# Performance Evaluation of Commercial Dryers for Drying of In-Hull Almonds

**Project No.:** **HARV4-Pan**

**Project Leader:**

Dr. Zhongli Pan

Adjunct Professor
University of California, Davis, CA
Mailing Address: 3018 Bainer Hall, Department of Biological and Agricultural Engineering
University of California, Davis, One Shields Avenue, Davis, CA 95616
Phone: 530-400-3400
FAX: 530-752-2640
E-mail: zlpan@ucdavis.edu

**Project Cooperators and Personnel:**
Companies & Farms:
Campos Brothers Farm Caruthers, CA
J.Y. Farm, Tranquility, CA
Emerald Farm, Maxwell, CA
West Valley Hulling Company, Firebaugh, CA
Wizard Manufacturing Inc. Chico, CA
Bakers Farm, Firebaugh, CA.

Food Processing Research Group at UCD:
Dr. Ragab Khir
Dr. Yi Shen
Chang Chen
Zhaokun Ning
Rentang Zhang
Xiangyu Cao
Xingzhu Wu
Lizhen Deng
Tianxin Wang

Almond Board of California:
Guangwei Huang

## A. Summary

This research was conducted using three different commercial dryers, including tunnel dryers at Campos Brother Farms, Caruthers, CA; stadium dryer at Emerald Farm, Maxwell, CA; and trailer dryer at West Valley Hulling Company, Firebaugh, CA. The main objective of this research was to evaluate the drying performance of different commercial dryers for drying off-ground harvested almonds. The off-ground harvested almonds with varieties of Independence, Monterey, and Fritz were used for conducting the drying tests.

For the tunnel drying, Independence almonds were dried using six tunnels under three different drying conditions, including ambient air drying started at the daytime, ambient air drying started at the nighttime, and hot air drying at 46°C (115°F) with the air velocity of 1 m/s. For the stadium drying, Monterey and Fritz almonds were dried by using four bins with heated air at 35°C (95°F) and air velocity of 0.7 m/s. For the trailer drying, the Monterey almonds were dried by using four trailers under two different drying conditions of 43°C (110°F) and 54°C (130°F) with the air velocity of 1.2 m/s.

Initial characteristics of freshly harvested almonds, including average moisture content, moisture content distribution, bulk density, weight ratio of major fractions (hulls, in-shell almonds, and in-hull almonds), insect damage, and kernel color, were measured. Drying characteristics, such as drying time, throughput, ambient temperature/relative humidity (RH), air temperature/velocity, and utility use, were determined. Quality attributes of the dried almonds, including finial moisture content distribution, cavity, concealed damage, kernel color, and oil quality, were also measured. The quality results of the dried almonds from the drying testes were compared with those of dried almonds from the conventional harvest. The key findings and recommendations from this research project are summarized as below:

- Off-ground harvested almonds were much cleaner and less insect damage (0.8 to 3.3%), compared to the conventional harvested almonds (2.0 to 10%). The off-ground harvest reduced insect damage by 57-67%.
- Among the three fractions (in-hull almond, in-shell almond, and hull) of freshly harvested and dried almonds, hulls had the highest moisture content. The in-hull almonds had higher moisture than the in-shell almonds.
- The initial moisture had significant effect on drying time. The drying time of hot air drying ranged from 5.8 to 16.9 hours from their initial whole almond moisture of 20.0-37.6% to 3.9-5.8% kernel moisture except for stadium drying of Fritz almonds due to its extremely high initial moisture content.
- The drying temperature had a significant effect on the drying time and cost. For the tunnel drying, the drying at 115°F reduced the drying time by 74% and had higher energy cost by 15% compared to the ambient air drying. For trailer drying, the hot air drying at 130°F had 11% shorter drying time but 109% higher energy cost than the drying at 110°F.
- Under the tested conditions, all products had no cavity, concealed damage, and change of kernel color after drying. Only almonds from trailer drying had peroxide values (1.33-1.83 meq/kg) and free fatty acid levels (0.26-0.31%) significantly higher than the conventional harvested almonds but far below the industrial standards (5 meq/kg and 1.5% for peroxide value and free fatty acid level, respectively). It is likely that the high numbers were due to the low initial moisture, which needs to be further studied.
- The energy costs ranged from 0.07 to 1.91 cents per pound of whole dried almonds or 0.21 to 6.5 cents per pound of dried almond kernels when electricity costs were calculated with the peak and off-peak rates of electricity at 0.15 and 0.25 $/kWh. The energy costs also depended up on initial moisture, dryer type and drying conditions. It is reasonable to expect the cost to be 1 – 4 cents/lb of dried kernels depending up on the efficiency of dryers when the almonds are harvested at normal moisture. It appeared that trailer drying was the most efficient method compared to other two types. The trailer drying had the lowest drying cost due to very low initial moisture. When the drying temperature was too low, it took a long time to dry the product, leading to a high energy cost due to electricity consumption from

the fans. A high initial moisture made significant contribution to the drying cost. Thus, it is important to harvest almonds at appropriate time.

- The available commercial dryers can be used for drying the off-ground harvested almonds without quality concerns. However, the optimum drying conditions need to be further studied to further reduce drying time and cost.

## B. Objectives

The ultimate goal of this research was to evaluate the drying performance of existing commercial dryers for drying off-ground harvested almonds. The specific objectives were to:

1. Determine the initial characteristics and moisture content (MC) distribution of the off-ground harvested almonds and their components (hull, shell and kernel).
2. Evaluate the drying performance and the product quality of different commercial drying technologies, including tunnel drying, stadium drying, and trailer drying.
3. Compare the qualities of almonds from off-ground harvest followed by drying using commercially available dryers and conventional harvest with natural drying.
4. Analyze the energy consumption and cost of the tested dryers under different drying conditions.

## C. Results

### C.1 Initial characteristics of off-ground harvested almonds

The tests used four batches (three varieties) of almonds, including Independence for tunnel drying, Monterey and Fritz for stadium drying, and Monterey for trailer drying. For each batch, samples were collected right before drying tests to determine the initial characteristics of almonds. The corresponding almond samples were also collected from the conventional harvest.

Compared to the almonds from the conventional harvest, the off-ground harvested almonds were much cleaner with less foreign materials like dust, leaves, rocks, and branches (Figure C.1). The percentages of insect damage were in the range of 0.8 - 3.3% and 2.0 - 10.0% for the almonds from off-ground harvest and conventional harvest, respectively (Table C.1). The high percentage of the insect damage of almonds from the conventional harvest was caused by the extended period on the ground which was about 10 days. The off-ground harvest reduced insect damage by 57-67% which is very significant to the new harvest practice.

Among the three fractions (hull, in-shell almonds, and in-hull almonds), in-hull almonds were the largest proportion (0.50 to 0.80) of total mass (Table C.1). The specific weight ratios of three fractions differed among the tested batches due to the differences in varieties and maturities. The bulk densities of the mixtures of almonds ranged from 296.0 to 391.6 kg/m$^3$ and the bulk density of Fritz almonds was the highest due to its high moisture content. The densities of each fractions are also listed in Table C.1.

Figure C.1 Almonds from off-ground harvest (left) and conventional harvest (right)

Table C.1 Initial characteristics (weight ratio, bulk density, and insect damage) of almonds before drying

| Dryer types | Variety | Weight ratio (as is) | | | Bulk density (kg/m3) | | | | Insect damage (%, based on numbers of kernels) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | In-hull | In-shell | hull | Overall | In-hull | In-shell | hull | Conventional | Off-ground |
| Tunnel | Independence | 0.50 | 0.17 | 0.33 | 318.7 | 341.6 | 311.8 | 297.8 | 10.0 | 3.3 |
| Stadium | Monterey | 0.56 | 0.28 | 0.16 | 306.2 | 329.6 | 348.9 | 249.7 | 9.1 | 2.8 |
| Stadium | Fritz | 0.80 | 0.04 | 0.17 | 384.4 | 391.6 | 329.2 | 313.1 | 7.7 | 3.3 |
| Trailer | Monterey | 0.68 | 0.07 | 0.25 | 280.3 | 296.0 | 301.3 | 169.2 | 2.0 | 0.8 |

The overall moisture contents of the four batch almonds ranged from 20.0 to 44.3% with Fritz almonds for stadium drying being the highest while Monterey almonds for trailer drying being the lowest (Table C.2). In general, the in-hull almonds had much higher average moistures (17.9 to 42.3%) with wider ranges than the in-shell almonds (9.4 to 18.2%) due to the high moisture of hulls (Table C.2).  The kernel moistures of in-hull almonds were higher than those of in-shell almonds (13.8 vs. 9.6, 13.9 vs. 11.3, 19.8 vs. 16.2, and 8.0 vs. 7.8% for four batches, respectively). Detailed information about the initial moisture contents and their distributions of each component (hull, shell, and kernel) for each batch can be found in Appendix H.1.

Table C.2 Summary of Initial moisture contents of the almond samples and the MC distributions of in-shell and in-hull almonds

| Type of dryer | Variety | Category | Whole almond $MC_{wb}$ (%) | | Kernel $MC_{wb}$ (%) | |
|---|---|---|---|---|---|---|
| | | | Average | Range | Average | Range |
| Tunnel | Independence | In hull | 39.9 | 21.0-57.9 | 13.8 | 6.3-25.8 |
| | | In shell | 10.7 | 7.3-15.9 | 9.6 | 6.0-13.7 |
| | | Hull | 48.1 | N/A | N/A | N/A |
| | | Overall | **37.6** | N/A | 12.9 | 6.0-25.8 |
| Stadium | Monterey | In hull | 26.2 | 9.9-51.4 | 13.9 | 4.5-29.2 |
| | | In shell | 12.6 | 8.1-21.1 | 11.3 | 5.2-24.7 |
| | | Hull | 38.8 | N/A | N/A | N/A |
| | | Overall | **24.4** | N/A | 12.6 | 4.5-29.2 |
| | Fritz | In hull | 42.3 | 17.0-65.3 | 19.8 | 5.7-35.2 |
| | | In shell | 18.2 | 10.8-32.4 | 16.2 | 8.1-31.0 |
| | | Hull | 57.2 | N/A | N/A | N/A |
| | | Overall | **44.3** | N/A | 17.7 | 5.7-35.2 |
| Trailer | Monterey | In hull | 17.9 | 9.6-48.9 | 8.0 | 5.1-27.1 |
| | | In shell | 9.4 | 6.4-24.9 | 7.8 | 5.0-19.5 |
| | | Hull | 28.6 | N/A | N/A | N/A |
| | | Overall | **20.0** | N/A | 8.0 | 5.0-27.1 |

## C.2 Drying performance

The moisture content and drying rate profiles were determined through the entire drying periods for all three types of dryers under different conditions. In general, high temperature reduced the drying time and high initial moisture contributed to long drying time needed.

As examples, Figures C.2 and C.3 show the moisture content and drying rate profiles of kernels (from in-shell and in-hull, and overall) and almonds (hull, in-shell, in-hull, and overall) from the tunnel hot air drying. The hulls and in-hull almonds had higher drying rates than in-shell almonds, but they needed longer drying times to reach the required moistures as they had higher initial moisture contents (Figure C.3). The moisture content differences among different fractions decreased gradually during the drying process (Figure 3.C).

The profiles of moisture content and drying rate of the other dryers and conditions were similar and can be found in Appendix H.2.

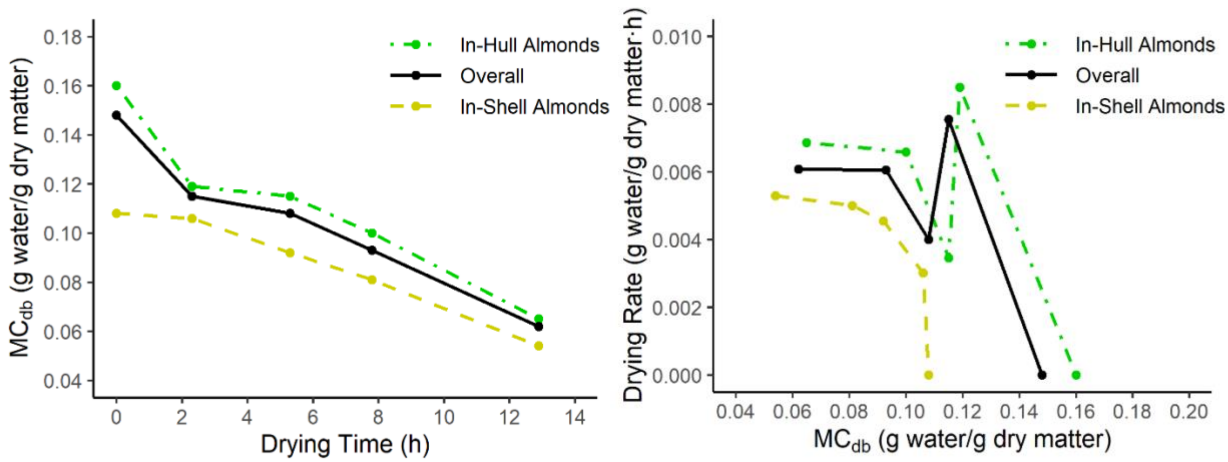


Figure C.2 Kernel moisture content (left) and drying rate (right) profiles of tunnel hot air drying

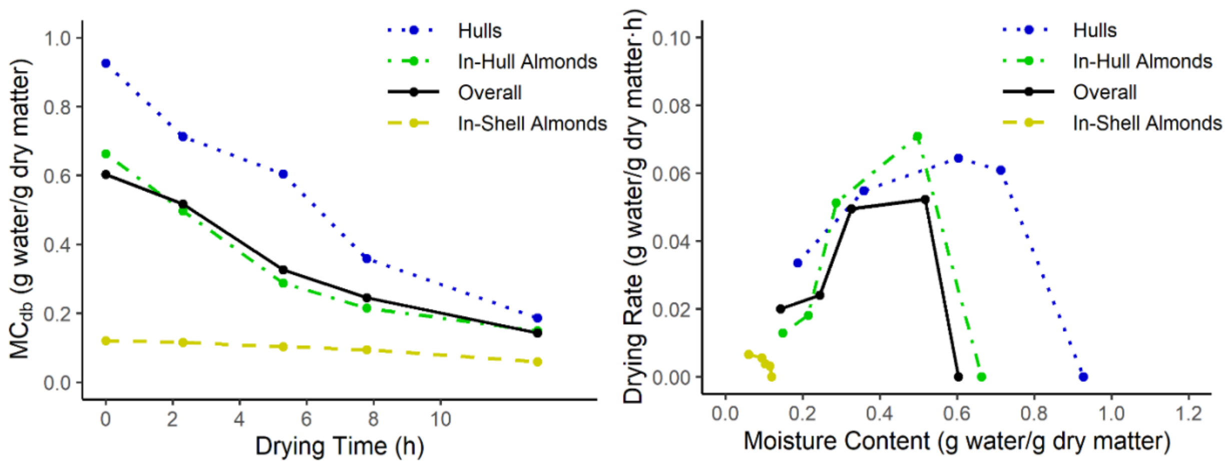


Figure C.3 Almond moisture content (left) and drying rate (right) profiles of tunnel hot air drying

It was found that the tunnel hot air drying used much shorter drying time (12.9 h) to reach even a lower moisture content (12.5%) than the tunnel ambient air drying of over 47 hours (Table C.3). The rapid drying with hot air was achieved with a steep rising period and a high rate at the constant period (Figures C.2 and C.3). It had drying rate of 0.036 (g water/g dry matter/hour) and the throughput of each drying tunnel of 1.54 ton/h (Table C.3). Therefore, it is important to use heated air drying for achieving high drying throughput. For the ambient air drying, the effect of starting time on drying was not clear since the entire drying was long, which took two days and nights.

