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Pasteurization of Shell Eggs

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SUMMARY

A method for pasteurizing shell eggs has been developed that not only destroys bacteria but causes shell eggs to retain their desirable physical properties much longer than do untreated eggs.

The following bacteria, known to cause spoilage in shell eggs have been destroyed by pasteurization, even when they had been injected into the albumen of shell eggs. *Aerobacter aerogenes, Alcaligenes bookeri, Alcaligenes faecalis, Eberthella oedematiens, Eberthella oxyphila, Escherichia coli, Flavobacterium aurescens, Proteus ichthyosmus, Proteus mirabilis, Proteus vulgaris, Pseudomonas fluorescens, Serratia marcesens, Staphylococcus albus, and Staphylococcus aereus.*

The results thus far obtained indicate that pasteurization may possibly eliminate or at least greatly reduce spoilage in shell eggs caused by bacterial contamination. Bacteria were destroyed in eggs which had been improperly washed several days before pasteurization was applied.

Pasteurization of shell eggs may be the means of reducing the bacterial content of frozen and dried eggs.

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Pasteurization of Shell Eggs

E. M. Funk

The pasteurization and sterilization of many food products has made possible the storage of such products for relatively long periods of time without spoilage. Shell eggs when stored for long periods (8 to 10 months) may suffer large losses, particularly if such eggs have been soiled and then improperly cleaned. Frozen eggs produced from shell eggs contaminated with bacteria may also spoil and dried eggs produced from contaminated eggs are of inferior quality.

If some satisfactory commercial method could be developed for destroying the bacteria present on the shell, in the shell and shell membranes and in the albumen and yolk of shell eggs, much of the loss from spoilage of such eggs could be prevented. With this objective in mind, investigations were inaugurated at the University of Missouri in an attempt to develop a suitable method for pasteurizing shell eggs and thereby destroying the microorganisms which cause spoilage.

REVIEW OF LITERATURE

To the author's knowledge no one has to date reported experimental results showing that shell eggs have been pasteurized to destroy the microorganisms which cause spoilage in such eggs when stored. Some of the processes for oil treating eggs at high temperatures did, no doubt, pasteurize the shell of the egg but the high temperatures recommended would not permit the heat to penetrate the egg sufficiently to pasteurize the albumen and yolk of the egg without coagulating that portion of the albumen next to the shell.

Nearly all eggs are free from bacteria when laid as shown by the work of Rettger (1913); Hadley and Caldwell (1916); Tittsler, Heywang and Charles (1928); Sharp (1937); Haines (1939); and others. *Salmonella pullorum* is the bacterium most often found in the few infected eggs at time of laying. Its presence does not impair the food value of the egg nor cause it to decompose.

Most bacteria found in eggs gain entrance through the shell after the egg is laid. The shell becomes coated with varying amounts and kinds of bacterial flora from the cloaca, dirt in the nest, dust in the air, etc. Pernot (1908), Priebe (1934) and Haines (1938) have studied the bacterial flora found on egg shells. The investigator last named found an average of 130,000 organisms per shell. Non-sporing rods constituted 38 per cent of the organisms, sporing rods 30 per cent, cocci 25 per cent, yeasts 4 per cent and actinomyces 3 per cent. Eggs soiled with feces had by far the largest numbers of bacteria.

The passage of bacteria through the shell and into the egg contents is influenced by the condition of the shell, the organisms present and the conditions under which the eggs are held.

Zorkendorfer (1893) showed that bacteria pass through the shell at certain spots which may be either pores or defects in the shell.

Washing eggs makes them more susceptible to bacterial penetration of the shell according to Lange (1907), Jenkins (1920), Bryant and Sharp (1934) and Haines (1938). The washing or cleaning of eggs by other methods increases the size of the pores and forces bacteria through them. Jenkins found that 1.9 per cent of clean eggs become inedible after 5 to 11 months storage as compared to 6.6 per cent for dirty unwashed eggs and 14.4 per cent for dirty eggs placed in a bucket of water and washed. Funk (1938) found that dirty eggs washed in 1.0 per cent sodium hydroxide solution kept as well as clean eggs and better than unwashed dirty eggs when held in cold storage.

