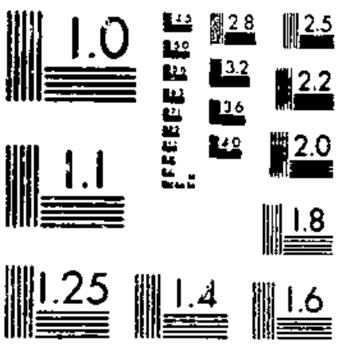
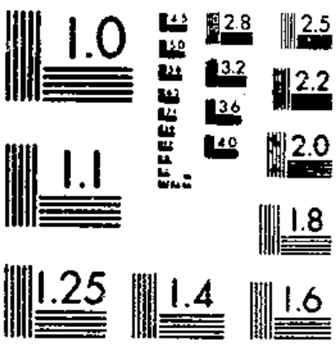
TB 996 (1950) USDA TECHNICAL BULLETINS UPDATA
USE OF ETHYLENE IN HARVESTING THE PERSIAN WALNUT (JUGLANS REGIA) IN
SORBER, D.G. KIMBALL, M.H. 1 OF 1

START



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Technical Bulletin No. 996. August 1950

UNITED STATES DEPARTMENT OF AGRICULTURE WASHINGTON, D. C.

Use of Ethylene in Harvesting the Persian Walnut (*Juglans regia*) in California[1]

By D. G. Sorber,[2] *Laboratory of Fruit and Vegetable Chemistry, Los Angeles, Calif., Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration, United States Department of Agriculture;* and M. H. Kimball, *agriculturist, Los Angeles County, Agricultural Extension Service, University of California*

CONTENTS

[1] Submitted for publication Dec. 15, 1948.

[2] Now special assistant to the director, Western Regional Research Laboratory, Albany, Calif., Bureau of Agricultural and Industrial Chemistry.

HISTORY OF WALNUT HARVESTING IN CALIFORNIA

Culture of the Persian walnut (*Juglans regia*) in the United States is confined to the Pacific coast region, most of the commercial orchards being in southern and central California. Early cultural operations, including harvesting, were primarily forest practices. An ax was used for pruning more commonly than the pruning saw. Seedlings only were planted until about 1902 or 1904. During the next 10 years plantings of budded or grafted varieties increased, and since about 1913 all plantings have been of this type.

Harvesting procedure in the early years consisted of gathering the walnuts from the ground after they had dropped from the trees by natural processes. In an effort to gather all the crop some growers used towers (figs. 1 and 2) to facilitate gleaning. Shaking poles (figs. 3 and 4), rubber-headed mallets, and other devices were used to some extent as aids in picking, but mainly to complete harvesting and gleaning.

Plantings increased rapidly. As the volume of walnuts to be marketed became greater, more and more attention was given to the production of a high quality product. The industry became particularly concerned with the fact that a large proportion of the crop developed mold. The California Walnut Growers Association, organized in 1912, sponsored a research program by the University of California, which resulted in the introduction of artificial dehydration as one means of speeding harvest and preventing mold. In 1923, Batchelor (*4*) [3] showed that slow or delayed harvest resulted in increased percentages of moldy kernels.

The industry gradually adopted new practices, all designed to speed the harvesting process. Those growers who advanced harvest into an earlier season, however, found a definite limiting factor in "green" nuts, or nuts with the hull unseparated from the shell, which later came to be called green sticktights. Pickers could not remove this hull by hand; and if they attempted to do so with the husking peg, fragments of adhering hull stained the shell, making the nut a cull. At first it was customary to throw these green nuts against the trunk of the tree and leave them until the hulls could be removed. Since owners objected to the pickers' removing these green nuts from the tree it finally became a common practice for the pickers to bury them, getting them out of sight to avoid criticism. Loss from these practices was considerable.

Color as a Factor in Walnut Quality

After World War I, in the early 1920's, the importation of walnuts from France increased to such an extent that they offered serious competition to California walnuts. The kernels of these imported nuts were characteristically light in color. As the supply of imported walnuts was greater than the domestic supply, consumers became familiar with the light-colored kernels and soon developed a preference for them. Because of the high percentage of light-colored kernels in some localities and a very high percentage of amber or light-brown kernels in others, depending upon the prevailing weather during the growing and harvesting season, California walnuts were at a

[3] Italic numbers in parentheses refer to Literature Cited, p. 77.

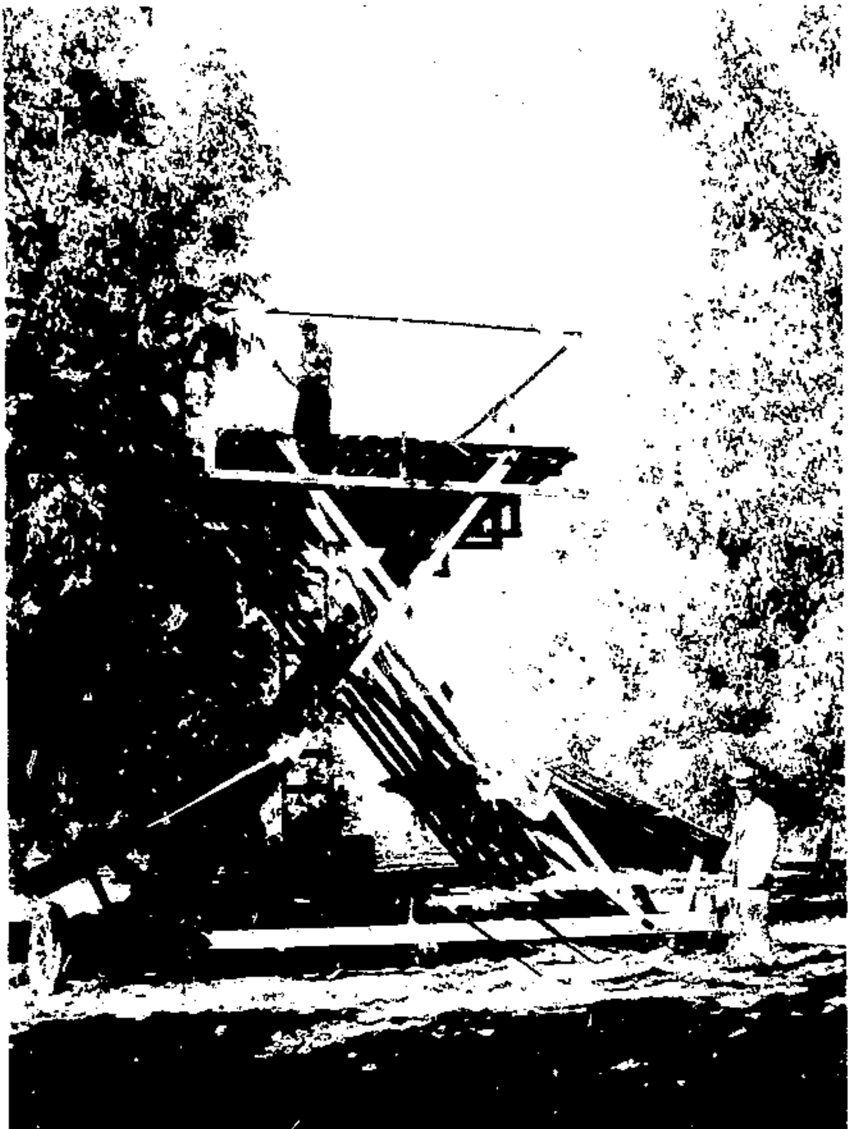


FIGURE 1.—A 16-foot tower with wide platform designed for young, widely spaced trees. The aprons assist in picking by localizing the nuts.

disadvantage, and the growers' association was compelled to stress color standardization of its products.

The development of color consciousness on the part of the California walnut industry was gradual. One of the first indications was the inclusion of a color chart supplied by the association in the bulletin published by Batchelor in 1923 (4). In 1926 the association established definite color standards, both as a basis for determining the value of walnuts delivered by its grower members and as a guarantee to the eastern trade. Significant price differentials were established on the basis of these color standards in combination with standards of soundness or edibility. These schedules underwent several revisions and refinements between 1926 and 1940.

During this period efforts to improve kernel color by various methods

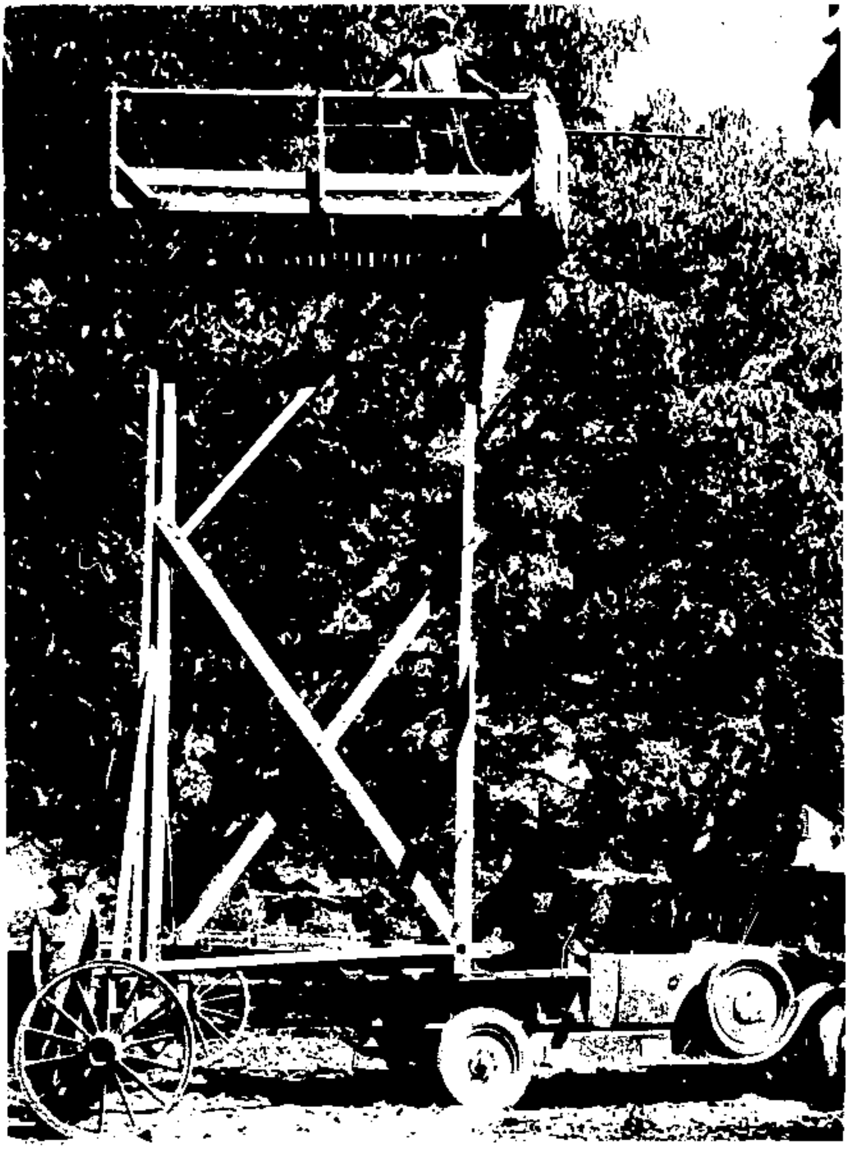


FIGURE 2. A 24-foot, semitrailer type of tower is typical of the design necessary where large trees leave little space for the tower to go through. It is easily maneuvered and can be built at low cost.

FIGURE 3.—Shakers with poles precede the pickers, who gather the nuts from the ground and put them in sacks.

[illegible] (2). Growers attempted to harvest earlier and with greater speed (2). A water-sweat process, which had been used by a few growers, was further developed [illegible]. In this process (fig. 5) the walnuts are placed in burlap sacks in the shade and drenched with water every 3 or 4 hours. They are covered with canvas or [illegible] wettings. This is really a method of refrigeration [illegible], which preserves the walnuts while natural [illegible] place. Use of shaking poles was advocated for the first [illegible] and of shaking towers for all pickings [illegible] gleanings only. In addition to the early use of shaking poles [illegible] towers, combined with weekly picking, to advance [illegible] of water-sweating was advocated (17, [illegible]).[4]

I[illegible], however, the proportion of light colored [illegible] walnut producing districts was unsatisfactory. [illegible] harvest progressed [illegible] waves that frequently occurred dur[illegible] part of the crop re[illegible] weather, lowering the kernel quality [illegible] a lower return to the growers.

M[illegible] to be a serious factor. Federal and State stand[illegible] tolerances for defects. Obvi[illegible] completely [illegible] up by moldy kernels no [illegible].

[4] [illegible] LOS ANGELES [illegible] CALIFORNIA, [illegible] SAN [illegible] 23 [illegible] [illegible]

As a consequence of this situation the entire industry was alert for improvements in harvesting that would preserve the light color of the kernels normally characteristic of the mature green sticktight walnut.

Definitions of Terms

After color and soundness standards were set up by the California Walnut Growers Association, certain terms came into general use in the industry. Since the research work was conducted in close cooperation with the association, their terms are used in this publication. Some of these terms are defined as follows:

Blight (*5*)—A bacterial disease which may infect the hulls of the

Figure 4.—Shaking poles, ranging from 10 to 30 feet in length, are used as aids in bringing walnuts down from the trees.

F[illegible] Sacks [illegible] stacked in the shade, to be treated [illegible] sweat process. W[illegible] through open tops of the sacks [illegible] day. [illegible] slat bottomed bins with a [illegible] are also frequently used.

[illegible] at various stages of their growth and maturity under [illegible] conditions. Infested full-sized nuts are often blanks. [illegible] unmarketable, except as culls, be-[illegible] It shows on the shell as black spots most [illegible] but often scattered over the entire surface.

P[illegible] Abnormal condition of the shell; leaves pink stains [illegible] removed by any practical bleaching process.

B[illegible] with no kernel or one so undeveloped as to [illegible] weight.

S[illegible] A partly developed kernel, heavier than a blow, which [illegible] may have some edible portions. A partial [illegible] fourth or less of the kernel is shrunken.

Sp[illegible] Light brown to black spots, of pin point size or larger, [illegible] of the kernel).

V[illegible] bundles in the pellicle, [illegible] definitely darker than the body of the [illegible]

S[illegible] —E[illegible] commonly expressed as a percentage.

L[illegible] defined by a carefully prepared color [illegible] expressed as a percentage.

A[illegible] A [illegible] color of kernel resulting from dark-[illegible] as the minimum stand-[illegible]

B[illegible] exceedingly dark brown [illegible]

Walnut Quality and Factors Causing Its Decline

The effects of different harvesting methods on walnut quality are given briefly in table 1. "Natural harvest" as used in the table refers to the gathering of walnuts after they have dehisced (opened naturally). "Water sweat" refers to the water-sweat process (*40*) used in handling the 10 to 20 percent of green nuts. The value of the early and rapid harvest made possible by the use of ethylene as shown by its effect on quality is indicated in the table. The table shows further that the use of the ethylene process reduces to a minimum the quality loss caused by five factors and increases the quality loss caused by one (veining). These factors are briefly discussed in the order in which they appear in the table, which is not necessarily the order of their importance.

Husk fly stains.—Boyce (*7*) shows that walnut husk fly infestation does not occur until late August in most seasons. The percentage of infested nuts increases rapidly as the season advances and the hulls soften so that the flies can lay eggs on them. Break-down of the hull caused by husk fly larvae results in severe staining of the shell. The prompt removal from the trees made possible by the ethylene process permits harvesting a large part of the crop in time to escape husk fly infestation.

Sunburn.—There is no consistent correlation between the extent of visible sunburn on the surface of the green hull and the severity of injury either to shell or kernel. In some localities and in some seasons a slight yellow coloration of the hull may be accompanied by an uninjured shell and kernel. In other years or other localities the shell may be injured and the kernel not injured, or vice versa. If the shell is not discolored by the sunburn, it is impossible to pick out the sunburned nuts after the hull is removed. Use of the ethylene process for loosening the hulls of green sticktight walnuts enables a grower to cull out sunburned nuts before the hull is removed.

Wormy.—The early start and speed made possible with the ethylene process, as compared with the most rapid natural harvest possible, reduces the number of wormy walnuts and also the number of walnuts with shells stained by worm tunnels, an effect similar to staining from husk fly infestation.

Mold.—With the ethylene process, and to a certain extent with water sweat, walnuts can be removed from the trees sufficiently early to prevent mold.

Veining.—For some unknown reason the exposure of walnuts grown under extreme coastal conditions to the temperature required for ethylene treatment darkens the fibrovascular bundles of the kernel pellicle excessively. This darkening does not take place when the water-sweat process is used.

Ambering.—Investigations proved that under normal conditions the walnut kernel has maximum quality when it first reaches full maturity. Under certain climatic conditions, the date at which this occurs may coincide with the loosening of the hull.

Under other climatic conditions the hulls may not loosen normally until as much as 30 days after the kernel has reached maturity, thus delaying the start of the natural harvest. During the delay kernel quality deteriorates rapidly. Picking walnuts in the green sticktight stage when the kernel is fully mature and loosening the hull with the

Table 1.—*The effect of various harvesting methods on walnut quality*

Factors of walnut quality	Natural harvest	Harvest with aid of—	
		Water sweat	Ethylene
Size	No effect	No effect	No effect.
External appearance of shell:			
Perforations	do	do	Do.
Discoloration:			
Blight	do	do	Do.
Pinkeye	do	do	Do.
Husk fly stains	Reduces slightly if harvest is rapid.	Reduces considerably	Almost eliminates.
Sunburn	Slow harvest increases; rapid harvest decreases.	Reduces somewhat through increased speed.	Reduces to minimum through early start and speed.
Soundness of kernel:			
Blight	No effect	No effect	No effect.
Blanks	do	do	Do.
Shrivel	do	do	Do.
Sunburn	Slow harvest increases; rapid harvest reduces.	Reduces somewhat through increased speed.	Reduces to minimum through early start and speed.
Wormy	Rapid harvest decreases slightly	Some improvement	Do.
Moldy	Slow harvest increases; rapid harvest reduces.	Reduces somewhat through increased speed.	Do.
Color of pellicle:			
Speckle	Apparently no effect	Apparently no effect	Apparently no effect.
Veining	do	Improves	Damaging on coast; little or no effect in other districts.
Ambering	Maximum speed of harvest reduces somewhat but loss may be severe.	Reduces through increased speed.	Reduces to a minimum through early start and speed.

aid of ethylene make it possible to preserve a far greater proportion of kernel quality. This is the greatest economic value of the ethylene process. The water-sweat process cannot be used effectively until the hulls are near normal loosening, but preserves whatever color quality remains at that time.

Chemical Processes in Development of Amber Color

Probably the same chemical reaction occurs in the formation of any color in the pellicle, whether it is speckling, veining, ambering, or "black" kernel, the last being an intensification of ambering. Speckling is localized, as the term implies. By the second day of a heat wave light-gray areas have been observed on the pellicle. These discolored areas are under minute droplets of moisture which form between the kernel and the shell tissue under conditions of extreme transpirational loss. Such light-gray, almost water-soaked areas turn dark brown or black in a few days.

So far as is known, the chemical compounds involved and the reaction that occurs have not been determined. There are two chemical reactions, however, one or both of which may account for the formation of amber color in the kernel pellicle or for speckling or veining. One of these reactions is the oxidation of the colorless compound hydrojuglone (1, 4, 5-naphthalenetriol) to form the brown juglone (5 hydroxy–1, 4-naphthoquinone). The crystals of juglone have a reddish-brown to brown color that blackens at higher temperatures. This color range is similar to that found in amber and speckled walnut kernels. The other reaction is the oxidation of tannin compounds. Both of these reactions are probably enzymatic in character.

The color produced by the enzyme-catalyzed oxidation of catechol tannins in varieties of peaches subject to browning (*35*) is very similar to that of many walnut kernels. Inasmuch as "in the walnut, juglone occurs combined with tannin in all parenchymatous tissues except the embryonic roots and leaves" (*1, pp. 699–701, 14*), the color change may be caused by both these reactions under some conditions and one or the other under different ones. In any event, as far as color is concerned, the result would be similar.

Origin of the Ethylene Process

For a long time ethylene as a constituent of smoke was used unknowingly as an aid in softening pears and persimmons and in the fruiting of mangoes and pineapples (*9*). In 1923 Denny (*22*) discovered that ethylene, as a product of incomplete combustion from kerosene heaters used in "sweating" citrus fruits, was responsible for the coloring of oranges and lemons. It has subsequently been found (*15, 16, 24, 28, 29, 30, 55*) that ethlylene is a constituent of the products of respiration of certain plants and serves some purpose in the normal functioning of plant processes. The use of ethylene to remedy deficiency conditions is no more an artificial procedure than is the addition of nitrogenous salts to the soil as a fertilizer.

Chace and Church (*10*), and Baier et al. (*3*) contributed additional information on the ethylene processing of citrus fruits. Harvey (*31*) and Hibbard (*32*) used ethylene to bleach celery and to stimulate the coloring of various fruits. Rosa (*50*) found that ethylene is an aid in the coloring of tomatoes. Davis and Church (*21*) used it for the coloring, softening, and removal of astringency of tree-ripe hard persimmons. Chace and Sorber (*11*) introduced its use into the pear industry as a means of softening the fruit before canning.

D. H. Rundle, manager of the Los Nietos and Ranchito Walnut Growers Association of Rivera, who was familiar with these uses of ethylene as well as with the green sticktight problem in the harvesting of walnuts, conceived the idea that ethylene might loosen the hulls of walnuts. Late in the harvest season of 1932 he placed two lots of green sticktight walnuts in the ethylene-treating room of a citrus-packing house. The encouraging result of this first trial was reported to the field manager of the California Walnut Growers Association and the Agricultural Extension Service of the University of California. Rundle's second trial was observed by members of the Extension Service, but it was inconclusive. In cooperation with the Laboratory of Fruit and Vegetable Chemistry of the United States Department of Agriculture, at Los Angeles, arrangements were made for more extensive trials, but it proved impossible to find sticktight walnuts for additional investigation in that year.

Three weeks before the normal beginning of the 1933 walnut-harvest season, experiments were conducted at the Laboratory of Fruit and Vegetable Chemistry, which confirmed Rundle's idea. It was immediately discovered, however, that many related problems had to be solved before ethylene could be used commercially by walnut growers. Extensive research in 1934, 1935, and 1936 provided the answers to most questions relating to the practical application of ethylene to the harvesting of walnuts.

Ethylene is a highly flammable gas. The concentrations recommended for the processes described in this publication are not explosive, but persons operating the equipment and working around the operation should avoid breathing the gas even in the low concentration for considerable periods of time as the anesthetic effect is cumulative.

Operators must use care in handling the cylinders containing the gas, operating the valves, piping, etc., to prevent leaks and the consequent forming of explosive and poisonous concentrations of the gas.

Cylinders must be stored in cool, well-ventilated places, away from oxygen cylinders, never in sunlight or where exposed to other sources of heat.

In places where concentrations of the gas greater than 100 parts per million of air are unavoidable, operators must wear a gas mask equipped with a canister guaranteed for filtering ethylene.

DEVELOPMENT OF THE ETHYLENE PROCESS FOR TREATING GREEN STICKTIGHT WALNUTS

Description of the Ethylene Process

The process consists in placing mature green sticktight walnuts in suitable containers in reasonably gastight rooms and exposing them to a 1 to 1,000 concentration of ethylene. As far as possible, temperatures are held between 65° and 80° F. The treating room is thoroughly ventilated two or three times daily, to remove excess moisture and accumulated carbon dioxide, and is recharged with ethylene after each ventilation. The hulls loosen in 1 to 3 days. As soon as at least 95 percent of the hulls are loosened, the walnuts are hulled and drying is started (*5, 6*).[6]

First Trials of the Process

The first laboratory experiment on loosening the hulls of green sticktight walnuts, started on August 21, 1933, was between 2 and 3 weeks in advance of the normal date of harvest as practiced by those who started as early as possible, and a month earlier than the beginning of harvest in the majority of orchards. The only evidence of approaching maturity was the presence of a small percentage of walnuts on a seedling tree with cracks in the hulls. This tree was known to be consistently early. It is well to note here that the hulls of slightly blighted, wormy, or otherwise weakened walnuts crack about 10 days to 2 weeks before those of normal walnuts.

Two samples of walnuts from the El Monte district, one of Placentia variety, the other from a seedling tree, were picked on August 20 and delivered to the laboratory for trial on August 21. The two samples were divided into four portions each. One lot (No. 1) of each variety was placed on shallow trays in a cabinet approximately 3 by 3 by 4 feet with an interior volume of about 1,000 liters. It was constructed of tongue-and-groove lumber, insulated on the inside with Celotex. A large sliding door permitted the entire end to open. The door could be clamped shut, making the cabinet practically airtight. Temperature, within the box, could be controlled by electric strip heaters equipped with a thermal regulator, which was set for 75° F. One liter of ethylene displaced by water from a flask was forced into the tightly closed cabinet through rubber tubing, giving a concentration of 1 to 1,000 on the basis of the total volume of the cabinet. During the treating period the cabinet was opened twice daily for half-hour periods, permitting complete ventilation. After each ventilation it was recharged with ethylene.