Table C.3 Summarized drying performance of tunnel drying under three different conditions

| Condition | Initial $MC_{wb}$ (%) | | Final $MC_{wb}$ (%) | | Drying time (h) | Throughput per tunnel (ton/h) | Drying rate (g/g·h) |
|---|---|---|---|---|---|---|---|
| | Overall | Kernel | Overall | Kernel | | | |
| Ambient air started at daytime | 37.6 | 12.9 | 16.8 | 7.8 | 51.8 | 0.35 | 0.008 |
| Ambient air started at nighttime | 37.6 | 12.9 | 17.9 | 8.0 | 47.5 | 0.38 | 0.008 |
| Hot air at 115°F | 37.6 | 12.9 | 12.5 | 5.8 | 12.9 | 1.54 | 0.036 |

For stadium drying, the drying times from their initial moisture contents to kernel moisture content of about 4% were from 16.3 to 17.7 h for Monterey and 48.0 h for Fritz. The long drying time for Fritz was due to extremely high initial moisture because it was harvested too early (Table C.4). The overall drying rate of Fritz was 0.015 g/g·h and slightly higher than that of Monterey at 0.014 g/g·h due to the difference in initial moistures.

Table C.4 Summarized drying performance of stadium drying using two different varieties

| Variety | Initial $MC_{wb}$ (%) | | Final $MC_{wb}$ (%) | | Drying time (h) | Throughput per stadium (ton/h) | Drying rate (g/g·h) |
|---|---|---|---|---|---|---|---|
| | Overall | Kernel | Overall | Kernel | | | |
| Monterey | 24.4 | 12.6 | 7.8 | 3.9 | 16.9 | 0.42 | 0.014 |
| Fritz | 44.3 | 17.7 | 6.5 | 3.8 | 48.0 | 0.16 | 0.015 |

For the trailer drying of Monterey, the drying times were 6.5 and 5.8 h at temperatures of 110°F and 130°F, respectively, with corresponding kernel moisture contents of 4.8% and 4.1% (Table C.5). When the drying temperature increased from 110°F to 130°F, the drying time was reduced from 6.5 to 5.8 hours with a higher drying rate and throughput of 2.28 ton/h. It is important to notice that the almonds dried at 130°F had much lower final moisture and the drying time could be much shorter if the almonds were dried to the same moisture.

Table C.5 Summarized drying performance of trailer drying under two different conditions

| Condition | Initial $MC_{wb}$ (%) | | Final $MC_{wb}$ (%) | | Drying time (h) | Throughput per trailer (ton/h) | Drying rate (g/g·h) |
|---|---|---|---|---|---|---|---|
| | Overall | Kernel | Overall | Kernel | | | |
| Hot air at 110°F | 20.0 | 8.0 | 8.3 | 4.8 | 6.5 | 2.06 | 0.025 |
| Hot air at 130°F | 20.0 | 8.0 | 7.8 | 4.1 | 5.8 | 2.28 | 0.037 |

## C.3 Quality of Dried Almond

### C.3.1 Final moisture content distribution of in-hull and in-shell almonds

The moisture content distributions of dried in-hull and in-shell almonds from both off-ground harvest and conventional harvest were measured and the results are shown in Appendix H.3. As the summary, the moisture distributions were in wide ranges (3.6-31.1, 3.2-9.7, 3.2-16.6, and 1.6-11.9% for Independence almonds after tunnel drying, Monterey almonds after stadium drying, Fritz almonds after stadium drying, and Monterey almonds after trailer drying, respectively). For tunnel drying, the in-hull almonds (8.4-25.2, 8.5-31.1, and 7.9-20.9% for ambient air drying started at daytime, ambient air drying started at nighttime, and hot air drying, respectively) had wider moisture ranges than the in-shell almonds (5.2-10.5, 6.1-12.9, and 3.6-10.2% for ambient air drying started at daytime, ambient air drying started at nighttime, and hot air drying, respectively). The tunnel hot air drying produced the products with narrower range of moisture distribution compared to ambient air drying. For different components after commercial drying, hull remained the wettest (5.1-39.4%) while shell (1.1-20.0%) and kernel (1.2-16.1%) became close.

### C.3.2 Cavity and kernel color

No cavity was observed for the samples from both the conventional harvest and off-ground harvest followed by mechanical drying. The sutures at the center of almond kernels remained intact (Figure C.4).

The kernel color was represented by the Whiteness Index (WI). There were no significant differences in color for the dried and fresh products from both harvesting methods (p-value > 0.05). Detailed information about the whiteness index of in-hull and in-shell almonds from different commercial dryers and conditions is shown in Appendix H.4 as reference.

For tunnel drying of Independence, the average whiteness index values were 77.5, 77.4, 77.6, 78.5, and 77.5 for almonds from conventional harvest, off-ground harvest, ambient air drying started at daytime, ambient air drying started at nighttime, and hot air drying, respectively. For stadium drying of Monterey, the values were 80.4, 80.9, and 80.0 for conventional harvest, fresh, and hot air drying, respectively. For stadium drying of Fritz, the values were 79.5, 80.9, and 80.8, for conventional harvest, fresh, and hot air drying, respectively. For trailer drying of Monterey, the values were 80.0, 79.9, 80.0, and 80.3, for conventional harvest, fresh, hot air drying at 110°F, and hot air drying at 130°F, respectively. It appeared that Independence was slightly darker than the other two varieties.

Figure C.4 Cavity inspection (left) and kernel color measurement (right) of samples after commercial hot air drying

### C.3.3 Concealed damage

The occurrence of concealed damage was evaluated based on the color development (CD) score after roasting. There were no significant differences in CD scores for all samples from both harvest methods (p-value > 0.05). Detailed information about the concealed damage scores of in-hull and in-shell almonds from different commercial dryers and conditions can be found in Appendix H.5 as reference.

As an example, the CD scores of tunnel dried almonds were 2.6 ± 0.8 and 2.8 ± 0.8 for in-shell and in-hull almonds, respectively, (Figure C.5.) The average CD scores of all tested conditions were less than 3 with low standard deviation, indicating no concealed damage for both harvest methods.

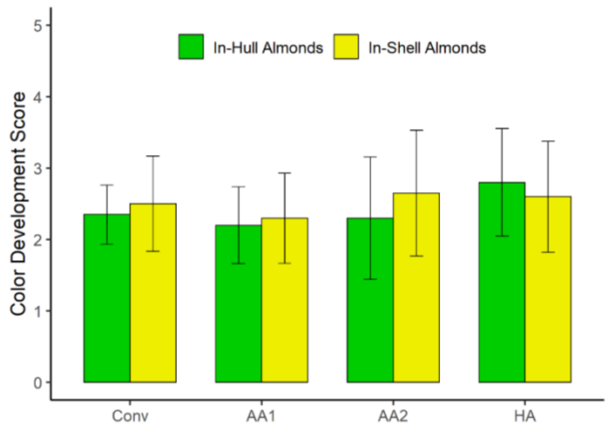


Figure C.5 Color development score results (left); Color development of samples from commercial hot air drying (right)

### C.3.4 Oil quality

The oil quality was evaluated using the Peroxide Value (PV) and Free Fatty Acid (FFA) content. The industrial standards of peroxide value and free fatty acid are 5 meq/kg and 1.5% of respectively. The PV and FFA values of all samples were far below the standards.

For tunnel drying, hot air dried almonds had higher PV than the fresh almonds, but the difference was small, while the difference between hot air dried and conventional harvested almonds was not significant. However, the conventional harvested almonds had a higher FFA than the other samples (Table C.6).

Table C.6 Summary of oil quality analyses for tunnel drying test

| Oil quality | | Fresh | Conv | AA1 | AA2 | HA |
|---|---|---|---|---|---|---|
| PV (meq/kg) | Ave | 0.798a | 0.979ab | 0.890a | 0.894a | 1.084b |
| | Std | 0.044 | 0.004 | 0.138 | 0.078 | 0.094 |
| FFA (%) | Ave | 0.135a | 0.202b | 0.138a | 0.140a | 0.130a |
| | Std | 0.007 | 0.019 | 0.005 | 0.006 | 0.004 |

Note: The same letters in the row means no significnat difference (P>0.05)

Table C.7 shows the oil quality of almnds from the stadium drying. The peroxide values were 1.109 and 1.092 meq/kg for hot air dried Monterey and Fritz, respectively (Table C.7). There was no significant difference in peroxide values among the samples from fresh harvest, hot air drying, and the conventional harvest. In contrast, the free fatty acid levels of samples from hot air drying (0.130 and 0.136% for Monterey and Fritz, respectively) were significantly lower than that from the conventional harvest (Table C.7), indicating a better quality.

Table C.7 Summary of oil quality analyses for stadium drying test

| Oil quality | | Fritz | | | Monterey | | |
|---|---|---|---|---|---|---|---|
| | | Fresh | Conv | HA | Fresh | Conv | HA |
| PV (meq/kg) | Ave | 0.875a | 0.950a | 1.109a | 1.008a | 0.775a | 1.092a |
| | Std | 0.012 | 0.066 | 0.391 | 0.035 | 0.035 | 0.217 |
| FFA (%) | Ave | 0.140b | 0.183c | 0.130a | 0.273b | 0.164c | 0.136a |
| | Std | 0.010 | 0.005 | 0.002 | 0.001 | 0.000 | 0.002 |

Note: The same letters in the row means no significnat difference (P>0.05)

For the trailer drying, the dried almonds had an average peroxide value of 1.332 and 1.828 meq/kg for 110°F and 130°F, respectively (Table C.8). The peroxide values for hot air drying were slightly higher than that of conventional harvested and fresh samples but far less than industrial standard of 5 meq/kg. Simlarly, the free fatty acid levels of allmonds from hot air drying was 0.259 and 0.311% for 110°F and 130°F, respectively, and were also higher than those of the conventional harvest and fresh samples but far less than industrial standard of 1.5% (Table C.8). The high numbers of PC and FFA might be due to the low initial moisutre of the almonds. It is important to conduct further study to confirm the cause.

Table C.8 Summary of oil quality analyses for trailer drying study

| Oil quality | | Fresh | Conv | 110°F | 130°F |
|---|---|---|---|---|---|
| PV (meq/kg) | Ave | 0.854a | 0.814a | 1.332b | 1.828c |
| | Std | 0.018 | 0.022 | 0.035 | 0.152 |
| FFA (%) | Ave | 0.145a | 0.178b | 0.259c | 0.311d |
| | Std | 0.003 | 0.005 | 0.008 | 0.001 |

Note: The same letters in the row means no significnat difference (P>0.05)

### C.4 Energy and cost analysis

The energy and cost analysis were conducted based on the utility use and charge rate obtained from the drying facilities. The overall energy cost was calculated based on whole dried almond weight and kernel weight, respectively, and presented as a range since the calculation used the electricity rates for peak and off-peak at 0.15 and 0.25 $/kwh.

In general, the energy cost of tunnel drying was less than 5 cents to produce one pound of dried products. The estimated energy costs of ambient air drying started at daytime, ambient air drying started at nighttime, and hot air drying were 2.7 to 4.5, 2.3 to 3.9, and 3.7 to 4.1 cents/lb of dried products, respectively (Table C.9). The overall energy costs of hot air and ambient air drying were similar since the electricity use of long drying time of ambient air drying contributed to the results even it did not energy for heating.

For the stadium drying, the estimated energy costs of drying Monterey and Fritz were 1.5 to 2.0 and 4.9 to 6.5 cents/lb, respectively (Table C.9). The high drying cost of Fritz was due to its high initial moisture and long drying time.

For trailer drying, the energy costs at 110°F and 130°F drying were 0.21 to 0.25 and 0.46 to 0.50 cents/lb, respectively (Table C.9). These numbers are very low due to the low initial moisture and short drying times.

