SECTION IV
Quality and Safety of Pistachio Nuts As Influenced By Postharvest Handling Procedures

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Project Objectives:
1) To evaluate the current postharvest handling procedures and alternatives that will make it possible to extend the duration between harvest and final drying while maintaining quality and safety of the nuts.
2) To investigate the effects of postharvest handling variables on appearance and flavor quality of the nuts, and on the potential for aflatoxin development.
3) To develop quality criteria that can be used as basis for standards for grades, and to develop objective methods for evaluation of these quality factors.

RESEARCH RESULTS:
I. Physiological and biochemical changes associated with maturation and senescence:

Samples were collected at weekly intervals from three Kernan trees growing at the Wolfskill Experimental Orchard. The sampling period extended from five weeks prior to normal harvest to one week past it. The moisture content of the kernels declined steadily over the six-week period, dropping from an initial 68% to a final value of about 50%. In contrast, the combined shell and hull had a moisture content of 60 to 63% until the final sampling when the value dropped to 50% (Figure 1). The dry weights of the kernel and the hull plus shell were determined through the sampling period (Figure 1). While the hull plus shell varied by only ± 5% from 1 g/nut (dry weight) during the entire period, the kernel’s dry weight increased steadily (from 0.42 to 0.65 g/nut. + 50%).

Since no data on pistachio respiration and production of the ripening hormone ethylene were available, measurements were made on 200 g (50-nut lots) from each sample of freshly-harvested nuts with hulls. The samples harvested in the first five weeks had high (≥ 100 ml CO₂/Kg-hr) initial respiration rates. Within two or three days of holding at 68°F, these rates fell to 40-50% of the initial values. Initial respiration rates of samples taken during the last two weeks were generally lower than those of the early samples. Ethylene production by all samples was initially quite low (0.1 to 0.3 μl/Kg-hr). In all cases this rate increased 10- to 20-fold over the course of the experiment (5-7 days at 68°F). Usually within a day of this sharp increase in ethylene production mold (Rhizopus sp.) growth was evident. Nuts left with their stems on did not rot so readily and had a delayed increase in ethylene production. Therefore, the increase in ethylene production was attributed to the fungus. We observed that Rhizopus growth developed most rapidly on nuts harvested during the latter half of the sampling period. This may be an indication of a ripening-associated decrease in disease resistance such as has been described for other fruits.

A Gardner color difference meter was used to measure changes in color of the hull and shell. The hull color lightened slightly over the six-week period but no changes in hue were measured. The shell, in contrast, showed no increase in color intensity. It does not appear that changes in color are clear enough to be used as an index of maturity.
Samples for compositional analyses were dried and stored for analysis at a later date. The components to be analyzed include oils (lipids), carbohydrates, proteins and amino acids, and insoluble residues. While analysis of carbohydrates and lipids has begun, the other analyses await development of appropriate techniques. The completed analyses of these samples will provide a picture of compositional changes associated with pistachio nut maturation and senescence. If conditions dictate alteration of harvest time, these data will provide the basis for an informed prediction about the effect of shifting the harvest on nut yield and quality. Compositional data may also provide an objective means of assessing quality of various varieties and of evaluating the effects of various storage and handling procedures on quality.

II. Ambient air drying of pistachio nuts:

Among procedures that might be useful in extending the processing season for pistachio nuts would be the stabilization of nuts on-farm prior to delivery. If this required hot-air drying facilities, then it could become as costly as additional central facilities. However, if the product could be successfully dried with non-treated ambient air, facilities could be simplified and drying costs and energy requirements greatly reduced.

Test procedures: During the 1978 harvest season, two tests were conducted to evaluate the potential for ambient air drying of pistachios, and to explore air flow requirements, drying bed depth, and nut quality. Kerman nuts for these tests were harvested near Durham, California, the first test on August 30, and the second test on September 13. Nuts were mechanically shaken onto tarps, boxed, and hauled to Davis for testing. On arrival, nuts were hulled, blanks and other light material separated by water flotation, and good nuts composited into small experimental drying bins.

