AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

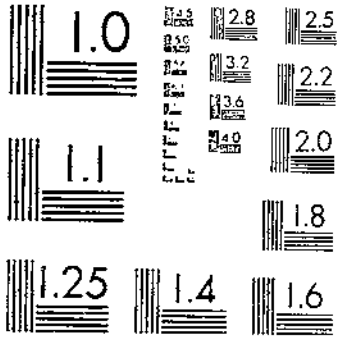
Give to AgEcon Search

AgEcon Search
http://ageconsearch.umn.edu
aesearch@umn.edu

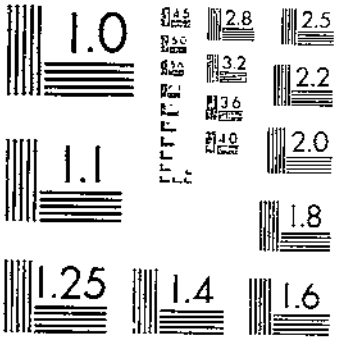
*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

SUBFREEZING TEMPERATURES LETHAL TO THE EUROPEAN CORN BORER INFESTING
BATCHELDER, C. H., QUESTEL, D. D.

START



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

30
53-1 TB 395 (1933)

TECHNICAL BULLETIN No. 395 October, 1933

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D.C.

SUBFREEZING TEMPERATURES LETHAL TO THE EUROPEAN CORN BORER INFESTING GREEN EARS OF SWEET CORN[1]

By C. H. BATCHELDER, *associate entomologist*, and D. D. QUESTEL, *junior entomologist, Division of Cereal and Forage Insects, Bureau of Entomology*

CONTENTS

	Page
Introduction	1
Exposure of free, or unprotected, larvae to cold	2
Procedure	2
Physical characteristics of exposed larvae	2
Mortality of exposed larvae	3
Exposure of eggs and pupae attached to corn foliage	4
Temperature reduction in uninfested green ears of corn	4
Exposure of infested green ears of corn	6
Exposure of husked ears in a plate freezer	7
Exposure of unhusked ears in a refrigerator and in cold rooms	10
Exposure to cold-storage temperatures in bushel packs	12
Summary	13

INTRODUCTION

DEC 15 1933

For purposes of interstate shipment it often is desirable that corn shall be so treated as to eliminate all risk of transmitting infestations of the European corn borer (*Pyrausta nubilalis* Hbn.). It thus became desirable to consider the effect of cold storage on the European corn borer infesting green corn and to determine the value of subfreezing temperatures in cold-sterilization practice. Experiments were therefore undertaken to determine the temperatures below 32° F. that are lethal to this insect and to what extent insulation provided by its host plant protects contained larvae when green ears of sweet corn are cold-processed.

The assembly of such information involved the determination of (1) the lethal threshold and the time required for complete mortality of unprotected larvae in lots exposed to low temperatures, (2) the temperature-time curve of green sweet-corn ears when subjected to cold treatment, (3) the time required for complete mortality of larvae infesting green ears, and (4) the safe exposure to low temperatures for boxed, green "produce" corn. Provision for obtaining data rela-

[1] Sweet corn, frozen by the methods described in this bulletin, was discovered by the Federal Plant Quarantine Board to be a product subject to interstate commerce and liable to infestation by the European corn borer. It was being transported from an area in New England then under quarantine against this insect. The Federal Plant Quarantine Board requested the Bureau of Entomology to determine whether the refrigeration methods used actually rendered the corn safe for interstate transportation as regards this insect, and, if so, what temperatures and conditions were required to obtain this result. This bulletin describes the investigations and gives the results requested by the quarantine board. Since this bulletin was prepared the Federal quarantine against the European corn borer has been withdrawn, but as the several States concerned still operate quarantines against this insect, it is believed that the information contained in it should be published for the benefit of the quarantine officers and other interested persons.

6014°—33

tive to the foregoing items was made through utilization of the facilities afforded by commercial refrigeration laboratories at Gloucester, Mass., and cold-storage warehouses at Boston, Mass., and Providence, R.I.[2] Heavily infested green sweet corn was obtained for the experiments on the United States Department of Agriculture developmental and demonstration farm at Berkley, Mass. Whipple Yellow, a variety producing ears of the largest size, and Golden Sunshine, also popular with commercial growers, were employed as host-plant material.

EXPOSURE OF FREE, OR UNPROTECTED, LARVAE TO COLD

A determination of the period of exposure to a given temperature necessary to kill the insect is fundamental to cold-sterilization practice. To this end experiments were arranged to determine the period of time intervening between the beginning of exposure and the lethal threshold, i.e., when the first larva died as a result of such exposure, and also the time necessary to kill all larvae so exposed. Different lots of fifth-instar larvae were exposed to the same air temperature during various periods of time, until it appeared that there had been established the approximate moments at which a fatal exposure begins and is completed.