Table C.9 Summary of energy consumption and cost analysis for tunnel drying

| Condition | Electricity | | Natural gas | | Specific energy consumption (MJ/kg) | Overall cost (cents/lb dried almonds) | Overall cost (cents/lb dried kernels) |
|---|---|---|---|---|---|---|---|
| | Use (kwh per tunnel) | Cost (cents/lb dried kernels) | Use ($m^3$ per tunnel) | Cost (cents/lb dried kernels) | | | |
| Ambient air started at daytime | 1596.2 | 2.7-4.5 | 0.0 | 0.0 | 1.3 | 0.86-1.43 | 2.7-4.5 |
| Ambient air started at nighttime | 1463.7 | 2.3-3.9 | 0.0 | 0.0 | 1.5 | 0.79-1.32 | 2.3-3.9 |
| Hot air | 397.5 | 0.6-1.0 | 1008.5 | 3.1 | 6.9 | 1.32-1.46 | 3.7-4.1 |

Table C.10 Summary of energy consumption and cost analysis for stadium drying

| Variety | Electricity | | Natural gas | | Specific energy consumption (MJ/kg) | Overall cost (cents/lb dried almonds) | Overall cost (cents/lb dried kernels) |
|---|---|---|---|---|---|---|---|
| | Use (kwh per bin) | Cost (cents/lb dried kernels) | Use ($m^3$ per bin) | Cost (cents/lb dried kernels) | | | |
| Monterey | 152.1 | 0.7-1.2 | 72.9 | 0.8 | 2.5 | 0.39-0.52 | 1.5-2.0 |
| Fritz | 432 | 2.4-4.0 | 206.9 | 2.5 | 3.1 | 1.44-1.91 | 4.9-6.5 |

Table C.11 Summary of energy consumption and cost analysis for trailer drying

| Condition | Electricity | | Propane | | Specific energy consumption (MJ/kg) | Overall cost (cents/lb dried almonds) | Overall cost (cents/lb dried kernels) |
|---|---|---|---|---|---|---|---|
| | Use (kwh per trailer) | Cost (cents/lb dried kernels) | Use ($m^3$ per trailer) | Cost (cents/lb dried kernels) | | | |
| 110°F | 36.1 | 0.06-0.11 | 0.08 | 0.15 | 1.2 | 0.07-0.09 | 0.21-0.25 |
| 130°F | 31.9 | 0.07-0.11 | 0.19 | 0.40 | 2.9 | 0.15-0.16 | 0.46-0.50 |

## D. Discussion and conclusions

Based on the obtained results, the following conclusions are drawn:

***Initial characteristics of fresh harvested almonds:*** The off-ground harvested almonds were much cleaner with less foreign materials like dust, leaves, rocks, and branches compared to the conventionally harvested almonds. Among the three fractions (hull, in-shell almonds, and in-hull almonds), in-hull almonds were the largest proportion of total mass. The initial moisture content of in-hull almonds was much higher than that of in-shell almonds. Hulls had the highest moisture content. Additionally, in-shell almonds had much uniform moisture distribution compared to in-hull almonds, which resulted in uniform moisture for the dried products. Moreover, compared to the conventional harvest, the off-ground harvest led to a huge reduction in insect damage.

***Drying performance and cost:*** The drying time to dry off-ground harvested almonds from their initial moistures to kernel moisture of about 6% differed depending upon the initial moisture content, almond variety, dryer type and drying conditions. Hot air drying at high temperature achieved high drying rate and short drying time. For tunnel drying, the drying time ranged from 12.9 to 51.8 hours and hot air drying had the higher drying rate than ambient drying. At the temperature of 115°F, it took less than 12.9 hours (74% shorter than ambient air drying) to dry almonds to kernel MC of 5.8% with the energy cost ranging from 3.7 to 4.1 cents/lb of dried kernels, which was 15% higher than that of ambient air drying (2.3-4.5 cents/lb). For stadium drying, it took 16.9 to dry the off-ground harvested Monterey from their initial MC of 24.4% to MC of about 4% kernel moisture with drying cost ranging from 1.5 to 2.0 cents/lb of dried kernels. While, Fritz almonds with very high initial moisture had much longer drying time (48 h) to reach to final kernel MC of 3.8%. The extended drying time resulted in higher energy cost ranging from 4.9 to 6.5 cents/lb. For trailer drying, the drying time ranged from 5.8 to 6.5 hours with energy cost ranging from 0.21 to 0.50 cents/lb of dried kernels to dry the almonds from their initial moisture of 20.0% to kernel moisture of about 4.5%. Compared to 110°F, the hot air drying at 130°F had 11% shorter drying time (5.8 and 6.5 h for 130°F and 110°F, respectively) but 109% higher energy cost (0.46-0.50 and 0.21-0.25 cents/lb of dried kernels 130°F and 110°F, respectively).

***Quality of dried almonds:*** Under all tested dryers and conditions, there were no cavity, kernel color change and concealed damage for all tested almond varieties. The oil quality indicators, including Peroxide Value (PV) and Free Fatty Acid (FFA), varied among the dyer types, drying conditions and varieties. However, the PV and FFA values of dried almonds under all tested conditions were far below the standards in the industry. But the low initial moisture may lead to increased value of PV and FFA which needs to be further studied.

In conclusion, the tested commercial dryers can be used for drying off-ground harvested almonds with reasonable cost. However, a further study is needed to determine the optimum drying conditions to improve the drying efficiency and reduce drying time and cost.

## E. Materials and methods

Three different types of commercial dryers, including tunnel dryers at Campos Brother Farms, Caruthers, CA; stadium dryer at Emerald Farm, Maxwell, CA; and trailer dryer at West Valley Hulling Company, Firebaugh, CA. were used to conduct the drying tests (Figure E.1). Table E.1. shows the detailed information about drying facility, almond variety, harvest time, and drying conditions.

The tunnel drying used six tunnels to dry Independence with three different drying conditions (two tunnels for each condition), including ambient air drying started at the daytime, ambient air drying started at the nighttime, and hot air drying at 46°C (115°F). The air velocity for all three conditions was 1 m/s. The stadium drying used four bins (three assigned to Monterey and one to Fritz) with the air temperature of 35°C and air velocity of 0.7 m/s. The trailer drying used four trailers to dry Monterey at two different drying conditions (two trailers for each condition) at 43°C (110°F) and 54°C (130°F), respectively, with air velocity at 1.2 m/s. In total, seven different tests were conducted for commercial drying of off-ground harvested almonds using three existing drying facilities.

Figure E.1 Tunnel dryers (left), Stadium dryers (mid), and Trailer dryers (right)

Table E.1. Information of the almonds, dryers and drying conditions

| Dryer | Almond | | | Drying condition | |
|---|---|---|---|---|---|
| | Variety | Orchard | Harvest date | Type of drying | Air velocity |
| | | | | Ambient air started at daytime | 1 m/s |
| Tunnel | Independence | JY Farm | 08/15 | Ambient air started at nighttime | 1 m/s |
| | | | | Hot air at 46°C (115°F) | 1 m/s |
| Stadium | Monterey | Emerald Farm | 09/23 | Hot air at 35°C (95°F) | 0.7 m/s |
| | Fritz | Emerald Farm | 09/23 | Hot air at 35°C (95°F) | 0.7 m/s |
| Trailer | Monterey | Bakers Farm | 10/08 | Hot air at 43°C (110°F) | 1.2 m/s |
| | | | | Hot air at 54°C (130°F) | 1.2 m/s |

Almonds were harvested using two different methods, off-ground harvest and conventional harvest. The harvested almonds were considered having three fractions: in-hull almonds, in-shell almonds, and hulls. Figure E.2. shows the experimental procedures. The conventional harvest left almonds on the ground for about 10 days for natural drying. Only natural dried almonds from conventional harvest were sampled. For off-ground harvest tests, fresh almonds (initial samples), almonds during drying, and almonds after drying (dried products) were collected.

For the off-ground harvest, fresh almonds (around 600 pieces) from each batch (Independence for tunnel drying, Monterey for stadium drying, Fritz for trailer drying, and Monterey for trailer drying) were collected for determination of the initial characteristics, including moisture content, bulk density, weight ratio of fractions, insect infestation, kernel color and oil quality. Moisture contents of different components (hull, shell, kernel) of 30 in-hull and 30 in-shell almonds were measured individually for the comparison of moisture distributions of fresh in-hull and in-shell almonds. Overall and kernel moisture contents of a mixture (around 60 samples) were determined and used to derive the drying curves (as the initial timestep t0).

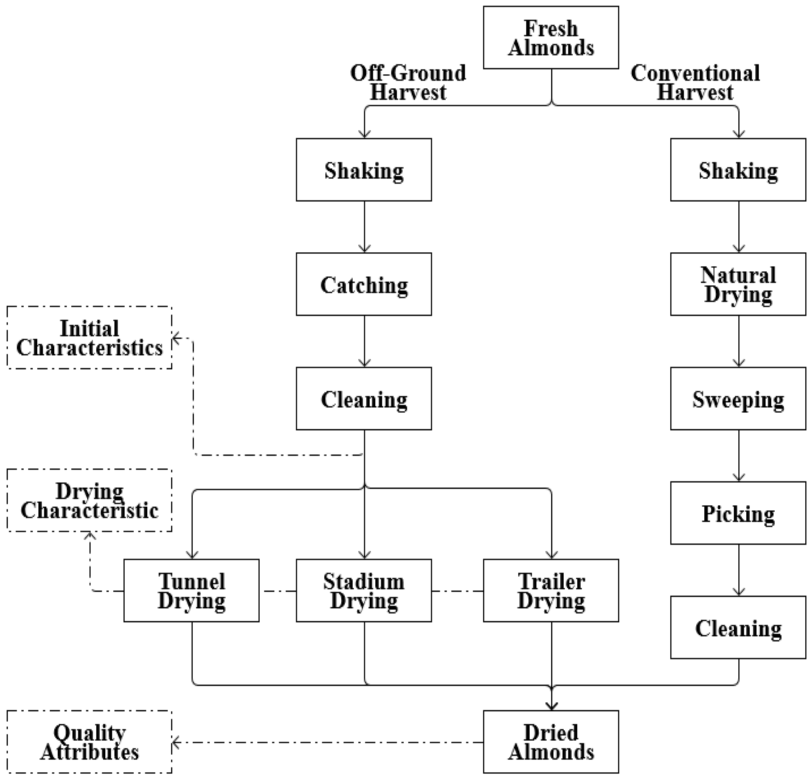


Figure E.2 Flow diagram of the research approach

For tunnel drying, 150 almonds from accessible locations of each drying unit, i.e., mid and bottom bins at air inlet/outlet of each tunnel (Figure E.1), top layer of each bin of stadium dryer, and top layer of each trailer, were collected at four different timesteps (t1, t2, t3, and t4 at the end of drying). Almonds were collected from 0.2 meters under the surface at center of each bin using a 1L plastic beaker.  The composite samples were produced using relevant samples. Overall and kernel moisture contents of a composite samples (around 60 samples) were then measured for the drying curve development. Drying characteristics, including drying time, throughput, ambient temperature/relative humidity (RH) of air, air temperature/velocity, and energy use were recorded.

After drying, around 600 dried almonds were obtained for each composite samples of each tests (7 tests in total). Thirty in-hull and thirty in-shell almonds were randomly picked and manually separated into different components for moisture content distributions of dried in-hull and in-shell almonds. Overall and kernel moisture contents of the samples were determined. The quality was evaluated based on cavity, concealed damage, kernel color, and oil quality of the dried products.

The moisture content was measured using the standard oven drying method (105°C and 24 h). The insect damage rate of almonds was quantified as the percentage of the numbers of insect damaged kernels in a 150 kernels sample (Figure E.3). Incidence of cavity was visually inspected by cutting 10 in-shell and 10 in-hull kernels of each sample into halves at the cross-section. For kernel color measurement, 20 kernels (10 in-shells and 10 in-hulls) from each sample were opened into halves at the suture. The color at the center of core was determined in L*a*b* color space using Minolta Chroma Meter CM700d (Minolta Crop., Ramsey, Japan) and then converted into the whiteness index (WI) using the following equation (Pathare et al., 2013):

$$\mathrm{WI} = 100 - \sqrt{(100 - L)^2 + a^2 + b^2}$$

The concealed damage was evaluated by splitting 10 in-shell and 10 in-hull kernels of each sample after roasting (135°C, 90 mins) and inspecting the color development score using the reference (Figure E.3) (Pearson, T.C., 1998). To assess the oil quality, the almond oil was extracted from the 10 kernels of each sample using hexane. Peroxide value and free fatty acid content of the oil were determined using potentiometer according to the AOCS (American Oil Chemists Society) official methods Cd8-53 and Ca5a-40, respectively.

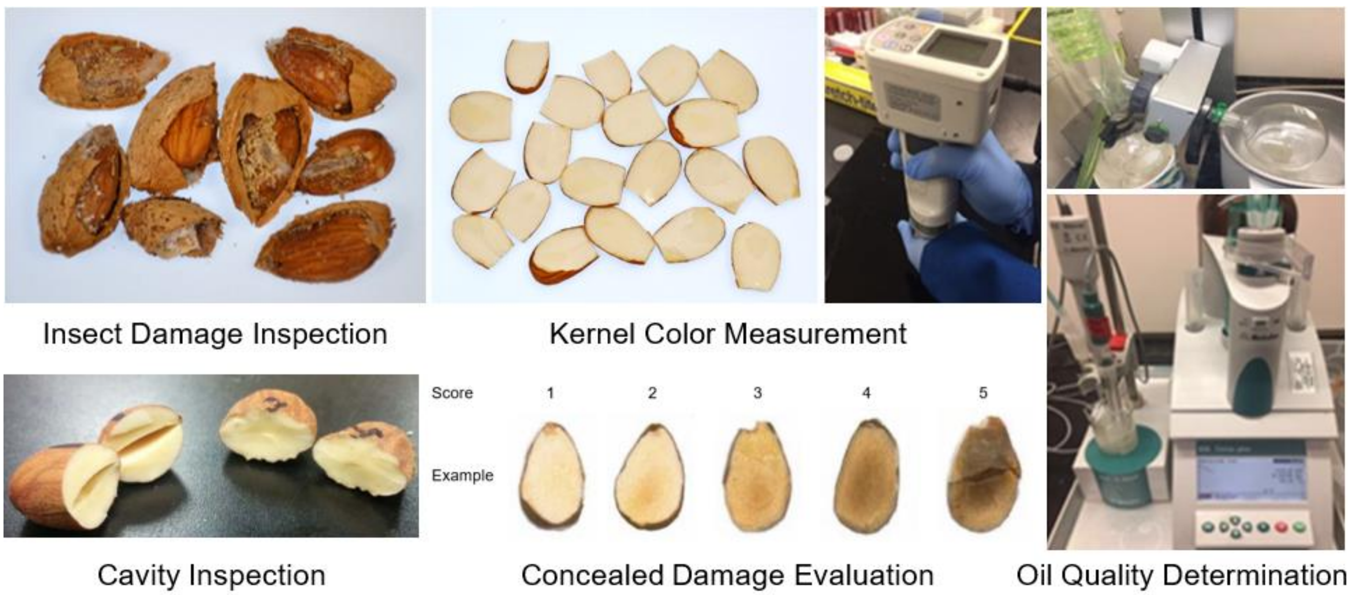


Figure E.3 Measurements of quality attributes

For the energy use and cost analysis, the utility use of each drying test, consisting of natural gas or propane use for the burners and electricity use for the blowers, was calculated using the numbers obtained from the drying facilities. The energy costs (cents/lb of dried kernels) were then derived with charge rates of 0.15 $/kWh for off-peak, 0.25 $/kWh for peak, 90 cents/therm for natural gas and 0.584 $/gallon for propane, respectively.