Since the water-sweat process (*40*) was the only means then known to assist in loosening walnut hulls—it was used as a check. Lot 2 of each variety, therefore, was water-sweated according to the standard field procedure (*40*).

The third portion of each sample (lot 3) was placed in single layers on apricot-drying trays in a cabinet similar to that used for lot 1. A wet burlap sack was placed over the walnuts to keep them damp, and ethylene was applied. This was a combination of the water-sweat and ethylene processes. The ventilation schedule was the same as for lot 1.

Lot 4 was handled precisely as was lot 2, with the exception that ethylene-saturated water was used in place of ordinary tap water for drenching the walnuts.[7]

The hulls of lot 1, treated dry with ethylene gas, were loose from the shells at the end of 88 hours. They were then placed in a dehydrator. Thirteen days were required to loosen the hulls of lot 2,

---

[6] Also Marsh, G. L. OPERATION OF WALNUT DEHYDRATORS. Calif. Agr. Expt. Sta. 6 pp. 1936. [Mimeographed.]

[7] Ethylene gas is soluble in water to the extent of about 2 percent by volume.

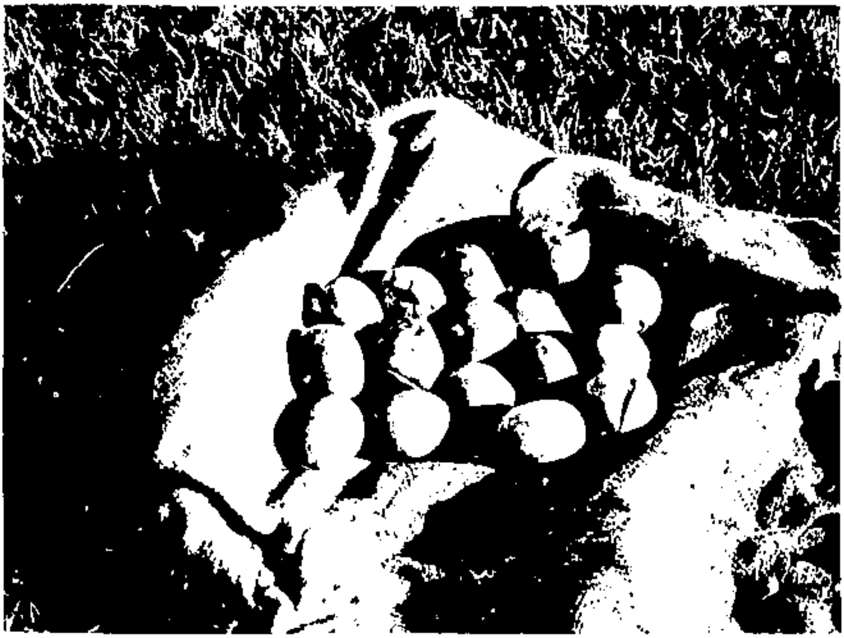


Figure 6.—In water sweating, the hulls crack open and become mealy as they loosen from the shells. Bacterial decay sets in quickly, staining the shells if the walnuts are allowed to remain in the water sweat too long.

the check lot in water sweat. After the eighth or ninth day of this treatment, considerable decay developed, and by the thirteenth day all hulls were badly discolored and decayed (fig. 6).

The hulls of lot 3 were not all completely loosened when the nuts were hulled 8 hours after lot 1. An additional day would have been necessary to have produced the same results as in lot 1. The ethylene added to the water in lot 4 had no effect in increasing the rate of hulling when compared with check lot 2. The results of this test are given in table 2.

Six things were brought out by this trial. (1) Ethylene stimulated the rate of hull maturity, causing the hulls to loosen from the shell in one fourth the time required by water sweating. (2) Maintaining a high humidity during treatment, as in lot 3, retarded the effect of ethylene. (3) No hull decay developed in the time required for hull loosening with either lot 1 or lot 3. (4) The hulls loosened by ethylene did not crack open and become mealy as did those loosened by water sweat. (5) In lot 1, the complete hull came off, leaving the shell bright and without any fiber adhering to it. (6) Ethylene loosened the hulls of immature walnuts. The fact that these walnuts were immature was shown by their appearance after dehydration. All were thin, some were shrunken, and all were dark in color. At that time, however, the significance of this dark color was not realized.

In all subsequent experiments, both in the laboratory and in the field, the rate of 1 part of ethylene to 1,000 parts of air in treating chambers was considered as a standard.

TABLE 2.—*Time required to loosen walnut hulls by treatment with ethylene and with water sweat*

Lot No.	Treatment	Placentia		Seedling		Condition of shell	Condition of kernel
		Duration of treatment	Condition of hulls	Duration of treatment	Condition of hulls		
		Hours		*Hours*			
1	1:1,000 ethylene, dry treatment.	88	No decay	88	No decay	Lighter than in normal harvest.	Thin, with appearance of immaturity.
2	Water sweat	312	Decayed	312	Decayed	Stained by decayed hulls	Do.
3	1:1,000 ethylene, walnuts covered with wet sack.	[1] 96	No decay	[1] 96	No decay	Lighter than in normal harvest.	Do.
4	Water sweat, water saturated with ethylene.	312	Decayed	312	Decayed	Stained by decayed hulls	Do.

[1] There were a few partial sticktights after 96 hours.

Effect of Ethylene-Treating Environment on the Walnut Kernel

After the discovery that ethylene stimulates the maturation processes of the hull, thus conditioning the nuts for rapid, easy hulling after a relatively short treating period, the next step was to determine what effect ethylene and the treating environment have on the quality of the kernel.

Table 3 shows the effect of temperature as a factor of treating environment and various treatments on field-hulled and green sticktight walnuts grown in an orchard at Whittier under semicoastal conditions. Three separate pickings 5 days apart were studied.

Table 3.—*Effect of environment during treatment on the color of field-hulled and green sticktight walnut kernels*

Lot No.	Condition of nuts	Treatment	Holding temperature	Time held	Lite percentage of kernels in walnuts picked—			
					Sept. 5	Sept. 10	Sept. 14	Average percentage of lite kernels
			° *F.*	*Hours*				
1	Field hulled		----	(1)	83.3	80.0	81.7	81.7
2	do		76	84	10.7	11.0	15.7	12.4
3	Green sticktights	(2)	----	(1)	[3] 95.3	[4] 91.0	78.0	88.1
4	do		76	84	88.7	75.7	62.7	75.7
5	do	Ethylene 1–1,000	70	84	82.7	78.0	70.0	76.9
6	do	do	80	84	79.3	73.0	64.7	72.3

[1] Drying started immediately.
[2] Hulls removed with mechanical wire brush; no ethylene used.
[3] 13 percent exhibited reddish-brown blotches on an otherwise lite pellicle, indicating the last stages of immaturity.
[4] 5.3 percent exhibited reddish-brown blotches on an otherwise lite pellicle, indicating the last stages of immaturity.

Lots 1 and 2 of all three pickings were field-hulled. Drying was started immediately with lot 1 of all picks, while lot 2 was stored at 76° F. for 84 hours without ethylene. Kernel color dropped from 81.7 to 12.4 percent as a result of long storage at high temperature. Lots 3 and 4 were green sticktight walnuts which were not treated with ethylene. The hulls of lot 3 were removed by buffing, and drying was started at once, thus preventing further loss of kernel color. The percentage of lite kernels was greater in this lot than in any other. Lot 4 was stored for 84 hours at 76°. An average of 12.4 percent of kernel color was lost when compared with the average of lot 3. Lots 5 and 6 were green sticktights treated with ethylene. Both were treated for 84 hours, but lot 5 was kept at 70°, 6° cooler, and lot 6 was kept at 80°, 4 degrees warmer than lots 2 and 4.

842372°--50---3

The loss of kernel color between the average of lot 3 and the average of lots 4, 5, and 6 was evidently due to temperature and not to ethylene. Lot 4, which received no ethylene, maintained a color comparable to that of lots 5 and 6, which received ethylene.

The average kernel color of green sticktights in lots 4, 5, and 6 after holding was 13.1 percent lower than that of lot 3 which was dried immediately. Field-hulled nuts held for 84 hours at 70° F. lost 69.3 percent of their kernel color. The contrast between losses shows the relative stability of kernel color in nuts in the green sticktight stage which have just reached full maturity.

When the hulls of green sticktight walnuts that were just entering the period of maximum color stability were buffed off and the walnuts were dried immediately (lot 3, table 3), irregular areas of a reddish-brown color appeared on the basically lite kernel pellicle. When walnuts were treated with ethylene several days or a week before this stage, the entire pellicle had this reddish-brown cast. This discoloration was observed in the first lot treated in 1933.

The last traces of immaturity, as indicated by the small, irregular reddish-brown blotches, disappeared when the walnuts were treated with ethylene. This was not true of those buffed. Apparently during the ethylene treating period the metabolism of the walnut kernel continued, removing this last visible trace of immaturity. In one test 13 percent of the green sticktights in the first picking, when buffed and dried, had such reddish-brown areas on otherwise lite kernels, and 5.3 percent in the second picking had them (table 3). The companion lots from the same picking, when exposed to ethylene for 36 hours at a temperature of 60° F. or higher, showed no evidence of this discoloration. When walnuts from this picking were held at 50° for 64 hours a slight amount of this immature color remained, indicating that at this temperature the rate of walnut metabolism is exceedingly low.

These and other studies clearly indicated that walnuts free of the hull cannot be included with green sticktights in treating bins without serious danger of deterioration of kernel color. Before this was fully understood, the amber color frequently observed after ethylene treatment was believed to be caused by the ethylene. The laboratory experiments disproved this. For the benefit of growers, however, several field experiments were run.

In three trials with two varieties of walnuts, samples were drawn at random from growers' deliveries and each lot was divided into equal portions. The hulls of one part of each lot were removed by a combination of water sweat and scraping with a knife over a 2-day period. The companion lots were treated with ethylene in the standard manner.

The condition of the kernels as determined by a "crack test" [8] is shown in table 4. There was no mold in the ethylene-treated lots. The untreated lots contained a few moldy walnuts, and one lot contained two nuts with a slightly immature appearance.

---

[8] The "crack test" used by the industry to determine soundness and kernel color consists in cracking 100 nuts, removing the kernels from the shells, and classifying them according to established standards. Both soundness and color are expressed as a percentage, with soundness first. Thus "90–50" means 90 percent sound, 50 percent lite.

TABLE 4.—*Percentages of sound and lite, kernels found in crack tests of ethylene-treated and untreated walnuts* [1]

Date picked	Variety	Treatment	Sound kernels	Lite kernels
			Percent	*Percent*
Sept. 25, 1940	Placentia	Untreated	67	59
		Ethylene treated	77	60
Do	Payne	Untreated	96	90
		Ethylene treated	96	90
Sept. 26, 1940	do	Untreated	95	88
		Ethylene treated	93	86

[1] Test made in field by H. B. Richardson, specialist in agricultural extension, University of California, Riverside, Calif.

PHYSIOLOGICAL PROCESSES AND THEIR RELATION TO STABILITY OF KERNEL COLOR

Data on the stimulation of walnut-hull maturity were supplied to A. H. Finch, associate horticulturist, University of Arizona, and agent, United States Department of Agriculture, who worked on pecans in 1935. Studies conducted by him in 1935 and 1936 indicated that "ethylene is effective in causing the shucks of the pecans to loosen from the shell, and the shucks when so loosened dehisce normally. * * *" This indicates that in a warm dry environment the same physiological processes affect the maturity of pecan hulls and walnut hulls alike (*27*).[9]

Ethylene not only stimulates the maturing of the walnut hulls but eliminates the last visible trace of immaturity from the kernel pellicle of walnuts picked a few days before full maturity is reached. At full maturity the walnut kernel is most stable from the standpoint of those chemical or physiological processes that control juglone oxidation or enzymatic oxidation of tannins that produce amber color. This maximum stability exists for a few hours to several days, depending on environmental conditions, primarily temperature.

If the life processes in the walnut are stopped at this stage by dehydration, the light color of the pellicle is fixed at its highest point. Otherwise, physiological processes continue to increase the extent of amber color. High temperatures and high humidity increase susceptibility to such change. Several physiological processes apparently take place in walnuts at the same time. Evidence indicates that environmental conditions control the rate of change of kernel color and of the maturing of the hull. Under some conditions the two may proceed simultaneously. Under other conditions kernel maturity and ambering may proceed more rapidly than hull maturity.

[9] Also FINCH, A. H. THE QUALITY OF THE 1936 YUMA PECAN CROP AS AFFECTED BY TREATMENT WITH ETHYLENE GAS AND ADVANCING THE DATE OF PICKING. Ariz. Agr. Expt. Sta. Cir. 7 pp. 1937. [Mimeographed.]

Quantity of Ethylene Required and Methods of Application

The minimum quantity of ethylene necessary to bring about the maximum rate of hull loosening at various temperatures has not been determined. Initial trials, based on experiments with other fruits, such as pears, oranges, lemons, and persimmons, were made at the rate of 1 part of ethylene to 1,000 parts of air space in the treating compartment. That a 1–1,000 concentration is ample for maximum hull loosening was proved during 1935–36 in experiments to determine the effect of accumulations of carbon dioxide on the rate of hull loosening. In these tests, the ethylene concentration in treating chambers was determined immediately after a large quantity was administered and at regular intervals throughout the 12-hour period between ventilations. For this purpose an ethylene detector was used. This instrument, which is identical with the combustible gas indicator, was designed for protection against carbon monoxide and other combustible gases in mines except that it is calibrated for ethylene. It was so designed as to give a satisfactory reading (plus or minus) of 4 parts per 100,000. Because of the volume occupied by walnuts in the treating cabinet the initial concentration was frequently 125 to 190 parts per 100,000, or from 25 to 90 percent higher than the 1–1,000 concentration based on the air volume of the cabinet. At the end of 12-hour periods the concentration within the cabinet ranged from 8 to 80 parts per 100,000.

In experiments on treating walnuts under canvas (*46*), concentrations of ethylene in the atmosphere of the treating chamber were carefully measured immediately after each charging and during the interval between ventilations. Concentrations were never higher than 1–2,000 and frequently less than 1–7,000, but loosening of walnut hulls was as rapid as in the check lots, where concentration was maintained continuously at 1–1,000.

In three experiments, concentrations of more than 1–1,000 did not increase the rate of hull loosening. The apparently equal effect of different concentrations of ethylene was also noted by Denny (*23*), working with lemons. He found that concentrations ranging from 1–1,000 to 1–200,000 had approximately the same effect on the coloring of lemons.

Excessive though concentrations of 1–1,000 may be, the low cost of the gas in relation to the benefit derived made it unnecessary to give detailed study to the minimum concentration that would produce the maximum rate of hull loosening. With the price of ethylene at 55 cents a pound, the cost of the quantity necessary for administering two charges a day for a 3-day period does not exceed 15 cents per dry ton of walnuts treated. Furthermore, the 1–1,000 concentration is one-thirtieth of the minimum explosive mixture of this gas with air, thus providing an ample margin of safety for commercial practice.

In commercial practice, ethylene is purchased and delivered to the consumer in steel tanks in pressures ranging up to 1,800 pounds per square inch. Regulating equipment consisting of pressure-reducing valves is available, and its use is essential for safety. Regulating valve assemblies include flow meters calibrated in cubic feet per minute. The gas can be conducted into a treating chamber through rubber tubing or permanent pipes. The location of the point of introduction is not important, as is pointed out in the next section.

Diffusion of Ethylene in Treating Chambers

More important than concentration of ethylene in treating chambers is its diffusion through the mass of walnuts. Ethylene has a density of 0.97. It diffuses readily throughout the air in a small treating chamber of 1,000-liter capacity, such as is used in laboratory experiments. However, when walnuts were placed in bins to the maximum depth of 8 feet (beyond which hull crushing occurs) diffusion was slow and inadequate. Tests were made in commercial bins. A series of copper tubes was placed in the bin at the time of filling. The tubes extended outside the bins and were so arranged that air could be drawn from each 2-foot level throughout the entire depth of walnuts. Thermal convection currents in different bins varied, but, in general, it was found that after a 1-1,000 charge was administered, either above or below the mass of walnuts, no gas could be detected at the opposite end during the entire 12-hour period between ventilations. The most rapid diffusion recorded was 3 hours.

In commercial practice, therefore, it is necessary to provide for sufficient mechanical circulation of the air to distribute the ethylene thoroughly throughout the walnuts.

Other Materials Tested for Their Effect on Hull Loosening

Ethylene chlorhydrin, chloroform, propylene oxide, and ethylene oxide were tested for their ability to loosen the hulls of sticktight walnuts. In all trials ethylene of the standard concentration was used as a check. All lots were examined as soon as the ethylene treatment had loosened the hulls. In no instance were the results as satisfactory as with ethylene. All tests were discontinued as soon as the ethylene lot was hulled.

Definite stimulation, or breaking of rest, has been found to result from a spray containing 2,4-dinitro-6-cyclohexylphenol when applied to deciduous fruit trees and shrubs that have not been subjected to sufficient cold during winter to enable the buds to develop normally under the influence of warm spring temperatures (*13*). Ethylene has the same effect (*14, 24*). Because of the similar effect of these two chemicals on dormancy, the effect of dinitro on the maturity of walnut hulls was tested. The sodium salt, sodium-dinitro-o-cyclohexylphenolate, both with and without soap as a wetting agent, was used. Walnuts were dipped into this solution for varying periods up to 5 minutes, but it had no effect on the rate of hull loosening.

The possible use of live steam or hot water was suggested. Fully mature Placentia walnuts and immature Eureka walnuts were tested in both steam and boiling water for periods ranging from 30 seconds to 10 minutes. Although some loosening of hulls was produced by both, a considerable percentage of sticktights remained after 1 minute in boiling water and 3 minutes in steam. Longer exposures slightly hastened the rate of hulling but caused the heat to penetrate to the kernel, producing serious discoloration and hastening the development of rancidity by breaking down the oil cells. The results of trials with steam and boiling water are given in table 5.

TABLE 5.—*Effect of steam and boiling water on hulls of green sticktight walnuts, Sept. 25, 1940*

Lot No.	Variety	Number of nuts	Condition of hull	Steam	Boiling water	Sticktights remaining	Results of crack test made Jan. 23, 1941						
							Sound	Lite	Black	Blank	Shriveled	Rancid	Oily
				Minutes	*Minutes*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
44	Placentia	110	Uncracked	Control	Control	22	94	57		3	3		
52	do	110	do		1	3	95	27		1	3		0
56	do	110	do		2	0	97	0		1	1		10
55	do	110	do		3	1	95	0-		1	4		
40	do	110	do		[1] ½ to 5½	1	96	0	1	1	2		([2])
66	do	69	do	3		1	99	0-		0	1	0	0
6	do	110	do	10		0	96	0		1	3		100
38	do	110	do	10		0	96	0	1	3		100	100
54	do	110	Cracked		3	0	92	0	1	5	1		5
42	do	110	do		5	0	89	0	2	2	5	20	20
46	do	24	Hulled		3		68	4	4	8	0		100
65	Eureka [3]	105	Uncracked		3	44	74	1	18	3	5		1
8	do	105	do		5	20	77	0	11	2	10		
63	do	55	do	3		32	68	0	11	4	17		100
43	do	55	do	5		16	62	0	25	5	7		100
49	do	55	do	10		4	69	0	1	5	24		100

[1] Hulls examined after ½ minute revealed a penetration of one-half the thickness of the hull. The nuts were returned to the boiling water for 5 minutes longer.

[2] Becoming oily.

[3] All immature walnuts.

Effect of Temperature and Duration of Treatment on Loosening Walnut Hulls

In order to study the effect of various temperatures on the rate of hull loosening during treatment with ethylene, six experimental cabinets in addition to those described previously were constructed. These cabinets, shown in figure 7, were 18 by 36 by 20 inches and were built to hold three boxes, each containing 330 walnuts. The cabinets were heavily insulated. The entire front of each cabinet was a door, which provided perfect ventilation and easy access to all three boxes for inspection. At the top and bottom of each door were holes through which tubes were inserted for introducing ethylene or withdrawing samples of the atmosphere for determination of ethylene or carbon dioxide concentrations.

One cabinet was constructed in a 40° F. refrigerator box, thus making it possible to maintain any desired temperature down to that point. Another was provided with an air-circulation chamber around an inside galvanized-iron shell, the air for which was drawn by blower from the 40° box. All cabinets were equipped with electric strip heaters controlled by thermal regulators. Thus with the combination of refrigeration and thermally controlled electric strip heaters, it was possible to control the temperature at any desired point above 40°. Each box was equipped with an automatic recorder, a thermograph, and a humidograph. The temperature of these boxes was regulated at approximately 50°, 60°, 70°, 80°, 90°, and 100°.

The accumulation of carbon dioxide [10] and excessive humidity within the treating chambers were controlled by flakes of sodium hydroxide placed in a heavy galvanized-iron container that covered the entire bottom of each cabinet.

The material for the temperature and duration experiments was obtained in three pickings at 5-day intervals from two orchards. One was near Whittier (Los Angeles County) under semicoastal conditions. The other was near Hemet (Riverside County) under interior conditions. After the walnuts were carefully culled to eliminate field-hulled nuts, cracked hulls, and nuts with any appearance of blight or sunburn, the remaining green sticktights were thoroughly mixed (fig. 8) and divided into lots of 330 each. Each lot was placed in a box with a wire-mesh bottom. Three such boxes were then placed in each of the six cabinets. Ethylene was administered in the standard manner, at a concentration of 1–1,000, with a 30-minute ventilation every 12 hours.

Three hundred and thirty walnuts of each picking were tested immediately to determine the number of hulls that were loose from the shell at the time the experiment started. One box of 330 walnuts was removed from each cabinet at the end of 36, 60, and 84 hours. The lots were put through a brush huller and a count was made of the number of complete sticktights. The hulls of partial and complete sticktights were then buffed off with a motor-driven wire brush. All lots were then dried in a thermally controlled dehydrator operating with a forced-air draft at a temperature not to exceed 100° F. Each lot was

[10] Carbon dioxide concentrations were measured with an improved gas analyzer.

later crack tested to determine the effect of temperature and time of treatment on the extent and rate of development of amber color in the kernels. The results of this work are shown in figures 9 to 16.

