AN APPARATUS FOR USE IN FREEZING STUDIES ON FRUITS, BULBS AND TUBERS

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The very simple form of freezing apparatus described by Detmer[1] has been extensively modified, thereby gaining certain desirable advantages. Such advantages include: a rapid and uniform cooling of the fruit, a temperature measurement which is the mean of four different parts of the fruit, a shorter lag period in recording temperature changes, and finally less injury to the fruit.

Principle of operation. The fruit or other experimental object is cooled by a current of cold air until freezing is effected. Changes in the temperature of the fruit are accurately followed by means of an electric thermocouple with junctions inserted in the fruit. The readings in millivolts thus secured are then converted to Centigrade degrees with the aid of a calibration curve or conversion factor.

Construction of the apparatus. An ice bath consisting of a crock insulated with asbestos constitutes the basis of the apparatus. Further insulation is effected by a wooden support and a dead air space under the jar. A thick wooden cover which provides additional heat insulation is supplied for the ice bath. This cover contains openings for a wire-loop stirrer with which to stir the ice and salt mixture, a thermometer for ascertaining the temperature of the ice-salt mixture, and a large cork in which the freezing chamber is held.

The freezing chamber is fitted with a cork lid which supports a small fan and fan guard. The fan is attached to a drive shaft consisting of glass and metal tubing which revolves in bearings of glass tubing. Power for driving the fan is supplied from an electric motor attached to the fan shaft by a flexible cable. Immediately beneath the fan is a guard consisting of a circle of enameled wire with a cross rod through the center from which the fruit is suspended. The fan guard also serves to keep the wires of the thermocouple clear of the fan. Four pairs of junctions of nickel and copper wire constitute the thermocouple employed in this apparatus. The four measuring junctions are embedded in the experimental fruit and the corresponding reference junctions inserted in a thermos bottle containing crushed ice. The lead wires from the thermocouple are attached to a millivolt meter which registers the potential difference. A thermometer is provided for measuring the air temperature within the freezing chamber.

Further heat insulation is effected by an enameled disk of heavy cardboard which fits closely over the top of the freezing chamber and is held in place by small wooden buttons. This disk is provided with openings which permit the thermocouple, fan-shaft housing, and freezing-chamber thermometer to pass through it.

A study of fig. 1 will give a more adequate idea of the assembly of these parts. This diagram represents a median-sectional view of the apparatus with a fruit suspended in place in the freezing chamber. Four junctions of the thermocouple are indicated as embedded in the tissues of the fruit.

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[1]Detmer-Moor. Practical Plant Physiology, 1909, p. 126.