## F. Publications that emerged from this work

The Almond Conference 2019, Sacramento, 12/10/19-12/12/19

1. Presentation: Efficient drying of off-ground harvested almonds without quality concerns,
2. Poster: Performance of commercial dryers for off-ground harvested almonds

Institute of Food Technologists (IFT) annual meeting 2020, Chicago, 07/12/20-07/15/20

1. Poster: Performance of commercial dryers for off-ground harvested almonds
2. Poster: Drying and quality characteristics of off-ground harvested almonds under hot air drying

American Society of Agricultural and Biological Engineers (ASABE) annual meeting 2020, Omaha, 07/12/20-07/15/20

1. Presentation: Drying performance and quality characteristics of off-ground harvested almonds dried using commercial dryers

## G. References cited


Pathare, P. B., Opara, U. L., & Al-Said, F. A. J. (2013). Colour measurement and analysis in fresh and processed foods: a review. *Food and bioprocess technology*, *6*(1), 36-60.

Pearson, T. C. (1998). *Detection and treatment of almonds with concealed damage* (Doctoral dissertation, University of California, Davis).

## Appendices

### H.1 Initial moisture content distribution

Tunnel drying

Table H.1 Summary of initial moisture contents of Independence in-hull and in-shell almonds for tunnel drying (ambient air started at daytime)

| $MC_{wb}$ (%) | Whole almond | | Kernel | | Shell | | Hull | |
|---|---|---|---|---|---|---|---|---|
| | Ave. | Range | Ave. | Range | Ave. | Range | Ave. | Range |
| In hull | 39.9 | 14.4-64.1 | 13.8 | 3.9-30.5 | 22.2 | 8.2-50.8 | 46.8 | 20.2-73.7 |
| In shell | 10.7 | 9.0-19.7 | 9.6 | 6.9-19.0 | 16.3 | 12.7-22.2 | N/A | N/A |

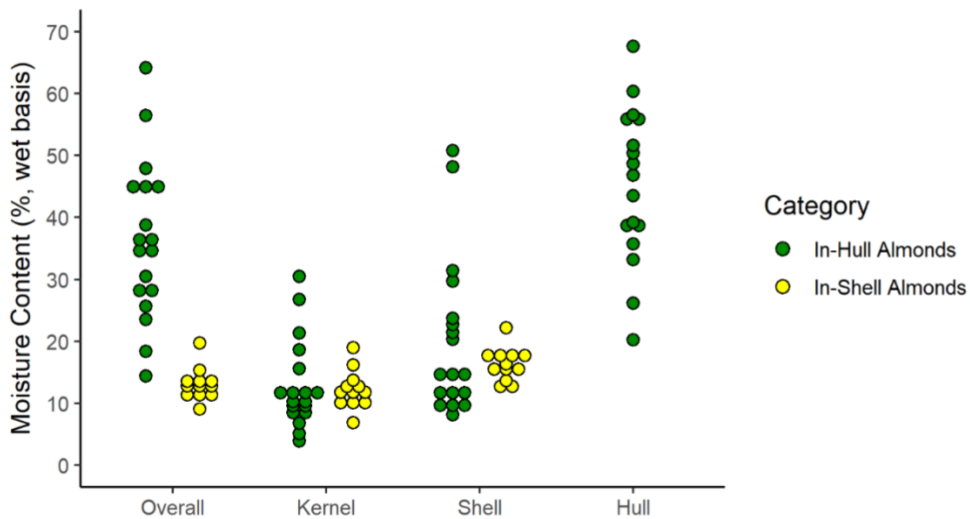


Figure H.1 Initial moisture content distributions of Independence in-hull and in-shell almonds for tunnel drying (ambient air started at daytime)

Table H.2 Summary of initial moisture contents of Independence in-hull and in-shell almonds for tunnel drying (ambient air started at nighttime)

| $MC_{wb}$ (%) | Whole almond | | Kernel | | Shell | | Hull | |
|---|---|---|---|---|---|---|---|---|
| | Ave. | Range | Ave. | Range | Ave. | Range | Ave. | Range |
| In hull | 39.0 | 17.6-58.7 | 14.1 | 5.8-23.6 | 19.5 | 8.9-34.1 | 50.6 | 27.2-73.1 |
| In shell | 14.5 | 11.0-24.3 | 13.5 | 10.1-23.1 | 16.7 | 10.8-27.3 | NA | NA |

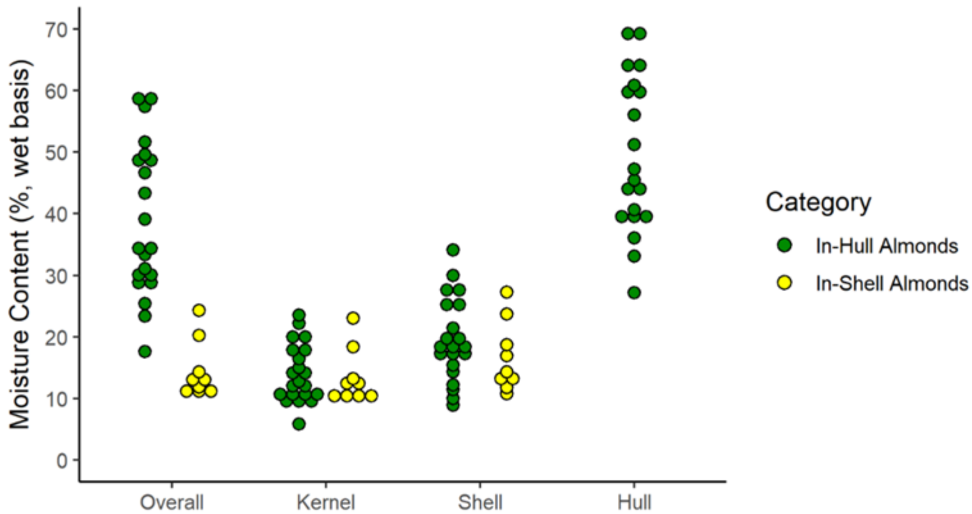


Figure H.2 Initial moisture content distributions of Independence in-hull and in-shell almonds for tunnel drying (ambient air started at nighttime)

Table H.3 Summary of initial moisture contents of Independence in-hull and in-shell almonds for tunnel drying (hot air)

| $MC_{wb}$ (%) | Overall | | Kernel | | Shell | | Hull | |
|---|---|---|---|---|---|---|---|---|
| | Ave. | Range | Ave. | Range | Ave. | Range | Ave. | Range |
| In hull | 37.2 | 21.0-57.9 | 13.3 | 6.3-25.8 | 19.4 | 11.1-37.8 | 49.4 | 30.5-70.8 |
| In shell | 10.6 | 7.3-15.9 | 9.5 | 6.0-13.7 | 13.6 | 9.6-21.2 | NA | NA |

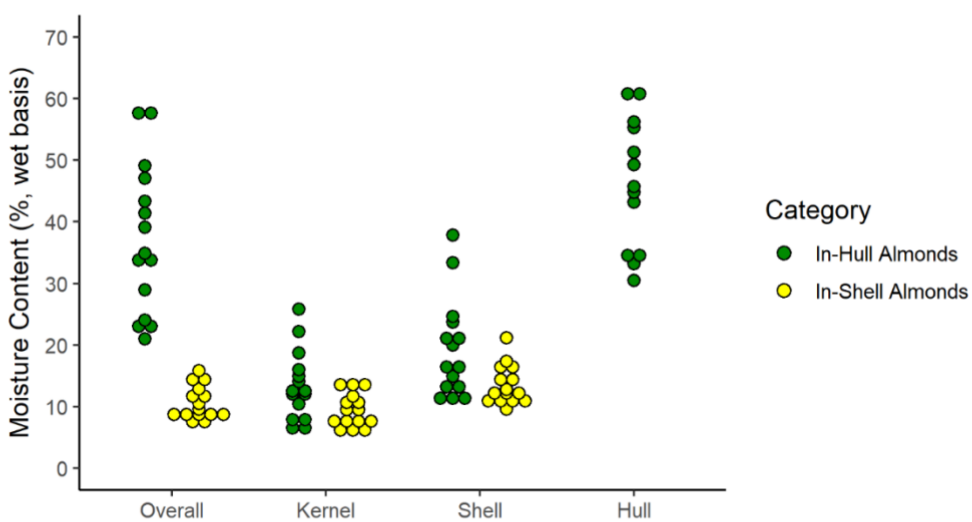


Figure H.3 Initial moisture content distributions of Independence in-hull and in-shell almonds for tunnel drying (hot air)

## Stadium drying

Table H.4 Summary of initial moisture contents of Monterey in-hull and in-shell almonds for stadium drying

| $MC_{wb}$ (%) | Whole almond | | Kernel | | Shell | | Hull | |
|---|---|---|---|---|---|---|---|---|
| | Ave. | Range | Ave. | Range | Ave. | Range | Ave. | Range |
| In hull | 26.2 | 9.9-51.4 | 13.9 | 4.5-29.2 | 17.2 | 8.5-42.0 | 35.7 | 13.8-66.1 |
| In shell | 12.6 | 8.1-21.1 | 11.3 | 5.2-24.7 | 13.6 | 10.2-19.1 | N/A | N/A |

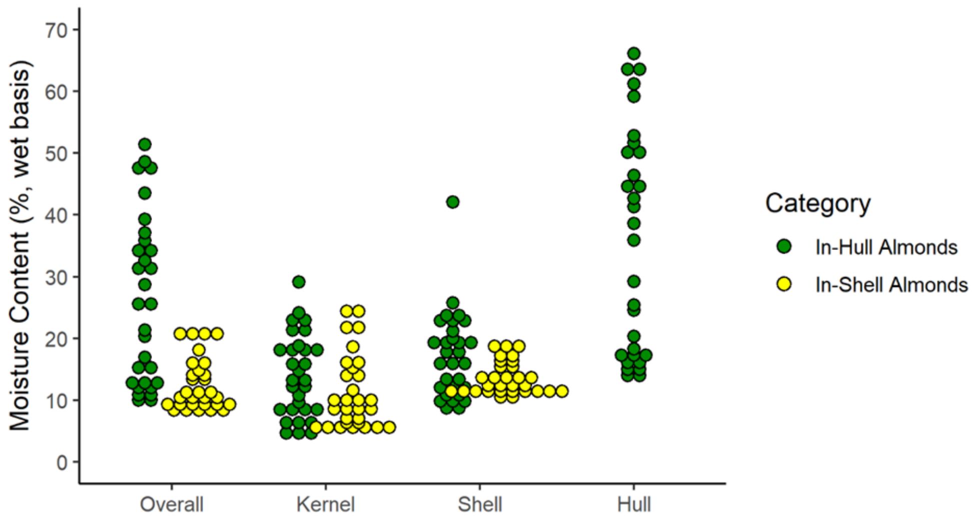


Figure H.4 Initial moisture content distribution of Monterey in-hull and in-shell almonds for stadium drying

Table H.5 Summary of initial moisture contents of Fritz in-hull and in-shell almonds for stadium drying

| Category | Whole almond $MC_{wb}$ (%) | | Kernel $MC_{wb}$ (%) | | Shell $MC_{wb}$ (%) | | Hull $MC_{wb}$ (%) | |
|---|---|---|---|---|---|---|---|---|
| | Ave. | Range | Ave. | Range | Ave. | Range | Ave. | Range |
| In hull | 42.3 | 17.0-65.3 | 19.8 | 5.7-35.2 | 26.5 | 10.6-41.6 | 53.3 | 24.1-78.2 |
| In shell | 18.2 | 10.8-32.4 | 16.2 | 8.1-31.0 | 20.6 | 13.6-34.3 | NA | NA |

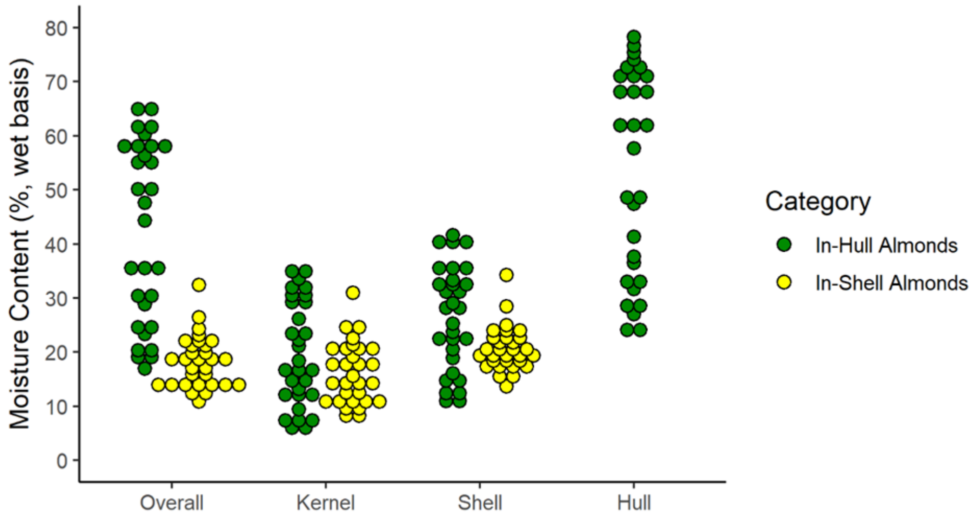


Figure H.5 Initial moisture content distribution of Fritz in-hull and in-shell almonds for stadium drying