Bins were constructed of one-half-inch plywood, sealed to resist moisture uptake. Bins were 12-inches square outside by 1.5-feet deep. Inside surfaces were lined with one-half-inch foam plastic to avoid air “channeling” along those surfaces, so nut performance would be similar to that encountered in the center of a large bin. Bin bottoms were of one-half-inch mesh hardware cloth to allow vertical air flow. To orient vertical stacks of bins, retainer cleats were secured at the top of the sides; and the bin lips were lined with approximately 3/8-inch foam to seal between adjacent bins in the stack. Depending on the individual test, stacks of 3 to 5 bins were used, providing drying bed depths of 4.5 to 7.5 feet.

After filling of the bins, at least one hour was allowed for drainage of surface water. Nuts in each individual bin were then carefully weighed, and drying stacks established. Thermocouples attached to a thermograph were positioned to monitor the temperature of the entering ambient air, and of selected positions within the stack. A hygrothermograph was located at the point of entry of ambient air to monitor relative humidity during the tests. Temperature was also monitored in the center of a single test bin of non-hulled nuts which were not being dried. This provided a comparison with temperatures within the drying bed.

Air flow was provided by a small centrifugal blower located at the base of each unit. By exhausting the air, no heat from the blowers was introduced into the system. Air thus flowed vertically through the nuts, entering the top and leaving the bottom. All drying was done under an open shed. Thus, the drying beds were sheltered from direct sun contact but not from natural air movement. Air flow was interrupted for a few minutes each morning and evening while individual bins were reweighed.

Results of first test: In Test 1, air flow rates of 40 and 100 feet per minute were established, each with five-high stacks of bins, for a 7.5-foot deep drying bed. Ambient air temperatures and relative humidity, along with drying patterns and quality evaluations for different depths within the bed are shown in Figure 2. Daytime high temperatures were near 90°F at the start and dropped to near 75°F toward the end of the test. Night-time lows were generally 55° to 60°F. Percent relative humidity remained in the mid to high 90s at night, generally dropping to the
Fig. 2. Drying patterns, ambient air temperatures and relative humidities, and appearance quality evaluations for Kerman pistachio nuts from various depths within the drying bed (Test 1).

**Drying Patterns**

- % WT Loss
- Depth: Feet
- Fast: 100 ft/min
- Slow: 40 ft/min

**Quality Evaluations**

- % Damage
- Fast
- Slow
- Stain only
- Stain + Decay

**Temperature**

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40's and 50's during the day. At the end of the test, the cumulative mean temperature was near 70°F and the relative humidity near 71%.

That serious deterioration would occur if no drying were provided was demonstrated with the nuts held in-hull without drying. Temperatures in the center of the small test bin rose from 78°F at the start of the test to 100°F within two days, and peaked at 110°F. Nuts were discarded after five days because the entire mass was severely invaded with decay. By comparison, nuts near the bottom of the drying bed (slowest drying position) ranged between 54° and 72°F and averaged 63.5°F for the five-day period. This is nearly 9°F cooler than ambient air entering the system, and represents evaporative cooling with the drying system.

Drying of all samples progressed fairly rapidly to about 40% of initial weight lost, then stabilized at about that level. With the low (40 ft/min) air flow, nuts in the first 1.5 foot depth achieved 40% weight loss in three days, but this amount of drying required eight days at the 7.5 foot depth. By contrast, with the fast air flow (100 ft/min), drying to 40% weight loss took about 2.5 days in the first 1.5 feet of bed depth, and five days at the 7.5 foot depth.