PROCEDURE

In conducting these experiments with free larvae, it was considered expedient to eliminate the possibility of unequal heat loss through conduction to previously cooled objects or to objects of high thermal conductivity, and to provide contact as far as possible with chilled air only. For this reason cardboard boxes 5 inches long, 3 inches wide, and 3 inches deep were lined with cotton cheesecloth and equipped with a cotton-screen floor 1½ inches above the bottom of the box. These boxes were cooled to the subfreezing temperature before they were loaded with larvae for an exposure, and during experimental use they were supported on wooden shelves placed near the thermometer in the cold room.

The larvae were dissected from green corn plants, graded for size, and used immediately. The exposure interval, as hereinafter referred to, includes the period between the instant of introduction to the subfreezing temperature and that of removal from it, the temperatures cited being in all cases the corrected air temperatures and not those of the refrigerant or of solids in the room. At the end of the exposure period the larvae were superficially examined and placed on corrugated cardboard strips in a screened cage so that, if they revived, they might crawl into the corrugated paper cells and spin up, as they do normally. The treated larvae, together with check lots, were then retained in an atmosphere of 75° F. and 70 to 75 percent relative humidity for subsequent observation until the decomposition of all the dead larvae was evident.

PHYSICAL CHARACTERISTICS OF EXPOSED LARVAE

When the larvae were removed from the cold room, they were examined with respect to color, shape, and body resilience. No changes in color were observed except a change attributable to a slight accumulation of frost on the external surface of sclerotic

[2] The writers acknowledge the helpful assistance of S. M. Davidson, of Gloucester, Mass., in obtaining records of temperature changes in the cob pith and grain of green sweet corn during treatments.

appendages and the body wall. When subjected to temperatures of −10°, −20°, and −25° F., the body curled and retained a crescent shape until some time after defrosting. This was particularly characteristic in cases where exposure resulted in the death of all larvae. When it had been exposed for one of the longer intervals to any temperature employed (i.e., between +30° and −25°), the body of the insect was stiff and brittle, gave forth a rattling sound when shaken in a cardboard box, and bounded like a solid when dropped, in these respects resembling any frozen food product, such as asparagus or fish fillets. This was assumed to be due to freezing of free body water, and, since many of the larvae survived, this indicated that death is not caused by such a condition.

MORTALITY OF EXPOSED LARVAE

Table 1 gives the mortality and survival results for various periods of exposure to several subfreezing temperatures, and table 2 summarizes the results of exposure to various temperatures. Individual differences in susceptibility to death by freezing were noted in all lots of larvae. The lowest temperature employed, −25° F., was found to kill all larvae during a 10-minute interval, but a lethal threshold for this temperature was not established. Since an exposure to −25° during 5 minutes was fatal to 60.9 percent of the larvae and since the threshold of mortality was found to be at 3 minutes for exposure to −20°, the threshold at −25° is assumed to be at so short a time as to require rather elaborate procedure to determine it. The interval

TABLE 1.—*Results of exposure of free larvae to low temperatures*

Temperature	Time of exposure	Dead larvae	Spun-up larvae	Surviving larvae	
°F.	*Minutes*	*Number*	*Number*	*Number*	*Percent*
−25	5	14	7	9	39.1
	10	25	0	0	0
	15	25	0	0	0
−20	½	0	20	20	100.0
	3	1	18	19	95.0
	5	4	9	16	80.0
	6¼	14	1	6	30.0
	10	18	1	2	10.0
	12½	10	0	0	0
	15	10	0	0	0
−10	7	0	19	20	100.0
	10	9	8	11	55.0
	15	19	1	1	5.0
	20	20	0	0	0
	25	20	0	0	0
0	10	1	24	24	96.0
	15	11	12	14	56.0
	20	12	10	13	52.0
	25	16	12	14	46.6
	30	22	4	8	26.6
	40	16	7	9	36.0
	60	20	3	5	20.0
	90	21	3	4	16.0
	120	23	1	2	8.0
	150	25	0	0	0
	180	25	0	0	0
+15	30	0	24	25	100.0
	40	1	24	24	96.0
	50	2	23	23	92.0
	60	1	23	24	96.0
	120	6	19	19	76.0
	150	7	18	18	72.0
	180	7	18	18	72.0
	[1] 1,440	19	4	6	24.0
	[2] 3,900	14	0	0	0

[1] Or 24 hours. [2] Or 65 hours.

between the lethal threshold and the mortality of the entire lot increased rapidly as higher temperatures were encountered. Comparatively short periods of exposure were fatal at and below −10°, but at 0° and at +15° the larvae exhibited greater resistance. At −20° the first larvae died after 3 minutes, and an exposure of 12½ minutes was fatal to all the larvae subjected to this temperature. It was found that certain larvae which survived exposure did not spin silk.

TABLE 2.—*Summary of effective lethal temperature exposures and lethal thresholds of fifth-instar larvae*

Temperature	Time between initial exposure and—		Temperature	Time between initial exposure and—	
	Lethal threshold	Complete mortality		Lethal threshold	Complete mortality
° F.	*Minutes*	*Minutes*	*° F.*	*Minutes*	*Minutes*
−25	----------	10	0	15	150
−20	3	12½	+15	120	[2] 3,900
−10	[1] 9	20			

[1] By interpolation. [2] Or 65 hours.