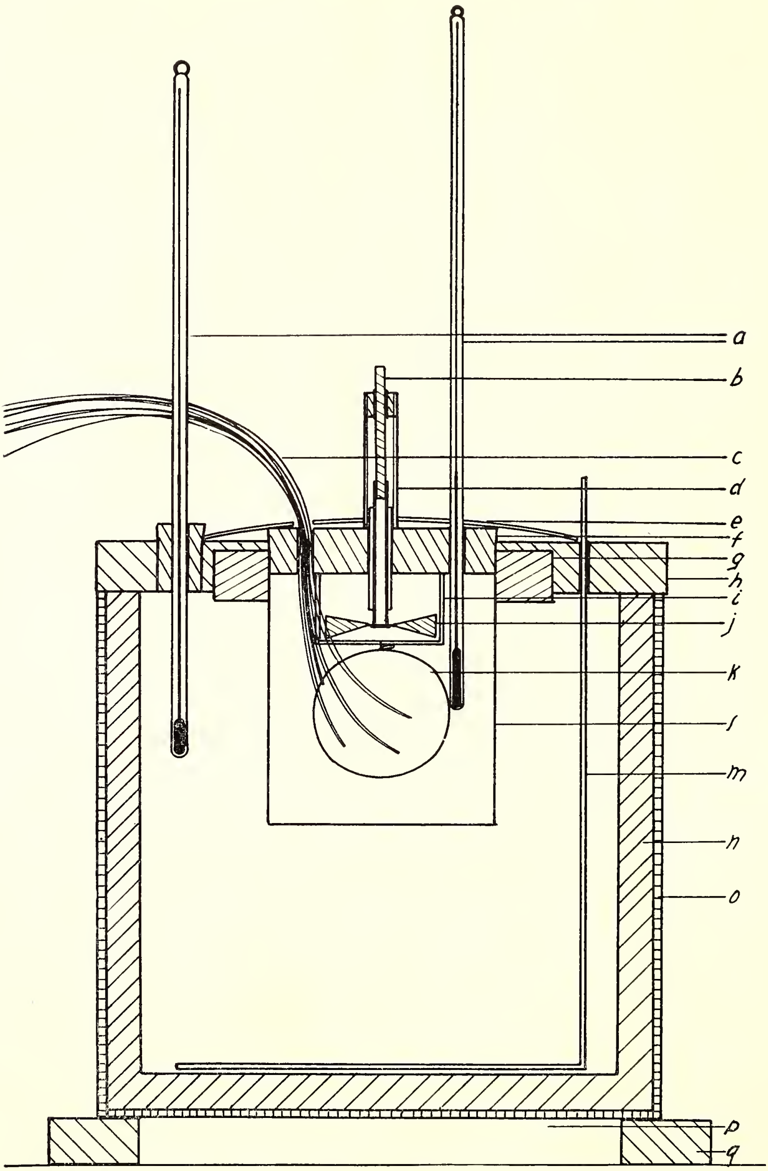

Fig. 1—Freezing Apparatus. (a) thermometers, (b) fan shaft, (c) thermocouple, (d) fan-shaft housing, (e) cardboard disk, (f) cork lid of freezing chamber, (g) cork support of freezing chamber, (h) wooden top of ice bath, (i) fan guard, (j) fan, (k) experimental fruit, (l) freezing chamber, (m) ice-mixture stirrer, (n) ice-bath crock, (o) asbestos insulation, (p) dead-air space, and (q) wooden base.

The arrangement of the entire apparatus including the companion equipment such as motor, thermos bottle, and millivolt meter may be seen from fig. 2.

Method of operation. A mixture of ice and salt is first placed in the insulated crock. This step is followed by attaching the wooden top with the freezing chamber in place. Next a fruit is weighed and measured, and then attached to the fan guard by means of a thread. Finally the thermocouple junctions are inserted in the fruit, the lid of the freezing chamber put into place, and the fan shaft attached to the flexible drive cable. The apparatus is then ready for operation.

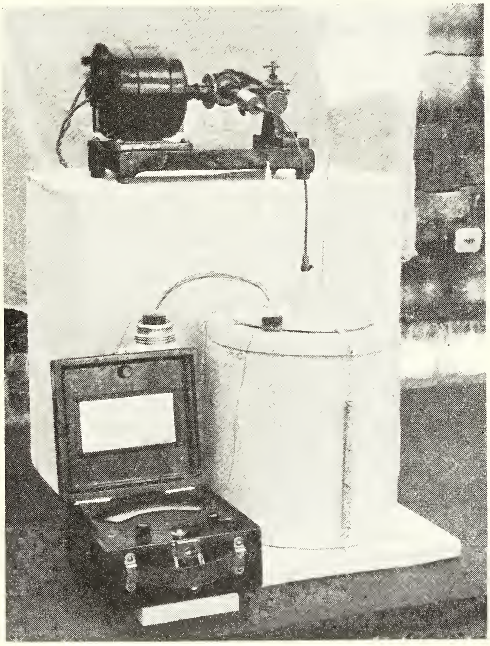

Fig. 2—Freezing apparatus ready for operation.
Photo by E. J. Kohl.

When the temperature of the fruit has fallen to zero on the Centigrade scale the leads to the millivolt meter are reversed and observations taken on the temperatures of the fruit, freezing chamber, and ice bath at three minute intervals until the fruit is frozen. Freezing is associated with a constant temperature of the fruit maintained for a considerable time. Verification of the frozen condition may be made by cutting the fruit open and examining it at the end of the experiment.

Illustrative experiments. In order to illustrate the calibration and use of the freezing apparatus, the results of several experiments are presented in graphical form. Different plant materials were used for indicating some of the various types of physiological problems which may be studied with the aid of this apparatus.

Fig. 3 shows the relationship between the potential in millivolts generated by the thermocouple and the corresponding temperatures when one set of junctions is immersed in crushed ice and the other set attached to a sensitive thermometer and submerged in a cooled liquid. Such liquids as olive oil and a 50 percent sucrose solution have been used for this purpose with practically identical results. Since the form of the curve is a straight line, its use may be supplanted by a conversion factor for converting millivolt readings to Centigrade degrees. The conversion factor obtained with this thermocouple was 1°C. = .037 m.v.

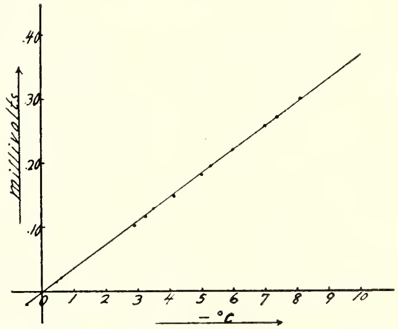

Fig. 3—Thermocouple calibration curve plotted from data obtained with a copper-nickel thermocouple consisting of four pairs of junctions.

Curve A (fig. 4) traces the fall in temperature of the cooled tuber to −3.8°C., followed by an abrupt rise to a peak and a subsequent horizontal region representing the freezing point at −2.7°C. The abrupt rise in temperature is due to the heat of fusion liberated by the sudden freezing of the super-cooled sap. Sufficient heat was liberated in this case to raise the recorded temperature above the freezing point for several minutes. With the potato tuber, the amount of under cooling was 1.1°C.