The effect of drying speed (and bed depth) on quality and deterioration of the nuts was readily seen. Under the fast air flow, shell staining remained near 5% at all depths; decay remained under 0.5% to the 4.5 foot depth, then increased, reaching 1.8% at the 7.5 foot depth. By contrast, staining of nuts dried under the slow air flow was 5% in the top three feet of bed, then increased to over 75% staining at the 7.5 foot depth; and decay reached 10% at 4.5 feet depth, and 75% at 7.5 feet depth. Visual appearance of these nuts may be seen in Figure 3.

Results of second test: The second test evaluated further the effect of air flow on drying rate and nut quality. Nuts were obtained from the same orchard, two weeks after the first harvest, and many more hulls and shells were cracked open at harvest. This provided a comparison of the effect of nut maturity on the final quality. The slow air drying treatment was restricted to a six foot bed depth because of the excessive deterioration encountered at the 7.5 foot depth in Test 1. A higher air flow rate was also included (150 ft/min), but bed depth had to be limited to 4.5 feet to attain this air flow. This added treatment would hopefully provide information on the upper limits of air flow that might be useful in ambient air drying.

The temperature and relative humidity information, along with drying patterns and quality evaluations for Test 2 are presented in Figure 4. The cumulative mean temperature during Test 2 was generally within 2° to 3°F of that in Test 1, with daytime temperatures slightly lower and night-time temperatures similar. At the end of the test the cumulative mean temperature was near 69°F (cf 70° in Test 1). The relative humidity during this test period was much lower than in Test 1, with a cumulative mean near 56% (cf 71% in Test 1). Night-time highs started in the 80's, but ended near 60%, and day-time lows were generally near 40% relative humidity.

This lower relative humidity substantially affected the speed of drying of the nuts. Under the slow air flow (40 ft/min), the first 1.5 foot depth dried to 40% weight loss in about the same time as Test 1 (3 days), but the 4.5 foot depth dried in under 4 days (cf over 5 days in Test 1). Under the fast air flow (100 ft/min), drying times were consistently about one day less than in Test 1. Under very fast air flow (150 ft/min), initial drying was very rapid, but nuts at all depths achieved 40% weight loss in about the same time achieved under the fast air flow (100 ft/min).

Moisture content of the nuts after drying ranged from 5.2 to 7.1% (dry weight basis).

Quality evaluation results show a much higher base level of both shell staining and decay in Test 2 than in Test 1. In Test 2, there was no consistent relationship between bed depth and incidence of shell staining, although staining was generally highest in the low air flow treatment (40 ft/min). In the slow and fast air flow treatments (40 & 100 ft/min), depth of nuts in the bed was directly related to incidence of decay, and decay was noted on some non-stained nuts at the greater depths. The higher than expected decay level in the nuts dried under very fast air flow is unexplained.

Discussion: While certain aspects of these tests are still under study, these preliminary results suggest that hulled pistachio nuts can be dried to about 60% of their initial weight using ambient air; reaching a relatively low moisture content. How effective this amount of drying will be in stabilizing the nuts for later processing is under study. Without drying, however, the nuts are quickly destroyed.

It appears that an air flow near 100 feet per minute is superior to a lower air flow rate in maintaining nut quality. A higher air flow showed no further improvement. A relatively shallow drying bed depth (perhaps as low as 3 to 4 feet) appears desirable in limiting the incidence of decay. Under conditions of these tests drying to equilibrium would take 2 to 3 days. Further tests will be needed to refine this information.
Fig. 4. Drying patterns, ambient air temperatures and relative humidities, and appearance quality evaluations for Kerman pistachio nuts from various depths within the drying bed (Test 2).

**DRYING PATTERNS**

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III. Effect of some postharvest treatments on storage-life and quality of fresh (green) nuts:

Several experiments were carried out to evaluate the effects of some postharvest variables on storage-life and quality of fresh pistachio nuts. Only evaluation of appearance quality (shell staining and decay incidence) has been completed as of 10/23/78. Samples from all treatments were dried to about 5% moisture content and stored for evaluation of other quality factors. These will include nutritional and taste quality as indicated by chemical analyses (oils, proteins, and carbohydrates) and by sensory evaluation. The latter will be carried out during spring, 1979, by a trained volunteer panel of 15 judges. In addition, selected samples will be analyzed for aflatoxins. Consequently, results reported here are tentative and based on only appearance quality data.