No attempt was made to determine the internal temperatures of the insect during these exposures. For a discussion of this and related subjects the reader is referred to articles by Back and Cotton,[3] Robinson,[4] and Payne.[5]

These experiments with free larvae have shown that, in the practice of sterilization by means of cold, it is essential to employ temperatures of 0° F. or lower.

EXPOSURE OF EGGS AND PUPAE ATTACHED TO CORN FOLIAGE

The effect of exposure of eggs and pupae attached to green corn foliage was next determined. Fifty egg masses from 1 to 10 hours old, 50 egg masses 70 hours old, and 20 pupae from 1 to 5 days old were placed in a cold room the temperature of which ranged from 0° to +3° F. and left there for 48 hours. At the end of this time the mortality was complete.

TEMPERATURE REDUCTION IN UNINFESTED GREEN EARS OF CORN

In connection with the practice of cold sterilization it is desirable to learn the rate and the period of temperature decline characteristic of the green sweet-corn ear when exposed to subfreezing temperatures.

The rate of cooling and freezing of green sweet corn on the ear when exposed in contact with metal plates held at a temperature of −22° F. was determined. The temperatures were measured by means of copper-constantan thermocouples and a potentiometer sensitive to 0.1 microvolt. Single-junction thermocouples were used and an ice-water bath was used for the constant-temperature junction.

The freezing apparatus was an experimental unit of a commercial

[3] BACK, E. A., and COTTON, R. T. COLD STORAGE AND INSECT CONTROL. Amer. Inst. Refrig. Proc. 1928: 103–111. 1928.

[4] ROBINSON, W. WATER BINDING CAPACITY OF COLLOIDS A DEFINITE FACTOR IN WINTER HARDINESS OF INSECTS. Jour. Econ. Ent. 20: 80–88, illus. 1927.

[5] PAYNE, N. M. FREEZING AND SURVIVAL OF INSECTS AT LOW TEMPERATURES. Jour. Morph. and Physiol. 43: 521–540, illus. 1927.

type in which the material to be frozen was placed in contact with thick metal plates and the refrigerant was circulated within the plates. In this apparatus the cob pith of the corn cooled rapidly to the freezing point of the water in the ear, the average temperatures of the ears being lowered from 68° to 30° F. in 40 to 50 minutes. When the corn began to freeze, the temperature remained relatively constant during 75 to 140 minutes, followed by a comparatively rapid cooling from 23° to 0° F. for 40 to 55 minutes. Three hours were required to cool an ear of Golden Bantam corn (1¼ inches in diameter) from 68° to the inception of freezing, freeze it, and cool it

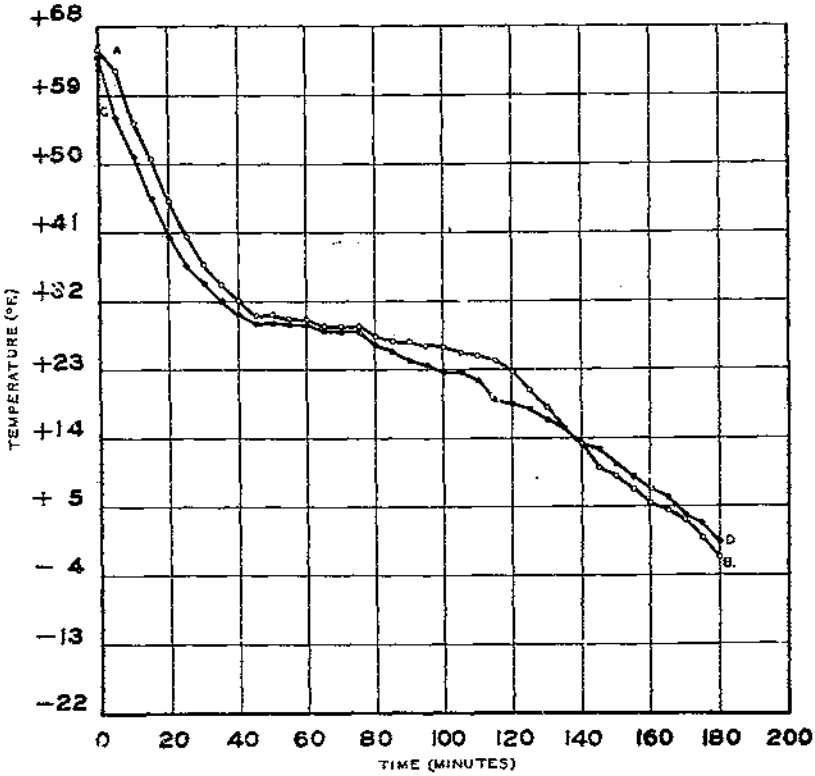


FIGURE 1.—Temperature-time curve for rapidly frozen green Golden Bantam sweet corn exposed to −22° F., showing the temperatures of the cob pith (A–B) and of the grain (C–D) during a 3-hour interval.

to 0°, while 4 hours were required to accomplish the same operation with an ear of Whipple Yellow corn (2¼ inches in diameter). The rate of cooling is shown graphically in figures 1 and 2.

Another lot of Golden Bantam corn was frozen and cooled to a temperature of 0° F. by exposure to cold air at 0° (fig. 3). The temperature of the corn was determined at intervals by means of alcohol thermometers thrust into the cob pith. Fifteen hours were required to cool the corn to its freezing point, freeze it, and cool it to 0°.

