

Tests on Freezing in Lemons

preliminary experiments on subcooling and freezing in lemons seek mechanism of ice initiation and spread

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Frost damage in a citrus orchard depends upon many factors, in addition to the minimum temperatures attained by the tree parts.

One prominent factor is subcooling—the extent to which tree parts cool below the freezing point without ice formation. The amount of subcooling appears, in turn, to depend upon many conditions.

To learn what those conditions are and how each affects the degree of subcooling, so they can be taken into account in orchard-heating operations, an investigation was initiated to study subcooling in citrus fruits—and because of their close relationship and interdependence—freezing initiation, and spread of freezing in tree parts.

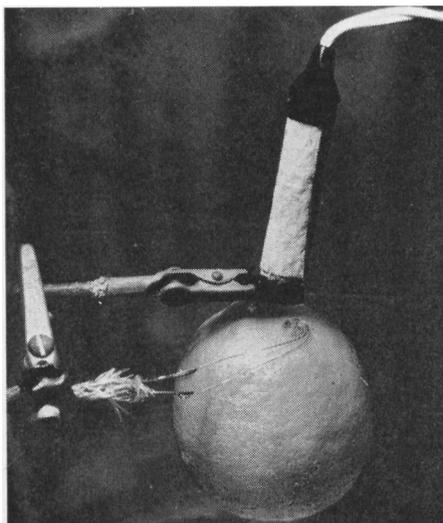
Tests with Eureka Lemons

All experimental specimens were obtained during the spring from a Eureka lemon tree on grapefruit root. The tree was not treated with insecticides or fungicides, and it received no special treatment during the course of the experiments. Lemons commercially graded as silver were used exclusively; their diameters varied from $1\frac{5}{8}$ " to $2\frac{1}{8}$ ".

Individual detached juice sacs, or vesicles—85 in number and resting on microscope slides—were placed in three closed petri dishes in a closed wooden specimen container and the temperature lowered.

Humidity was controlled by sulfuric acid solutions, and a lining of polyethylene film on the inside of the wooden container served as a vapor barrier. Checks of actual humidities were made by the dew point method.

The temperature was measured by means of a thermocouple—an electrical instrument for measuring temperature differences—whose junction was inside an extra vesicle in one of the dishes. At 10° F no vesicle had begun freezing but when the temperature had fallen below 0° F, 42 vesicles were frozen. A thermocouple whose temperature was about 10° F was thrust into several of the subcooled juice sacs, one at a time. In each case, the vesicle froze very rapidly, and the recorded temperature rose to approximately 28° F, showing that the low temperature attained without freezing was not due to a lowering



Lemon in specimen container with spiral thermocouple and stem heater in place. Note the uncoated wires of the thermocouple are wound in flat spirals to permit the junction of the wires to be held $1/32$ " above the surface of the fruit. The stem of the lemon is held in a heating cap, covered with asbestos, which maintained the stem temperature above 32° F.

of the freezing point in the detached juice sacs.

A rough check was made on the rate of spread of freezing in a subcooled system comprising a fruit and stem with attached leaves. Temperatures were recorded at four points: one thermocouple was inserted $1/4$ " into the cut stem end; another was imbedded in the midrib of a leaf; the third was inside the pulp of the fruit; and the last was 1 " below the stem, midway between the fruit and the cut stem end.

Many test runs were made, and subcooling was followed each time by apparent simultaneous freezing throughout the system, as indicated by the fact that the temperature measurements at the points, taken at two-minute intervals, rose together.

Freezing was found to spread from one fruit to another on the same branchlet in a similar manner. The velocity with which freezing spread in branchlets was found to be greater than 6 " per minute at a subcooled temperature of 22.6° F. Other observations strongly suggest that this rapid spread takes place through the water conducting vessels.

The fact that freezing spreads quickly in subcooled tissues indicates that ice

nucleation ordinarily occurs at one point only in such a system, just as it does in small volumes of subcooled water.

Freezing initiation did not appear to take place, preferentially, in the cut stem under the conditions in which the fruits were cooled.

Moisture Condensation

Spiral thermocouples were used with groups of fruits cooled in atmospheres of 8%, 55%, and 90% relative humidity. The surfaces of all the fruits in these groups appeared dry to the naked eye throughout the tests. Frost appeared on the inside surface of the plastic lining in the 90% relative humidity runs but had no apparent effect on fruit subcooling. There was no significant difference in spontaneous freezing point among these three groups.

When the temperature of one of the three spiral thermocouples first fell to 30° F, and thereafter at 1° F intervals, the fan—which maintained uniform temperature in the specimen container—was turned off, the door of the freezer compartment moved aside, the container lid opened, and laboratory air forced into the box.

Each time air was blown in, moisture was seen to condense on the fruit surfaces. Frost formation on the inside surface of the plastic lining was prevented by a thin coating of glycerol.

During the subcooling of another group of lemon fruits frost was allowed to form on the plastic lining. The mean of the spontaneous freezing points was 27.7° F. The higher temperature was apparently due to ice inoculation of the fruits by frost particles from the lining.

During the course of preliminary condensation experiments, it was noted that water frozen on a fruit surface was followed—a short time later—by freezing of the fruit. The heavy covering on some herbaceous plants which can prevent ice inoculation from the surface is evidently not present on lemons.