1. Effect of delay between harvest and hull removal:

Delay at 77°F for up to 36 hours with adequate air movement did not result in any increase in shell staining. However, nuts kept for 48 or 72 hours at 77°F before hull removal exhibited a small increase in shell staining. Delay at 86°F under conditions simulating commercial handling practices (nuts held in bins) for 18 hours or longer resulted in a substantial increase in the severity of shell staining. This became more serious with extended delay time (between 18 and 72 hours). Also, decay incidence was accelerated during the delay especially beyond 24 hours. Holding at 86°F with limited air circulation resulted in heating of the nuts especially those in the center of containers where nut temperature averaged 95°F after 48 hours.

2. Storage of fresh (green) nuts with the hulls:

It was possible to store sorted fresh nuts with the hulls for up to six weeks at 32°F and about 80% relative humidity without any detrimental effects on ease of hull removal or appearance quality. In contrast, nuts held after hull removal for 4 and 6 weeks exhibited a slight and moderate incidence of decay, respectively. The hulls provided good protection for the nuts from decay organisms without influencing shell staining under these conditions.

3. Effect of temperature and relative humidity on storage-life and quality of hulled fresh nuts.

The limit for storage of hulled fresh nuts at >90% relative humidity without detrimental effects on appearance quality was about two weeks at 32°F, one week at 41°F, 4 days at 50°F, 2 days at 68°F, or 1 day at 86°F. Decay incidence was the principal cause of deterioration (Figure 5). In addition, sprouting of the kernels occurred at the two higher temperatures. Lowering the relative humidity at 32°F or 50°F extended storage-life relative to nuts held at >90% relative humidity at the same temperatures. The best storage conditions for hulled fresh nuts were 32°F and 40-50% relative humidity for up to three weeks.

4. Freezing of fresh hulled nuts:

Nuts frozen and held at -40°F for 2, 4, and 6 weeks, then thawed and dried to 5% moisture content showed no appearance defects. These samples will be evaluated for textural quality in addition to composition and sensory evaluation. Such data will be important in evaluating freezing as a possible alternative for stabilizing fresh nuts between harvest and drying.

IV. Relation of temperature, moisture content of the nuts, and potassium sorbate to fungal contamination and aflatoxin accumulation during storage:

The relation of the moisture content of nuts to their stability and freedom from aflatoxin contamination under various temperature conditions is being studied in tests still underway at the time of preparation of this report (10/23/78). The object of the tests is to determine the feasibility of storing nuts that have been hulled but not completely dried. Thus, we are exploring the possibility that, if hulling was to be done near the orchard, the hulled nuts could be stored for several months to materially extend the time for processing operations. If freshly harvested, high moisture nuts cannot be successfully stored, a second possibility is that nuts partially dried by ambient air using the forced-air principle, would be sufficiently stable to permit storage.

To test these possibilities we have stored freshly-harvested nuts (67% moisture on a dry weight basis) at 32, 50 and 77°F. A humidity was provided which ensured that nuts would neither dry nor absorb moisture during storage. One-half the nuts had been fogged with spores of the fungus Aspergillus Flavus to determine if the fungus would infect the nuts and produce aflatoxin. The fungistat potassium sorbate was applied to a portion of the nuts to determine its efficacy in preventing fungus development in storage. All nuts are examined periodically for the presence of mold growth or other evidence of deterioration.

The above parameters are repeated using partially air-dried nuts at 18%, 8.9% and 5.6% moisture on a dry-
weight basis (about 16, 8, and 5% on a wet weight basis). Here again, a humidity was provided which prevented the nuts from changing their moisture contents during storage.