EXPOSURE OF INFESTED GREEN EARS OF CORN

The European corn-borer population of sweet-corn ears is not always distributed in different parts of the ear in the same ratio. Examination of 130 of the ears employed in these experiments showed

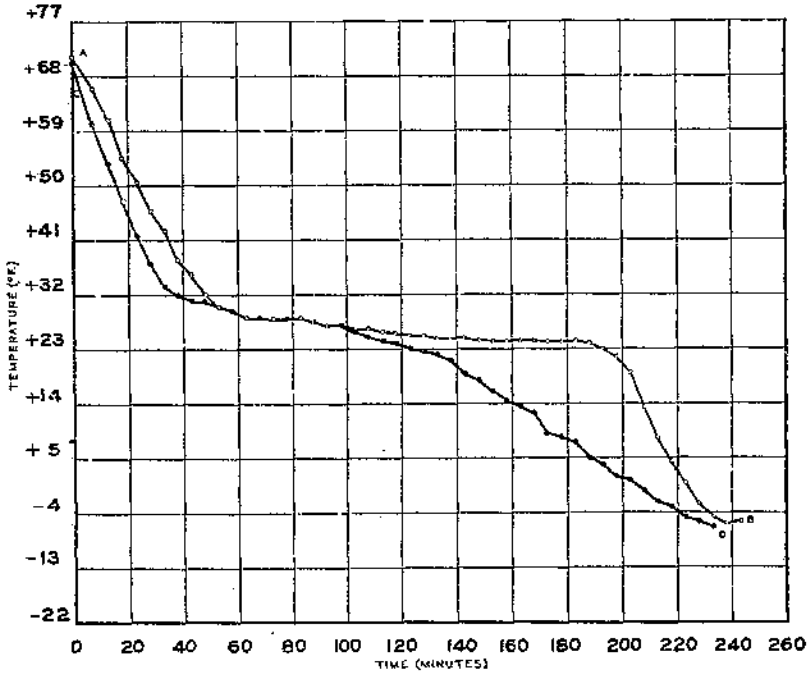


FIGURE 2.—Temperature-time curve for rapidly frozen green Whipple Yellow sweet corn exposed to —22° F., showing the temperatures of the cob pith (A–B) and of the grain (C–D) during a 4-hour interval.

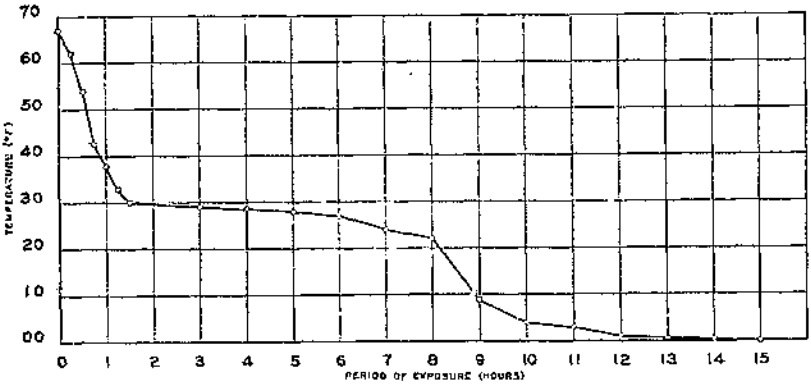


FIGURE 3.—Time-temperature curve for slow-frozen green Golden Bantam sweet corn exposed to 0° F. in a cold room, showing the temperatures of the cob pith during a 15-hour interval.

the distribution of the larvae to be as follows: 214, or 44 percent, in the grain; 134, or 27.6 percent, in the shank; and 138, or 28.4 percent, in the cob pith. As noted by Caffrey and Worthley,[6] the larvae

[6] CAFFREY, D. J., and WORTHLEY, L. H. A PROGRESS REPORT ON THE INVESTIGATIONS OF THE EUROPEAN CORN BORER. U.S. Dept. Agr. Bul. 1476, 154 p., illus. 1927.

develop throughout the husk and grain during the initial period of the infestation and subsequently, in the fourth and fifth instars, some of them tunnel into the cob and shank. These tunnels are sometimes deep and sinuous, littered with silk-felted frass (fig. 4), and are frequently directed into the center of the cob pith, where there is good protection from external influences. The problem of effectively sterilizing corn ears by means of cold is complicated by the presence of larvae in such situations.

Infested ears of green sweet corn in which larvae occupied tunnels in the cob were exposed to several subfreezing temperatures to determine the time of exposure necessary to sterilize such infested corn. Several methods of procedure were employed, as described in the paragraphs that follow.