[illegible] experimental study of [illegible] humidity, and carbon [illegible] in the bottom of the cabinet [illegible] for the absorption of either mois- [illegible] should be made according [illegible] the National Elec- [illegible]

FIGURE 8.—W[illegible] experimental tests: A, Frame, [illegible] B, [illegible] bins, huller; C, sort[illegible] should be made in accordance with [illegible] the [illegible] and the National Electrical Code [illegible]

These charts show that: (1) At 50° F. the percentage of hulls loosened was low [illegible] was markedly increased, resulting [illegible] the greatest relative improvement in the percentage of [illegible] proportional to temperature change; (3) at 70° the rate of [illegible] loosening was better than at 60° but was definitely disproportional to the temperature change; (4) between 70° and 80° the rate of [illegible] loosening increased very slightly and remained practically [illegible] between 80° and 90°; (5) at 100°, in all instances there was a slight depression of [illegible], resulting in a slightly [illegible] rate of [illegible] loosening [illegible] with the exception of the first picking from the W[illegible] orchard (fig. 9) more than 80 percent of the hulls were loose at the end of 36 hours at 60°, and with the same exception more than 90 percent of the hulls were loose in 36 hours at 70° and above. This fact is particularly significant when studied [illegible] percentage of light-colored kernels in each lot at each temperature as the length of treatment was extended. No appreciable [illegible] practically all the hulls were loose, [illegible] the stage of maximum kernel color stability [illegible]. From this stage forward the development of

[illegible] temperature the increase [illegible] in temperature. They [illegible] with all the fruits, [illegible] where the heat produces [illegible]

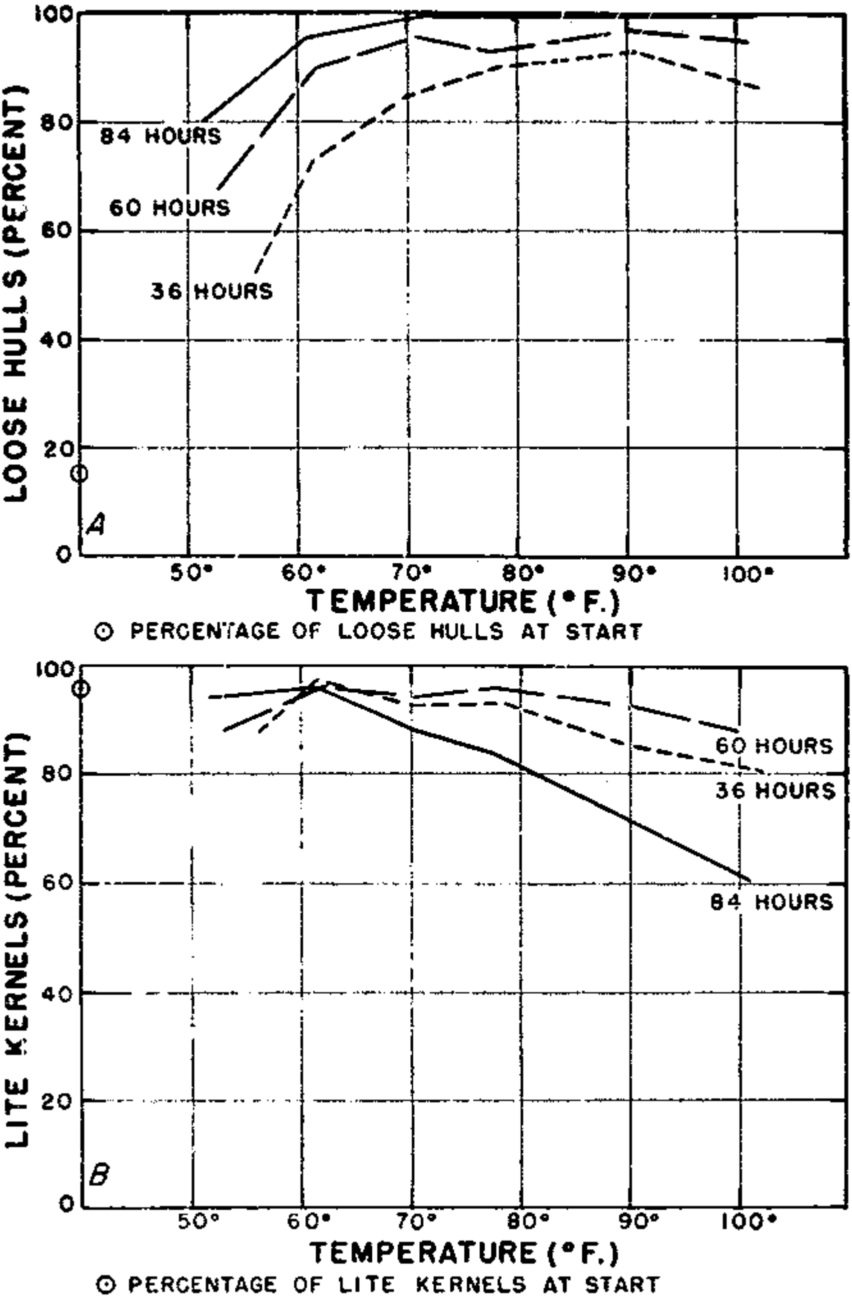


FIGURE 9.—Effect of temperature and duration of treatment on (*A*) rate of hull loosening and (*B*) development of amber-colored kernels. First picking at Whittier, Los Angeles County, Calif., in 1935.

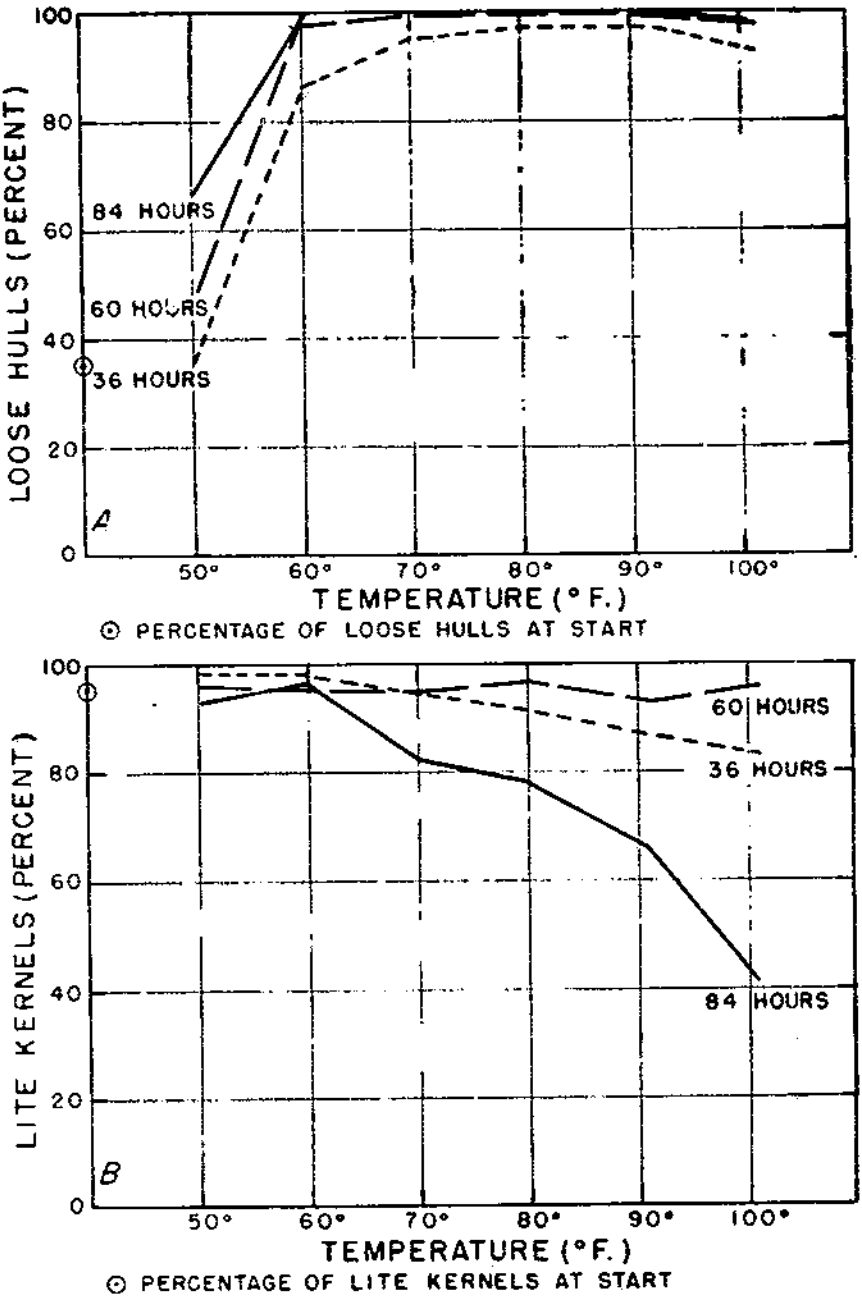


FIGURE 10.—Effect of temperature and duration of treatment on (*A*) rate of hull loosening and (*B*) development of amber-colored kernels. Second picking at Whittier, Los Angeles County, Calif., in 1935.

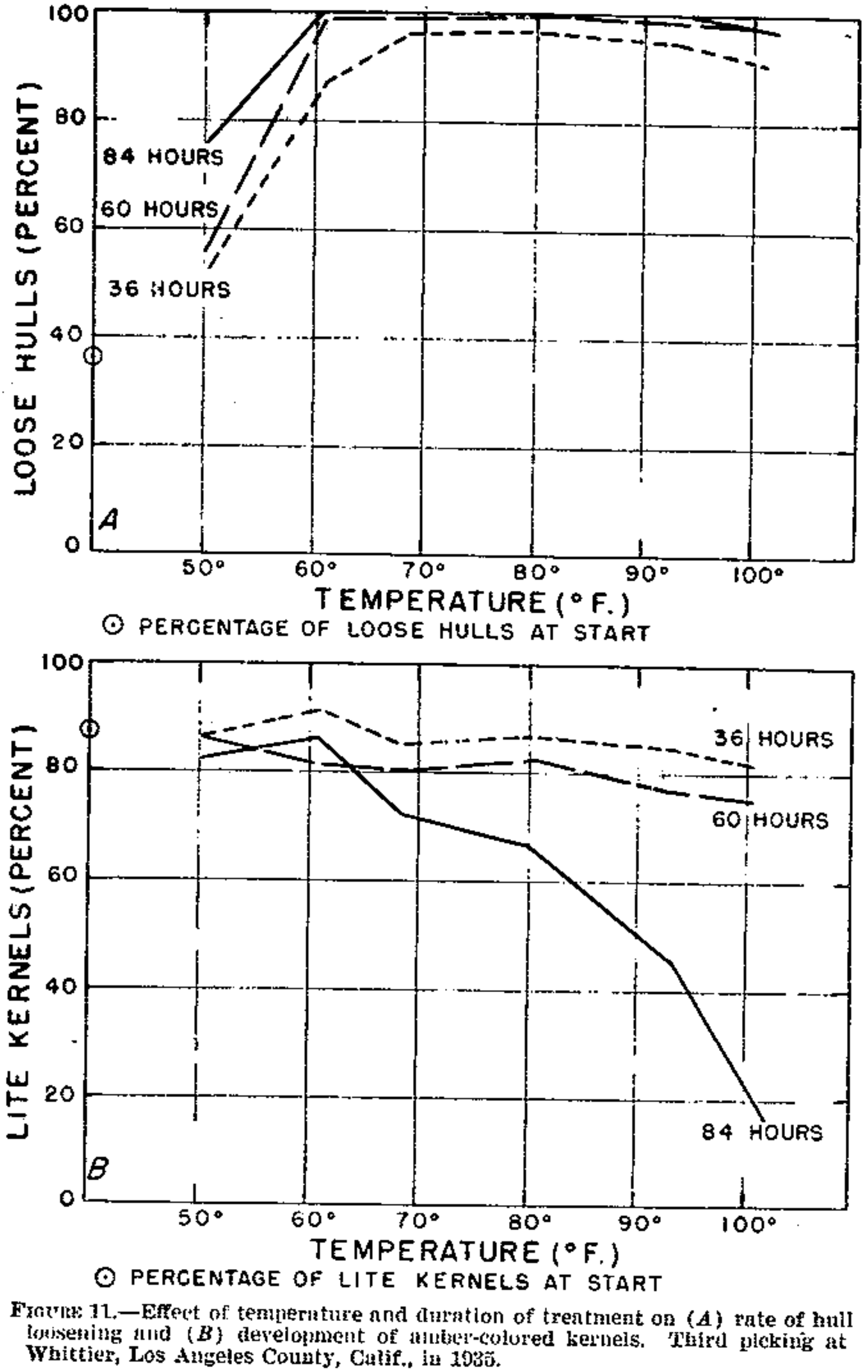


FIGURE 11.—Effect of temperature and duration of treatment on (*A*) rate of hull loosening and (*B*) development of amber-colored kernels. Third picking at Whittier, Los Angeles County, Calif., in 1935.

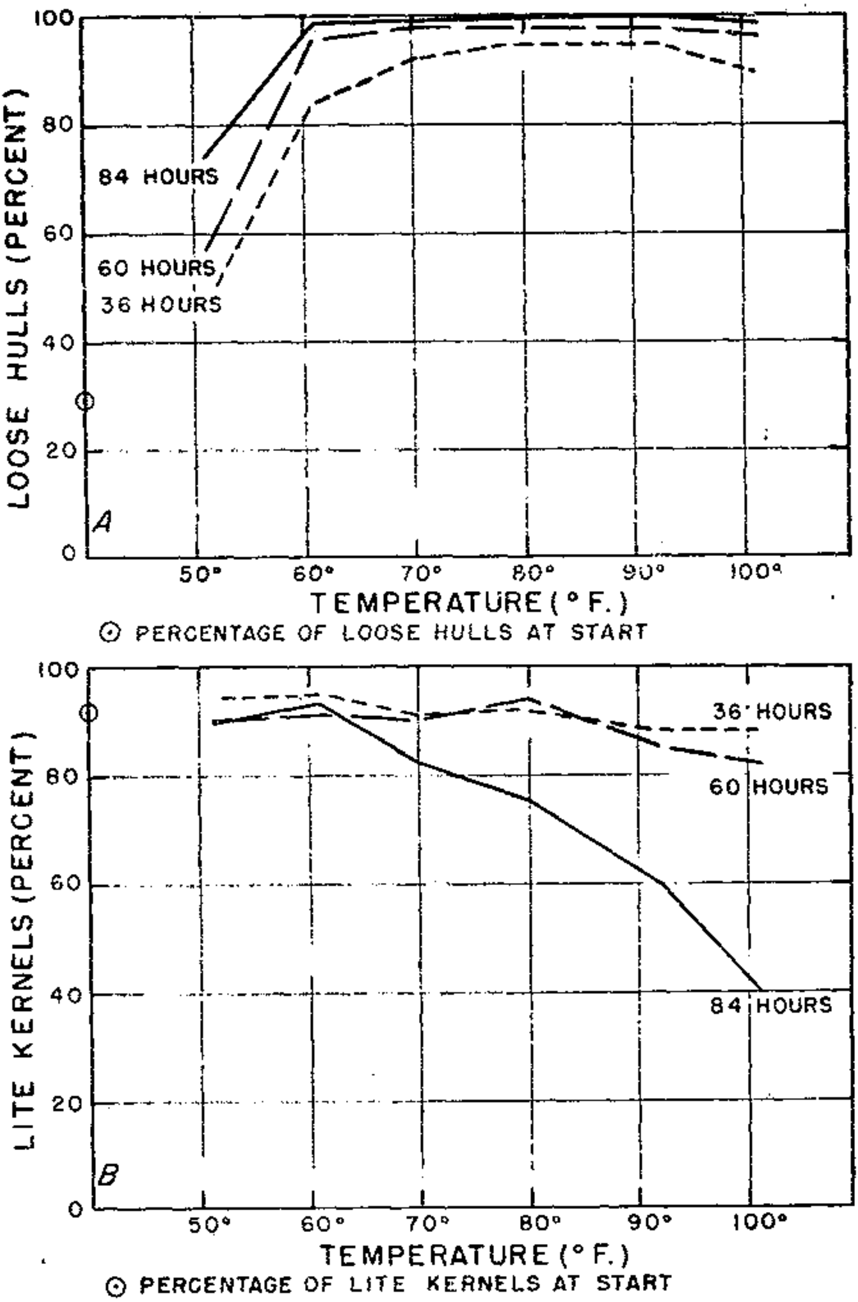


FIGURE 12.—Effect of temperature and duration of treatment on (*A*) rate of hull loosening and (*B*) development of amber-colored kernels. Average of all pickings at Whittier, Los Angeles County, Calif., in 1935.

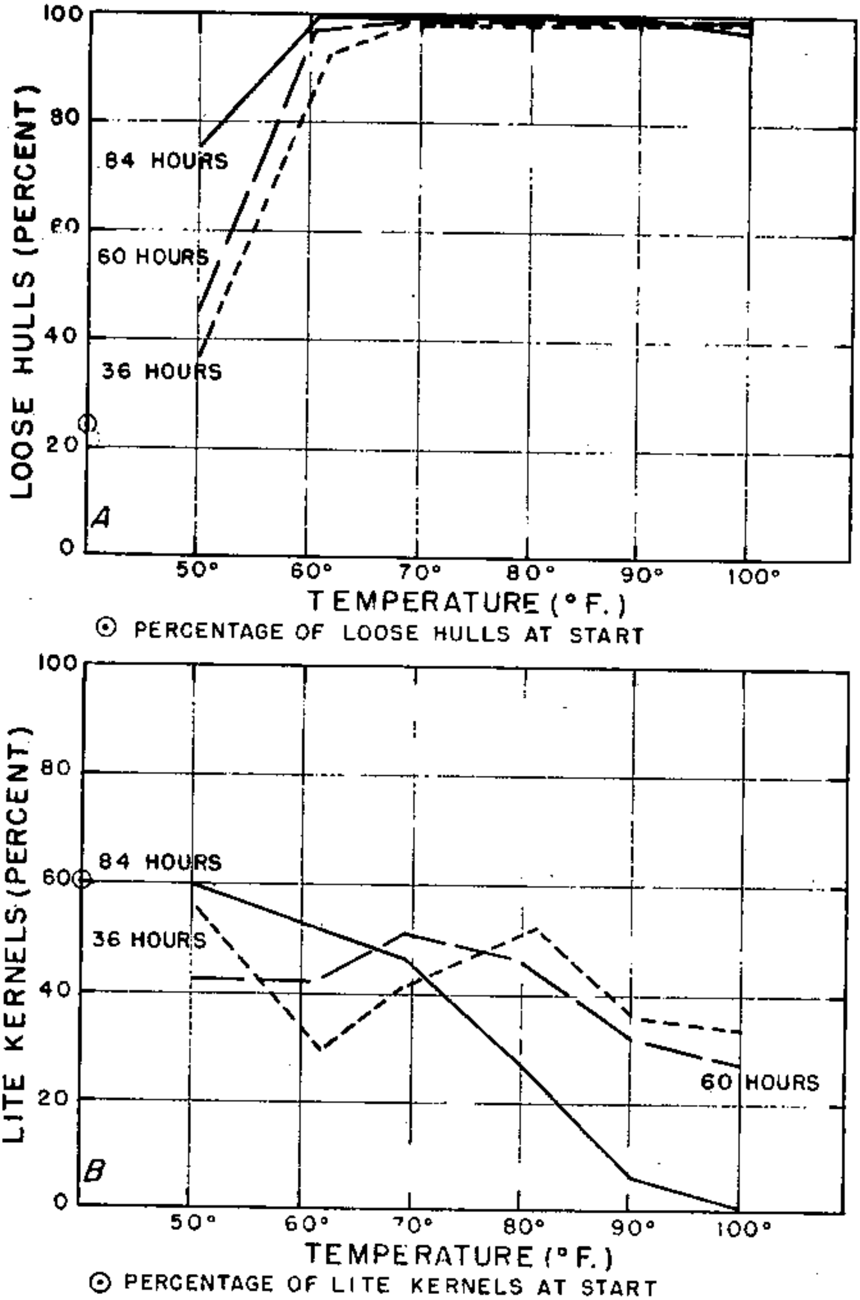


FIGURE 13.—Effect of temperature and duration of treatment on (*A*) rate of hull loosening and (*B*) development of amber-colored kernels. First picking at Hemet, Riverside County, Calif., in 1935.

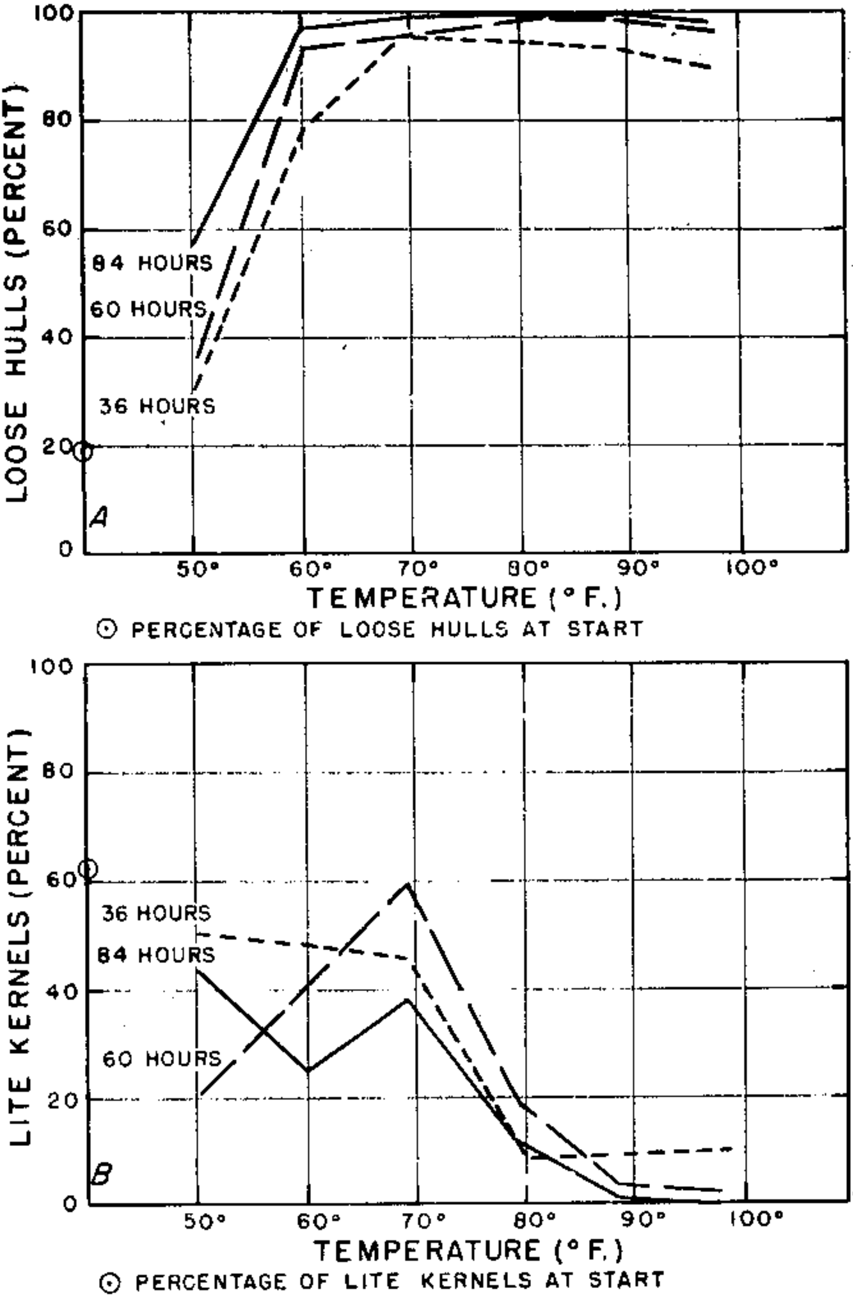


FIGURE 14.—Effect of temperature and duration of treatment on (*A*) rate of hull loosening and (*B*) development of amber-colored kernels. Second picking at Hemet, Riverside County, Calif., in 1935.

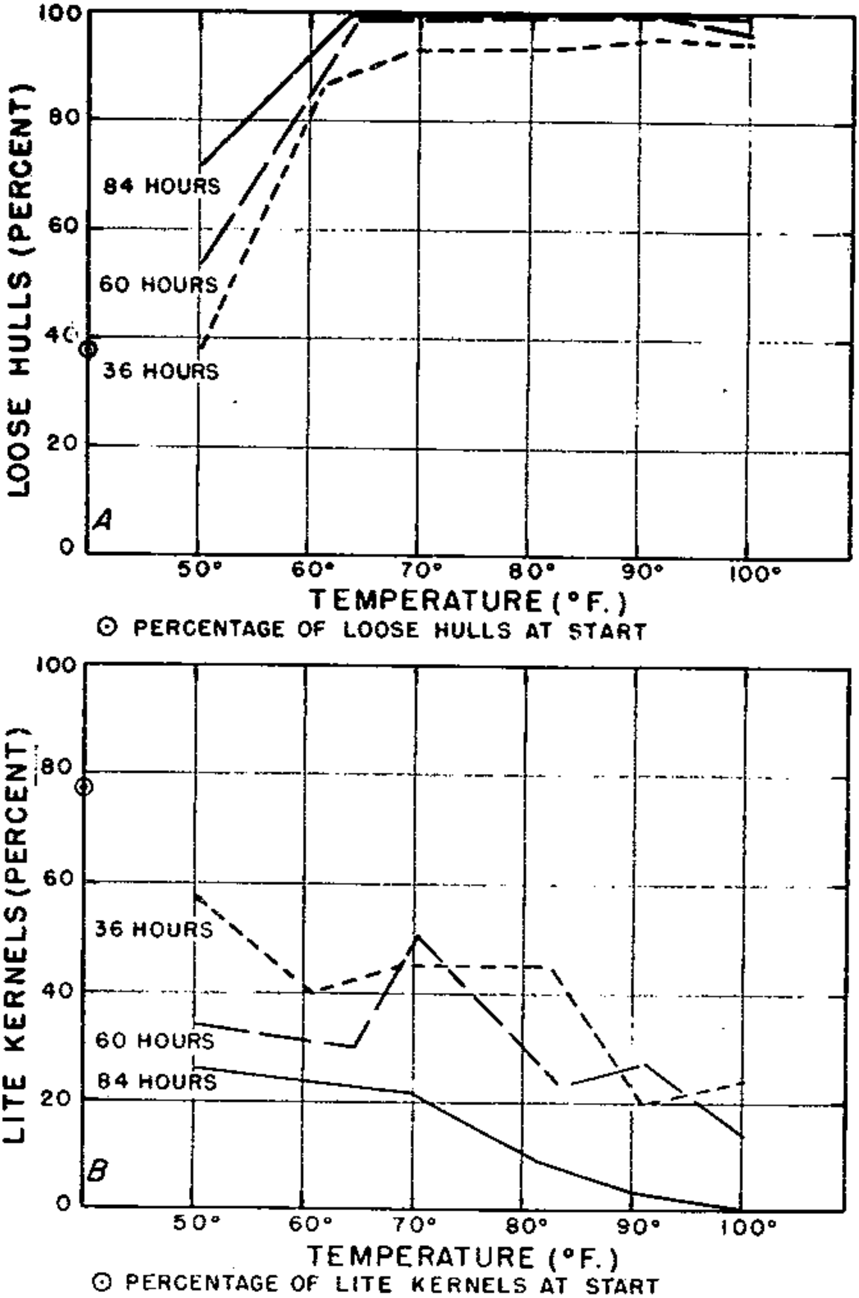


FIGURE 15.—Effect of temperature and duration of treatment on (A) rate of hull loosening and (B) development of amber-colored kernels. Third picking at Hemet, Riverside County, Calif., in 1935.