## Trailer drying

Table H.6 Summary of initial moisture contents of Monterey in-hull and in-shell almonds for trailer drying

| Category | Whole almond $MC_{wb}$ (%) | | Kernel $MC_{wb}$ (%) | | Shell $MC_{wb}$ (%) | | Hull $MC_{wb}$ (%) | |
|---|---|---|---|---|---|---|---|---|
| | Ave. | Range | Ave. | Range | Ave. | Range | Ave. | Range |
| In hull | 17.9 | 9.6-48.9 | 8.0 | 5.1-27.1 | 10.3 | 6.9-31.4 | 25.8 | 14.8-68.6 |
| In shell | 9.4 | 6.4-24.9 | 7.8 | 5.0-19.5 | 11.2 | 0.7-30.1 | N/A | N/A |

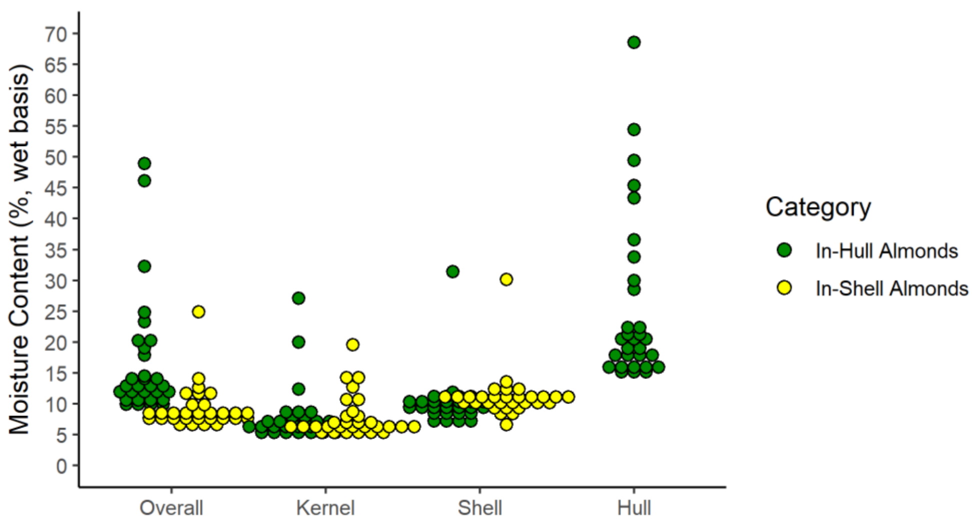


Figure H.6 Initial moisture content distribution of Monterey in-hull and in-shell almonds for trailer drying

## H.2 Moisture content and drying rate profile

Tunnel drying

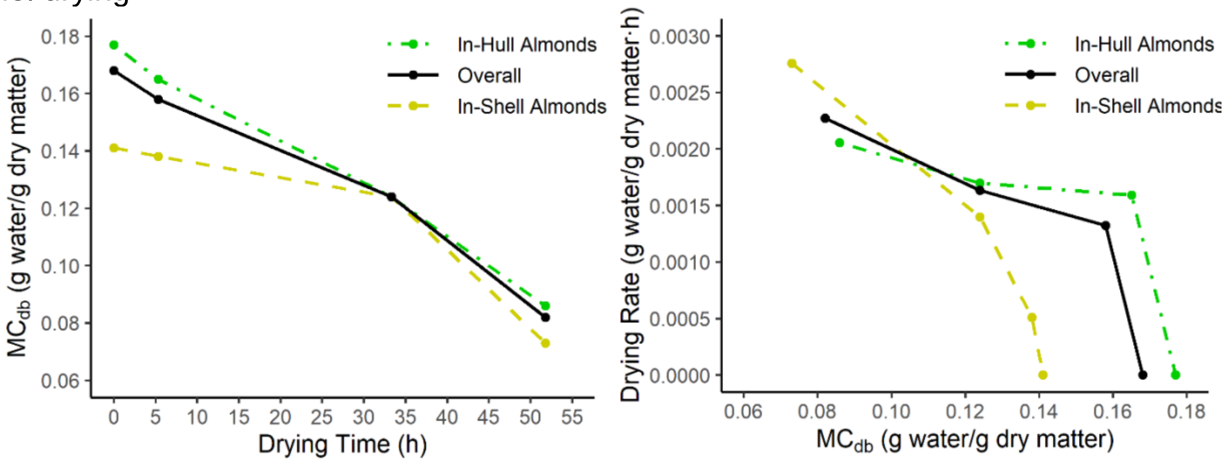


Figure H.7 Kernel moisture content (left) and drying rate (right) profiles for tunnel ambient air drying started at daytime

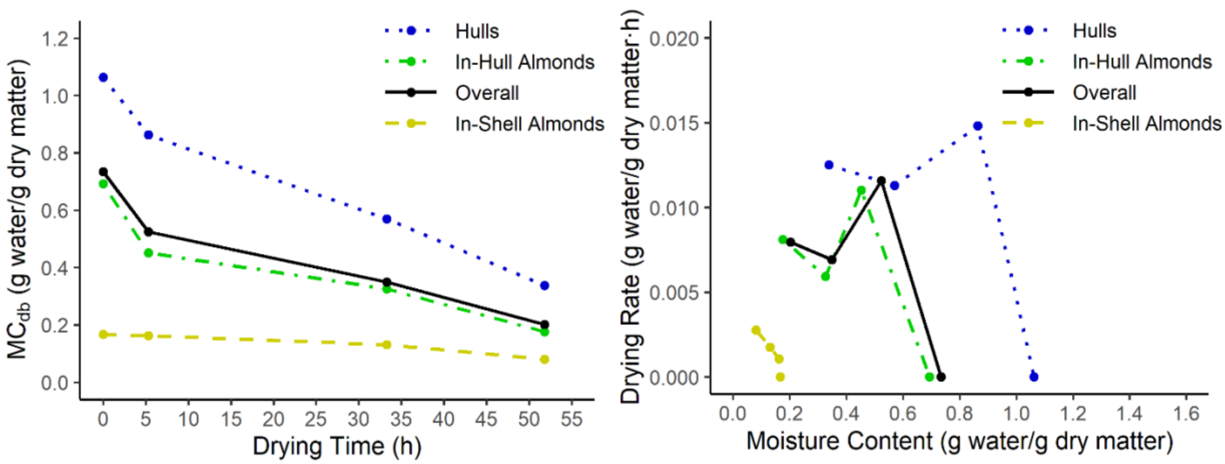


Figure H.8 Whole almond moisture content (left) and drying rate (right) profiles for tunnel ambient air drying started at daytime

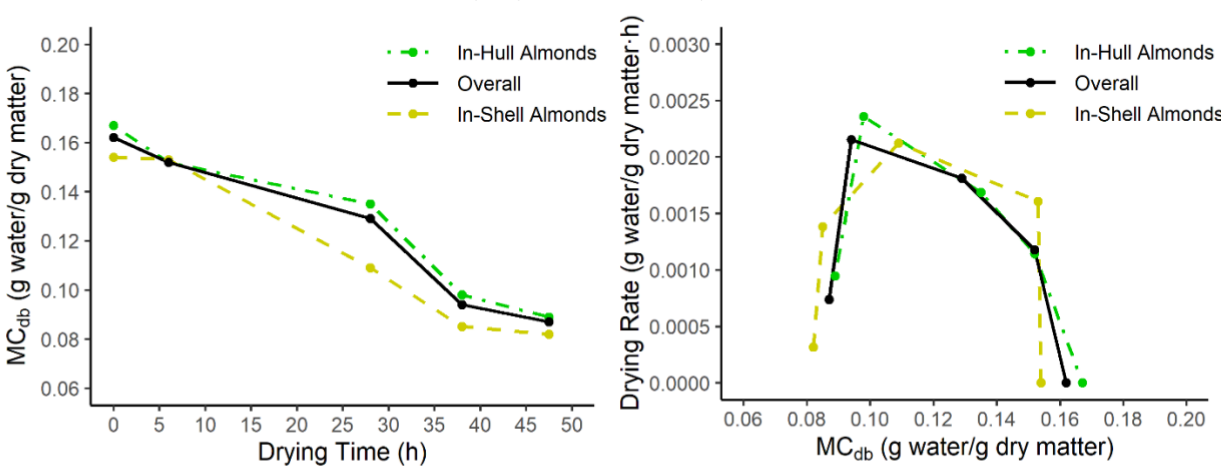


Figure H.9 Kernel moisture content (left) and drying rate (right) profiles for tunnel ambient air drying started at nighttime

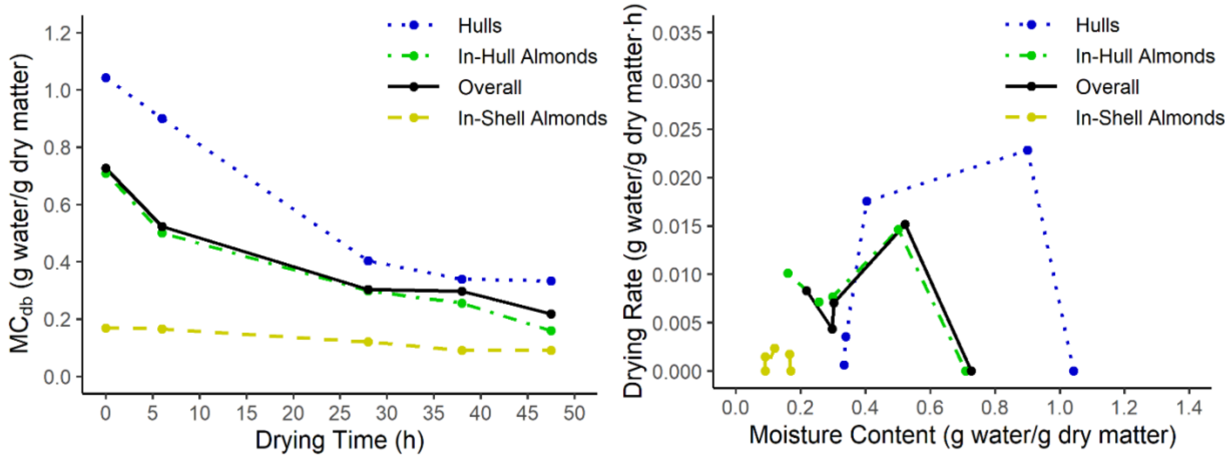


Figure H.10 Whole almond moisture content (left) and drying rate (right) profiles for tunnel ambient air drying started at nighttime

Stadium drying

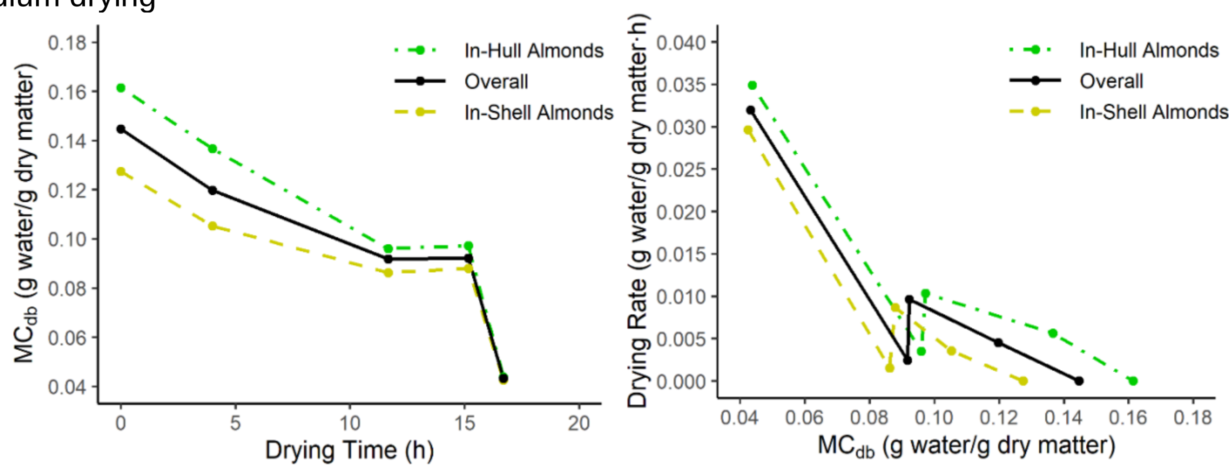


Figure H.11 Kernel moisture content (left) and drying rate (right) profiles for stadium drying of Monterey almonds

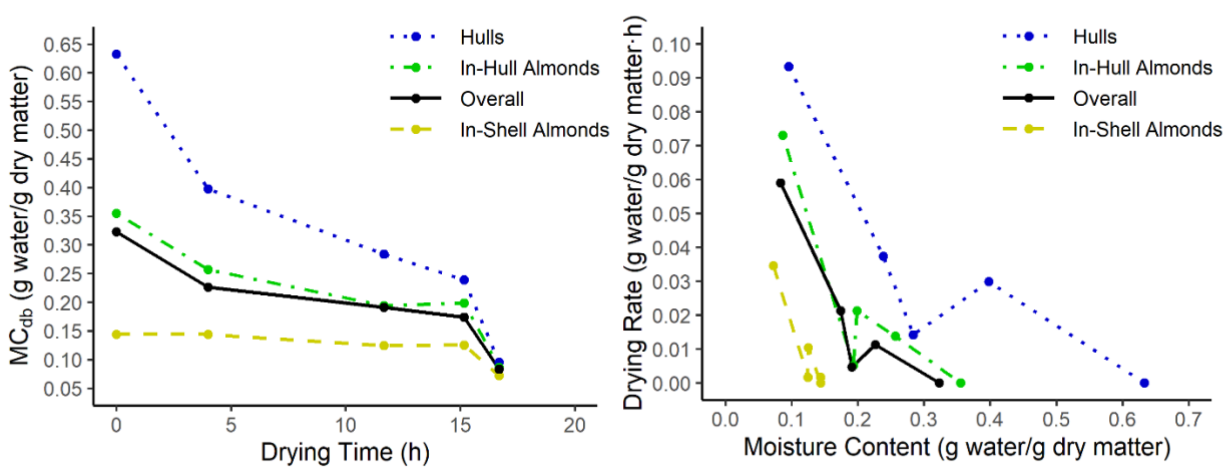


Figure H.12 Whole almond moisture content (left) and drying rate (right) profiles for stadium drying of Monterey almonds