EXPOSURE OF HUSKED EARS IN A PLATE FREEZER

One method involved the use of a mechanical refrigerator of the quick-freezing type (fig. 5). Two lots of green Whipple Yellow corn, from which, to insure proper contact for maximum conductivity, all the husks except the innermost layer had been stripped, were packed one layer deep in paper cartons and placed between metal plates 2

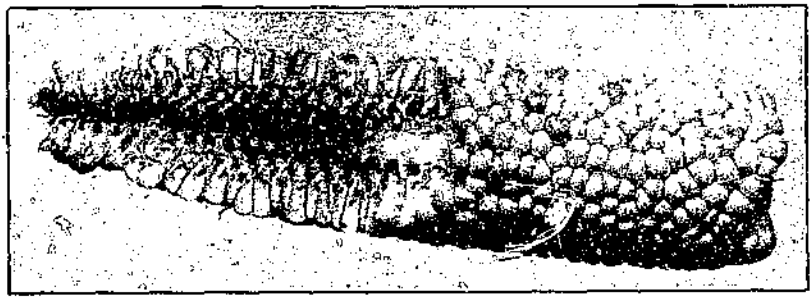


FIGURE 4.—Tunnels of the European corn borer in the cob pith.

inches thick through which the refrigerant was circulated. These plates were then adjusted to make contact under slight pressure with the top and the bottom of each carton. The ears were exposed thus to −22° F. for 4 hours while the temperature of the cob pith was brought to 0°. At the end of this time one lot was defrosted immediately at +65° and the other was stored for 24 hours in a cold room at −20° in accordance with one of the commercial practices.

The results with this method of exposure are given in table 3, lots 1 and 2.

The effectiveness of this method of refrigeration in cold-sterilization practice is apparent when the results are compared with those obtained with unprotected larvae. It has been shown (table 2) that when fifth-instar larvae are cooled in air at 0° an exposure of 150 minutes is required to obtain complete mortality. However, in Whipple Yellow corn that had been plate-frozen for 4 hours the temperature at the center of the cob pith was maintained at or below 0° during a period of 25 minutes or less (fig. 2) and such exposure (table 3, lots 1 and 2) was fatal to all infesting larvae. Inasmuch as all the borers were killed during a 4-hour freezing treatment, storage at −20° is apparently unnecessary for purposes of sterilization.

TABLE 3.—*Summary of data showing effect of exposure of European corn-borer larvae to low temperatures*

Lot no.	Ears	Treatment				Larval population of—				Larvae surviving in—				Mortality
		Preparation of ears	Cooling method	Temperature of exposure	Duration of exposure	Cob pith	Shank	Grain	Total	Cob pith	Shank	Grain	Total	
	Number			*°F.*	*Hours*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Percent*
1	6	Husked [1]	Plate freezer	−22.0	4	6	3	2	11	0	0	0	0	100.0
2	8	do	do	−22.0	[2] 4	6	5	5	16	0	0	0	0	100.0
3	20	Not husked	Refrigerated show case.	+17.6	65	12	9	14	35	3	0	0	3	91.4
4	20	do	Cold room, ventilated	0	42	15	8	17	40	1	0	0	1	97.5
5	20	do	do	0	65	21	20	37	78	0	0	0	0	100.0
6	20	do	do	−20.0	18	18	10	35	63	0	0	0	0	100.0
					Days									
7	71	Bushel pack	do	+30.0	6	(3)			109				92	15.6
8	55	do	do	+30.0	14	(3)			63				42	33.3
9	124	do	do	0	[4] 6	(3)			86	(3)	0	0	0	100.0
10	137	do	Cold room, not ventilated for 2 days.	0	[4] 6	(3)			164	2	0	0	2	98.8
11	50	do	Cold room, ventilated	0	[4] 8	72	87	111	270	0	0	0	0	100.0
12	100	do	None (check) [6]	+48.0 to +95.5	7				129				122	5.4

[1] All of husk except innermost layer removed.
[2] Stored 24 hours in cold room at −20° F.
[3] Distribution of population not taken in these lots.
[4] After reaching 0° F. at center of pack (approximate in lot 10).
[5] Artificial infestation of cob pith in some ears.
[6] Stored in outdoor screened insectary.

This difference in the time required to bring about complete mortality of larvae may be explained as follows: In the case of the unprotected larvae, heat was lost through direct exposure to the air, and this method of cooling requires an extended period of time. In the case of the larvae inhabiting tunnels in plate-frozen ears of corn, the borers were in contact with a solid, and when the corn ear was chilled heat was lost by conduction from the insect to the tunnel wall. Furthermore, in the plate freezer each ear was in indirect contact along both the lower and the upper surfaces with a solid the temperature of which was −22° F., so that rapid conduction of heat from the corn