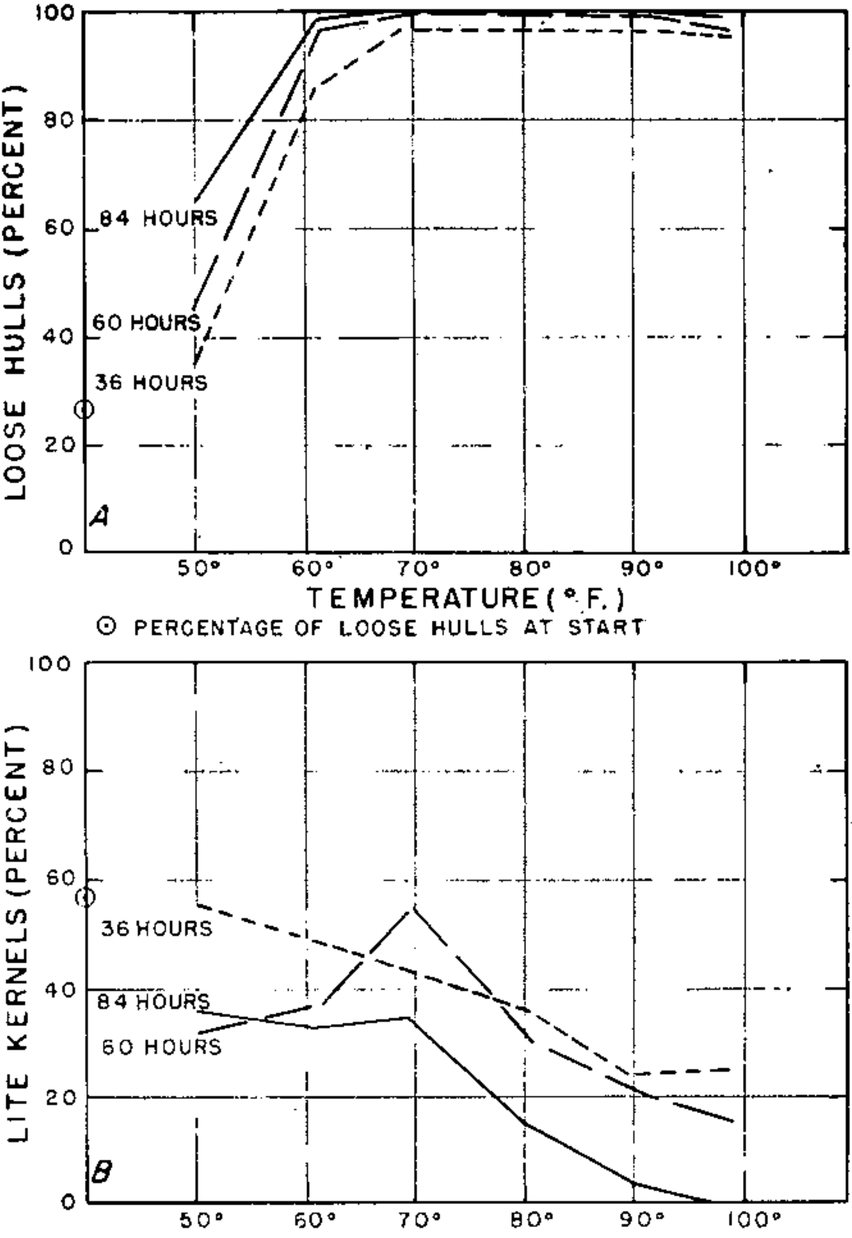


FIGURE 16.—Effect of temperature and duration of treatment on (A) rate of hull loosening and (B) development of amber-colored kernels. Average of all pickings at Hemet, Riverside County, Calif., in 1935.

842372° —50——5

ambering was in direct proportion to the rise in temperature and duration of treatment.

The green sticktights in the first picking at Whittier, from which the hulls were buffed, contained 13 percent of slightly immature kernels. This proves that the walnuts were picked at the beginning of the stage of maximum kernel-color stability. That fact is further substantiated by the longer time required to loosen the hulls of this lot in comparison with the second and third pickings.

In this test it was necessary to add heat in all instances to maintain the temperature of the walnuts at 100° F. In numerous field trials both in small treating compartments containing less than 1 ton of walnuts and in large commercial lots of as many as 15 tons (dry basis) stacked in field boxes in a citrus-treating room, maximum temperatures were very definitely self-regulated between 90° and 93°. In these cases the walnuts had been properly culled to eliminate decaying or blighted hulls. In no commercial plant has a temperature above 93° been observed except when decaying hulls were present. A maximum of 102½° was observed in one instance when decayed hulls were present. These field trials occurred at times when the temperature outside was below 90°, indicating definitely that the rise of temperature was caused by the increased respiration of the walnuts and that respiration was retarded at the higher temperatures, resulting in self-regulation at a point not dangerous from the standpoint of kernel color, provided the walnuts were hulled as soon as the hulls were loose.

Figures 9 to 16 also show the effect of length of treatment on rate of development of amber color. They provide additional evidence that: (1) walnut hull metabolism proceeds very slowly at temperatures below 60° F.; (2) less amber color results from treatment of 60 hours or less, regardless of temperature, than from more prolonged treating periods; (3) development of amber color is greater at all temperatures above 60° as the time of treatment lengthens; (4) development of amber color even at 100° may not be serious for 36 hours, or even as long as 60 hours, provided treatment is started at the beginning of the zone of maximum stability.

In general, this part of the experiment indicates that the rate of hull metabolism is relatively low at 50°; at 60°, though somewhat higher, it is still too low; but at 70°, as indicated by the speed of hull loosening, it is satisfactory. At the same time higher temperatures up to 90° or 100° can be tolerated from the standpoint of kernel color provided the time of treatment does not exceed 60 hours.

Under interior conditions, less amber color developed in the first picking than in either the second or third picking, as indicated in figures 13 (*B*), 14 (*B*), and 15 (*B*). The rate of amber-color development in this instance in the interior (fig. 13 (*B*)) is comparable to the average rate of kernel-color development at Whittier under semicoastal conditions (figs. 9 (*B*), 10 (*B*), 11 (*B*), and 12 (*B*)). The rate of decline for the second and third pickings under interior conditions (figs. 14 (*B*) and 15 (*B*)) was materially higher. The condition of the kernels and the rate of hull loosening in all lots indicate that the maturity of the second and third pickings at Hemet was much further advanced. This is additional evidence that the rate of amber-color development is much higher when walnuts are picked during the latter part of the stage of greatest kernel-color stability.

When it is realized that 95 percent or more of the hulls were loose at the end of 60 hours, as shown by figures 9 (A) to 16 (A), the reason for the rapid increase in the percentage of amber-colored kernels is apparent. Maturation processes had carried the kernels to the end of the stage of maximum physiological stability at that time. This condition is reached in the nut when the hull loosens. Thus, the fact that 95 percent or more of the hulls were loose indicates that the lot as a whole had reached the end of the stability stage, and the 24-hour period from 60 to 84 hours of continued warm, moist environment increased the percentage of amber-colored kernels. To prevent the chemical changes causing ambering at this point, a cool temperature is required.

From these data it can be safely said that fully matured walnuts treated with ethylene under proper conditions of humidity and carbon dioxide at temperatures from 70° to 90° F. will be 95 percent or more ready to hull at the end of 60 hours. The possible retarding effect of excessive moisture and carbon dioxide will be discussed later. The need for treating longer than 60 hours can be taken as an indication of too early picking with consequent immaturity, low temperatures at the start of treatment, insufficient diffusion of ethylene, or some other improper factor in the process.

Cooling Walnuts During Treatment

Walnuts in treating bins can be cooled satisfactorily with ventilating fans except when outside temperatures are between 85° and 95° or 100° F. with high humidity. Since under these conditions transpirated moisture evaporates from the surface of the walnuts too slowly for satisfactory cooling, the nuts should be liberally sprinkled with water just before ventilation.[12] It is not necessary to saturate the entire lot: in fact, saturation was found to be detrimental because it made too long a ventilation necessary in order to evaporate the water. After the sprinkling, ventilator fans should be operated long enough to dry the walnuts thoroughly. This system of cooling can be used only where forced-draft ventilation is available.

Effect of Humidity in Treating Chamber on Rate of Hull Loosening

In the first laboratory ethylene-treating experiment, it was found that maintaining high humidity by placing a wet sack over the walnuts in the treating cabinet resulted in slower loosening of the hulls than treating walnuts dry in a similar cabinet. During the first season's work it was found that when a treating enclosure was nearly filled with walnuts and their temperature dropped below the dew point of the atmosphere surrounding them the nuts became covered with condensed moisture and the rate of hull loosening was retarded. The effect of excessive moisture in treating chambers was therefore investigated in the laboratory.

The experiment was in many respects comparable with the first laboratory experiment already referred to. Twenty-five walnuts picked on July 5 were placed with the stems down on water-saturated

[12] Unpublished data of B. D. Moses, associate professor of agricultural engineering, University of California.

cotton. They were then put on apricot drying trays in the 1,000-liter treating cabinet. At the same time 35 nuts of the same picking were placed on an apricot drying tray in a duplicate box with no cotton and no added moisture. Both lots were treated with ethylene gas at the same concentration and at the same time. The results on hull loosening are shown in table 6.

TABLE 6.—*Effect of humidity of treating chamber on rate of hull loosening of walnuts treated with ethylene*

Treatment	Date and time begun	Hulls loose on—			
		July 9 (4 days)	July 10 (5 days)	July 11 (6 days)	July 12 (7 days)
		Percent	*Percent*	*Percent*	*Percent*
25 nuts on saturated cotton	July 5 at 2:30 p. m.	0	84	96	
35 nuts, dry	do	([1])	100		
22 nuts in desiccator with 50 ml. of water.	do	0	0	0	24

[1] Hulls were loose on a few nuts.

Twenty-two nuts from the same picking were placed in a 10-liter desiccator into which 50 milliliters of water had been placed. The nuts were supported on a tray above the water, and ethylene was introduced. The atmosphere in the desiccator was completely saturated, as indicated by the precipitation of moisture on the sides. The hulls of all the walnuts treated dry were loose at the end of 5 days, but it was 24 hours later before 96 percent of the hulls of those on water-saturated cotton were loosened. In contrast, only 24 percent of the nuts maintained at 100-percent saturation had loose hulls at the end of 7 days.

Similar treatments without ethylene were tried. The dry walnuts began to wilt and a few hulls were partly loosened on the fourth day. Those on saturated cotton showed no loosening until they began to decompose. The lot in the desiccator, which represented water-sweat conditions, had 75 percent of loose hulls on the fifteenth day, but the hulls were badly decomposed.

The laboratory data were further substantiated by a field test designed primarily to determine the type of structure necessary for successful ethylene treatment of walnuts (*46*).[13] Fifty-two citrus field boxes filled with walnuts were placed in an open shed under two layers of 7-ounce canvas supported by a light wooden framework in such a way as to provide air space around the entire lot. A partial first charge of ethylene was administered, followed by continuous trickling. The remainder of the same picking, which had been intimately mixed before division, was placed in a large bin in a commercial ethylene-treating chamber. At the beginning of each ventilation period, it was found that moisture had condensed on the walnuts in the

[13] Unpublished data of B. D. Moses, associate professor of agricultural engineering, University of California.

bin below the top 2 or 3 inches. The walnuts under the canvas were at no time moist from condensation. There were 225 partial sticktights from the 52 boxes of treated walnuts after 72 hours of treatment.

As there were no decayed hulls in the lot and the hulls were crisp, they were handled readily by the mechanical huller. In contrast, the lot treated in the bin, although it contained proportionately no more sticktights, did contain a considerable proportion of decayed and mushy hulls, which badly clogged the huller.

Effect of Carbon Dioxide Accumulations on Rate of Hull Loosening

In investigations on the use of ethylene to color citrus fruits, it was found that an accumulation in the treating room of carbon dioxide equaling 1 percent visibly retarded the rate of coloring (*3*). In treating walnuts in certain commercial plants, unexplainable delays occurred in the rate of hull loosening, and carbon dioxide was suspected as a possible cause. Accordingly, investigations were designed to determine the effect of accumulations of carbon dioxide and also the concentrations that retarded the rate of hull loosening. The delay in rate of hull loosening in commercial plants was later found to be caused by slow diffusion of ethylene among the walnuts rather than by carbon dioxide.

Tests for carbon dioxide accumulations were made over a 3-year period. The most intensive work was done in the laboratory, using the cabinets described in the section, Effect of Temperature and Duration of Treatment on Loosening Walnut Hulls, p. 21. The findings of these tests were as follows:

(1) No measurable retardation of the rate of walnut-hull loosening occurred with carbon dioxide concentrations of less than 3 percent.

(2) Because of the variability of the normal time required to loosen walnut hulls, the effect of concentrations between 3 and 7 percent was questionable.

(3) Definite retardation occurred with concentrations of 7 percent or more. For example, while check lots showed only 1 to 3 sticktights out of 300 walnuts in chambers where all carbon dioxide was absorbed, lots subjected to concentrations of 7.3 to 7.7 percent of carbon dioxide had 11 to 27 sticktights in 300. On a percentage basis this amounts to 0.3 to 1 percent with no carbon dioxide present as compared with 3.7 to 9 percent with slightly over 7 percent of carbon dioxide.

(4) The highest concentration of carbon dioxide found in commercial treating structures at the end of a 12-hour period just before ventilation was 5 percent. Only in rare cases did the concentration exceed 3 percent, and usually it was less than 2 percent.

Since some commercial structures are so built that total air space within the treating room is very little greater than the volume of walnuts placed in the chamber—a ratio as low as 1.2 to 1—it was thought that the respiration of the walnuts might reduce the oxygen content of the atmosphere enough to affect the rate of hull loosening. This was based on the fact that the research on the coloring of citrus fruit previously referred to showed that carbon dioxide accumulations above 1 percent visibily reduced the rate of coloring but did not affect the rate of metabolism (*3*). Accordingly, a test was made in the laboratory treating cabinets in which both ethylene and oxygen were added. The ethylene-treated control lot and the lot treated with ethlylene and oxygen were maintained at the same temperature. The rate of hull loosening was the same in both lots. It was concluded that absorption of oxygen or lack of oxygen in treating chambers did not affect the rate of hull loosening.

Although no specific studies on respiration were carried on, some interesting facts relative to respiration were obtained from the data gathered in the experiments to determine the effect of carbon dioxide on the rate of hull loosening. The quantity of carbon dioxide in the atmosphere of the treating cabinets was determined at the end of each 12-hour period, just before ventilation and recharging with ethylene. Two samples of gas were analyzed in each case, one from the top and the other from the bottom of the cabinet. In the tests made in 1936 the temperature of the cabinets was maintained at 90° F. A small electric fan in one of the cabinets kept the air stirred continuously, while in the other there was no atmospheric disturbance between ventilations.

Similar tests were carried on in 1937 with the same treating cabinets. The temperature was maintained at approximately 80° F. The results of both series of tests are given in table 7.

TABLE 7.—*Carbon dioxide in treating cabinets just before each ventilation period, in tests made in September 1936 and 1937*

Length of treatment (hours)	1936						1937		
	Sept. 5		Sept. 12		Sept. 18		Sept. 1	Sept. 6	Sept. 8
	Fan	Still air	Fan	Still air	Fan	Still air	Still air	Still air	Still air
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
12	1.2	2.4	5.3	9.3	5.8	8.9	2.8	2.8	4.0
24	1.4	1.9	5.1	8.0	6.0	7.6	3.4	3.4	3.5
36	1.3	1.4	4.4	7.3	6.8	7.2	3.2	2.4	3.8
48	1.1	2.1	4.6	6.8	4.9	6.8	3.5	2.4	3.2
60	.6	1.6	4.4	7.0	6.0	6.2	2.0	2.4	3.0
72							1.1	1.5	
86								.8	

In every case where the treatment was carried on in still air, the quantity of carbon dioxide was greatest near the beginning of the treating period. There was a definite decline as the treating period approached 60 hours when, except in excessively high concentrations of carbon dioxide, the hulls of all the nuts in the lots were loose. In the two instances where the treatment was carried on longer, one for

72 hours and the other for 86 hours, the decline was marked. This observation is in keeping with the experience of several other workers with various fruits. Kidd and West (*36*), in their work with apples, applied the term "climacteric" to the period immediately preceding full maturity, during which the increase in rate of respiration is greater than at any other time in the life cycle of the fruit.

Davis and Church (*21*) report that ethylene stimulated the softening, color development, and respiratory activity of persimmons as they approached full maturity before normal softening—"the stage corresponding to that which Kidd and West designated as climacteric in apples." They show that the stimulative effect of ethylene on respiration declined as the fruit ripened, especially in the last stages. Baier et al. (*3*) found the same thing to be true of oranges—that is, the effect of ethylene on respiration is to increase the rate considerably over that in air alone, and ethylene-colored fruit taken from the bins in the packing house respired much more slowly than average lots immediately after picking, either with or without ethylene.

In view of the observations by these workers, it would seem reasonable to assume that walnuts with green sticktight hulls are at a stage of maturity similar to the climacteric in apples, and that the rate of respiration declines sharply as this stage is passed and the hulls are loosened. This period appears to be coincident with the stage of maximum stability of color.

MATURITY STUDIES

Up to the time these studies were started, no investigation had been made of walnut maturity because harvest had necessarily followed natural loosening of the hull, and no problem of maturity existed. The first lot of walnuts treated with ethylene was picked 2 or 3 weeks before the usual harvesttime. A crack test showed that between 30 and 40 percent of these nuts were noticeably shrunken because of immaturity.

The percentage of shrunken kernels, later called immature shrivel, in the Placentia variety and seedling lots treated decreased rapidly during the next 2 weeks. A similar immaturity was apparent when the first lots of Eureka variety were treated on October 2 and 3. The appearance of immature shrivel disappeared in this late variety in 10 to 14 days.

These observations led to the belief that ethylene could loosen the hulls of immature walnuts. This belief was confirmed on July 3, 1934, when walnuts of the Placentia variety picked on June 28 were loosened after 5 days' treatment. When picked, this lot of walnuts was in the "jelly" stage, that is, no solid material had been formed in the developing cotyledons. When dried and crack tested, they showed 100 percent of immature shrivel.

The 1933 investigations revealed a need for detailed study of the maturity question. At this time the urgent need of a definite sign of maturity that can be readily observed with certainty by any one while the walnuts are on the tree (*52*) led to investigation of the relationship between maturity and "darkening of the fibrovascular bundles (veins) leading from the stem, the development of dark

TABLE 8.—*Factors observed in developing maturity test. Season of 1934 (300 walnuts from each picking examined)*[1]

Location	Variety	Date of picking	Nuts with hulls cracked	Abscission layer		Fibrovascular bundles from stem to kernel		Condition of packing tissue				Results of crack test (300 nuts)			
				Twig to stem	Stem to nut	Yellow	Brown	White	Spotted	Brown	Dried	Lite	Veined	Shriveled[2]	Sound
			Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Ventura, Ventura County.	Placentia	Aug. 15	30	32	7	32	78	36	62	2	0	6	51	34	63
		Aug. 20	2	20	10	34	66	12	32	56	0	24	59	11	87
		Aug. 27	90	49	13	7	93	1	9	90	14	7	77	4	95
		Sept. 3	-------	--	---	---	---	---	---	---	---	0	100	0	100
Tustin, Orange County	---do-----	Aug. 16	0	66	1	48	52	26	28	46	0	19	10	11	86
		Aug. 21	14	60	1	23	77	7	9	84	0	45	4	2	95
		Aug. 28	49	53	16	6	94	0	3	97	7	58	0	1	95
		Sept. 4	-------	56	24	16	84	0	4	96	48	51	0	2	94
Puente, Los Angeles County.	---do-----	Aug. 9	1	76	2	57	43	21	47	32	2	46	1	15	83
		Aug. 13	1	64	5	22	78	4	35	61	1	30	0	13	86
		Aug. 18	5	61	8	16	84	0	4	96	8	53	0	14	84
		Aug. 18	[3] 3	50	5	10	90	0	9	91	4	70	0	3	87
		Aug. 26	38	47	15	1	99	1	0	99	32	54	0	6	93
		Sept. 2	-------	40	72	2	98	0	0	100	80	66	0	1	96
Do-------------	Chase----	Aug. 8	2	69	4	67	33	40	35	25	5	72	3	14	84
		Aug. 12	5	67	7	27	73	15	27	58	2	46	0	10	90
		Aug. 17	1	63	1	13	87	1	17	82	5	50	0	8	91
		Aug. 24	[4] 46	-----	12	2	98	0	2	98	7	55	0	4	93
		Aug. 31	-------	37	44	0	100	0	0	100	61	65	0	5	91

Moreno Valley, Riverside County.	Placentia	Aug. 10	0	48	17	19	81	3	24	23	20	21	0	43	55
		Aug. 14	0	34	25	14	86	2	14	84	33	23	0	48	51
		Aug. 22	0	49	24	0	100	0	0	100	12	43	0	23	75
		Aug. 29	-------	48	19	0	100	0	0	100	80	46	0	8	91
		Sept. 5	-------	-------	-------	-------	-------	-------	-------	-------	-------	49	0	6	84
		Sept. 10	14	25	62	0	100	0	0	100	100	53	0	10	81

[1] Full maturity was reached in each orchard between the 2 pickings separated by horizontal line.

[2] Because of lack of experience of observers in distinguishing immature shrivel from naturally thin kernels, some of the latter were undoubtedly wrongly classified as "shriveled." Subsequent experience proved that there is only an occasional immature shrivel after 95-100 percent of the nuts develop brown packing tissue.

[3] Hand-picked from lower limbs of tree from which regular picking was done (line above).

[4] Free of hull. Field hulled.

842372°—50——6

TABLE 9.—*Percentages of lite, moldy, and sound kernels in ethylene-treated and field-hulled walnuts in 4 climatic areas of southern California in 1934*

Location of orchard	Variety	Date of picking [1]	Ethylene-treated			Field-hulled			
			Lite	Moldy	Sound	Percentage of picking	Lite	Moldy	Sound
			Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Coastal—Ventura County	Placentia	Aug. 15	6	0	63	30	48	1	61
		Aug. 20	24	0	87	47	71	1	89
		Aug. 27	7	0	95	90	40	1	97
		Sept. 3	0.	0	100	------	58	0	98
		Sept. 9	------	------	------	------	81	0	97
		Sept. 17	------	------	------	------	61	1	96
		Sept. 25	------	------	------	------	64	0	97
		Sept. 28	------	------	------	------	59	1	96
Average	------	------	------	0	------	------	------	0. 6	------
Intermediate coastal—Orange County	Placentia	Aug. 16	19	0	86	4	6	0	6
		Aug. 21	45	0	95	14	60	1	76
		Aug. 28	58	0	95	49	46	1	97
		Sept. 4	51	0	94	------	38	2	92
		Sept. 12	------	------	------	------	13	7	84
		Sept. 20	------	------	------	------	10	23	73
		Sept. 28	------	------	------	------	10	2	91
Average	------	------	------	0	------	------	------	5. 1	------

Intermediate interior—Los Angeles County	Placentia	Aug. 9	46	0	83	0	----	----	----
		Aug. 13	30	0	86	0	----	----	----
		Aug. 18	53	0	84	5	----	----	----
		Aug. 26	54	1	93	39	79	2	94
		Sept. 2	66	1	96	58	61	5	94
		Sept. 7	----	----	----	89	53	4	93
		Sept. 18	----	----	----	----	26	13	87
		Sept. 27	----	----	----	----	30	13	86
Average	----	----	----	.4	----	----	----	7.4	----
Intermediate interior—Los Angeles County	Chase	Aug. 8	72	0	84	0	----	----	----
		Aug. 12	46	0	90	0	36	0	48
		Aug. 17	50	1	91	14	77	5	88
		Aug. 24	55	2	93	46	80	3	95
		Aug. 31	65	1	91	----	78	6	92
		Sept. 7	----	----	----	97	56	11	86
		do	----	----	----	----	52	12	87
		Sept. 14	----	----	----	----	39	6	88
		Sept. 24	----	----	----	----	32	9	86
Average	----	----	----	.8	----	----	----	6.5	----
Interior—Riverside County	Placentia	Aug. 10	21	0	55	0	----	----	----
		Aug. 14	23	0	48	0	----	----	----
		Aug. 22	48	0	75	0	----	----	----
		Aug. 29	46	0	91	0	57	3	89
		Sept. 5	49	2	84	17	25	13	60
		Sept. 10	53	4	81	14	21	16	71
		Sept. 18	----	----	----	----	19	4	81
		Sept. 26	----	----	----	----	3	10	80
		Oct. 4	----	----	----	----	0	25	55
Average	----	----	----	1	----	----	----	11.8	----
General average [2]	----	----	----	0.5	----	----	----	5.91	----

[1] Full maturity was reached in each orchard between the 2 pickings separated by horizontal line.
[2] Arithmetic average—all lots of equal size.

areas in the packing tissue inside of the shell and also the development of abscission layers either in the stem or next to the walnut."