Wilm (1895) and Haines (1940) demonstrated that small motile bacteria penetrate egg shells more readily than large non-motile bacteria.

The presence of moisture aids in the penetration of egg shells by bacteria according to Lamson (1909), Benjamin (1915) and Jenkins (1920). Eggs that were handled in such a manner that they sweated developed more rots than eggs that were prevented from sweating.

A warm temperature favors bacterial penetration of egg shells as pointed out by Piorkowski (1895), Lamson (1909), Poppe (1910), and Maurer (1914). Haines (1940) soaked warm eggs in a cold suspension of bacteria. As the eggs cooled and the contents contracted, bacteria were drawn through the shell.

Only a few of the many kinds of bacteria that are capable of penetrating egg shells cause decomposition.

Zorkendorfer (1893) isolated two kinds of bacteria from spoiled eggs. One kind when inoculated into fresh eggs produced black rot and the other produced a greenish blue rot.

Artault (1894) found the *Proteus* group of bacteria to be the most common in lots of black rot eggs.

Bohart (1930) isolated both aerobic and anaerobic bacteria from black rot eggs. Cultures of the *Clostridium* group inoculated into fresh eggs produced black rot.

Bennetts (1931) isolated bacteria of the *Serratia* group from black rot eggs. When these organisms were inoculated into fresh eggs, black rot developed.

Miles (1937) isolated *Proteus melanovogenes* from black rot eggs and reproduced this condition in fresh eggs by rubbing cultures of this organism on the shells of fresh eggs.

Haines (1938) has made an extensive study of the bacteria found in rotten eggs. He found *Pseudomonas, Proteus, Escherichia, Alcaligenes* and *Aerogenes* groups of bacteria in black rot eggs. In nearly every case the egg contained only one kind of bacteria. He inoculated fresh eggs with some of the cultures and produced black rot in 14 days.

Epstein (1941) reported that the Seal Test, Inc. Research Laboratories had reduced the total number of microorganisms from 371,000 to 1,500 per gram and B. coli from 3,800 to 0 per gram in sugared yolk by heating this material at a temperature of 143° F. for 30 minutes. Epstein reported that it was not commercially practical to pasteurize egg whites because of the low temperature (127° F.) at which they were coagulated.

Winter (1942) after investigating the cause of black rot in fresh eggs reported: *Alcaligenes, Escherichia* and *Proteus* groups of bacteria were found most frequently in black rot eggs. *Alcaligenes* and *Proteus* groups of bacteria produced black rot readily in fresh eggs. The bacteria found in black rot eggs are also found in fecal material, soil and water. The source of infection in most black rot eggs is dirt on the shell or in the water used in cleaning eggs. The best way to prevent black rot in eggs is to produce clean eggs.

EXPERIMENTAL

Experimental procedures as recommended for bacteriological laboratory work were employed in this investigation. Special techniques used for egg work are described and discussed.

Source of Microorganisms

Pure cultures of bacteria were isolated from spoiled eggs removed from cold storage. Other organisms were obtained from Dr. A. R. Winter, Department of Poultry Husbandry, Ohio State University; and the Departments of Botany, Dairy Husbandry, and Pathology and Medical Bacteriology of the University of Missouri. The name of the microorganisms used in this investigation and their sources are given in Table 1. Except where otherwise noted, the organisms used were those which had caused spoilage in eggs stored by the Department of Poultry Husbandry in 1942 or were reported by other investigators as having been found in spoiled eggs.

TABLE 1.—LIST OF BACTERIA USED FOR PASTEURIZATION INVESTIGATIONS AND THE SOURCE OF THE STRAIN USED.