Because the storage period has not been completed, it is impossible to present conclusions. Nevertheless, some observations to date can be reported. Fresh, high moisture, nuts held at 77 and 50°F quickly molded as expected. At 32°F the nuts remained free of mold for three weeks only if they had been treated with potassium sorbate. The mold fungi were predominantly Alternaria alternata, Cladosporium herbarum and Fusarium spp. unless the nuts had been inoculated with Aspergillus flavus spores, in which case that fungus was also abundantly present. The presence of the first three fungi is not believed to present a health hazard but the moldy appearance of the endocarp would be extremely objectionable.

Nuts with 18% moisture held at 50 and 32°F and those with 8.9% moisture at all temperatures are still bright (after six weeks in storage) and appear similar to nuts which had been completely dried (i.e., 5.6% moisture) before the start of the test. The nuts will be analyzed for aflatoxin and checked for flavor difference at completion of the storage period.

These observations permit us to be encouraged about the possibility of temporary storage for 2 to 4 months. Evidently, however, prior partial drying will be necessary.

V. Studies related to description and evaluation of pistachio nut quality:

Several studies have been initiated but these will not be completed before March, 1979 after carrying out the chemical analyses and sensory evaluation. These studies are aimed at identifying which components are important to good pistachio flavor and the effects of some postharvest and processing variables on nut quality.

1) Genotypic differences: samples of 'Kerman', 'Red 'Aleppo', 'Trabonella', and 'Bronte' were harvested, dried to 5% moisture, and stored at 32°F for chemical analysis and sensory evaluation at a later date.

2) Production areas: samples of 'Kerman' nuts were harvested from Bakersfield, Durham, and Winters. These samples will be used to evaluate the effect of production area on nut quality.

3) Influence of moisture content: in order to study the effect of moisture content on nut flavor. Kerman nuts were dried to about 20, 15, 10 and 5% moisture. These samples are stored at 32°F awaiting chemical analysis and sensory evaluation.

4) Drying method: Kerman nuts were dried in three ways: (a) ambient air dried. (b) dried at 100°F for 18 hours, and (c) dried at 160°F for 8 hours. These nuts will be evaluated for compositional and flavor quality.

5) Storage temperature for dried nuts: Kerman nuts which were dried to about 5% moisture are being held at 32, 41, 50, 68, and 86°F in sealed Scotch-pak bags. These samples will be evaluated for composition and flavor quality after 6 and 12 months in storage.

CONCLUDING REMARKS:

Specific conclusions must await completion of the research work in progress and in some cases additional research in the 1979 season. However, some general points can be made at this time and are listed below.

1. Several options are likely to be available to California pistachio producers and processors for extending the duration between harvest and drying without any undesirable effects on nut quality and safety. The most promising of these appear to be:
   a. Holding fresh nuts (hulled or with hulls) at 32°F and about 50% relative humidity for a few weeks. Sorting the nuts to eliminate defected nuts (which are much more susceptible to decay) before storage would be necessary. Use of a fungistat such as potassium sorbate may be a useful supplement in this case.
   b. Partial drying of the nuts to about 18% moisture followed by holding at 32 to 50°F for several weeks until final drying (to about 5% moisture).

2. Modification of the bins used for hauling and holding pistachio nuts to include side vents (at least 5% of the surface) would be very helpful in achieving proper temperatures throughout the bin.

3. Delays between harvest and drying should be minimized especially when ambient temperatures exceed 80°F. If some delays cannot be avoided, the bins should be kept in the shade. In addition, moving air through the nuts would help in preventing heating of the nuts and consequently minimize losses due to decay.

4. Ambient air drying is a viable alternative to hot-air drying facilities. It is much more economical in terms of initial cost and energy use. Further tests are needed to define optimum conditions for this drying method.

5. We intend to continue this project for another season (1979) if industry interest and support make it possible.