0	98.3	1.7
	T2	95.8	4.2
	T4	86.7	13.3

The nuts that remained longer on the orchard floor (T4) had the highest incidence of insect damage

Table 3: Effect of pre-harvest incubation times (T4, T2 and T0) on the Kernel color read on the Minolta-Colorimeter.

Site	Treatments	L*	A*	B*	C*
Bakersfield	T4	54.1	18.2	35.8	40.2
	T2	51.9	21.0	34.9	40.8
	TO	55.2	21.1	37.7	43.3
Chico	T4	49.7	21.4	32.8	39.2
	T2	49.6	22.8	33.7	40.7
	T0	54.9	22.5	38.3	44.4

(L* indicates lightness, a* is the red/green coordinate, b* is the yellow/blue coordinate, and C* represent Chroma).

Table 4: Aflatoxin test results for each treatment yield < 0.1 ppb for Aflatoxins B1, B2, G1, G2 and the total Aflatoxin was <0.4 ppb.

Site	Treatments	Aflatoxin B		Aflatoxin G		Total Aflatoxin
		B1	B2	G1	G2	
Bakersfield	T4	<0.1	<0.1	<0.1	<0.1	<0.4
	T2	<0.1	<0.1	<0.1	<0.1	<0.4
	T0	<0.1	<0.1	<0.1	<0.1	<0.4
Chico	T4	<0.1	<0.1	<0.1	<0.1	<0.4
	T2	<0.1	<0.1	<0.1	<0.1	<0.4
	T0	<0.1	<0.1	<0.1	<0.1	<0.4

Table 5: Analysis of Variance Table: Response: sqrt (`Free Fatty Acids (FFA) %`) for almonds samples incubated under the following an RCBD design with T4, T2, T0 treatments respectively four weeks, two weeks, and 0 weeks pre-harvest

	Df	Sum Sq	Mean Sq	F Value	Pr(>F)
Site	1	22.303	22.3031	25.189	6.213e-06***

Year	1	6.912	6.9125	7.807	0.007229**
Treatment	2	21.666	10.8329	12.235	4.279e-05***
Year: Trt	2	1.006	0.5030	0.568	0.570044

*Trt: Treatment

Bakersfield -lsmeans for post hoc comparison:

Treatment	lsmean	SE	df	Lower.CL	Upper.CL
T0	1.1605	0.247	53	-4.467	0.0001
T2	2.5172	0.247	53	-3.300	0.0048
T4	2.1628	0.247	53	1.167	0.4780

Contrast- Pairwise comparison of Treatments:

Contrasts	Estimate	SE	df	t. ratio	p.value
T0 – T2	-1.357	0.304	53	-4.467	<.0001
T0 – T4	-1.002	0.304	53	-3.300	0.0048
T2 – T4	0.354	0.304	53	1.167	0.4780

Chico - lsmeans for post hoc comparison:

Treatment	lsmean	SE	df	Lower.CL	Upper.CL
T0	-0.0589	0.247	53	-0.554	0.436

T2	1.2978	0.247	53	0.803	1.793
T4	0.9435	0.247	53	0.449	1.438

Contrasts	Estimate	SE	df	t. ratio	p.value
T0 – T2	-1.357	0.245	51	-5.534	<.0001
T0 – T4	-1.002	0.245	51	-4.088	0.0004
T2 – T4	0.354	0.245	51	1.446	0.3256

Contrast- Pairwise comparison of Treatments:

Table 6 ANOVA Response and interaction plot for Kernel Color: 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		
Signif. codes	0 '***'	0.001'**'	0.01'*'	0.05 '.'	0.1 ''1

Table 7 ANOVA Response and interaction plot for Kernel Color: 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		
Signif. codes	0 '***'	0.001'**'	0.01'*'	0.05 '.'	0.1 ''1

Table 8 ANOVA Response and interaction plot for Kernel Color: 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		
Signif. codes	0 ‘***’	0.001’**’	0.01’*’	0.05 ‘.’	0.1 ‘‘1