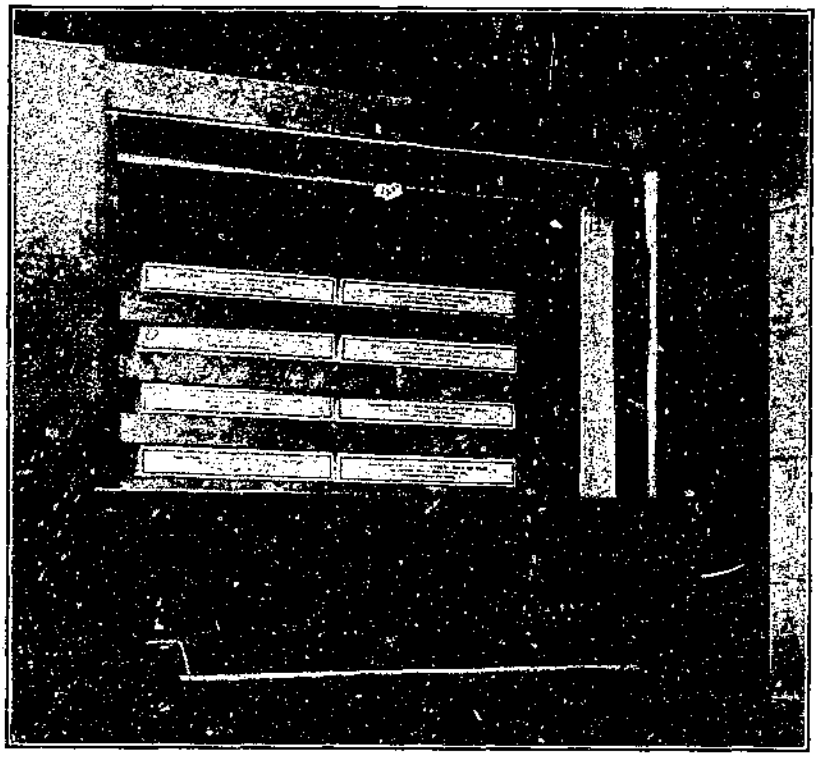


FIGURE 5.—Plate freezer used in quick freezing. Green ears of sweet corn were packed in paraffined-paper cartons for cold-sterilization tests. The cartons are shown here in contact with the metal plates through which a refrigerant circulates.

was provided. When the temperature of the tunnel walls in this corn reached 0°, the heat loss from infesting larvae was greatly accelerated and susceptible tissues within the larvae were cooled to a lethal temperature sooner than if the heat were lost by direct exposure to the air.

It is therefore apparent that the greater lethal effect of cooling on larvae in the tunnels of a quick-frozen ear of corn than on larvae exposed in still air is due to the method of cooling. Little importance is attached to the tunnel opening as a means of cooling the larvae inhabiting the cob pith. The tunnels of the cob pith in the corn used in these experiments were deep, slightly sinuous, and littered with silk-felted

frass (fig. 4), and the dead air contained in such a tunnel is more likely to insulate a larva than to freeze it.

Stiles [7] has considered at length this difference in cooling rate obtaining when materials are exposed in air and when in contact with a substance of higher thermal conductivity. In one experiment comparing the time required to cool a 5-percent gelatin solution from 20° C. (68° F.) to −2° C. (28.4° F.) in still air at −10° C. (14° F.) and in still brine at the same temperature [8], he found that 960 minutes was required when the gelatin was cooled in still air whereas in still brine 173 minutes was sufficient. We thus see that the gelatin cooled 5.5 times as rapidly in contact with the brine as in still air.

EXPOSURE OF UNHUSKED EARS IN A REFRIGERATOR AND IN COLD ROOMS

Another method of cooling consisted in exposing unhusked ears in a refrigerated show case and in the cold rooms of a cold-storage plant. The ears of one lot were placed in the open bins of the refrigerator, where they were cooled for 65 hours at 17.6° F., those of another lot were placed in the wooden bins of a cold room at 0° for 42 hours, and those of a third lot were exposed under conditions identical with those for the preceding lot except that the exposure was lengthened to 65 hours. The results are shown in table 3, lots 3, 4, and 5, respectively. In lot 3 three larvae, occupying tunnels in the cob pith, survived the exposure and exhibited externally no abnormal effects, in lot 4 one apparently normal larva was found in a cob-pith tunnel, whereas in lot 5 none of the larvae survived. It is therefore seen that, in order to obtain complete sterilization by this method, the time of treatment must be longer than when a plate freezer is used.

A cold-room exposure of loose ears during 18 hours at −20° F. resulted in 100 percent mortality of the contained larvae (lot 6), and the use of this temperature and this exposure period is considered safe in treatment of products for interstate shipment. Before comparing the results with those for the larvae exposed in the plate freezer, however, consideration should be given to the conditions of this experiment. Previous to the exposure these ears had been stored in bushel boxes in a room the temperature of which was 76° F. In the cold room they were then piled from 4 to 8 deep in a wooden bin. Although the air temperature of this room was only 0°, some of the ears were not so situated as to permit rapid cooling, and all of them were protected by their natural husks. In the centrally placed ears the rate of temperature decline is slower than in the ears at the surface of the piles or in contact with materials whose conductivity is greater than that of air. For this reason the rate of temperature decline from the cob pith in such ears is not comparable with that when the corn is exposed in the plate freezer. Furthermore, cold-room chilling methods are subject to air pocketing that is difficult to avoid unless the products being treated are exposed in a single layer.

Still more individual variation in the rate of heat loss occurs when the ears are placed in a cold room in bushel boxes. Corn packed in this manner has many air pockets which insulate the material from the chilled air of the room; the box carries warm air with it into the

[7] STILES, W. THE PRESERVATION OF FOOD BY FREEZING WITH SPECIAL REFERENCE TO FISH AND MEAT: A STUDY IN GENERAL PHYSIOLOGY. [Gt. Brit.] Dept. Sci. and Indus. Research, Food Invest. Bd. Spec. Rpt. 7, 186 p., illus. 1922.