On the start of work in 1934, it was decided that observations of the behavior of the packing tissue[14] should be made in considerable detail.

As the nuts approached maturity, brown spots appeared toward the blossom end of the walnuts in this packing tissue. These spots spread rapidly until the entire mass of packing tissue became light brown. At about this stage the tissue began to dry and produce a cavity around the kernel.

During the 1934 harvest season, a representative sample of each lot used for all purposes of the investigation was carefully examined for the following physical factors: Cracked hull, abscission layer (either twig to stem or stem to nut), darkening of fibrovascular bundles from stem to center of kernel, and the condition of the packing tissue, whether "white," "spotted," "brown," or "dry." The data thus obtained were classified and correlated with the results of final crack tests of 300 nuts each. In the crack tests, the nuts were observed to see whether they were lite, veined, shriveled, sound. These data have been arranged in table 8, pp. 3–9. A line is drawn across the table to separate the pickings between which full maturity was reached. Correlation of these data with the development of brown color of packing tissue led to the development of the final maturity test.

The results of the crack test on these lots are presented in table 9, pp. 40–1. Here, as in table 8, pp. 38–9, the line across the table indicates that the crop reached full maturity between the picking date above and the one below. A study of this table shows that green sticktight walnuts picked just after 100 percent of the packing tissue had become brown had practically as high a percentage of lite and sound kernels as field-hulled lots. The fact that a few lots of field-hulled nuts contained a slightly higher percentage of lite kernels is further evidence that under favorable weather conditions walnuts that are field-hulled retain a better color of kernel than the same nuts would have if exposed to the temperatures required by the ethylene process.

The quantity of sound field-hulled nuts that could have been harvested as soon as the entire crop was mature, as indicated in the table, varies from none in the interior area to 46 percent for the Chase variety and 39 percent for the Placentia variety in the intermediate-interior area. The decline these field-hulled nuts would suffer as the result of temperature during ethylene treatment (table 3) indicates the need for separating field-hulled nuts from green sticktight walnuts before treating.

In 1935 Davis (*19*) reported detailed chemical and physical investigations in which he studied "specific gravity of the whole walnut, ratio of the weight to the volume of the kernel; a percentage of chemical constituents such as oil, protein, tannin, starch, sugar, and glucoside." He subsequently stated (*20*) that "it appears that the optimum har-

[14] "Packing tissue" is the white, pithy tissue that during the period of growth of a developing walnut, fills all the space between the lobes of the cotyledons and between the cotyledons and the shell. In the dry walnut the remains of this packing tissue form the major and minor septums and the thin layer that lines the shell.

vesttime can be better ascertained by the well-known crack test than by any other means found up to this time." He further calls attention to the difficulty of sampling, as follows: "It is difficult to obtain satisfactory samples from a walnut grove, and yet the whole matter of changing the harvesttime depends on securing representative samples." He suggested that the crack test be based on buffing the hulls from walnuts with a circular, revolving wire brush, followed by washing and standard drying, and believed that the packing-house manager or a well-trained field man could take care of the classification of crack-test results since the greater part of the work would come before actual harvesting began.

Davis' implied conclusions that specific gravity could not be used as a satisfactory test for maturity were confirmed in attempts to salvage the mature nuts from several tons of walnuts blown from trees by a high wind at Hemet on August 23, 1935. All nuts blown down were green sticktights. Two days after the storm, the nuts were gathered from the ground and placed in treating chambers. After 2½ days in ethylene, samples were placed in a tank of water. The results are shown in table 10. According to the maturity test, described later, 15 and 34 percent of the Placentia walnuts and none of the Eureka walnuts showed all brown packing tissue.

TABLE 10.—*Percentage of mature and immature walnuts, as indicated by color of packing tissue, in a lot separated by specific gravity at Hemet, Calif., Aug. 27, 1935, and percentage of sound and lite kernels as determined by crack test*

Variety	Orchard	Color of packing tissue						Sound kernels	Lite kernels
		White		Spotted		Brown			
		Floated	Sank	Floated	Sank	Floated	Sank		
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Placentia	1	26	10	44	1	19	0	54	7
	2	16	7	42	1	34	0	66	4
Eureka	3	1	47	28	24	0	0	0	0

These findings were substantiated by subsequent crack tests. A large percentage of the nuts was commercially sound, however. It will be noted that while none of the mature nuts sank, a large proportion that floated were immature, as indicated by the color of the packing tissue. Eureka walnuts were exceedingly immature when blown from the trees, as indicated by total absence of brown packing tissue.

The investigations in 1934 led to tentative maturity recommendations by Kimball (*41*) in June 1935. These recommendtions, based on the development of brown color in the packing tissue, were as follows: "If the walnuts when shaken (not hand picked) from the trees and opened are found to have 100 percent darkened and drying packing tissue with some cavity around the kernel between the halves, it is believed there is no danger of immaturity."

During 1935 approximately 150 field tests were made for verification of the tentative recommendations (*44*). A careful procedure was followed to obtain representative samples. Sampling began about August 15 and was continued at regular intervals in the same orchards until all walnuts were fully mature. The data for two typical orchards, table 11, show the relation between brown packing tissue and full maturity. From the information thus gathered, definite recommendations were made as follows (*44*): "When a sample of at least 100 nuts shaken from all parts of several trees is found to have 100 percent brown packing tissue, with cavities forming around the kernels, the walnuts will be safe for harvest."

TABLE 11.—*Typical maturity data obtained with Placentia variety of walnuts in 1935*

Date	Cracked hulls	Color of packing tissue: White	Color of packing tissue: Spotted	Color of packing tissue: Brown	Color of packing tissue: Immature	Fully mature	Condition of immature kernels
COASTAL SECTION OF LOS ANGELES COUNTY							
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
Aug. 22	0	76	24	0	100	0	Shriveled, dark.
Aug. 31	0	18	76	6	74	26	Do.
Sept. 4	1	0	43	57	64	36	Do.
Sept. 10	3	1	35	64	49	51	Plump, off-color.
Sept. 14	..	0	26	74	12	88	Do.
Sept. 19	1	1	0	90	2	98	
Sept. 22 [1]	....	0	0	100	0	100	
INTERMEDIATE SECTION OF LOS ANGELES COUNTY							
Aug. 24	0	0	47	53	59	41	Dark.
Aug. 28	0	8	44	48	42	58	Some red spotting.
Sept. 2	6	0	4	96	2	98	Do.
Sept. 5	-----	0	0	100	0	100	

[1] Picking started on Sept. 24.

The only condition under which this maturity test was found to need modification was when the walnuts were grown in extremely dry soil. Then the packing tissue was brown and dried back, forming a cavity around the kernel as early as a week before maturity was reached.

The necessity for careful sampling cannot be overemphasized. Nuts for the maturity test should be shaken from all parts of trees with the same vigor as is used in harvesting. Failure to do this has caused some losses (*43*). Hand-picked samples do not yield a representative cross section. The two pickings on August 18 of the Placentia variety from the Puente orchard (table 8) indicate the difference in percentage of brown packing tissue that may be expected. Greater differences were found on other occasions.

Maturity recommendations were made available to growers through the Agricultural Extension Service, University of California.[15]

In 1936 the question was raised of the possible presence of an abscission layer in the center of the walnut at the point where the conductive tissue from the stem branches into the pellicle. It was felt that if such a layer did exist its formation would necessarily coincide with the maturity of the cotyledons. This possibility was investigated with the assistance of the Division of Pomology of the College of Agriculture and the Department of Botany, of the University of California. Carefully prepared samples were examined microscopically and no abscission layer tissue was found.[16]

PREPARATION OF WALNUTS FOR TREATMENT

Research revealed that a departure from customary harvesting practice was necessary when ethylene was used. These changes are discussed under the appropriate heads.

Picking

It has been general knowledge among growers that walnuts can be shaken from the tree more readily in the early morning when the atmospheric humidity is high than later in the day when the relative humidity is lower and the temperature has risen. When picking dates were advanced to permit harvesting as soon as the kernels were mature, regardless of the condition of the hull, it was found that immature walnuts frequently came from the tree as easily as those that were mature. This emphasized the need for maturity tests before any shaking was undertaken. Furthermore, in some years there seems to be a very limited formation of any abscission layer, either between the twig and the stem or between the stem and the walnut, so that there is great difficulty in shaking any walnuts from the trees. The factors responsible for this variation have not been determined. In most seasons, however, picking walnuts in the green sticktight stage when the kernels are mature is entirely practical.

In intermediate climatic areas at some distance from the coast, picking of walnuts is occasionally complicated by uneven ripening. This condition is brought about by uneven and prolonged blooming and setting of nuts in the spring as a result of abnormal dormancy (*12*, *13*). Such an experience in 1940 is reported in the section, Climatic Limitations to the Use of Ethylene for Walnut Harvest, p. 56.

---

[15] KIMBALL, M. H., SUGGESTIONS ON DETERMINING MATURITY OF WALNUTS, Calif. Agr. Ext. Serv. 2 pp. 1936; THE DETERMINING OF WALNUT MATURITY FOR EARLY HARVEST BY ETHYLENE, Calif. Agr. Ext. Serv. 2 pp. 1938. [Mimeographed.]

[16] E. L. Proebsting, Division of Pomology, University of California, gathered the samples, and Ethel Nast, Department of Botany, reported the negative findings in an unpublished letter.

Ground Scald

It has been common harvesting practice for shaking crews to precede pickers by a few hours to a day. It was suggested in 1933 that exposure of green sticktight walnuts to direct sunlight on the ground was hazardous. This belief grew in subsequent years to such an extent that limited tests were made, in which more than 100 nuts each were used. The temperature of the nuts was obtained by burying the bulbs of mercury thermometers in the center of at least one walnut in each lot. A check lot was kept in the shade. In a test at Whittier exposure of green sticktights to the sun ranged from 30 minutes to 4 hours and 40 minutes. It was found that the temperature of the walnuts in the hull became materially higher than those with the hull removed, the former reaching as much as 23° F. higher than the air temperature in the shade, the latter only 16° higher. This difference was due to the greater ability of the hulled walnut to give up moisture. The loss of color quality under these conditions is shown in table 12.

The data under Puente in table 12 were obtained in a test made there on a clear, hot day when the temperature in the shade was 104° F. A thermometer just under the surface of the soil registered 144°. A thermometer in green sticktight walnuts on the surface of the soil registered 126° at the end of 30 minutes. During this time no discoloration of the hull, or sun scald, developed. The exposed lots contained 30 percent of lite kernels, as compared with 87 percent for the check lot not exposed.

Table 12.—*Effect of direct sunlight on green sticktight walnuts*

Location and exposure	Green sticktights						Field-hulled walnuts			
	Highest temperature			Lowest temperature		Lite kernels	Highest temperature		Lowest temperature	Lite kernels
	Air	Nut	Soil	Air	Nut		Air	Nut	Nut	
	° F.	*° F.*	*° F.*	*° F.*	*° F.*	*Percent*	*° F.*	*° F.*	*° F.*	*Percent*
Whittier:										
In shade	92			78		92	92	78		69
In sun 3 hours		109			90	80		106	84	71
In sun 4 hours and 40 minutes		115			90	60		108	84	89
Puente:										
In shade	104			104		87				
In sun for half hour			144		126	30				
Hemet:[1]										
Hulls not scalded						74				
Hulls scalded						7				

[1] Walnuts gathered during commercial harvest; length of time exposed to sun not known.

A green sticktight walnut exposed to direct sunlight on an exceedingly hot day will soon assume a definitely scalded appearance, similar in every way to that produced by dipping a walnut into boiling water. Walnuts from Whittier and Puente (table 12) did not become scalded. The figures for Hemet are for walnuts gathered during commercial harvest. Walnuts were shaken from trees in the normal process of harvest in the late morning and were gathered from the ground by the pickers during the afternoon. The samples were later drawn from sacks. Nuts that showed at least some scalded hull tissue were compared with specimens from the same sack that showed no scald. The temperature during the day is not known, but it was exceedingly high, presumably more than 110° F. in the shade.

Subsequent field observations at Puente, on a day when the temperature in the shade was 112°, revealed that 30 minutes was sufficient to produce complete scald of hulls both on the side exposed to the sun and that in contact with the ground. It is safe to assume, therefore, that the scalded walnuts in the Hemet test had lain in the sun for at least 30 minutes or more and that the unscalded walnuts had lain in the shade. The loss in value between 74 percent lite, 90 percent sound of the unscalded lot and 7 percent lite, 90 percent sound of the scalded lot would be approximately 5.3 cents a pound.

These data show that green sticktight walnuts must not be allowed to lie on the ground in the sun long enough to permit them to become heated. The time depends on the temperature in the sun.

Need for Separation of Nuts in Preparation for Treating

The stability of the creamy white color of the walnut pellicle, which is normal in walnuts grown under favorable conditions, decreases rapidly after the kernel has reached full maturity. It is most stable before any loosening of the hull while on the tree, less stable when the walnut has been picked and placed in a treating bin. As soon as the hull loosens, whether on the tree or in the treating bin, the tendency for the amber color to develop is greatly increased. The rate of ambering increases rapidly when walnuts are confined in ethylene-treating chambers with loose or cracked hulls or with hulls removed. The same high rate of amber-color development is maintained in the hulled walnut during any interval between hulling and dehydration or during intermittent dehydration. The rate increases in all stages in proportion to the rise in temperature, while environmental conditions (adhering loose hull, high humidity of treating bins and storage bins, or intermittent dehydration) prevent any appreciable dehydration, resulting in saturation of the atmosphere in the cavity around the kernel.

The following test to determine the effect of storage temperature on the development of amber color in both green sticktights and field-hulled walnuts was made in 1935. A special picking was thoroughly mixed and divided into lots of 110 nuts each. Hulls of one lot of green sticktights were immediately buffed off with a power-driven circular wire brush and the walnuts were promptly dried and crack tested to determine the color inherently present in the entire lot. One lot of field-hulled walnuts was likewise dried and crack tested. One lot of green sticktights was held at 74° F. for 95 hours without ethylene. A field-hulled lot was placed in a treating bin comparable in every way with those in which the green sticktights were placed. They were not treated with ethylene, but were held at 74° for 95 hours. The other green sticktight lots were placed in temperature-controlled compartments at 50°, 60°, 70°, 80°, 90°, and 100° and exposed to ethylene for 91 hours. The results of this test are shown in table 13.

The field-hulled lot held in humid storage was definitely injured in quality. Green sticktight lots held at 60° F. and warmer could have been hulled long before 91 hours as far as hull loosening was concerned. The extra time represented unnecessary exposure to warm humid conditions similar to those imposed on field-hulled nuts or nuts with cracked, loose hulls at picking time that are put into treating chambers.

TABLE 13.—*Relation of stage of hull maturity at time of treatment and temperature during treatment to loss of color quality of Placentia walnuts, Ventura County, 1935*

Condition of nuts	Treatment	Temperature	Time held	Condition of kernels		
				Lite	Amber	Sound
		° F.	*Hours*	*Percent*	*Percent*	*Percent*
Green sticktights	Hulls buffed			86	9	95
Field hulled	Dried and cracked without delay.			60	31	91
Do	Held in cabinet; no ethylene.	74	95	3	85	88
Green sticktights	No ethylene	74	95	69	25	94
Green sticktights	Ethylene-treated	50	91	68	27	95
Green sticktights	Ethylene-treated	60	91	41	53	94
Green sticktights	Ethylene-treated	70	91	14	81	95
Green sticktights	Ethylene-treated	80	91	2	96	98
Green sticktights	Ethylene-treated	90	91	0	96	96
Green sticktights	Ethylene-treated	100	91	3	90	93

A loss of nearly 70 percent of the lite color occurred in the field-hulled lot held at 76° F. without ethylene for 84 hours (table 3, p. 15). Results with hulled walnuts held in humid warm storage without ethylene for 16 hours are given in table 14. The fact that the experiment related primarily to dehydration is of no moment. The conditions of storage, humidity, and temperature were similar.

These data indicate that to subject field-hulled walnuts or walnuts with hulls cracked and loose from the shell to the warm moist environment of ethylene-treating chambers will result in development of amber color—a loss of color quality. Such nuts should be separated and hulled and dehydration should be started promptly.

TABLE 14.—*Effect of delayed or intermittent dehydration on kernel color of walnuts* [1]

Treatment	Lite	Moldy
	Percent	*Percent*
Drying started immediately after hulling	79	3
Placed in storage bin over dehydrator for 16 hours before dehydration	48	8
Shelled after hulling and kernels dried	96	0
Continuous dehydration at 107½° to 109° F	85	0
Interrupted dehydration:		
Lot 1	81	1
Lot 2	79	1

[1] Test made by H. B. Richardson, assistant farm advisor of Riverside County, Calif.

METHODS OF SEPARATION

Several methods of separating green sticktights from nuts free of the hull have been utilized by growers. The simplest is to have the pickers keep them apart, but this system is not entirely satisfactory because of the human element. A more satisfactory method is to bring all nuts in from the field and pass them over a sorting belt, where a smaller, more highly trained crew can separate them. Even with this procedure a large number of partial sticktights get to the huller, with the result that the hulling is incomplete and the nuts with adhering hulls become culls unless they are subsequently water-sweated. In this method, if any doubt exists as to whether or not a nut is a sticktight or a partial sticktight, it should be included in the lot to be ethylene treated, even though a slight crack may exist in the hull.

Field experience has indicated that certain mechanical processes can effect a reasonably complete separation. Many walnuts, particularly by middle or late harvest season, have hulls entirely loose from the shell but with no cracks in the hull to indicate their condition. If such walnuts are subjected to a vertical drop of approximately 4 feet, striking a solid board placed at a 45° angle, most of the loose but uncracked hulls are broken, making it possible to pick them out. Two careful field trials made in midseason revealed that from 15 to 22 percent of what were apparently green sticktight walnuts had entirely loose hulls. The vertical drop so cracked the hulls as to permit them to be separated and sent to the huller and dehydrator rather than to the ethylene-treating bin, where their kernel color would have been damaged during the 48- to 60-hour treatment. This drop should precede any mechanical or picking-belt separation.

Three types of mechanical separators have been developed. One type consists of a revolving open-end cylinder with the sides of the parallel rod so spaced as to permit hulled walnuts to drop through, while those with the hulls on, whether cracked or uncracked, are carried through. Hand picking from belts for such mixtures is of course necessary. Another type is a shaker table with parallel bars across it. This table can be constructed with close-spaced bars at the receiving end to eliminate trash, such as leaves, twigs, and broken hulls. A second section with wider bar spacings permits field-hulled walnuts to fall through, while nuts with hulls are carried to the end of the table. The third type, shown in figure 17, consists of parallel bars on eccentric bearings so spaced that as the walnuts roll down the bars the trash and hulled walnuts fall through, while those in the green hulls are carried to the end of the table.

Decayed or Blighted Walnuts

That the environment of treating chambers accelerates bacterial decay of the hulls was recognized in the first year's work. In one of the first ethylene-treated lots, a small proportion of sunburned, blighted, and badly bruised walnuts was included. During the normal time of treating, the hulls of the entire lot turned black. When hulled, it was found that the shells were stained and the kernels were chocolate brown. This gave rise to the practice in subsequent experimental work of rigidly separating nuts with decayed or blighted hulls from all lots being treated. In commercial practice, walnuts with decayed or blighted hulls should not be placed in ethylene-treating chambers either by themselves or mixed with green sticktights. They should be hulled at once and thoroughly washed. If necessary, they should be held in water sweat until any adhering hull loosens.

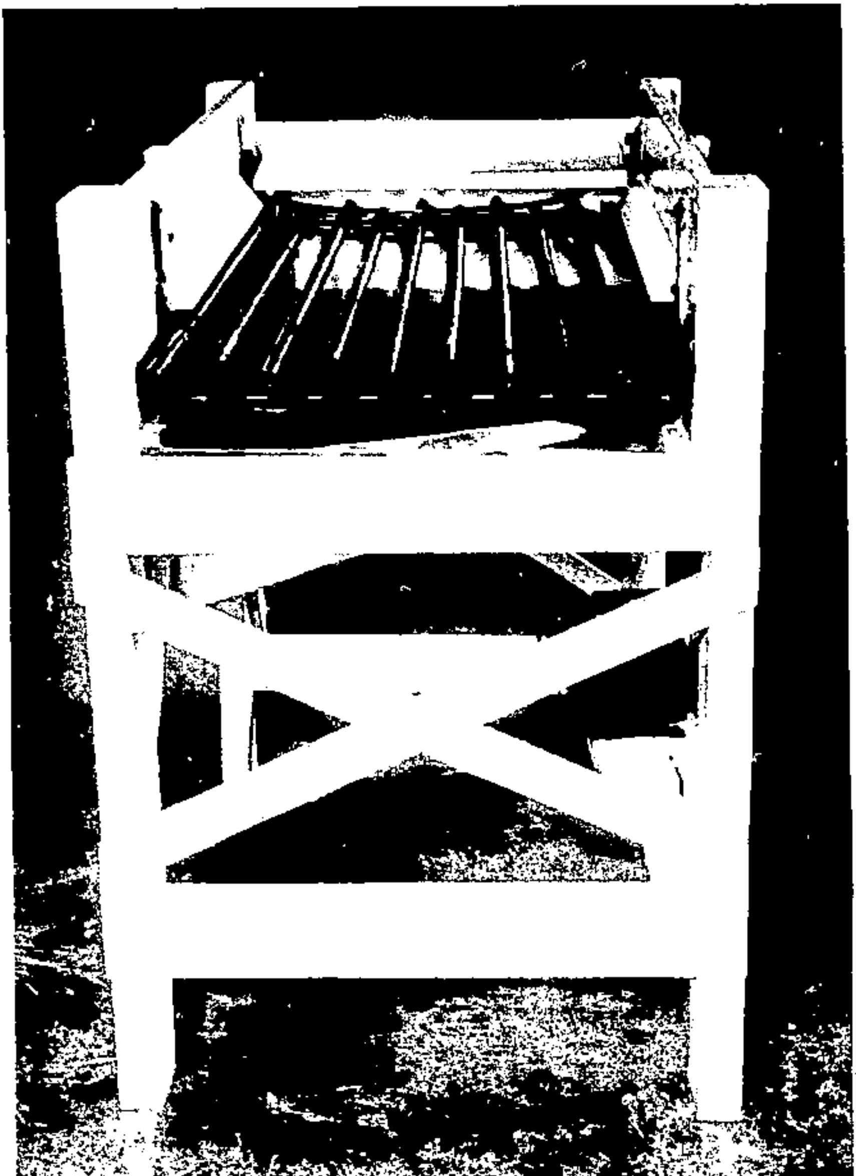
Some growers have not followed this practice, either because of lack of time or facilities or because they did not appreciate its importance. Numerous lots have been observed which, when removed from the treating chamber, were so broken down by bacterial decay as to be virtually one slimy mass. Detailed experimental data on this particular phase were not gathered.

Sunburn

Sunburn of the walnut hull results in a discoloration ranging from a light yellowish cast on the side of an otherwise green hull to dark brown or black areas, which may or may not be shrunken, depending on the time of year when the sunburn occurs. The extent of injury to either the shell or the kernel is not uniformly proportional to the extent of visible sunburn. This variation is the result of several factors, among which are the time when sunburn occurs in relation to the development of the nut, thickness of hull, and climatic conditions in the general area involved.

Most frequently sunburn that results in severe injury to the kernel discolors the shell, thus making it possible for the nut to be culled in the packing house. In some instances, however, presumably when sunburn occurs late in the season after the shell tissue is completely formed, the shell may show no injury, whereas the kernel may be darkened or burned. This condition may occur in nearly any walnut-growing district in the State, but it is most common in the warmer interior sections. Its occurrence, even there, varies with weather conditions in different seasons.