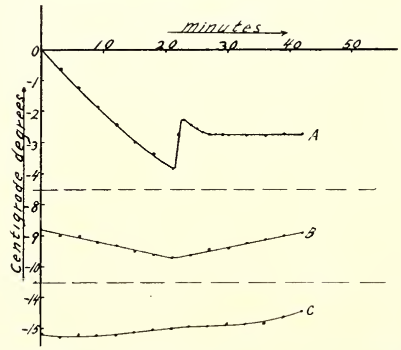

Fig. 4—Results of an experiment with a potato tuber. A = freezing curve for a White-Cobbler potato tuber (fresh weight = 96.5 gm. freezing temperature = 2.7°C.). B = freezing-chamber temperature curve. C = ice-bath temperature curve.

Curves B and C represent the temperatures of the freezing chamber and ice-salt mixture respectively. The freezing chamber curve reflects the temperature changes of the tuber, since the air in the chamber continuously absorbs heat from the tuber.

Curves A and B of fig. 5 represent the freezing data secured for two mature Jonathan apples. Both curves indicate that considerable under-cooling took place, i.e., 3.85°C. for apple A and 4.35° for apple B. The freezing points of the two apples are seen to be in close agreement, −2.9°C. for apple A and −3.0° for apple B.

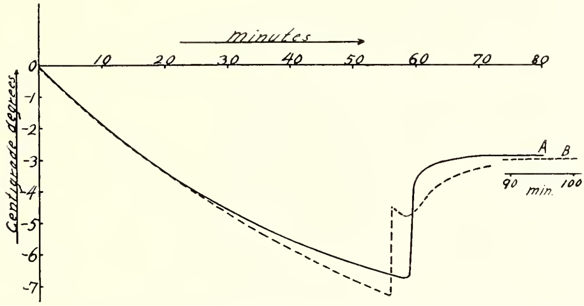

Fig. 5—Freezing curves for Jonathan apples. A = apple with a fresh weight of 66.6 gm. B = apple with a fresh weight of 84.1 gm.

With citrus fruits undercooling was again evident (fig. 6) in this case, 2.9°C. for the orange and 2.15° for the lemon. The freezing point for the orange was noticeably lower than that of the lemon, −4.05°C. contrasted with −3.75°. This is in accord with the fact that lemon fruits on the tree are sooner injured by falling temperatures than are oranges.

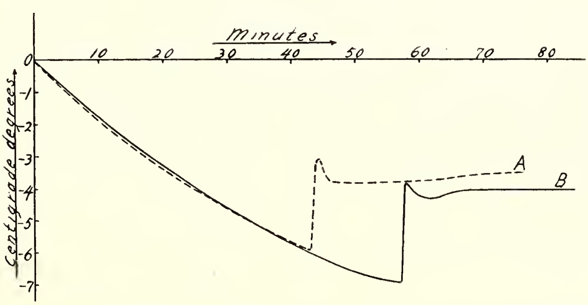

Fig. 6—Freezing curves for citrus fruits. A = lemon with a fresh weight of 89.7 gm. B = orange with a fresh weight of 103.4 gm.

The freezing points of bulbs of different degrees of hardiness were compared to ascertain the relationship, if any, between hardiness and freezing temperature. (Fig. 7). A hyacinth bulb was chosen as representing a hardy species. The freezing temperature for this bulb was −2.7°C. An onion bulb (Yellow Globe variety) was chosen to represent a less hardy species. The freezing temperature of this bulb was only −1.55°C., or 1.15° higher than that of the hyacinth. This difference in freezing temperatures is interesting in that it is indicative of different physiological conditions within the hyacinth and onion tissues, whereby the hardier species is enabled to hold its cell sap more tenaciously and thus better resist the physiological drought accompanying freezing.

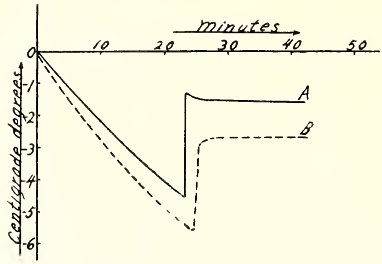

Fig. 7—Freezing curves for tender and hardy bulbs. A = Yellow Globe onion (tender) with a fresh weight of 83.7 gm. B = hyacinth (hardy) with a fresh weight of 62.4 gm.

Concluding remarks. A perusal of the foregoing experiments may serve to suggest other types of studies involving the determination of freezing temperatures. The time required for setting up and performing an experiment of this kind ranges from two to three hours, and the technique is relatively simple. In consequence, the apparatus has found successful employment in laboratory classes for advanced students in plant physiology.