[8] Stiles, W. Op. cit., p. 91.

cold room; and finally, owing to rapid metabolism, the corn continues to generate heat until artificial cooling has caused its temperature to drop to a level at which limited metabolism takes place.

An experiment during which the temperature decline for the early part of the exposure was recorded emphasizes the importance of this factor. Four boxes of heavily infested Golden Sunshine green sweet corn were stacked on a table in a cold room maintained at 0° F. Stick separators were not employed and the room was not provided with forced-air circulation. The cover of each box was nailed in place and handle holes and other openings were closed. Through the sides of each of the two middle boxes a wooden tube open at both ends was inserted to protect an alcohol thermometer that ex-

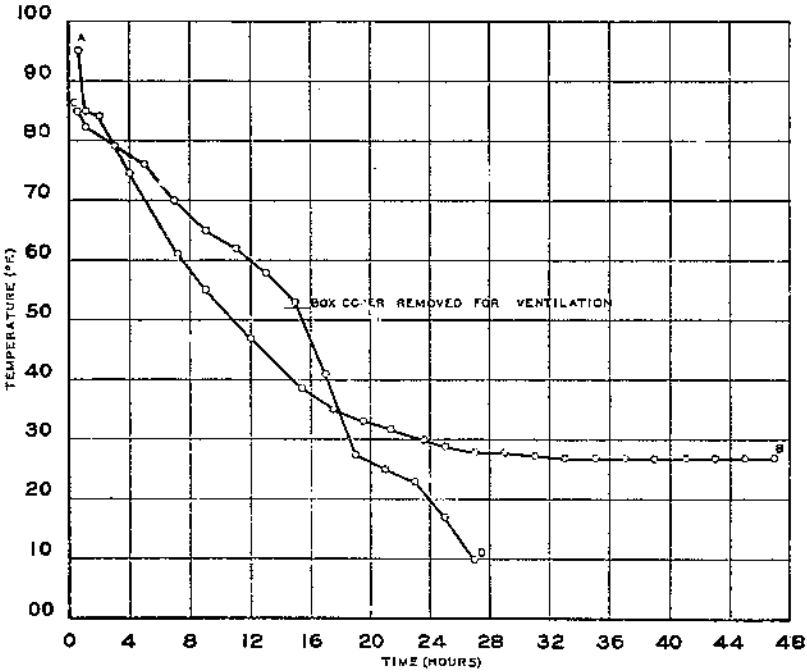


FIGURE 6.—Temperature-time curve for the central air spaces of bushel-box packs of green Golden Sunshine sweet corn exposed at 0° F. in a cold room. Curve A–B, no ventilation for 48 hours; curve C–D cover of box removed after 15 hours.

tended into spaces between the ears at the center of the pack. The effect of ventilation on the decline in temperature when the box covers were removed after 15 hours and after 48 hours is shown in figure 6. In the box that was ventilated the general decline was rapid after the cover was removed, whereas in the box that remained closed the temperature dropped during 33 hours to a point where equilibrium was reached between heat lost to the exterior and that gained from the ears.

It is believed that heat production is also greatly accelerated by micro-organisms which infect tunneled corn, and this may have been an important cause of the high temperature of this corn when it was placed in storage. This corn was harvested when the air temperature in the field was 89° F. and it was packed in the shade. It was

placed in the cold room (0°) 1 hour after being packed. It will be noted in figure 6 that 30 minutes after being placed in the cold room the temperature within one box was 95° (curve A–B) and in the other 85° (curve C–D). This would indicate that during the 60 minutes that these boxes had been covered previous to exposure in the cold room a considerable rise in temperature had occurred.

In commercial packs sweet corn is rarely boxed with close-fitting covers. Two slats usually take the place of a cover; otherwise, owing to the rapid metabolism occurring at this time, heat accumulates faster than it can be conducted to the exterior and the value of the corn is seriously affected.

EXPOSURE TO COLD-STORAGE TEMPERATURES IN BUSHEL PACKS

The value, in cold sterilization, of two commonly available cold-storage temperatures, 0° and +30° F., was determined when the usual commercial packing methods were followed.

Heavily infested green ears of Golden Sunshine sweet corn were packed in standard bushel boxes and placed immediately in cold rooms. Open-top ventilation and separator sticks were employed to facilitate rapid chilling, and the temperatures prevailing in spaces between ears at the center of the pack were obtained by means of alcohol thermometers.

The procedure and the mortality and survival data for these experiments are summarized in table 3 (lots 7 to 12). Lots 7 and 8 were held at +30° F. for 6 and 14 days, respectively. Lot 9 consisted of two boxes of naturally infested ears that had also been artificially tunneled and infested in the cob pith. After insertion of the larvae the holes had been stopped with squared plugs. Some of the larvae bored out of these tunnels. These ears were exposed to 0° for 6 days, and it is believed that ventilation was ample. Lot 10 was also exposed to 0° for 6 days, but was not ventilated during the first 2 days of exposure. Lot 11 consisted of 6 boxes of corn exposed to 0° for 8 days with the usual ventilation.