In interior districts when late sunburn has occurred, resulting in discoloration of the kernel pellicle without damage to the shell, it has been found profitable to remove sunburned from uninjured green sticktights and treat the lots separately (*45*). When cracked, the sunburned lots were found to be nearly 100 percent amber, with many



F[illegible] 17.—W[illegible] separator used [illegible] of [illegible] for ethylene [illegible]. Every other bar is stationary. Alternate bars are activated by [illegible]. S[illegible] hulled [illegible] to fall through, while those [illegible]. This separator was designed by W. E. S[illegible] [illegible] Vegetable Chemistry.

almost black kernels. The uninjured walnuts frequently were first grade. At Riverside a net profit of 78 cents per hundred pounds was made on the crop from several orchards handled in this way.

Conditioning Walnuts for Ethylene Treatment

Experimental trials have shown that the rate of hull loosening in ethylene-treated walnuts is very slow below 60° F. Walnuts should not be placed in a treating chamber if the temperature is under 60°. On the other hand, the heat of respiration causes a steady rise in temperature during the treating period. It is better therefore that walnuts be cool when treatment starts, preferably near 70°.

Natural conditions in the field during harvest can be utilized to bring about this desirable temperature. If night temperatures are low, walnuts picked early in the morning should be put in the sun, in sacks, for a sufficient time to allow them to absorb heat to approximately the desired temperature. If, on the other hand, day temperatures are so high that when walnuts are picked from the tree their temperature is well above 70°, they can be cooled by letting the sacks stand in the shade. If temperature of walnuts is unavoidably high when they are placed in treating bins, ventilating fans should be operated long enough to equalize temperature within the bins and at the same time cool the nuts.

HANDLING WALNUTS AFTER TREATMENT

Hulling

The removal of walnuts from the trees while in the green sticktight stage introduced the problem of bruised hulls. Most of this bruising is caused by the impact of the falling nut. When a walnut drops 50 or 60 feet and strikes a stone, a hard clod, or another walnut, the hull is bruised. Some bruising is caused by rough handling during sorting and separating at plants. These bruises may be only a small scratch or may affect one-fourth or one-third of the hull. All unshelled walnuts to be marketed commercially are bleached to give them a light uniform color. It has long been known that juice from the hulls bruised during harvest, either by a husking peg or by a mechanical huller, stains the shells of the nuts so that they will not bleach satisfactorily. Such unbleachable walnuts are discarded as culls on the basis of external appearance. In certain cases, up to 72 percent of the green sticktight walnuts coming in from the field were found to be bruised. The percentage varied with soil conditions, size of trees, and methods of handling.

The effect on a green sticktight walnut of a bruise caused by falling is somewhat different from that of a huller bruise or a husking-peg wound that cuts through the hull to the shell. The tissue of the bruised area is destroyed, but in most cases the shell is not directly exposed. When such walnuts are put into treating chambers, ethylene has no effect on the bruised areas. The dead tissue dries and adheres closely to the shell. When the rest of the hull loosens and is removed by the huller, the dried tissue of a bruised area remains as a blemish on the shell. Up to 60 percent of the severely bruised walnuts hulled after ethylene treatment were found thus damaged.

Normal washing, it was discovered, would not remove these bits of adhering dried hull. It was necessary to hold the nuts in a squirrel-cage type of washer for several minutes and to keep the machine so filled that nuts rolled 4 to 6 inches deep. The short soaking plus the friction of one walnut against another effectively removed the adhering hull particles. The shell under them was not materially stained. This extra washing can be accomplished in a standard washer of the squirrel-cage type merely by partly closing the exit with a narrow board, thus backing up the walnuts until they fall over the board.

Walnuts direct from the field that are put through the huller before the hulls are loose are so damaged by the hulling process that they do not respond to ethylene treatment. Nor do such damaged nuts respond to additional ethylene treatment if they have come from the treating chamber. In order to preserve these walnuts until the remaining portions of hull are loosened, they must be washed immediately to remove juices of the crushed hull and be kept under water-sweat conditions for 12 to 24 hours, or until the remaining hull is loosened.

Effect of Slow Handling After Hull Removal

The physiological condition of the fully mature walnut that permits the formation of color in the kernel pellicle remains unchanged until the walnut begins to dry. When dehydration starts, the humidity of the cavity between the kernel and the shell is reduced. The lowering of humidity apparently changes the environment of the kernel pellicle sufficiently to check the development of amber color. As long as dehydration is continuous and the humidity of this cavity is low, the development of amber color is kept at the minimum. If at any time before the walnuts are fully dry dehydration is interrupted, for instance by shut-downs at night or failure of air-circulating systems, adverse conditions such as saturated humidity and high temperature are immediately built up and the amber color increases.

The effect on field-hulled walnuts of high humidity and high temperatures in storage is indicated in lines 1 and 2 of table 3. In the test summarized in this table field-hulled nuts that were dried immediately averaged 81.7 percent of light-colored kernels, while a companion lot held at 76° F. for 84 hours averaged 12.4 percent of light-colored kernels. Table 13 shows that there was a drop from 60 to 3 lite kernels when field-hulled nuts were held at 74° for 95 hours.

Effect of Delayed Dehydration and Use of Holding Bins

In attempting to increase the efficiency of dehydration equipment, many growers have stored walnuts as they came from the huller in the warm atmosphere above the dehydrator, thinking that this warm air would dry them or at least prepare them for dehydration by warming them. Even before there was a definite understanding of the cause of ambering, it had been found in the field that such a practice was damaging. In one large plant it was found necessary to install a special air-circulating system in the overhead storage or holding bins, thus actually creating a dehydrator, to make the bins usable. Many growers, thinking that temperature was more important than air circulation, closed their dehydrators tightly at night, holding a temperature of 105° to 110° F. inside. The humidity built up, creating a condition of high temperature and high humidity that caused rapid development of amber color in the walnuts.

Holding walnuts under any conditions after hulling and before complete dehydration is detrimental (*48, 49*). Subjecting walnuts to such treatment is comparable to putting field-hulled walnuts into the high humidity and relatively high temperature of an ethylene-treating chamber, or to allowing walnuts to remain in the hulls on the tree after the hulls are completely loose.

Numerous field trials were made to determine the effect on color of storage under different conditions. The results of one such test are summarized in table 14, p. 49. In this test, percentage of lite kernels declined from 79 to 48 in 16 hours in a storage bin. Mold increased from 3 to 8 percent. Table 14 also shows the effect of interruptions in dehydration, as well as the increase in amber color that normally occurs during dehydration. One portion of a lot of walnuts was shelled immediately after hulling, and the kernels were dried at 109° F. for about 1½ hours. A second portion was dried continuously in a standard dehydrator at temperatures of 107½° to 109°. A third portion was subjected to daytime dehydration with shutdowns at night. There were 11 percent fewer lite kernels in the lot continuously dried as compared with those dried out of the shell, showing the effect of standard dehydration. Interrupted dehydration reduced the proportion of lite kernels by 5 percent. This phenomenon is also discussed by Marsh.[17]

RELATION BETWEEN ETHYLENE TREATMENT AND MOLD DEVELOPMENT IN WALNUTS

Many conditions during the harvesting of walnuts are conducive to development of moldy kernels (*4*). All are in one way or another definitely associated with a time-temperature-humidity relationship after the first cracking of the hull. The procedure of picking walnuts as soon as they are mature, promptly loosening the hull with ethylene, and immediately starting dehydration, reduces the percentage of moldy kernels. From the commercial standpoint the control of mold is exceedingly important. Both Federal and State standardization laws specify a maximum tolerance of 10 percent of inedible kernels from all causes. In addition to mold, worm infestation, shrivel, black color, and rancidity, as well as several minor defects, are classed as causes of inedibility. It is commercially impossible to eliminate 100 percent of such defects by culling during the packing process. Therefore, if the entire tolerance is absorbed by moldy kernels, many otherwise valuable lots are necessarily reduced in sales value or are thrown into the cull classification.

The percentage of moldy kernels in field-hulled (natural harvest) walnuts from an orchard in each of the four climatic areas is given in table 9, p. 40. Treated walnuts averaged only 0.5 percent moldy, while the field-hulled lots averaged 5.9 percent moldy, indicating the commercial importance of ethylene treatment. The average of

[17] (See footnote 6, p. 12.)

the data in table 9 is included with other data in table 15. In all experimental lots treated with ethylene, there were almost no moldy kernels. The average for the entire period of experimentation was only a fraction of 1 percent. Similar lots of field-hulled walnuts were not available for comparative purposes. Crack tests were subsequently made on the two portions of each picking.

TABLE 15.—*Comparison of percentages of moldy kernels in treated and untreated walnuts, for period Aug. 8–Oct. 4, 1934*

Source of data	Nuts treated with ethylene	Nuts not treated (field hulled)	Excess in untreated over treated lots
	Percent	*Percent*	*Percent*
Experimental lots:[1] 41 special treated lots of 300 nuts each from 4 climatic areas, 6 to 8 pickings	0.5	5.91	5.41
Commercial harvest: Merchantable crop average from 2 comparable seedling orchards in Los Angeles County, 1934	4.1	8.4	4.3
Merchantable crop average from 6 budded orchards, crop treated, and 7 budded orchards, crop not treated, Los Angeles County, 1934	4.6	7.5	2.9
Merchantable crop average from 2 seedling orchards, crop treated, and 3 seedling orchards, crop not treated, Los Angeles County, 1935	5.7	8.5	2.8
Merchantable crop average from 17 budded orchards, crop treated, and 15 budded orchards, crop not treated, Los Angeles County, 1935	2.9	7.4	4.5
Merchantable crop average from 1 orchard, Chase variety, treated and untreated portions, Los Angeles County, 1940	2.16	6.16	4.0
From 3 budded orchards, treated and untreated portions, Riverside County, 1939			4.4
From 12 budded orchards, crops not treated, and 11 budded orchards, crops treated, Riverside County, 1939			6.9
From 5 budded orchards, crops not treated, and 6 budded orchards, crops treated, San Bernardino and Los Angeles Counties, 1939			2.7

[1] Field-hulled nuts were sorted out and only walnuts with uncracked green hulls were treated. Dehydration of the field-hulled nuts was started immediately. Crack tests were subsequently made on the 2 portions of each picking. See table 9, p. 40.

The remaining data in table 15 were compiled from packinghouse records for treated and untreated crops for the entire season. In these data, the ethylene-treated crops are comparable to the combination of treated and field-hulled in the experimental lots, because only the early pickings of the so-called ethylene-treated crops were actually treated. The data thus present a composite of the entire merchantable crop. Treated crops are shown to contain from 2.7 to 6.9 percent fewer moldy kernels than untreated crops.

CLIMATIC LIMITATIONS TO THE USE OF ETHYLENE FOR WALNUT HARVEST

Studies of the maturity of the walnut kernel in relation to hull loosening indicate that the kernel matures most rapidly during warm weather, whether humid or dry. On the other hand, hull maturity, which might reasonably be called synonymous with hull loosening, proceeds most rapidly during weather with reasonably cool, humid nights. In the coastal areas, where day temperatures are moderate and nights are relatively cool, kernel maturity is somewhat retarded and hull maturity is accelerated. The difference in time seldom exceeds a few days. In the interior, where nights are relatively warm, with low humidity, the kernels mature rapidly, but hull maturity is delayed until fall weather arrives with cool nights and higher humidity. The interval between the maturity of the kernel and that of the hull may be as long as 3 to 4 weeks.

Walnuts grown in all portions of the State have been treated with ethylene. The data accumulated indicate that under certain climatic conditions the use of ethylene is not only unnecessary but even detrimental.

In general, in the entire coastal section, from Mendocino and Napa Counties in the north to the western sections of Ventura County in the south, walnut kernels mature and hulls loosen at about the same time. Under these conditions the percentage of lite kernels is normally high, and there is no need for stimulating hull loosening. Furthermore, in all coastal sections, the vascular bundles that form a network in the kernel pellicle darken when walnuts are held at the required temperature for the time necessary for ethylene treatment, producing an undesirable striped or veined appearance. The use of ethylene is detrimental under such conditions. Table 8 shows the relationship of veining to climate. From 51 to 100 percent of the walnuts from Ventura became veined. At Tustin, some 10 miles inland, veining occurred only before the nuts became fully mature. At Puente, 30 miles inland, from 1 to 3 percent showed veining about 10 days before the full maturity stage was reached. At Moreno Valley, 60 miles inland, no veining appeared.

In Santa Barbara and Ventura Counties warm winters cause dormosis (*12, 13*), resulting in an extremely long blooming season. Walnuts may be blooming and nuts setting for nearly 2 months. While the harvesting period is somewhat shorter than the blooming period, there will be fully mature walnuts that have fallen from the trees as well as walnuts on the trees in which the kernels have just solidified and are 4 to 5 weeks from full maturity. Walnuts in all stages of maturity are removed from the tree during shaking. This uneven maturity makes the use of ethylene inadvisable. Uneven harvest caused by delayed foliation occasionally results in complications in intermediate climatic areas after extremely warm winters.

Under the climatic conditions of the northern Sacramento Valley, the central and southern San Joaquin Valley, and the interior sections of Los Angeles, Riverside, and San Bernardino Counties, kernel maturity precedes natural loosening of the hull by 10 days to 4 weeks. In these sections the ethylene process is of maximum benefit.

Intermediate between those sections normally having typical coastal weather and the interior sections is a zone subject to both long and short-time variations in weather conditions. This area is typified by the southern Sacramento and northern San Joaquin Valleys, and Contra Costa, eastern Ventura, Los Angeles, and Orange Counties. In this intermediate climatic zone there is usually a period of 1 to 3 weeks between kernel maturity and hull maturity. In most seasons the use of the ethylene process preserves the kernel color.

Occasionaly after warm winters the uneven blossoming with resultant uneven maturing produces conditions comparable with those of the warmer coastal sections, such as Santa Barbara and Ventura Counties. Such a season was 1940. The winter of 1939–40 set a record for high temperature. The blooming season of 1940 extended over 6 to 8 weeks. Growing conditions during the summer were more coastal than normal, so that a greater amount of veining was found after ethylene treatment than had ever before been observed in these districts. Furthermore, the uneven ripening of walnuts resulted in a wide range of maturity during the first picking. When such uneven maturity occurs as a result of an unusually warm winter, a compromise between picking a few immature walnuts and allowing most of the crop to hang too long is advisable in order that the kernel color may be preserved to the greatest extent possible. Experience at Puente has proved that even under these conditions the use of ethylene is profitable.

Weather variations in northern sections, such as Contra Costa County, may make the use of ethylene advisable. In 1940 kernel maturity preceded hull maturity by the length of time usual in more interior sections. Several crops were saved from serious loss of kernel color by the ethylene process. However, in such districts the ethylene process should not be necessary as a regular practice, and in most seasons, under coastal weather conditions, it will cause veining. In most years it is better to use the water-sweat process to loosen the hulls of the sticktights that are brought down by normal shaking during the harvest. It is only when characteristically interior weather conditions prevail at harvesttime that ethylene treatment is beneficial.

The effect of climatic factors on maturity is shown in figures 18, 19, 20, and 21. Each figure shows the percentage of lite kernels resulting from the treatment of green sticktights with ethylene from the date when first trials were started until so few sticktights were encountered in the advancing harvest that treatment was discontinued. These charts also show when the first field-hulled walnuts were found. A vertical line marked "M", in figures 19–21, indicates the date on which a maturity test showed the crop to be ready for picking. The data from which these charts were made are from tables 8 and 9.

At Ventura (fig. 18), under extreme coastal conditions 1 mile from the ocean, full hull maturity was reached on August 27. At that time 90 percent of the walnuts shaken from the trees were so mature that they were free of the hull. The weather conditions that produced this degree of hull maturity were favorable to the preservation of the lite color of the kernel pellicle. Treatment with ethylene produced no beneficial effect. On the contrary, it darkened the fibrovascular veins to such an extent that the commercial grade was lowered.

At Tustin, Orange County (fig. 19) (*53*), 10 miles inland, under moderate coastal conditions, harvest with ethylene could have started

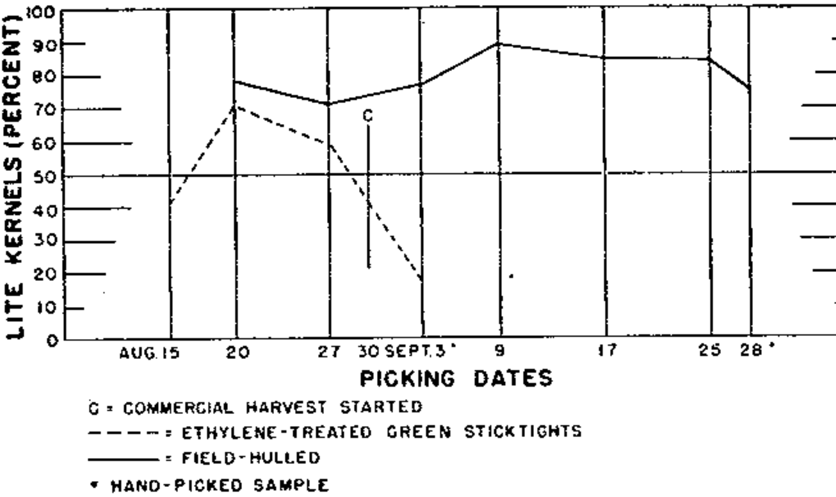


FIGURE 18.—Percentage of lite kernels in green sticktights and field-hulled walnuts before and after start of commercial harvest. Ventura, Ventura County, Calif., 1934.

about August 25. At that time 65 percent of the first picking were green sticktights. Commercial picking in an orchard started on September 3. The beginning of harvest could have been advanced about 9 days in 1934.

At Puente (fig. 20) (*53*), 30 miles inland, under intermediate climatic conditions, harvest by the ethylene process could have been started on August 20. At that time 90 percent of the walnuts were in the green sticktight condition and would have gone into ethylene treatment. In this district commercial picking without ethylene was started by the earliest operators on August 31. The majority did not begin until a week to 10 days later. With the aid of ethylene, harvest

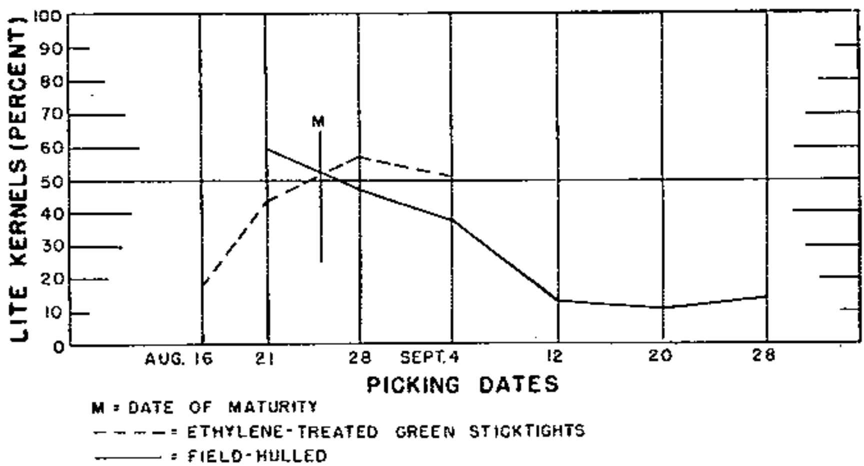


FIGURE 19.—Percentage of lite kernels in green sticktights and field-hulled walnuts before and after maturity. Tustin, Orange County, Calif, 1934.

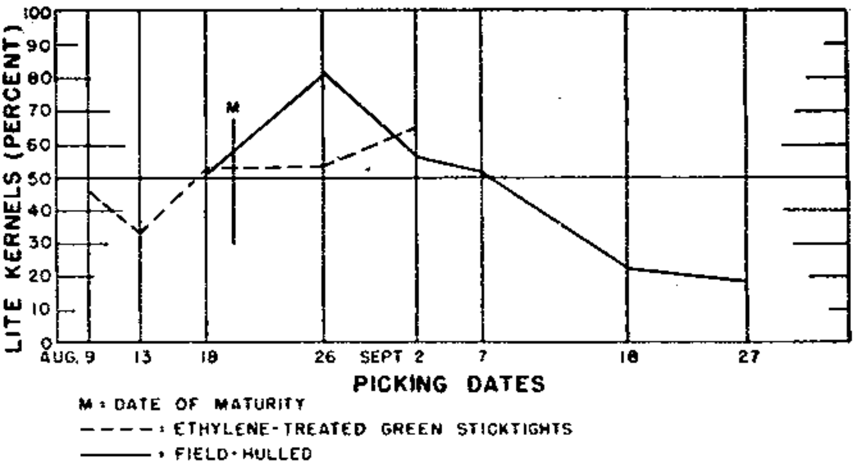


FIGURE 20.—Percentage of lite kernels in green sticktights and field-hulled walnuts before and after maturity. Puente, Los Angeles County, Calif., 1934.

could have been started 11 days earlier than the earliest normal harvest and 14 to 18 days earlier than the average.

In the interior (fig. 21) (*53*), harvest with the use of ethylene could have started on August 25. This district is approximately 60 miles inland. At that time 100 percent of the walnuts were green sticktights. The first field-hulled walnuts were found on August 29. The earliest harvesting began on September 11, and the majority of operators did not begin until the 15th or the 18th. Thus even the earliest operators lost 17 days of potential harvesttime, and the majority delayed between 3 and 4 weeks. During this period the highly perishable lite kernel color was subjected to the unfavorable condition of full maturity inside a green sticktight hull at the high temperatures characteristic of that district.

It will be noted that the percentage of lite-colored kernels of walnuts treated with ethylene increased from the earliest pickings to approximately the time of full maturity, with relatively little improvement

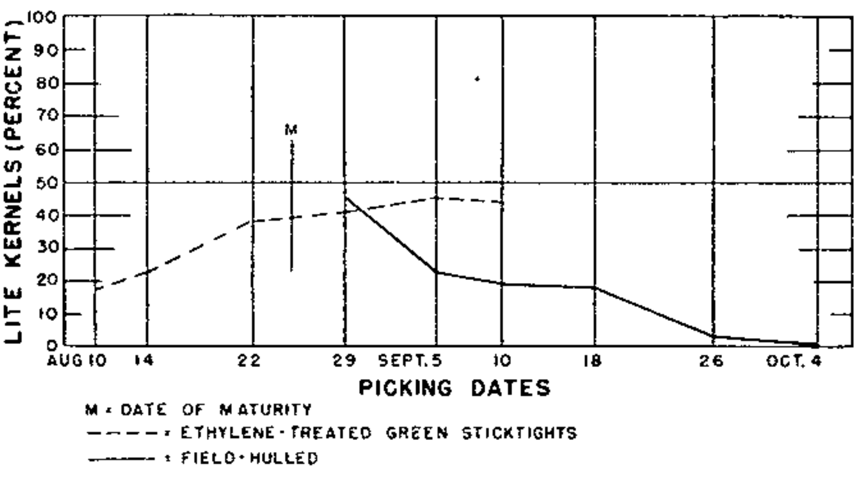


FIGURE 21.—Percentage of lite kernels in green sticktights and field-hulled walnuts before and after maturity. Moreno, Riverside County, Calif., 1934.

thereafter. The characteristic development of amber color that occurs during ethylene treatment of immature walnuts accounts for the greater percentage of amber-colored kernels early in the season. This illustrates what has been said previously concerning the necessity of timing harvest to agree with full maturity. A more detailed discussion of the relation of climate to ethylene is given by Sorber (*53*, *54*.)

PHYSICAL CHARACTERISTICS OF THE PERSIAN WALNUT

The change of practice introduced by the ethylene process called for information on the physical characteristics of walnuts. The following data were obtained as a basis for proper engineering in plant construction, dehydrator capacity, etc.

Table 16 shows that: (1) Green sticktight walnuts weigh from 29.8 to 33.5 pounds per cubic foot; (2) 1 ton of green sticktight walnuts requires approximately 63 cubic feet of bin or box volume; (3) approximately 225 cubic feet of green sticktight walnuts are equivalent to approximately 1 ton of dry-hulled walnuts; (4) 1 ton of dry-hulled walnuts occupy approximately 100 cubic feet of space.

The percentage of moisture loss in ethylene-treated and water-sweated green sticktights, as well as in field-hulled walnuts, is shown in table 17. The date at which harvest by the ethylene process could have started, as shown by maturity tests, is indicated. The proportion of green sticktights existing at that date provides an index to the value of the ethylene process and indicates the proportion of the total crop to be treated.

In connection with the engineering work (*26*), it was found that green sticktight walnuts have a natural angle of repose of approximately 35 degrees, or a slope that rises 8 inches per foot of horizontal distance.