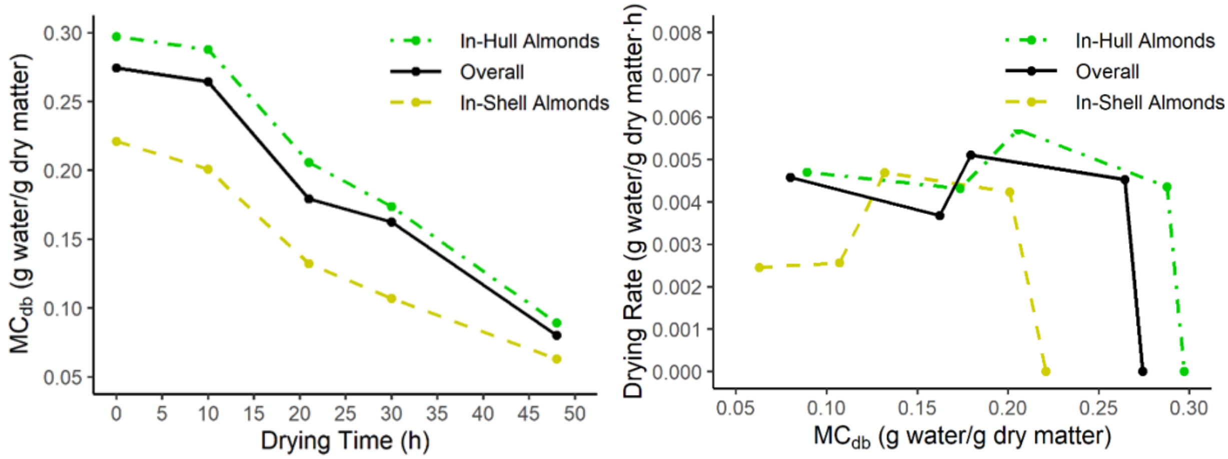


Figure H.13 Kernel moisture content (left) and drying rate (right) profiles for stadium drying of Fritz almonds

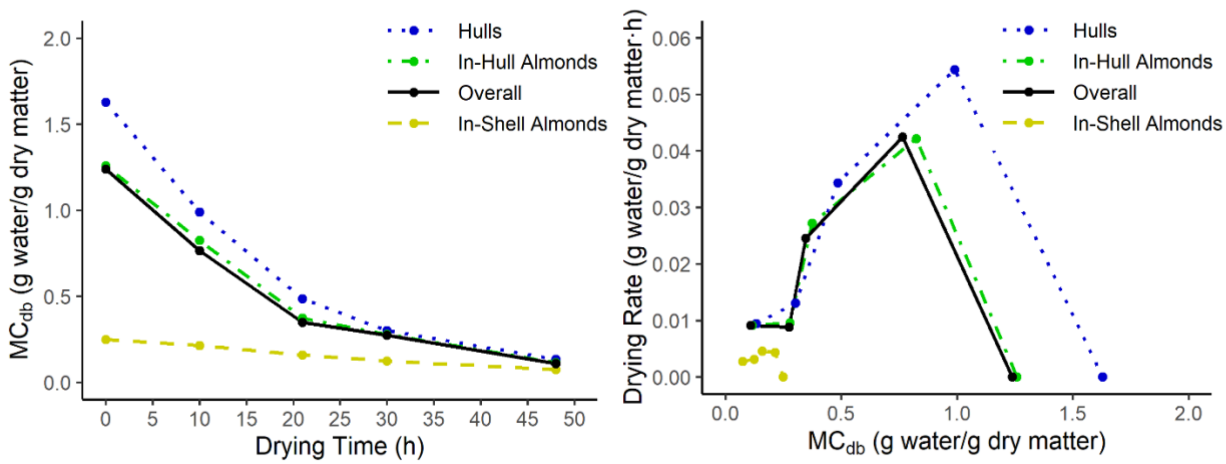


Figure H.14 Whole almond content (left) and drying rate (right) profiles for stadium drying of Fritz almonds

## Trailer drying

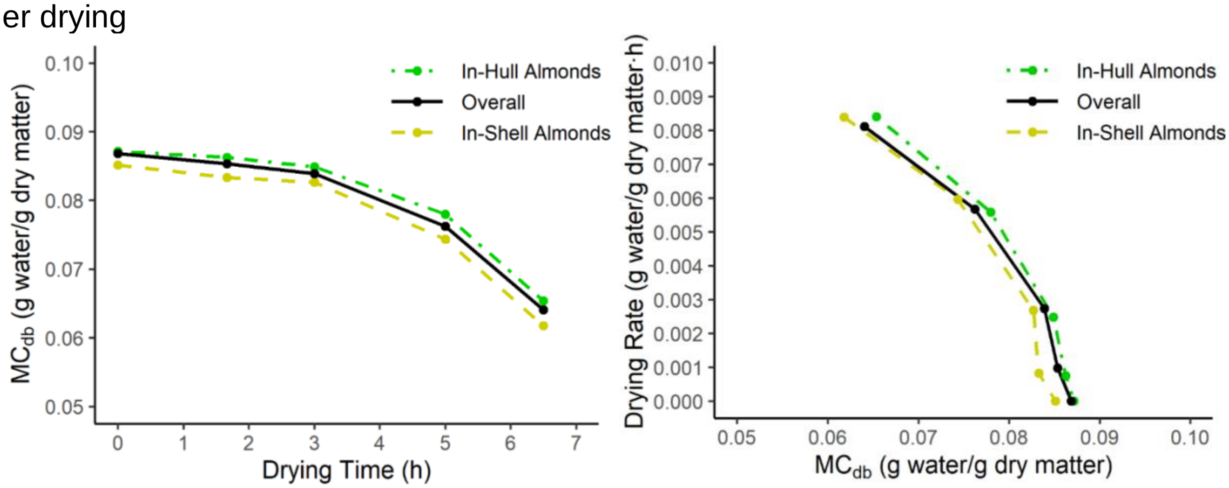


Figure H.15 Kernel moisture content (left) and drying rate (right) profiles for trailer drying at 110°F

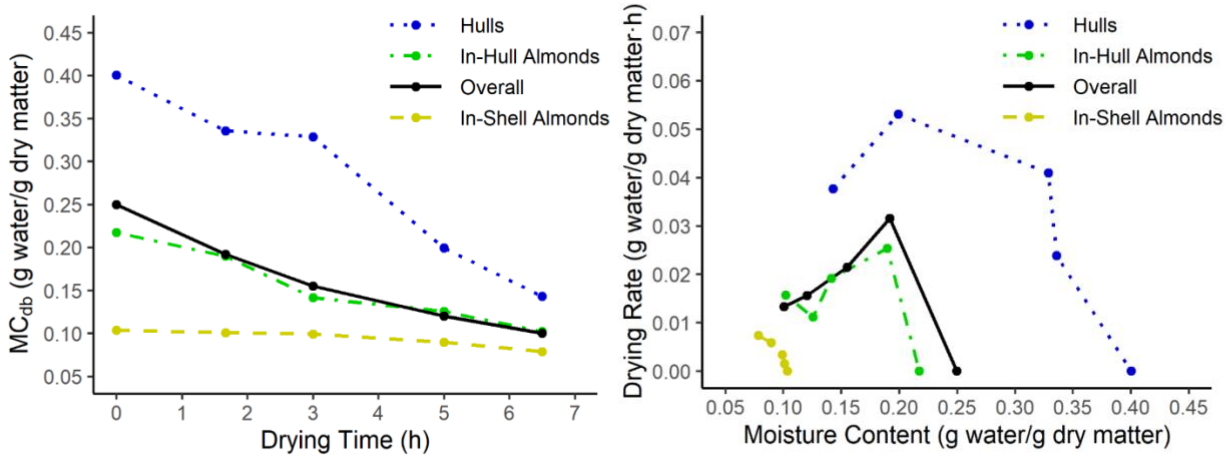


Figure H.16 Whole almond moisture content (left) and drying rate (right) profiles for trailer drying at 110°F

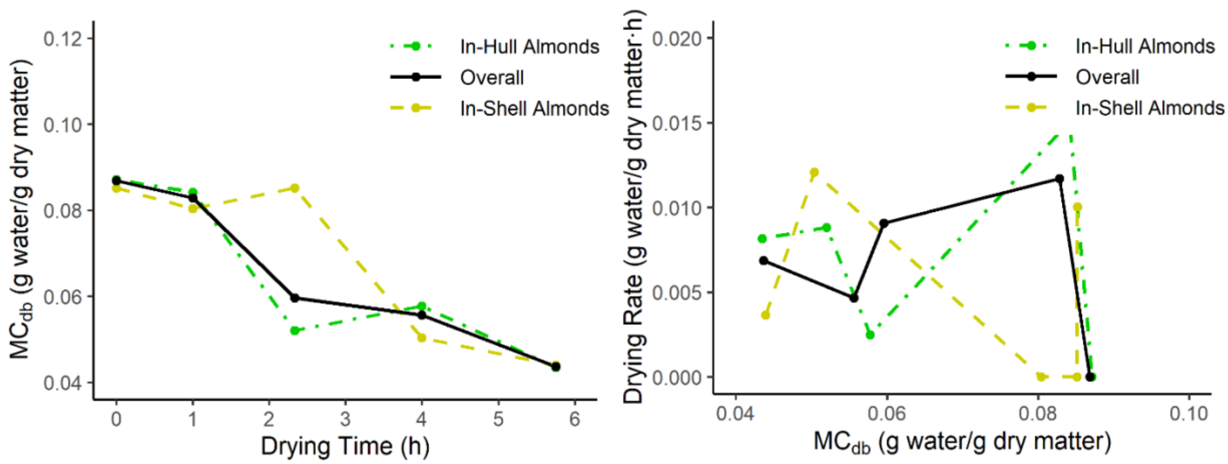


Figure H.17 Kernel moisture content (left) and drying rate (right) profiles for trailer drying at 130°F

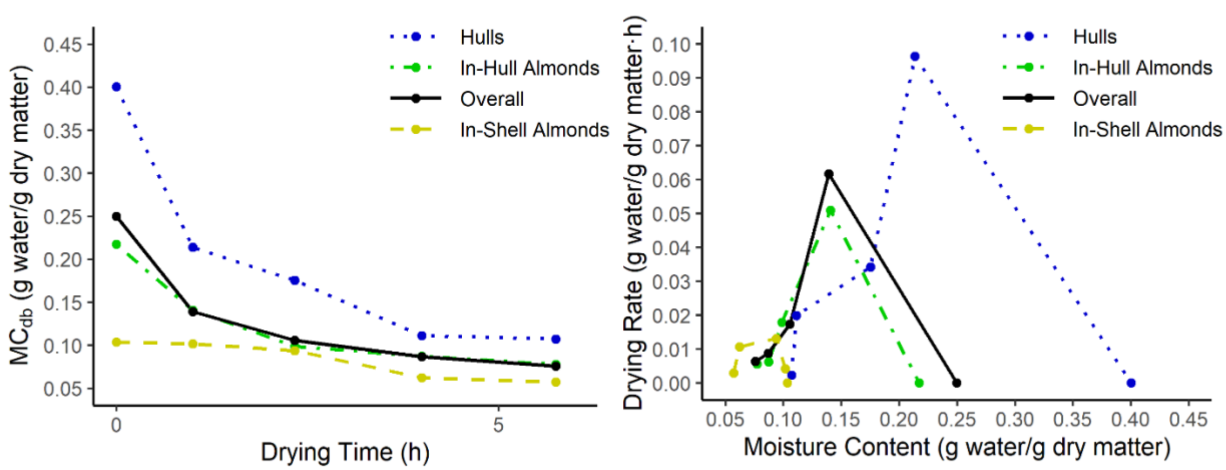


Figure H.18 Whole almond moisture content (left) and drying rate (right) profiles for trailer drying at 130°F

## H.3 Final moisture content distribution

Tunnel drying

Table H.7 Summary of final moisture content of Independence in-hull and in-shell almonds from conventional harvest

| $MC_{wb}$ (%) | Whole almond | | Kernel | | Shell | | Hull | |
|---|---|---|---|---|---|---|---|---|
| | Ave. | Range | Ave. | Range | Ave. | Range | Ave. | Range |
| In hull | 4.6 | 2.0-6.2 | 2.8 | 1.3-5.8 | 5 | 1.5-10.9 | 5.5 | 0.9-7.2 |
| In shell | 3.2 | 2.1-4.0 | 2.3 | 1.5-3.9 | 5.5 | 3.6-6.9 | N/A | N/A |

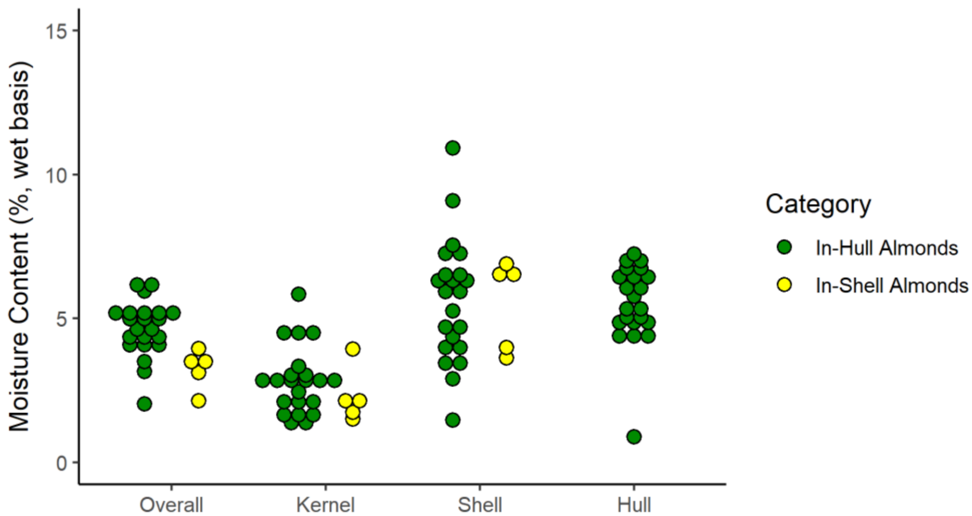


Figure H.19 Final moisture content distribution of Independence in-hull and in-shell almonds from conventional harvest