The high survival of the larvae in lots 7 and 8 (84.4 and 66.7 percent, respectively) indicates that +30° F. is not a practicable temperature for cold sterilization. In the lots exposed at 0°, however, the mortality of the larvae was practically complete. Two fourth-instar larvae inhabiting cob-pith tunnels in ears of lot 10 survived the exposure and completed their life cycle. Since the ears in this lot were not ventilated during the first 2 days of storage, the results are only approximate. The importance of ample ventilation in sterilizing green corn by exposure to 0° is emphasized, however.

In cold-sterilization practice it has been established that when bulk lots of green sweet corn are chilled at 0° F. in the cold room, the bushel containers being provided with stick separators and open-top ventilation, infesting larvae of the European corn borer are killed during an exposure of 8 days after the central spaces of the pack have reached a temperature of 0°.

SUMMARY

A study was made of the temperatures that are lethal to the European corn borer infesting green ears of sweet corn and the time of exposure necessary to secure complete mortality.

When exposed, unprotected, in still air, the following exposures were found to be lethal to fifth-instar larvae: 10 minutes at −25° F., 12½ minutes at −20°, 20 minutes at −10°, 150 minutes at 0°, and 65 hours at 15°.

Eggs and pupae attached to foliage were destroyed by exposure to approximately 0° F. for 48 hours.

Uninfested ears of green sweet corn exposed to −22° F. in a plate freezer showed a reduction of the cob-pith temperature to 0° after 3 or 4 hours, according to the variety; but when exposed to 0° in a ventilated cold room 15 hours were required for the cob-pith temperature to drop to 0°.

The following exposures of infested ears of corn produced complete mortality of the larvae occupying tunnels in the cob pith: 4 hours in a plate freezer at −22° F., 18 hours in a cold room at −20°, and 65 hours in a cold room at 0°. Exposure of ears packed in bushel boxes in a cold room at 30° killed only 15.6 percent of the larvae after 6 days.

When green sweet corn is packed in bushel boxes having nonventilating covers, heat is accumulated, previous to the chilling, as a result of the rapid metabolism of the ears, and such packs are chilled with difficulty in a cold room at 0° F. When corn was packed in ventilated boxes, however, and exposed in a cold room according to commercial practice, and the central spaces of the pack were subjected to 0° for 8 days, all the infesting larvae were killed. The treatment of corn in this manner for 8 days following establishment of air temperature of 0° in the central spaces of the pack is considered to provide a safe minimum interval of exposure in cold-sterilization practice.

These experiments indicate that, owing to the resistance to cold characteristic of the European corn borer, and because it inhabits a host providing insulation, corn must be processed by means of zero, or subzero, temperatures (Fahrenheit) if all the infesting larvae are to be killed.

ORGANIZATION OF THE UNITED STATES DEPARTMENT OF AGRICULTURE WHEN THIS PUBLICATION WAS LAST PRINTED

Secretary of Agriculture	HENRY A. WALLACE.
Assistant Secretary	REXFORD G. TUGWELL.
Director of Scientific Work	A. F. WOODS.
Director of Extension Work	C. W. WARBURTON.
Director of Personnel and Business Administration.	W. W. STOCKBERGER.
Director of Information	M. S. EISENHOWER.
Solicitor	SETH THOMAS.
Bureau of Agricultural Economics	NILS A. OLSEN, *Chief.*
Bureau of Agricultural Engineering	S. H. MCCRORY, *Chief.*
Bureau of Animal Industry	JOHN R. MOHLER, *Chief.*
Bureau of Biological Survey	PAUL G. REDINGTON, *Chief.*
Bureau of Chemistry and Soils	H. G. KNIGHT, *Chief.*
Office of Cooperative Extension Work	C. B. SMITH, *Chief.*
Bureau of Dairy Industry	O. E. REED, *Chief.*
Bureau of Entomology	LEE A. STRONG, *Chief.*
Office of Experiment Stations	JAMES T. JARDINE, *Chief.*
Food and Drug Administration	WALTER G. CAMPBELL, *Chief.*
Forest Service	R. Y. STUART, *Chief.*
Grain Futures Administration	J. W. T. DUVEL, *Chief.*
Bureau of Home Economics	LOUISE STANLEY, *Chief.*
Library	CLARIBEL R. BARNETT, *Librarian.*
Bureau of Plant Industry	WILLIAM A. TAYLOR, *Chief.*
Bureau of Plant Quarantine	A. S. HOYT, *Acting Chief.*
Bureau of Public Roads	THOMAS H. MACDONALD, *Chief.*
Weather Bureau	CHARLES F. MARVIN, *Chief.*

Agricultural Adjustment Administration	GEORGE N. PEEK, *Administrator.*
	———, *Coadministrator.*

This bulletin is a contribution from

Bureau of Entomology	LEE A. STRONG, *Chief.*
Division of Cereal and Forage Insects	W. H. LARRIMER, *Principal Entomologist, in Charge.*

U. S. GOVERNMENT PRINTING OFFICE: 1933

For sale by the Superintendent of Documents, Washington, D.C. - - - - - - - - Price 5 cents

END