TABLE 16.—*Volume weights and equivalents of green sticktight, wet-hulled, and dried walnuts, moisture loss in dehydration, and size of nuts* [1]

Orchard No. [2]	Date of picking 1934	Pounds per cubic foot of walnuts: Green in hull	Pounds per cubic foot of walnuts: Hulled, Wet	Pounds per cubic foot of walnuts: Hulled, Dry	Cubic feet per ton of walnuts: Green in hull	Cubic feet per ton of walnuts: Hulled, Wet	Cubic feet per ton of walnuts: Hulled, Dry	Cubic feet of walnuts green in hull to make 1 ton of dry	Loss of moisture on drying	Size of nut
FIRST PICKING OF MATURE GREEN STICKTIGHT WALNUTS—ETHYLENE TREATED										
									Percent	*Inches*
3	Aug. 26	32.9	26.6	19.3	60.8	75.2	103.6	227.9	30.8	79/64–85/64
4	Aug. 24	33.5	28.1	20.1	59.7	71.2	99.5	213.1	34.0	85/64+
5	Aug. 29	30.2	24.4	18.7	66.2	82.0	107.5	216.3	29.2	79/64–85/64
LAST PICKING OF GREEN STICKTIGHT WALNUTS—ETHYLENE TREATED										
1	Aug. 27	29.8	26.2	17.9	67.1	76.3	111.7	258.6	34.0	79/64–85/64
2	Sept. 4	32.5	28.3	21.3	61.5	70.7	93.9	247.0	31.5	79/64–85/64
3	Sept. 2	31.1	25.2	19.6	64.3	79.4	102.0	223.6	28.0	79/64–85/64
4	Aug. 31	32.5	29.7	20.7	61.5	67.3	96.6	208.8	33.5	85/64+
5	Sept. 10	30.7	25.0	19.6	65.1	80.0	102.0	214.2	28.4	79/64–85/64
FIRST PICKING OF FIELD-HULLED WALNUTS										
1	Aug. 15		27.2	17.5		73.5	114.3		39.7	69/64–79/64
2	Aug. 28		30.7	21.6		65.1	92.6		33.3	79/64–85/64
3	Sept. 2		26.3	20.7		76.0	96.6		25.8	79/64–85/64
4	Aug. 24		30.7	21.8		65.1	91.8		32.4	79/64–85/64
5	Sept. 10		23.4	18.0		85.5	111.1		26.7	79/64–85/64
LAST PICKING OF FIELD-HULLED WALNUTS										
1	Sept. 25		20.4	20.1		98.0	99.5		5.4	79/64–85/64
2	Sept. 28		26.2	24.3		76.3	82.3		13.0	79/64–85/64
3	Sept. 27			20.9			95.7		4.6	79/64–85/64
4	Sept. 24		22.7	21.8		88.1	91.7		7.1	79/64–85/64
5	Oct. 4		21.4	19.2		93.5	104.2		9.6	79/64–85/64

[1] All the walnuts were the Placentia variety except those from orchard 4, which were the Chase variety.

[2] Locations: Orchard 1, Ventura, Ventura County, extreme coastal, 1 mile from ocean. Orchard 2, Tustin, Orange County, intermediate coastal, approximately 10 miles inland. Orchard 3, Puente, Los Angeles County, intermediate interior, approximately 30 miles inland. Orchard 4, Puente, Los Angeles County, intermediate interior, approximately 30 miles inland. Orchard 5, Moreno Valley, Riverside County, extreme interior, approximately 60 miles inland.

TABLE 17.—*Moisture loss of ethylene-treated, water-sweated, and field-hulled walnuts and percentage of field-hulled walnuts in each picking from 5 orchards in 4 different climatic zones of southern California, 1934*

Climatic zone and location	Variety	Date picked [1]	Loss of moisture on drying: Ethylene-treated	Loss of moisture on drying: Water-sweated	Loss of moisture on drying: Field-hulled	Percentage field-hulled
			Percent	*Percent*	*Percent*	
		Aug. 15 [2]	46.9	52.0	39.7	30
		Aug. 20 [2]	44.5	44.8	35.6	47
		Aug. 27	34.0	41.3	30.3	90
Coastal: Ventura County	Placentia	Sept. 3	-----	-----	29.4	100
		Sept. 9	-----	-----	31.1	100
		Sept. 17	-----	-----	20.3	100
		Sept. 25	-----	-----	5.4	100
		Aug. 16 [2]	41.5	45.1	-----	4
		Aug. 21 [2]	39.3	40.5	41.4	14
		Aug. 28 [2]	34.1	35.4	33.3	49
Intermediate coastal: Orange County	do	Sept. 4	31.5	-----	31.0	-----
		Sept. 12	-----	-----	21.2	-----
		Sept. 20	-----	-----	8.9	100
		Sept. 28	-----	-----	13.0	100
		Aug. 9 [2]	44.8	48.0	-----	0
		Aug. 13 [2]	40.9	47.3	-----	0
		Aug. 18 [2]	35.4	41.5	-----	5
Intermediate interior: Los Angeles County	do	Aug. 26	30.8	37.0	-----	39
		Sept. 2	28.0	29.3	25.8	58
		Sept. 7	-----	-----	22.2	89
		Sept. 18	-----	-----	1.8	100
		Sept. 27	-----	-----	4.6	100

Los Angeles County	Chase	Aug. 8[2]	41.8	59.5	----------	0
		Aug. 12[2]	39.7	44.2	----------	0
		Aug. 17[2]	34.1	39.1	33.3	14
		Aug. 24[2]	34.0	37.8	32.4	46
		Aug. 31	33.5	33.9	----------	----------
		Sept. 7	----------	----------	21.9	97
		Sept. 14	----------	----------	17.5	100
		Sept. 24	----------	----------	7.1	100
Interior: Riverside County	Placentia	Aug. 10[2]	----------	47.2	----------	0
		Aug. 14[2]	39.9	45.7	----------	0
		Aug. 22[2]	33.3	36.0	----------	0
		Aug. 29	29.2	31.7	----------	----------
		Sept. 5	28.7	----------	----------	17
		Sept. 10	28.4	----------	26.7	14
		Sept. 18	----------	----------	24.9	----------
		Sept. 26	----------	----------	19.7	----------
		Oct. 4	----------	----------	9.6	----------
		Oct. 4	----------	----------	[3] 21.8	100

[1] Full maturity was reached in each orchard between the 2 pickings separated by a horizontal line.
[2] A large percentage of the green sticktights were immature.
[3] Loose in hull.

COMMERCIAL UTILIZATION OF THE ETHYLENE PROCESS

Effect of Ethylene on the Flavor of Walnuts

The introduction of ethylene in a new harvesting procedure brought the need for determining the possible effect on the flavor of the walnut. Investigation had revealed that many walnuts have a noticeable flavor considered objectionable by many persons for a period of 2 to 4 weeks after dehydration, especially when harvested early. Even field-hulled walnuts have this abnormal or off-flavor for a short period. The flavor proved natural and disappeared in 1 to 3 weeks. That this peculiarity of Persian walnuts had never previously been noticed was in all probability due to the lack of early critical examination and to the fact that walnuts had always been harvested after natural hull loosening and dehydration.

Sixteen lots of walnuts, comprising the El Monte, Eureka, Mayette, and Franquette varieties, were especially prepared for a detailed flavor test. Eight of the 16 lots were treated with ethylene, 3 were water-sweated, and 5 were field-hulled. Ethylene-treated, water-sweated, and field-hulled samples were taken from the same tree of each variety. One lot of each variety was duplicated. Thus 20 lots were arranged for taste testing, submitted with number identification only. The nine testers, who were well qualified to judge walnut flavor, were unfamiliar with the different treatments used. They were requested to classify the lots as excellent, good, fair, poor, or very poor, according to the following definitions of terms: *Excellent*—Fresh nutty flavor, no evidence of staleness or bitterness, crisp and sweet. *Good*—Entirely passable but lacking in fresh nutty flavor, no staleness, may be slightly bitter. *Fair*—Flat taste, may have slight indication of staleness or rancidity, bitterness may be present to the extent normally found in walnuts under certain conditions. *Poor*—Decided staleness, rancid or strong taste, includes other off-flavors. *Very Poor*—Inedible.

The results of this test are given in table 18. In another test, 28 samples of walnuts were classified by the inspection department of the California Walnut Growers Association, according to the previously indicated flavor standard. The result of this test is shown in table 19. From these tests it appears definite that ethylene treatment has no detrimental effect on flavor. The inconsistency of testers in judging the duplicated samples is shown in table 18.

TABLE 18.—*Results of flavor test on ethylene-treated, water-sweated, and field-hulled walnuts, 1934*

Lot No.	Variety	Treatment	Verdict of testers [1]									Numerical summary				
			1	2	3	4	5	6	7	8	9	E	G	F	P	VP
175	El Monte	Ethylene	F	F	P	F	F	VP	G	G	F	0	2	5	1	1
175	do	do	(2)	P	P	P	F	E	G	F	F	1	1	3	3	0
177	Eureka	do	F	G	F	G	G	F	E	E	G	2	4	3	0	0
177	do	do	(2)	G	F	(2)	(2)	F	E	E	E	3	1	2	0	0
176	do	do	E	P	P	P	F	P	G	G	G	1	3	1	4	0
178	do	do	G	F	F	G	E	G	G	G	E	2	5	2	0	0
179	do	Water sweat	G	P	P	G	P	G	G	G	G	0	6	3	0	0
180	do	Field hulled	F	F	F	E	F	G	G	G	E	2	3	4	0	0
183	Mayette	Water sweat	G	G	E	G	E	G	P	F	E	3	4	1	1	0
183	do	do	(2)	G	E	F	G	F	F	F	E	2	2	4	0	0
181	do	Ethylene	F	E	E	E	G	G	G	G	E	4	4	1	0	0
182	do	do	F	G	F	F	P	P	G	G	E	1	3	3	2	0
184	do	Field hulled	G	P	P	G	G	G	F	F	E	1	4	2	2	0
185	do	do	G	G	G	G	E	P	G	G	G	1	7	0	1	0
188	Franquette	Water sweat	F	F	P	E	F	P	G	F	G	1	2	4	2	0
188	do	do	(2)	F	F	G	G	P	F	P	E	1	2	3	2	0
186	do	Ethylene	G	G	G	F	F	F	G	F	F	0	4	4	1	0
187	do	do	G	P	P	E	G	F	F	P	E	2	2	2	3	0
189	do	Field hulled	G	F	G	E	G	P	F	P	F	1	3	3	2	0
190	do	do	G	P	F	P	F	G	G	F	G	0	4	3	2	0
	Total ethylene-treated											16	29	26	12	1
	Total not treated											12	37	27	14	0

[1] E=Excellent, F=Fair, G=Good; P=Poor, VP=Very Poor.
[2] Omitted from numerical summary. These classifications are defined in the text.

TABLE 19.—*Summary of flavor test of ethylene-treated, water-sweated and field-hulled walnuts in 1933*

Treatment	Samples	Ratings				
		Excellent	Good	Fair	Poor	Very poor
	Number					
Ethylene	14	1	7	5	1	0
Water sweat	7	0	3	4	0	0
Field hulled	7	2	1	3	1	0

EFFECT OF ETHYLENE ON THE KEEPING QUALITY OF WALNUTS

To determine whether ethylene-treated walnuts would keep as well as walnuts from which the hulls had loosened naturally a special lot of the Placentia variety was obtained in midseason so that approximately half, as they came from the field, would be green sticktights. The sticktights were given standard ethylene treatment for 60 hours in a commercial plant at Puente. After treatment the hulls were removed, and the nuts were dehydrated in the same machine and under the same conditions as were the field-hulled nuts. Both lots, field-hulled and ethylene-treated, were subjected to standard packing-house procedure. From the two lots, 100 pounds each were taken at random and stored under commercial conditions by the California Walnut Growers Association.

Crack tests were made immediately on arrival at the storage plant and on the first and fifteenth of the month following. They were sampled on the fifteenth of each month for a year, as indicated in table 20.

The color quality of all lots declined slightly, but the rate of decline was the same for the field-hulled as for the ethylene-treated walnuts. This test indicates that the ethylene treatment has no detrimental effect on keeping quality.

These specially conducted flavor and storage tests were supplemented by observations and studies by research workers, cooperating growers, packing-house managers, and others. With one exception (*56*) no data were recorded in such cases, but in no instance was it possible to distinguish ethylene-treated from nontreated walnuts. The tests indicated that there was no lowering of grade because of ethylene treatment.

COMMERCIAL ADOPTION AND UTILIZATION OF THE ETHYLENE PROCESS

The ethylene process has been established as an integral part of walnut harvesting in many districts of California. In 1934, seven ethylene-treating plants were constructed. Of these, three were in central California under interior climatic condition, one was in the San Fernando Valley of Los Angeles County under semi-interior climatic conditions, and three were in the San Gabriel Valley under intermediate climatic conditions. Various growers in other places utilized ethylene treating rooms in citrus packing houses. One commercial treating plant was built by Mr. Rundell at the Rivera Walnut Growers Association under semicoastal conditions. In all, 77 growers, owning 1,883 acres of walnuts, and producing approximately 1,000 tons, processed their crops in whole or in part. More than 200 tons were treated. In 1935, 22 additional plants were constructed in various parts of the State. In 1938, a partial survey, made with the assistance of the California Walnut Growers Association, reported 27 plants. In addition to these, data were gathered on 15 others, making a total of 42 plants in operation that year. One of these, a large plant in Riverside County, was built especially for custom work. The Rivera plant went out of existence in 1936 at the time the association ceased functioning. These plants serve 3,968 acres, with a total yield of 1,627 tons. Most plants do some custom work. The acreage served by the total number of plants is approximately double that of the property on which they are located. Exterior and interior views of two of the early plants are shown in figures 22, 23, and 24.

TABLE 20.—*Results of crack tests on ethylene-treated and field-hulled walnuts stored under commercial conditions for 13 months*

Date	Ethylene-treated				Field-hulled			
	Sound	Lite	Lite speckled	Total lite	Sound	Lite	Lite speckled	Total lite
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1937:								
Sept. 24	92	70	9	79	92	80	6	86
Oct. 1	91	72	8	79	91	73	7	80
Oct. 14	94	75	7	83	92	72	10	82
Nov. 15	97	72	8	80	94	72	9	81
1937-38:								
Dec. 15	91	72	6	78	91	70	6	76
Jan. 15	92	71	8	80	92	68	7	75
Feb. 15	91	71	7	78	93	71	9	80
Mar. 15	95	67	10	77	94	67	11	78
Apr. 15	92	68	8	75	94	69	13	82
May 15	91	65	12	77	93	64	13	77
June 15	93	65	9	74	91	61	13	74
July 15	93	68	9	76	92	64	9	71
Aug. 15	89	64	11	75	92	63	16	79
Sept. 15	91	66	7	73	95	61	12	72
Oct. 15	90	64	10	74	92	62	11	73
Average [1]	92.5	72.6	8.6	77.2	92.5	67.8	10.1	77.7

[1] This is an average of the monthly averages. Each sample had the same number of walnuts.

The 27 plants covered by the partial survey of the association actually treated 690 tons. The 15 plants not covered by the survey served approximately 2,000 additional acres and treated approximately 1,200 tons. The total number of growers whose walnuts were ethylene-

FIGURE 22.—The first ethylene-treating unit constructed near Puente. It has sufficient capacity to handle green stockpile walnuts equivalent to 12 tons of dried walnuts. (The United States Department of Agriculture recommends the guarding of all belts, pulleys, and other open drives within 6 feet of the floor or ground.)

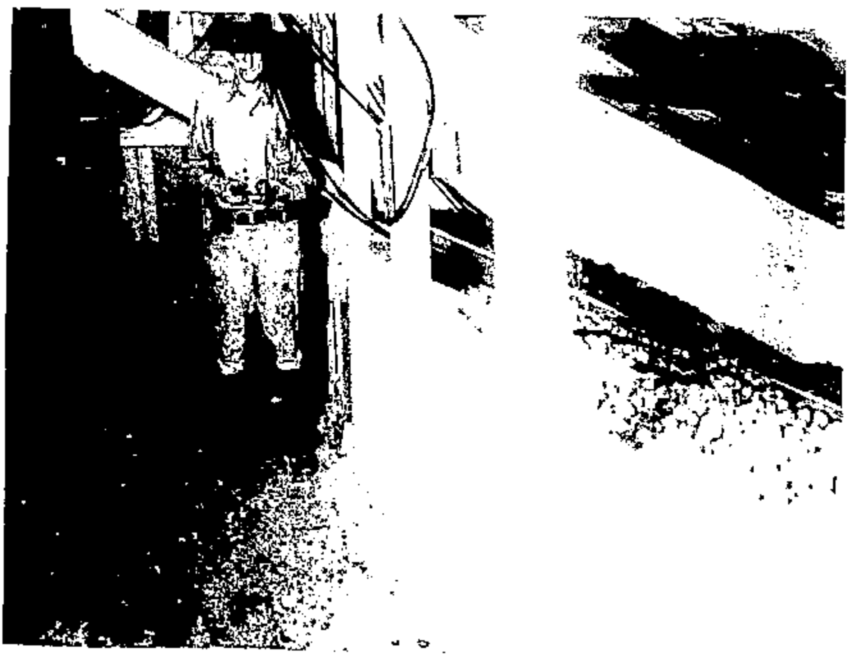


FIGURE 23.—[illegible] view of first ethylene-treating unit during tests by Agricultural Engineering Division, University of California.

treated is not known definitely because of the custom treating, but it is known to be approximately 300, the commercial plant in Riverside having more than 100 customers. The 1938 survey shows considerable variation in the use of treating facilities by the growers. One operator treated 25 percent of the first picking only. From this low percentage the proportion runs to 100 percent of the three pickings. The average use of treating facilities is in the neighborhood of 80 percent of the first picking, 45 percent of the second, and 30 percent of the third. All 27 operators used ethylene for the first picking, 19 used it for the second, and only 7 used it for the third.

In this survey growers who used the ethylene treatment were asked if they felt that they derived benefit from it. All but one answered

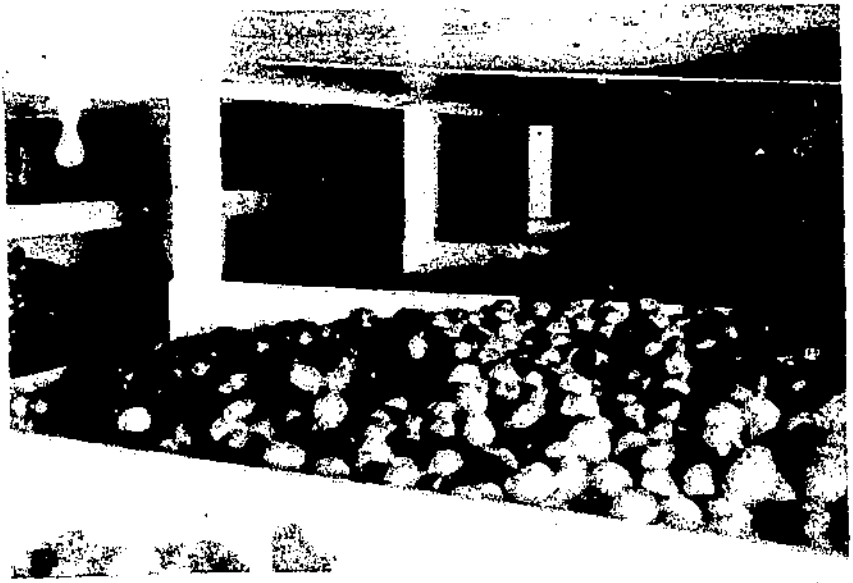


FIGURE 24.—Interior view of large ethylene-treating unit built in 1935 in San Fernando Valley, Calif. It has sufficient capacity to handle green stickights in excess of the equivalent of 50 tons of dried walnuts. The walnuts are 8 feet deep. Note the shape of the bins.

in the affirmative. In answer to the question, "Was any injury caused by the process?" three indicated that there had been some injury, stating, however, that this injury was the result of picking immature walnuts (*43*)). The proportion of the crop injured was very small.

Foreign Shipment of Green Walnuts

Because of inability to remove the hull, the California Walnut Growers Association had been unable to supply green walnuts to England before the development of the ethylene process. The English trade desired nearly mature walnuts that were hulled but not dried, so the pellicle could be peeled and the cotyledons eaten. In 1934 the association ethylene-treated a few hundred 21-pound bags of walnuts in early August. The hulls were removed satisfactorily.

In 1935 the association shipped to England 10,853 bags of 21 pounds each, all of which had been treated with ethylene to remove the hull. However, the expense of handling, including freight, coupled with low prices in England and competition with French walnuts available on short haul, made this outlet unprofitable. No subsequent shipments have been made.

Improvement in Grade and Increase in Value Resulting From Commercial Use of Ethylene in Walnut Harvest

The potential economic value of the ethylene process was recognized immediately by a few growers who had been attempting to preserve the quality of the crop at its peak a short time before normal harvesting. General recognition came within 4 or 5 years. Increased cost of harvesting was studied in 1934 and 1935 (*42, 51*). Harvesting walnuts in the green sticktight stage for ethylene treatment costs from three-fourths to 1 cent a pound more than natural harvest. This is caused by the difficulty and expense of shaking, the need for the use of towers in all pickings, close coordination of shaking and gathering green sticktights from the ground to prevent ground scald, the need for rigid separation, the greater bulk and weight of green sticktights as compared with field-hulled nuts, the necessity of passing all treated walnuts through mechanical hullers, the longer dehydration necessary to remove the moisture content of treated walnuts, and the overhead on additional capital investments.

The economic aspects of the process were studied in southern California orchards in 1934, 1935 (*42, 45*), 1936, and 1939 (*18*). Data were obtained from 512 orchards in the four seasons. The results of these cost studies are summarized in table 21.

Table 21.—*Increase in "on tree" value of walnuts resulting from prompt and rapid harvest with aid of ethylene*

Season	Kind of trees	Location	Value per hundredweight		
			Not treated	Treated	Gain
1934	Seedling	Puente, Los Angeles County	$5.66	$6.54	$0.88
	Budded	do	7.98	8.37	.39
1935	Seedling	do	4.38	5.78	1.40
	Budded	do	7.60	8.51	.91
1936	Seedling	Los Angeles County	5.21	8.00	2.79
	Budded	Los Angeles and Riverside Counties.	6.43	8.60	2.17
1939	do	Los Angeles, San Bernardino, and Riverside Counties.	6.85	8.16	1.31
Average for all years			6.30	7.71	1.41

In calculating the values in table 21, harvesting costs were deducted, leaving an "on tree" value. This gives a true picture of the gains made possible by the use of ethylene.

In 1934, at Whittier, a 30-acre orchard produced 18 tons of walnuts having a value of $4,188. No ethylene treatment was used. In 1935, with the ethylene treatment, the same orchard produced 14 tons with a value of $4,900. This was a net increase of $117 per ton, in spite of the 1 cent lower price per pound for all grades in 1935 as compared with 1934. The same price per pound as in 1934 would have added another $20 per ton to the increase in value resulting from the use of the ethylene process. All lots in the 1935 crop were Diamond grade,[18] with the exception of two small lots, the color of which was adversely affected because of improper dehydration. In 1934, 30 days were required to complete the harvest; in 1935, only 10 days were required. The value of an early and short harvest period has been previously discussed in connection with walnut husk-fly infestation and development of mold.

Sawyer and Jungerman (*51*) show that the grades and values of ethylene-processed walnuts in Stanislaus County (central California) in 1934 as compared with those of the 1931, 1932, and 1933 crops proved the commercial value of the process under interior climatic conditions. Their data show that the increased cost of the additional operations incident to the use of ethylene was 81 cents per hundredweight of dry-weight walnuts. This increased cost included interest and depreciation charges on the equipment used by the grower. The improvement in grade which resulted, shown in table 22, is discussed in the following statement taken from their article:

TABLE 22.—*Percentage of nuts by grades* [1]

Variety	Grade	Nontreated			Ethylene treated, 1934
		1931	1932	1933	
El Monte	Diamond				78.2
	Emerald	18.2	26.9		2.4
	Suntand	56.2	45.3	49.2	5.6
Eureka	Diamond	8.0	3.8	5.2	60.3
	Emerald	20.9	55.5	67.6	21.9
	Suntand	61.3	26.0	9.8	1.6
Concord	Diamond				77.0
	Emerald	35.8			1.4
	Suntand	45.7	78.4	86.8	1.6
Payne	Diamond	71.2	34.7	46.7	77.7
	Emerald	8.1	35.6	11.6	6.7
	Suntand	.5	3.4		.4
Franquette	Diamond	28.3	83.7	82.3	80.0
	Emerald	57.4	11.3	6.5	15.8
	Suntand				
Mayette	Diamond	66.8	48.7	83.7	76.2
	Emerald	21.8	45.2	6.3	14.0
	Suntand	1.5			1.4

[1] Sawyer orchard (*51*).

[18] Brand name of California Walnut Growers Association for first-grade walnuts, which at that time were guaranteed to contain 60 percent or more of light and 90 percent or more of sound kernels.