Table H.8 Summary of final moisture content of Independence in-hull and in-shell almonds from ambient air drying started at daytime

| $MC_{wb}$ (%) | Whole almond | | Kernel | | Shell | | Hull | |
|---|---|---|---|---|---|---|---|---|
| | Ave. | Range | Ave. | Range | Ave. | Range | Ave. | Range |
| In hull | 14.5 | 8.4-25.2 | 8.1 | 3.3-17.6 | 11.3 | 4.4-19.6 | 18.7 | 11.4-31.4 |
| In shell | 7.4 | 5.2-10.5 | 6.8 | 4.8-9.9 | 9.1 | 5.9-12.5 | N/A | N/A |

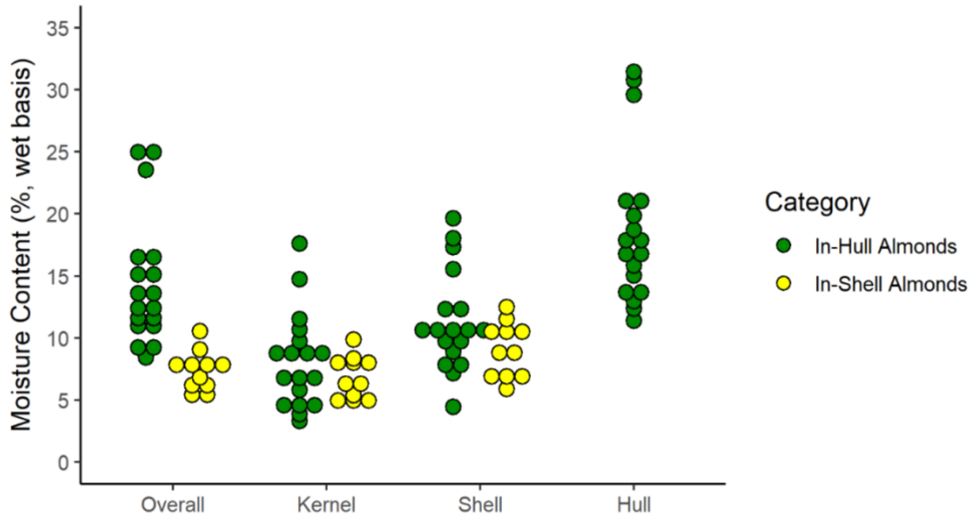


Figure H.20 Final moisture content distribution of Independence in-hull and in-shell almonds from ambient air drying started at daytime

Table H.9 Summary of final moisture content of Independence in-hull and in-shell almonds from ambient air drying started at nighttime

| $MC_{wb}$ (%) | Whole almond | | Kernel | | Shell | | Hull | |
|---|---|---|---|---|---|---|---|---|
| | Ave. | Range | Ave. | Range | Ave. | Range | Ave. | Range |
| In hull | 15.7 | 8.5-31.1 | 8 | 3.7-15.4 | 11.3 | 5.3-20.0 | 20.7 | 11.1-39.4 |
| In shell | 8.4 | 6.1-12.9 | 7.6 | 5.4-12.7 | 10.6 | 7.8-14.3 | N/A | N/A |

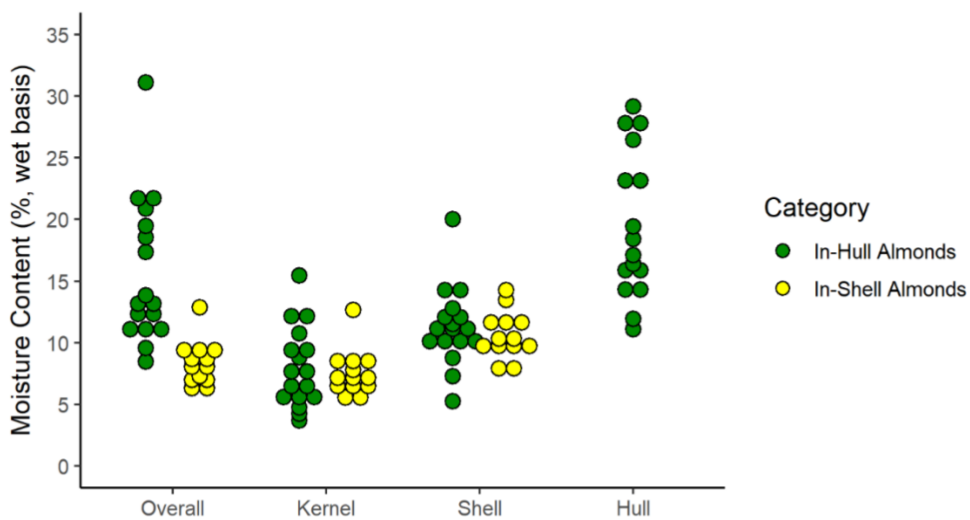


Figure H.21 Final moisture content distribution of Independence in-hull and in-shell almonds from ambient air drying started at nighttime

Table H.10 Summary of final moisture content of Independence in-hull and in-shell almonds from hot air drying

| $MC_{wb}$ (%) | Whole almond | | Kernel | | Shell | | Hull | |
|---|---|---|---|---|---|---|---|---|
| | Ave. | Range | Ave. | Range | Ave. | Range | Ave. | Range |
| In hull | 12.8 | 7.9-20.9 | 6.1 | 4.4-10.0 | 9.4 | 5.9-13.4 | 17.2 | 8.7-28.5 |
| In shell | 5.6 | 3.6-10.2 | 5.1 | 2.5-9.6 | 6.9 | 4.0-11.3 | N/A | N/A |

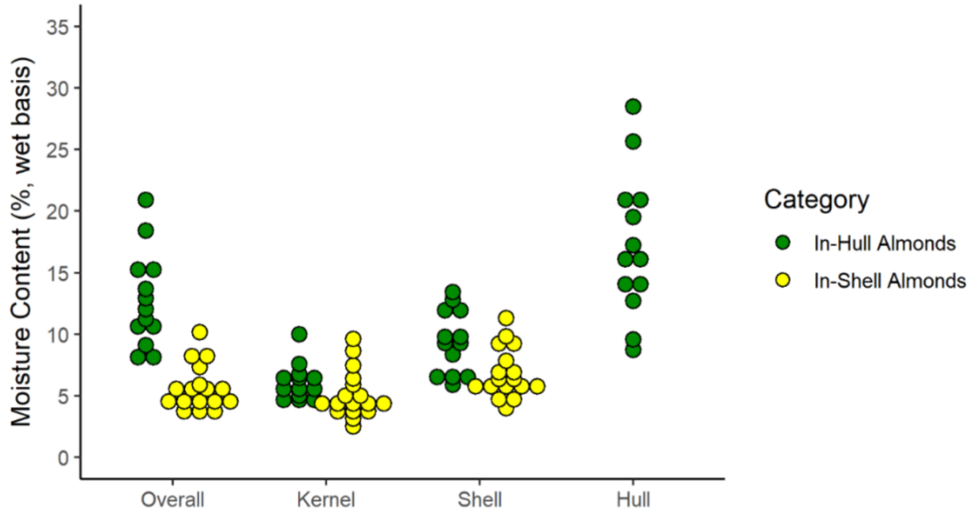


Figure H.22 Final moisture content distribution of Independence in-hull and in-shell almonds from hot air drying

## Stadium drying

Table H.11 Summary of final moisture content of Monterey in-hull and in-shell almonds from conventional harvest

| $MC_{wb}$ (%) | Whole almond | | Kernel | | Shell | | Hull | |
|---|---|---|---|---|---|---|---|---|
| | Ave. | Range | Ave. | Range | Ave. | Range | Ave. | Range |
| In hull | 8.6 | 7.3-12.5 | 4.6 | 2.9-6.6 | 7.7 | 4.8-10.3 | 11.4 | 9.5-14.8 |
| In shell | 5.9 | 2.4-8.3 | 4.6 | 1.0-6.3 | 7.6 | 4.3-10.5 | N/A | N/A |

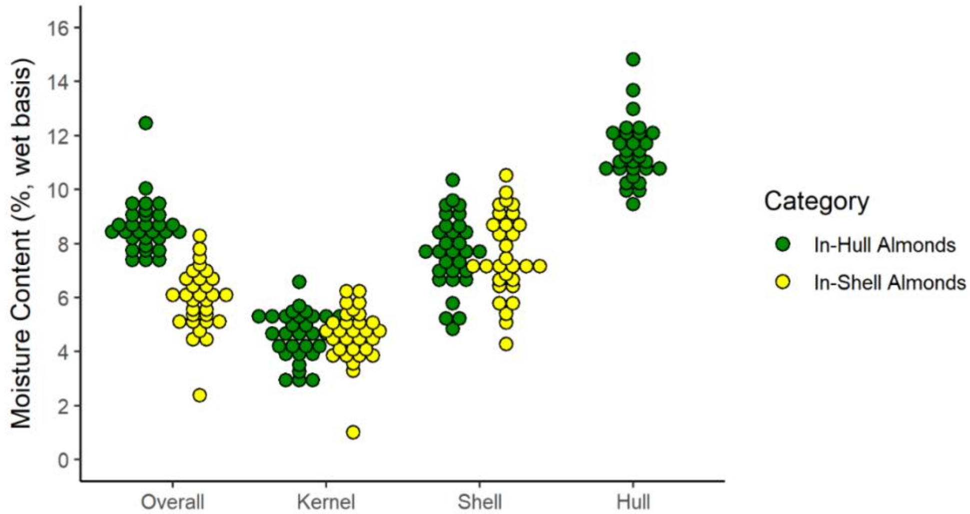


Figure H.23 Final moisture content distribution of Monterey in-hull and in-shell almonds from conventional harvest

Table H.12 Summary of final moisture content of Fritz in-hull and in-shell almonds from conventional harvest

| $MC_{wb}$ (%) | Whole almond | | Kernel | | Shell | | Hull | |
|---|---|---|---|---|---|---|---|---|
| | Ave. | Range | Ave. | Range | Ave. | Range | Ave. | Range |
| In hull | 6.4 | 5.1-7.4 | 3.8 | 2.6-5.2 | 6.6 | 5.5-7.9 | 8.0 | 6.7-10.2 |
| In shell | 5.5 | 4.7-6.7 | 4.0 | 2.5-5.8 | 7.1 | 4.8-8.3 | N/A | N/A |

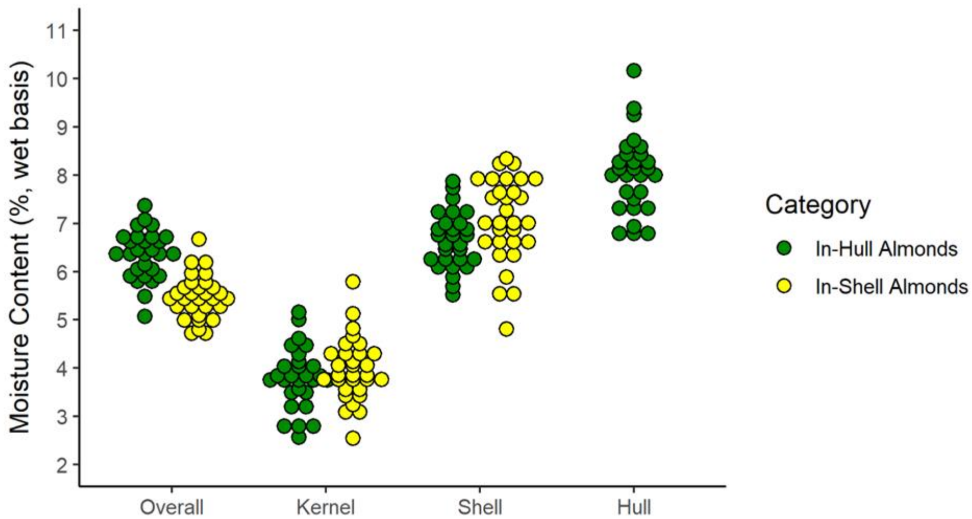


Figure H.24 Final moisture content distribution of Fritz in-hull and in-shell almonds from conventional harvest

Table H.13 Summary of final moisture content of Monterey in-hull and in-shell almonds from stadium hot air drying

| $MC_{wb}$ (%) | Whole almond | | Kernel | | Shell | | Hull | |
|---|---|---|---|---|---|---|---|---|
| | Ave. | Range | Ave. | Range | Ave. | Range | Ave. | Range |
| In hull | 7.2 | 5.1-9.7 | 4.5 | 2.3-7.6 | 6.7 | 4.1-11.1 | 9.3 | 6.6-11.6 |
| In shell | 5.6 | 3.2-8.5 | 4.2 | 1.6-6.7 | 7.0 | 4.4-15.3 | N/A | N/A |