Fruits completely submerged in methyl alcohol were cooled. The temperature recorded was that of a thermocouple resting on the top surface of each fruit. These fruits subcooled more than fruits cooled under both dry and wet surface

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Leaf Potassium

Valencia fruit size relationship shown to be variable by studies

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The value or need of potassium fertilization—to increase Valencia orange fruit size—must be determined for each Valencia growing area because no critical level of leaf potassium can be universally assigned.

The relations between the concentration of potassium in the Valencia orange leaves and fruit size are generally positive, but the results of a study of representative leaf samples from 283 Valencia orchards in Ventura, Los Angeles, Orange, Riverside, and San Bernardino counties and the Escondido area of San Diego County show the relationship is not numerically consistent.

To determine whether such a relationship is general throughout the citrus growing areas—and whether leaf analysis is a means of ascertaining the need of potassium fertilization to increase fruit size—a representative leaf sample was obtained from each of the orchards in the survey.

They were analyzed in the laboratory for potassium, nitrogen, phosphorus, calcium, magnesium, and sodium.

Spring-cycle leaves were picked during a three-month period—November

Large-Fruit Orchards vs. Small-Fruit Orchards in the Same Areas

No. of areas	Relation of Potassium to size	Per cent Potassium		Per cent 252 and larger	
		Small fruit orch.	Large fruit orch.	Small fruit orch.	Large fruit orch.
25		.819	.929	34.7	55.3
16	Positive	.729	.948	32.0	53.4
9	Negative	.978	.897	39.7	58.6

through January. Twenty leaves per tree from five representative trees were composited for a single sample of one hundred leaves for each orchard. In groves where more than one known rootstock was planted—or where there were blocks of trees of different ages—a separate sample was obtained to represent each type.

The laboratory analysis of the plant tissue was adjusted on the basis of previous research on the seasonal trend in leaf mineral composition so that all the data would be on a comparable basis as to sampling date.

A statistical study of the data was made to determine the relationship between fruit size—as obtained in the survey—and the mineral content of the leaves. The fruit size index for each orchard was based on a three-year harvest record and included fruit packed of size 252 and larger.

Each of 25 community areas was studied individually and the findings showed that the mean values of leaf potassium and fruit size varied greatly from one area to another. When the orchards in each community were separated into two groups—those having the larger fruit and those having the smaller fruit—it was found that on the average, the large-fruit orchards had the higher percentage of potassium in the leaves.

Of the 25 local areas considered, 16 had a positive, and nine a negative, relation between leaf potassium and fruit size. In the 16 local areas in which a positive relation existed the large-fruit orchards contained 0.219% more leaf potassium than did the small-fruit orchards. In the nine local areas in which a negative relation existed the large-fruit orchards contained only 0.081% less leaf potassium than did the small-fruit orchards.

When all 283 Valencia groves are considered as a unit the positive relationship between leaf potassium and fruit size is lost. The areas in which the largest fruit were produced contained the lowest mean percentage of potassium in the leaves, which means that factors other than potassium were more influential in affecting fruit size.

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conditions. The freezing points of sample fruits obtained with thermocouples in the pulp, during a second freezing, exhibited no deviation from the freezing point of fruits not previously in alcohol. This appears to indicate that the lower spontaneous freezing point of fruits in alcohol can not be attributed to internal dehydration.

Immersion in alcohol undoubtedly greatly reduces the freezing point, and also the chance of freezing initiation, at and adjacent to the surface of the fruits, which indicates that freezing initiation occurred near the surface of the fruits cooled in air.

The possibility that rubbing together of wet fruit surfaces hinders subcooling was checked with a group of fruits. When the temperature of a spiral thermocouple first dropped to 29° F—and at each degree below that—fruits wet at the point of contact were brought to-

gether and rubbed against one another. These fruits subcooled less than any other fruits tested.

As a check, fruits in another group were cooled with water droplets on their

Effect of Surface Conditions on Subcooling of Detached Lemons and Lemon Parts

Group	Treatment	Spontaneous freezing point*
		° F
1	Detached vesicles	below 10
2	Fruits in 90% relative humidity	24.1
3	Fruits in 90% relative humidity and stems heated	24.5
4	Fruits in 55% relative humidity	24.8
5	Fruits in 8% relative humidity	24.9
6	Condensation on fruits	24.2
7	Fruits in alcohol	21.0
8	Fruits rubbed on water droplets	27.4
9	Fruits rubbed but not on droplets	24.7

* The values are the mean of 9 fruits.

surfaces and were rubbed together, but not at the location of a droplet. These fruits subcooled to an extent comparable to those cooled with no rubbing and no water droplets on them.

The effectiveness of rubbing of wet fruit surfaces in reducing subcooling may explain reports that dew and wind lessen subcooling in citrus fruits in the orchard.

These investigations seeking the mechanism or mechanisms of ice initiation in citrus have disclosed that once freezing begins it spreads rapidly throughout a subcooled tree part; that freezing initiation appears to occur near the surface of detached lemons; and, that rubbing of wet fruit surfaces markedly reduces subcooling. However, further investigation of all these processes—on a larger scale—is highly desirable.

John W. Lucas was Research Assistant in Subtropical Horticulture at the time the studies reported above were conducted.

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