The first 3 years, 1931 to 1933, inclusive, the nuts were not treated, while in 1934 all were treated. Varieties such as El Monte, Eureka, and Concord showed striking improvement in quality as the result of the ethylene-gas treatment. The grower was never able to obtain Diamond grade on El Montes in the three previous years, but in 1934 with the gas treatment they ran 78.2 percent Diamond grade. The Concords, where previously no Diamonds were harvested, gave 77 percent Diamond with ethylene treatment. The Eurekas, which are an excellent nut for production in this territory, made 60.3 percent Diamond grade where previously the highest Diamond percentage was 5.2 percent. There was also improvement in Paynes, Franquettes, and Mayettes. The Payne grade was 77.7 percent Diamonds in 1934, whereas in 1932 and 1933 this variety showed 34.7 percent and 46.7 percent Diamonds, respectively. The Franquettes showed that some years this variety drops down in Diamond grade, as in 1931 when they ran 28.3 percent Diamonds, and the Mayettes in 1932 only produced 48.7 percent Diamonds. With the gas treatment all of these approached 80 percent Diamond grade in 1934, which was a season of subnormal quality in the San Joaquin Valley.

In considering the comparative figures in the chart, it should be noted that the percentages in each quality grade are on an orchard-run basis. In other words, the percentages of Diamonds, Emeralds, and Suntands [19] for a given variety on a given year, when added together, give the total percentage of merchantable nuts, and the difference between that total and 100 percent represents culls and blows. In the majority of cases the ethylene treatment materially increased the percentage of merchantable nuts as well as their quality.

The increased net return resulting from this improvement in grade is indicated as follows (*51*):

This very striking result in improving quality by the use of ethylene treatment resulted in this orchard producing the second highest quality of all the groves in the cost study. The highest quality grove had a higher average grade because of having all Mayettes, which usually make Diamond grade.

The grower's average price on all varieties and grades was $11.40 per hundredweight. The average in the study was $10.43 for 1934. The grower estimates conservatively that the ethylene treatment for the 1934 harvest increased his net return over all costs between $1,500 and $2,000 on a 40-ton crop.[20]

In 1935 a summary of the walnut cost study of Stanislaus County [21] showed the results of 2 years' use of ethylene on one orchard and 1 year's on another. The grade was improved to such an extent that the value of the crop increased from $1 to $2.12 per hundredweight. The harvesting cost increased $0.50 to $0.75 per hundred pounds, making a net increase of $0.50 to $1.37 per hundred pounds.

Tables 23 and 24 show the improvement in quality and the increase in net income resulting from the use of the ethylene process on another orchard under interior climatic conditions (Merced County). The income was 1½ cents per pound higher, while at the same time the price scale averaged 1 cent lower, thus producing an actual higher value of 2½ cents. From this there should be deducted 0.82 cent a pound for increased cost of harvesting, leaving a net gain of 1.68 cents.

On the basis of cost data gathered at Puente, Los Angeles County, in 1939, Christie (*78*) calculated the value of the ethylene treatment for a 1,000-pound yield. His figures are presented in table 25. The use of ethylene resulted in a net profit of $9.98 an acre. The culls

[19] Emerald and Suntand are California Walnut Growers Association brands for second- and third-grade walnuts.

[20] Equivalent to $1.87 to $2.50 per hundred pounds.

[21] JUNGERMAN, A. A., and BURLINGAME, B. B. FIFTH ANNUAL WALNUT SUMMARY OF STANISLAUS COUNTY WITH 5-YEAR SUMMARY. Calif. Agr. Ext. Serv. 24 pp. 1935. [Mimeographed.]

from treated crops are worth more than untreated culls because they contain less mold, particularly in the latter part of harvest, and a higher proportion of lite kernels.

TABLE 23.—*Grades of ethylene-treated Placentia walnuts in a Merced County orchard in 1935 compared with those of untreated walnuts in the 3 previous years*

Season	Grade		
	Diamond	Emerald	Suntand
	Percent	*Percent*	*Percent*
Not treated:			
1932	--------	38	62
1933	--------	66	34
1934	7	62	31
Treated: 1935	94	6	--------

TABLE 24.—*Values of ethylene-treated Placentia walnuts in a Merced County orchard in 1935 compared with those of untreated walnuts in 1934*

Item	Value per pound	Increase in value per pound in 1935
Harvesting cost:		
1934 (untreated)	$0.0143	----------
1935 (treated)	.025	$0.01
Scale of prices:		
1934 (untreated)	.135-.180	----------
1935 (treated)	.132-.169	[1] -.01
Average price received:		
1934 (untreated)	.15	----------
1935 (treated)	.165	.015
Actual value	----------	.025
Net gain (actual increase in value minus additional harvesting cost)	----------	.015

[1] Minus sign (−) indicates a decrease.

STRUCTURES FOR TREATING WALNUTS WITH ETHYLENE

In the fall of 1933 the first walnuts treated with ethylene in the field became so cold that the rate of hull loosening was seriously retarded. The walnuts were in boxes and sacks under two and three layers of canvas in frame buildings and in galvanized-iron dehydrators located in galvanized and frame dehydrator buildings. As a result of these experiences, the Agricultural Engineering Division of the University of California was requested to make a study of structures suitable for maintaining the necessary temperature, between 70° and

90° F. Accordingly, during 1934, 1935, and 1936 extensive studies were made. The plans produced (*26*) call for insulation for roofs exposed to direct sunshine, balancing the thermal conductivity of double-walled construction. Insulation was advised for side walls in close proximity to some source of heat, such as a dehydrator. Construction details with sample safety factors based on the physical properties of green sticktight walnuts are given.

TABLE 25.—*Net gains from ethylene treatment of walnuts*

Item	Quantity	Value
Untreated:	*Pounds*	*Dollars*
Yield per acre	1,000	
Blows (17.4 percent)	174	
Salable nuts	826	
Culls (31.2 percent)	312	[1] 9.86
Merchantable grades	514	[2] 44.72
Total return		54.58
Treated:		
Yield per acre	1,000	
Blows (17.4 percent)	174	
Salable nuts	826	
Culls (17.4 percent)	174	[3] 8.00
Merchantable grades	652	[4] 66.57
Total return		74.57
Additional harvesting cost of 1 cent a pound		10.00
Net income		64.57
Net gain of treated over untreated		9.99

[1] At $3.16 a hundredweight.
[2] At $8.70 a hundredweight.
[3] At $4.60 a hundredweight.
[4] At $10.21 a hundredweight.

It was later realized that the early part of the 1933 walnut-harvest season was unusually cold. Under the pressure of economy, growers in various sections utilized several types of temporary structures. Rooms built of half-inch building plyboard in large sheets, single-wall sulfur houses, and rooms made of two thicknesses of canvas located in open sheds were used, and were satisfactory. The temperatures of walnuts during treatment remained within the range of safety. One careful test of the rate of hull loosening and the effect on kernel color was conducted with walnuts in boxes placed under two layers of canvas in open sheds with galvanized-iron roofs. The test showed that this type of structure, as well as all the commercial temporary structures tried, was satisfactory. A good low-cost temporary ethylene chamber can be built with walls of baled hay and a double-canvas roof. Double-thickness canvas is used for the ends, which are raised for ventilation. The cost of this type of unit is less than the costs shown in table 26. The hay used is not damaged.

These trials and experiences (*46*) over a period of years have led to the conclusion that in most seasons first-class, double-wall construction with insulation is not necessary to control the temperature of walnuts during treatment. Eliminating this feature reduces the cost of installation materially, as is indicated by the data in table 26, which were gathered in connection with the cost study of 1935 (*46*). This table gives data on nine plants with double-wall insulation, on the basis both of the acreage of the orchard in which they were built and of the acreage they served for their owners and for custom work. Figures for two plants built for custom work of building-board or canvas construction in which walnuts were treated in orange field boxes are included in the table.

TABLE 26.—*Investment in, and overhead cost of, ethylene treating plants*

Item	Permanent bin construction on—		Temporary construction with building board or canvas sides; boxes as containers on—
	Basis of owner acreage	*Basis of acreage served*	*Basis of acreage served*
Number of plants	9	9	2
Acreage	616	943	632
Tonnage	351.7	493.3	301.5
Total investment	$8,943.50	$8,943.50	[1] $2,470.00
Per acre	14.52	9.48	3.90
Per ton	25.43	18.13	8.21
Interest at 5 percent on one-half average investment	223.59	223.59	61.75
Per acre	.36	.24	.10
Per ton	.64	.45	.21
Depreciation	407.55	407.55	[2] 173.50
Per acre	.66	.43	.28
Per ton	1.16	.83	.58
Total overhead:			
Per acre	1.02	.67	.38
Per ton	1.80	1.28	.79

[1] Roof, supports, and concrete floors, $1,470; boxes, $1,000.
[2] Depreciation on building, 5 percent; on boxes, 10 percent.

There is a difference of $6 to $10 an acre in the cost of the two types of construction. Annual interest and depreciation charges are much lower for the temporary-construction plants as compared with the permanent type, even on the basis of the total acreage served. A temporary room with baled-hay walls and double-canvas ceilings and ends costs even less than the permanent structures in table 26. In fact, the cost of such treating chambers is less than the cost of boxes or other containers to hold the walnuts during treatment.

In connection with investments it should be pointed out that a huller must be available for ethylene-treated walnuts.

SUMMARY

Preserving the lite color of the kernel in the Persian walnut as grown in certain parts of California constitutes a major problem of the industry.

The maximum number of kernels are lite-colored when they have reached full maturity and for a short time thereafter. In all sections of the State removed from the coast, maturity of the hull, as evidenced by its separation from the shell, occurs 10 days to 4 weeks after the kernel has reached maturity. During this period the kernel color deteriorates. The hulls of walnuts in which the kernels are mature can be loosened from the shell by exposure to ethylene gas at a concentration of 1 part of ethylene to 1,000 parts of air.

Ethylene is most effective in loosening the hulls of walnuts at temperatures between 70° and 90° F. Below 60° it is almost nonoperative, and at 100° it retards the rate of hull loosening.

The hulls of mature walnuts are loosened from the shell by 60 hours of treatment under proper conditions of temperature and humidity.

Since ethylene also loosens the hulls of immature walnuts, a careful maturity test is necessary. A simple test that is easy to use under field conditions has been developed.

The rate of loosening of the hulls is most rapid when the humidity of treating chambers is maintained below saturation; condensation of moisture on the walnuts is thus avoided.

Carbon dioxide is produced in large quantities during ethylene treatment, but concentrations exceeding 3 percent were found only once in commercial practice.

To guard against high humidity and excessive accumulations of carbon dioxide, the treating chambers should be ventilated at least every 12 hours and recharged with ethylene.

Green sticktight walnuts lying on the surface of the ground in the hot sun are quickly and severely injured.

Lots of walnuts should be specially prepared for ethylene treatment by removal of those with loose hulls, those badly sunburned, and those with blighted or decayed hulls. Mechanical means have been developed to facilitate separation.

In some districts and in some years it is commercially practical to remove before treatment all walnuts having any evidence of sunburned hulls as a means of improving the grade.

To avoid decline of kernel-color quality, walnuts should be hulled and dehydration started as soon as the hull has loosened.

Vigorous washing is necessary after hulling to remove pieces of bruised hulls that adhere to the shell.

Rapid harvesting with the use of ethylene will practically eliminate moldy walnuts.

Under coastal climatic conditions there is no need for the ethylene process, but in interior areas the process is always practical.

In intermediate climatic areas the process has resulted in improvement of grade each year. After exceedingly warm winters, when delayed foliation results in uneven maturity, less improvement in color quality can be expected, but the reduction of mold alone justifies the use of the process.

Walnuts in the green hull are two and one-half times as bulky as hulled walnuts and weigh approximately five times as much as dried hulled walnuts.

Ethylene treatment has no effect on the flavor or keeping quality of the Persian walnut.

The ethylene process has been adopted commercially in California in intermediate and interior climatic areas, where it is increasing the value of crops by approximately 1½ to 2 cents per pound after approximately 1 cent per pound has been deducted for additional harvesting cost occasioned by more difficult picking and shaking, greater tonnage and volumes to be handled, and overhead on additional equipment.

Rather simple equipment can be used for effective treating under the usual weather conditions of harvesttime. Heating may be necessary in the occasional cold season.

LITERATURE CITED

(1) Abderhalden, E.
1911. Biochemisches Handlexikon. Vol. 1, Pt. 1. Berlin.

(2) Anderson, W. C.
1933. A new system of harvesting walnuts. Shaking on sheets and transferring to portable field hullers reduces labor costs and improves quality. Diamond Walnut News 15 (4): 6, illus.

(3) Baier, W. E., Nedvidek, R. D., Gunn, A., Ramsey, H. J., Van Duyne, R. D., Nelson, A. E., and Nixon, H. W.
1932. Coloring citrus fruit. Calif. Fruit Growers Exch., 82 pp., illus.

(4) Batchelor, L. D.
1923. Methods of harvesting and irrigation in relation to moldy walnuts. Calif. Agr. Expt. Sta. Bul. 367: 677–696, illus.

(5) ——— and Bracher, O. L.
1930. Walnut culture in California. Calif. Agr. Expt. Sta. Bul. 376, rev., 26 pp., illus.

(6) ——— Christie, A. W., Guthier, E. H., and LaRue, R. G.
1924. Sun-drying and dehydration of walnuts. Calif. Agr. Expt. Sta. Bul. 376, 26 pp., illus.

(7) Boyce, A. M.
1933. The walnut husk fly in 1932. Recommendations for control in 1933. Diamond Walnut News 15 (3): 8–9, illus.

(8) Bracher, O. L.
1937. Early and prompt harvesting pays. Walnuts are perishable. Delay in harvest reduces quality and price. Diamond Walnut News 19 (5): 3.

(9) Chace, E. M.
1935. The ethylene process and its place in walnut harvesting. A new application for an old process. Diamond Walnut News 17 (2): 19.

(10) ——— and Church, C. G.
1927. Effect of ethylene on the composition and color of fruits. Indus. and Engin. Chem. 19: 1135–1139.

(11) ——— and Sorber, D. G.
1928. Use of ethylene for softening Bartlett pears intended for canning or drying. Canner 67 (13): 15–16.

(12) Chandler, W. H.
1938. Failure of walnut tree buds to open normally after especially warm winters. Cause of delay and possibility of prevention. Diamond Walnut News 20 (4): 8.

(13) CHANDLER, W. H., KIMBALL, M. H., PHILP, G. L., TUFTS, W. P., and WELDON, G. P.
1937. CHILLING REQUIREMENTS FOR OPENING OF BUDS ON DECIDUOUS ORCHARD TREES AND SOME OTHER PLANTS IN CALIFORNIA. Calif. Agr. Expt. Sta. Bul. 611, 63 pp., illus.

(14) CHEMINAU, R.
1904. MICROCHEMICAL INVESTIGATIONS OF SOME GLUCOSIDES. Trav. du Lab. Mater. Méd. École Supr. de Pharm. 2, 1048. Paris.

(15) CHRISTENSEN, B. E., HANSEN, E., and CHELDELIN, V. H.
1939. DETERMINATION OF ETHYLENE IN THE INTERNAL ATMOSPHERE OF PLANT TISSUES. Indus. and Engin. Chem., Analyt. Ed. 11: 114–116, illus.

(16) ——— HANSEN, E., CHELDELIN, V. H., and STARK, J. B.
1939. THE DETERMINATION OF ETHYLENE EVOLVED BY APPLES AND PEARS. Science 89: 319–321, illus.

(17) CHRISTIE, A. W.
1930. BELIEVE IT OR NOT! EARLY HARVESTING DOES PAY—HERE IS PROOF. Diamond Walnut News 12 (4): 5.

(18) ———
1940. LESSONS FROM THE 1939 HARVEST. EARLY HARVEST WITH THE AID OF ETHYLENE OR WATER SWEAT INCREASED NET RETURNS. Diamond Walnut News 22 (4): 8–9.

(19) DAVIS, W. B.
1935. OBSERVATIONS ON THE MATURATION OF WALNUTS. EARLY HARVESTING AND USE OF ETHYLENE MAKE DETERMINATION OF MATURITY IMPORTANT. Diamond Walnut News 17 (3): 14–15, illus.

(20) ———
1937. AN ILLUSTRATION OF THE USE OF THE CRACK TEST AS A MATURITY STANDARD FOR WALNUTS. Diamond Walnut News 19 (4): 10–11.

(21) ——— and CHURCH, C. G.
1931. THE EFFECT OF ETHYLENE ON THE CHEMICAL COMPOSITION AND THE RESPIRATION OF THE RIPENING JAPANESE PERSIMMON. Jour. Agr. Res. 42: 165–182, illus.

(22) DENNY, F. E.
1923. METHOD OF COLORING CITRUS FRUITS. U. S. Patent No. 1,475,938.

(23) ———
1924. HASTENING THE COLORATION OF LEMONS. Jour. Agr. Res. 27: 757–769, illus.

(24) ——— and MILLER, L. P.
1935. PRODUCTION OF ETHYLENE BY PLANT TISSUE AS INDICATED BY THE EPINASTIC RESPONSE OF LEAVES. Boyce Thompson Inst. Contrib. 7 (2): 97–102, illus.

(25) ——— and STANTON, E. N.
1928. CHEMICAL TREATMENTS FOR SHORTENING THE REST PERIOD OF POT-GROWN WOODY PLANTS. Amer. Jour. Bot. 15: 327–336, illus.

(26) FAIRBANK, J. P.
1935. MECHANICAL DEVELOPMENTS IN TREATING WALNUTS WITH ETHYLENE GAS. TEMPERATURE CONTROL BY AIR CIRCULATION FOUND ESSENTIAL. Diamond Walnut News 17 (1): 8–10, illus.

(27) FINCH, A. H.
1937. THE USE OF ETHYLENE TO IMPROVE PECAN HARVESTING. Amer. Soc. Hort. Sci. Proc. 34: 74–77, illus.

(28) GANE, R.
1935. THE FORMATION OF ETHYLENE BY PLANT TISSUES. Jour. Pomol. and Hort. Sci. 13 (4): 351–358.

(29) HANSEN, E., and CHRISTENSEN, B. E.
1939. CHEMICAL DETERMINATION OF ETHYLENE IN THE EMANATIONS FROM APPLES AND PEARS. Bot. Gaz. 101: 403–409.

(30) ——— and HARTMAN, H.
1935. THE OCCURRENCE IN PEARS OF METABOLIC GASES OTHER THAN CARBON DIOXIDE. Oreg. Agr. Expt. Sta. Bul. 342, 10 pp. illus.

(31) HARVEY, R. B.
1928. ARTIFICIAL RIPENING OF FRUITS AND VEGETABLES. Minn. Agr. Expt. Sta. Bul. 247, 36 pp., illus.

(32) HIBBARD, R. P.
1930. THE PHYSIOLOGICAL EFFECT OF ETHYLENE GAS UPON CELERY, TOMATOES, AND CERTAIN FRUITS. Mich. Agr. Expt. Sta. Tech. Bul. 104, 30 pp., illus.

(33) Hooper, W. B.
1931. THIS IS THE YEAR TO PROTECT QUALITY BY PROPER HARVESTING. DON'T LET DELAY IN GATHERING, HULLING, AND DRYING ADD TO THE ALREADY ABNORMAL DAMAGE. Diamond Walnut News 13 (4): 4.

(34) ———
1933. HAVE YOU BUILT THAT TOWER YET? MANY TYPES AVAILABLE—HERE IS A NEW ONE. Diamond Walnut News 15 (4): 7, illus.

(35) Kertesz, Z. I.
1933. THE OXIDASE SYSTEM OF A NONBROWNING YELLOW PEACH. N. Y. State Agr. Expt. Sta. Tech. Bul. 219, 14 pp.

(36) Kidd, F., and West, C.
1925. THE COURSE OF RESPIRATORY ACTIVITY THROUGHOUT THE LIFE OF AN APPLE. [Gt. Brit.] Food Invest. Bd. Rpt. 1924: 27–34, illus.

(37) Kimball, M. H.
1930. HARVESTING AND PROFIT. A LATE SLOW HARVEST CAN MAKE A POOR GRADE OF THE BEST WALNUTS. Diamond Walnut News 12 (4): 4–5.

(38) ———
1933. HARVESTING METHODS AND QUALITY PRESERVATION. RAPIDITY AND METHOD OF HARVESTING IMPORTANT FACTORS IN QUALITY OBTAINED. SEPARATE SHAKING CREWS AND TOWERS IMPROVE QUALITY RETURNS. Diamond Walnut News 15 (4): 4–5.

(39) ———
1934. EARLY, RAPID HARVEST AND SHAKING TOWERS AS QUALITY FACTORS. NEW HARVESTING SYSTEM INCREASES RETURNS. Diamond Walnut News 16 (4): 3, illus.

(40) ———
1935. HARVESTING RECOMMENDATIONS. PROPER HARVESTING RESULTS IN BETTER QUALITY AND HIGHER RETURNS. TIMELY ADVICE ON AN IMPORTANT SUBJECT. Diamond Walnut News 17 (4): 11.

(41) ———
1935. MATURITY TEST RECOMMENDATIONS FOR 1935. CAUTION ISSUED AGAINST HARVESTING TOO EARLY FOR ETHYLENE PROCESS. Diamond Walnut News 17 (3): 4.

(42) ———
1936. DOES ETHYLENE GASSING PAY? COMPARATIVE RECORDS ON COSTS AND RETURNS WITH AND WITHOUT ETHYLENE. Diamond Walnut News 18 (4): 6.

(43) ———
1936. MATURITY KEY TO SUCCESS OF ETHYLENE GAS HARVESTING. GROWERS MUST KNOW CROP IS MATURE BEFORE PLACING WALNUTS IN GAS. Diamond Walnut News 18 (3): 6.

(44) ———
1936. WHEN IS A WALNUT MATURE? HOW TO DETERMINE WHEN TO START HARVEST FOR MAXIMUM QUALITY. Diamond Walnut News 18 (4): 3.

(45) ———
1937. DOES MODERN HARVESTING PAY? THE LATEST INFORMATION ON METHODS AND EQUIPMENT. Diamond Walnut News 19 (4): 4–5.

(46) ———
1940. HOW ETHYLENE GAS OR WATER SWEAT CAN BE USED BY SMALL GROWERS. Diamond Walnut News 22 (4): 6.

(47) Long, J. D.
1934. HOW TO BUILD A SHAKING TOWER. UNIVERSITY'S [CALIFORNIA] AGRICULTURAL ENGINEERS PREPARE PLANS FOR INEXPENSIVE TOWERS. Diamond Walnut News 16 (3): 6–7, illus.

(48) Marsh, G. L.
1939. RECOMMENDED DEHYDRATION PRACTICES. COLOR OF KERNELS AFFECTED BY IMPROPER OPERATION OF DEHYDRATORS. Diamond Walnut News 21 (5): 12–13.

(49) ——— and Bedford, C. L.
1936. WALNUT DEHYDRATION STUDIES. EFFECT OF TEMPERATURE AND HUMIDITY ON KERNEL COLOR DURING BIN STORAGE AND DEHYDRATION. Diamond Walnut News 18 (5): 10–12, illus.

(50) Rosa, J. T.
1925. RIPENING OF TOMATOES. Amer. Soc. Hort. Sci. Proc. 22: 315–322.

(51) SAWYER, G. H., and JUNGERMAN, A. A.
1935. ETHYLENE GAS TREATMENT INCREASES QUALITY AND NET RETURNS. NOMINAL EXPENDITURES FOR EQUIPMENT AND EARLIER HARVESTING PAY HANDSOME DIVIDENDS. Diamond Walnut News 17 (3): 8, illus.

(52) SOBBER, D. G.
1934. THE USE OF ETHYLENE GAS FOR LOOSENING WALNUT HULLS. PRELIMINARY INVESTIGATIONS PROVES ENCOURAGING. Diamond Walnut News 16 (3): 3-4.

(53) ———
1935. TWO SEASONS' EXPERIMENTAL WORK WITH ETHYLENE TREATMENT OF WALNUTS. NEW PROCESS AFFORDS HIGHER RETURNS IN MANY DISTRICTS BY INCREASING PERCENTAGE OF SOUND AND LIGHT COLORED KERNELS. Diamond Walnut News 17 (2): 11-14, illus.

(54) ———
1939. THE USE OF ETHYLENE IN THE WALNUT HARVEST. WHERE AND WHY IT IS ADVANTAGEOUS—DIRECTIONS AND PRECAUTIONS FOR USE OF ETHYLENE. Diamond Walnut News 21 (5): 10-11 and 14.

(55) THORNTON, N. C.
1940. THE FACTS ABOUT "ARTIFICIALLY" RIPENED FRUIT. Food Indus. 12 (7): 48-50, 80; (8): 51-52. *Also in* Boyce Thompson Inst. Prof. Paper 1 (31): 281-290, illus.

(56) WRIGHT, R. C.
1941. INVESTIGATIONS ON THE STORAGE OF NUTS. U. S. Dept. Agr. Tech. Bul. 770, 35 pp., illus.

○

END