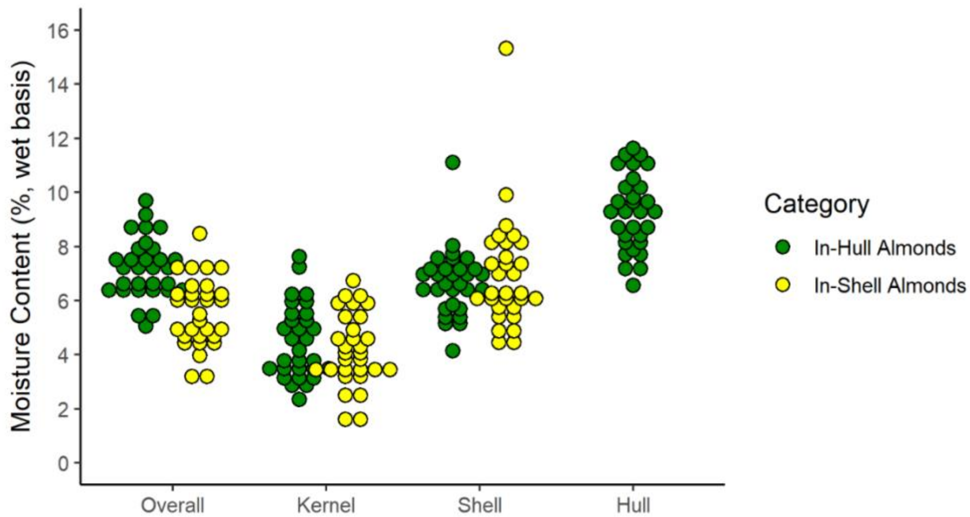


Figure H.25 Final moisture content distribution of Monterey in-hull and in-shell almonds from stadium hot air drying

Table H.14 Summary of final moisture content of Fritz in-hull and in-shell almonds from stadium hot air drying

| $MC_{wb}$ (%) | Whole almond | | Kernel | | Shell | | Hull | |
|---|---|---|---|---|---|---|---|---|
| | Ave. | Range | Ave. | Range | Ave. | Range | Ave. | Range |
| In hull | 8.8 | 4.9-16.6 | 6.5 | 2.2-16.1 | 8.4 | 4.3-15.0 | 10.3 | 5.8-17.9 |
| In shell | 5.6 | 3.2-9 | 4.7 | 1.2-9.2 | 6.8 | 3.3-9.4 | N/A | N/A |

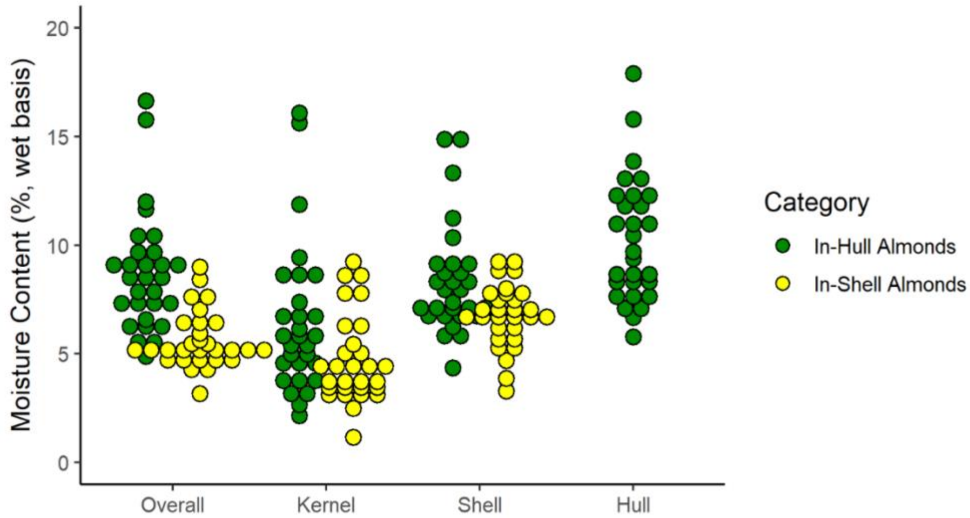


Figure H.26 Final moisture content distribution of Fritz in-hull and in-shell almonds from stadium hot air drying

## Trailer drying

Table H.15 Summary of final moisture content of Monterey in-hull and in-shell almonds from conventional harvest

| $MC_{wb}$ (%) | Whole almond | | Kernel | | Shell | | Hull | |
|---|---|---|---|---|---|---|---|---|
| | Ave. | Range | Ave. | Range | Ave. | Range | Ave. | Range |
| In hull | 6.2 | 5.3-7.5 | 3.8 | 2.9-5.1 | 7.1 | 5.1-8.8 | 8.0 | 6.6-12.2 |
| In shell | 5.3 | 4.3-7.1 | 4.0 | 3.3-5.2 | 7.1 | 5.5-11.1 | NA | NA |

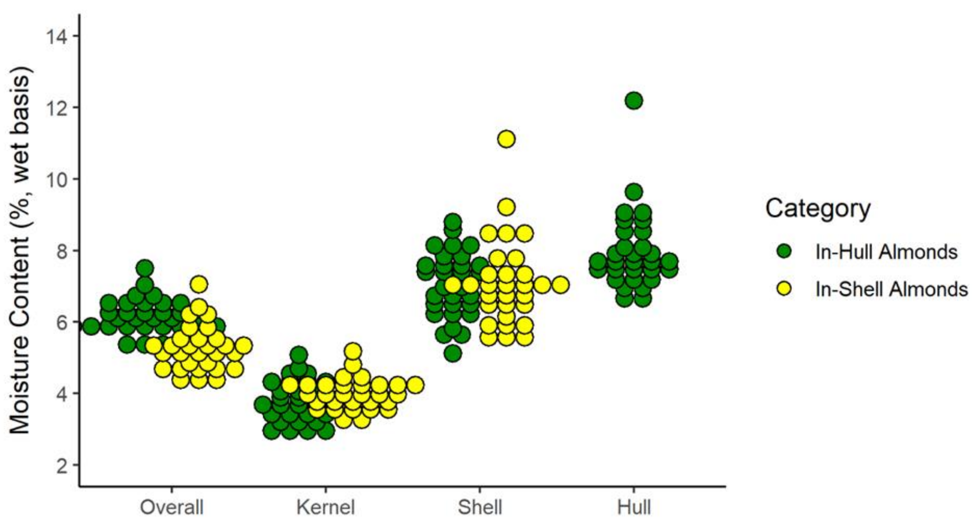


Figure H.27 Final moisture content distribution of Monterey in-hull and in-shell almonds from conventional harvest

Table H.16 Summary of final moisture content of Monterey in-hull and in-shell almonds from trailer hot air drying at 110°F

| $MC_{wb}$ (%) | Whole almond | | Kernel | | Shell | | Hull | |
|---|---|---|---|---|---|---|---|---|
| | Ave. | Range | Ave. | Range | Ave. | Range | Ave. | Range |
| In hull | 5.5 | 3.9-11.9 | 4.0 | 2.3-11.8 | 4.7 | 2.8-9.1 | 7.4 | 5.1-13.3 |
| In shell | 4.4 | 2.6-7.3 | 4.2 | 2.0-8.9 | 4.5 | 1.8-6.7 | N/A | N/A |

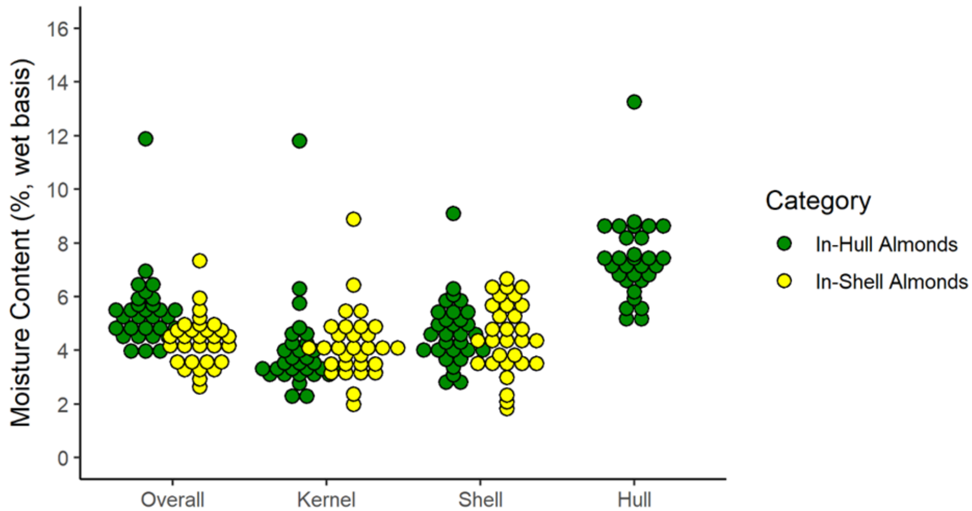


Figure H.28 Final moisture content distribution of Monterey in-hull and in-shell almonds from trailer hot air drying at 110°F

Table H.17 Summary of final moisture content of Monterey in-hull and in-shell almonds from trailer hot air drying at 130°F

| $MC_{wb}$ (%) | Whole almond | | Kernel | | Shell | | Hull | |
|---|---|---|---|---|---|---|---|---|
| | Ave. | Range | Ave. | Range | Ave. | Range | Ave. | Range |
| In hull | 5.8 | 4.4-7.3 | 3.5 | 2.0-8.1 | 3.8 | 2.8-6.3 | 9.4 | 6.8-12.1 |
| In shell | 3.7 | 1.6-5.6 | 3.5 | 1.9-6.4 | 3.9 | 1.1-6.3 | NA | NA |

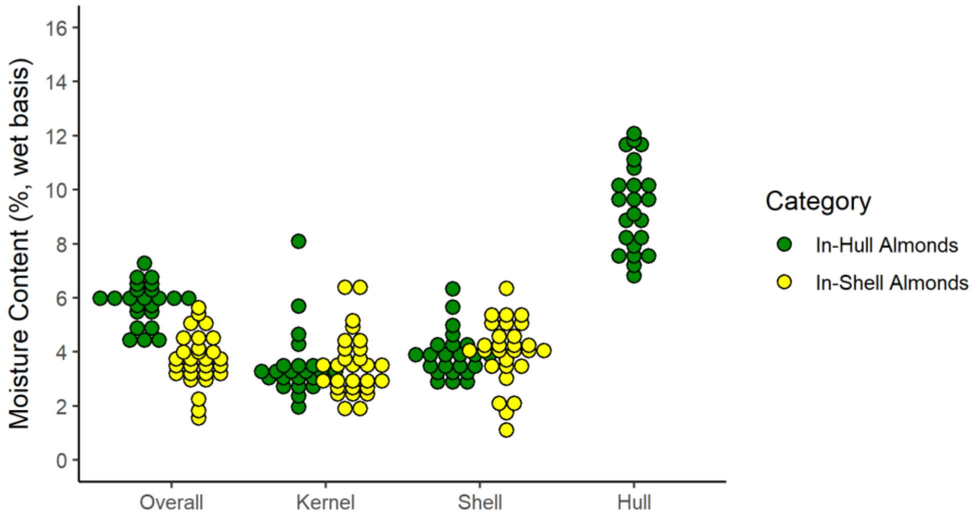


Figure H.29 Final moisture content distribution of Monterey in-hull and in-shell almonds from trailer hot air drying at 130°F

### H.4 Kernel color

Tunnel drying

Table H.18 Summary of kernel color result of Independence almonds

| WI | Control (before drying) | | Conv | | AA1 | | AA2 | | HA | |
|---|---|---|---|---|---|---|---|---|---|---|
| | IH | IS | IH | IS | IH | IS | IH | IS | IH | IS |
| Ave | 77.9 | 76.9 | 77.1 | 77.9 | 77.8 | 77.4 | 78.8 | 78.1 | 77.3 | 77.7 |
| Std | 1.7 | 1.7 | 1.5 | 1.6 | 1.2 | 2.2 | 1.1 | 1.3 | 2.1 | 2.0 |

Stadium drying

Table H.19 Summary of kernel color result of Monterey almonds

| WI | Control | | Conv | | HA | |
|---|---|---|---|---|---|---|
| | IH | IS | IH | IS | IH | IS |
| Ave | 81.0 | 80.7 | 81.0 | 79.8 | 79.4 | 80.6 |
| Std | 0.3 | 1.5 | 0.4 | 1.4 | 2.7 | 0.9 |

Table H.20 Summary of kernel color result of Fritz almonds

| WI | Control | | Conv | | HA | |
|---|---|---|---|---|---|---|
| | IH | IS | IH | IS | IH | IS |
| Ave | 79.6 | 82.1 | 79.7 | 79.3 | 80.8 | 80.7 |
| Std | 2.7 | 2.2 | 1.4 | 0.8 | 1.0 | 2.0 |

Trailer drying

Table H.21 Summary of kernel color result of Monterey almonds

| WI | Control | | Conv | | 110°F | | 130°F | |
|---|---|---|---|---|---|---|---|---|
| | IH | IS | IH | IS | IH | IS | IH | IS |
| Ave | 79.9 | 79.8 | 80.1 | 79.8 | 80.5 | 79.4 | 80.4 | 80.2 |
| Std | 0.9 | 1.5 | 1.0 | 0.9 | 1.7 | 0.5 | 0.8 | 1.2 |

### H.5 Concealed damage

Tunnel drying

Table H.22 Summary of color development score result of Independence almonds

| | Conv | | AA1 | | AA2 | | HA | |
|---|---|---|---|---|---|---|---|---|
| | IH | IS | IH | IS | IH | IS | IH | IS |
| Ave | 2.4 | 2.5 | 2.2 | 2.3 | 2.3 | 2.7 | 2.8 | 2.6 |
| Std | 0.4 | 0.7 | 0.5 | 0.6 | 0.9 | 0.9 | 0.8 | 0.8 |

Stadium drying

Table H.23 Summary of color development score result of Monterey almonds

| CD | Conv | | HA | |
|---|---|---|---|---|
| | IH | IS | IH | IS |
| Ave | 2.4 | 2.2 | 2.3 | 1.9 |
| Std | 0.5 | 0.7 | 0.6 | 0.5 |

Table H.24 Summary of color development score result of Fritz almonds

| CD | Conv | | HA | |
|---|---|---|---|---|
| | IH | IS | IH | IS |
| Ave | 1.9 | 2.0 | 2.2 | 1.9 |
| Std | 0.5 | 0.7 | 0.7 | 0.6 |

Trailer drying

Table H.25 Summary of color development score result of Monterey almonds

| CD | Conv | | 110°F | | 130°F | |
|---|---|---|---|---|---|---|
| | IH | IS | IH | IS | IH | IS |
| Ave | 1.9 | 1.5 | 1.7 | 1.6 | 1.6 | 1.9 |
| Std | 0.6 | 0.6 | 0.7 | 0.3 | 0.3 | 0.5 |