Name	*Source*
Aerobacter aerogenes	Medical Bacteriology
Achromobacter lipolyticum	Dairy Department
Alcaligenes bookeri	Ohio State University
Alcaligenes faecalis	Eggs
Alcaligenes viscosum	Dairy Department
Eberthella oedematiens	Ohio State University
Eberthella oxyphila	Eggs
Escherichia coli	Eggs
Escherichia coli	Ohio State University
Flavobacterium aurescens	Eggs
Flavobacterium aquatile	Eggs
Proteus ichthyosmus	Ohio State University
Proteus ichthyosmus	Dairy Department
Proteus mirabilis	Eggs
Proteus vulgaris	Eggs
Pseudomonas aeruginosa	Dairy Department
Pseudomonas fluorescens	Eggs
Pseudomonas fluorescens (musty strain)	Eggs
Sarcina lutea	Botany Department
Sarcina rosea	Botany Department
Serratia marcesens	Ohio State University
Serratia marcesens	Botany Department
Staphlococcus albus	Medical Bacteriology
Staphlococcus aureus	Medical Bacteriology
Staphlococcus citreus	Botany Department

Preparation of Cultures for Use in Inoculating Eggs

Precautions were taken to prepare cultures which were uniform as to age and resistance. When a new culture was used suspensions were prepared as follows: The culture was grown on agar slants and and a transfer was made to broth. Then three successive daily transfers were made from broth to broth. A 24-hour broth was used for inoculation purposes.

Inoculation of Eggs

Two methods of inoculation were used, (a) by immersion and (b) by injecting broth cultures into the albumen of the egg.

To simulate natural conditions where soiled eggs are cleaned by washing with water, warm eggs were immersed in cold solutions of broth suspensions of bacteria cultures. This method was employed so the organisms would be drawn through the shell into the egg.

For inoculating eggs by immersion the following procedure was employed: A heavy inoculation from agar to 5 cc. of nutrient broth was made. After 24 hours incubation this 5 cc. culture was poured into 250 cc. of broth and incubated 24 hours. This 250 cc. culture was transferred to 2000 cc. quantities of nutrient broth. After 24 hours incubation this was placed in a refrigerator for approximately 6 hours where the temperature reached 46° to 50° F. Eggs were held for 4 hours in an incubator at 100° F. and then washed in warm 1:1000 mercuric chloride solution and rinsed with warm sterile water. A portion of these washed eggs were placed in sterile containers and kept as negative controls.

The remaining sterile eggs were immersed for one hour in 46° to 50° F. bacterial suspension. Part of these eggs were placed in containers and labeled positive controls. The rest were treated and when treatment was complete put in sterile containers.

Portions of the shell from treated, positive and negative controls were moved, as free from bacterial contamination as possible, and put in tubes of nutrient broth. Part of the outer shell membrane was peeled out and put in broth. Then 1 cc. of albumen was transferred to broth.

Since bacteria could not be recovered from the albumen when eggs were inoculated by the immersion method, and since it was desirable to determine the possibility of destroying bacteria present in the albumen, eggs were inoculated by injecting broth cultures of specific bacteria into the albumen. The area surrounding the point of inoculation was swabbed with a ten per cent solution of tincture of iodine. The sterile shell was pricked with a sharp sterile instrument and 0.1 cc. or 0.2 cc. of a 24-hour broth culture of the bacteria injected into the albumen of the egg by means of a tuberculin syringe equipped with a 25 gauge hypodermic needle. The average count for these suspensions was about 50,000,000 per 0.1 cc.

Pasteurization of Shell Eggs

Eggs which had been inoculated with the bacteria listed in Table 1 and adjusted to room temperature were divided into two lots, one lot serving as untreated controls and the other group being treated by rotating the eggs for 10 minutes, except where noted, in oil held at 140° F. This is the approximate time limit for pasteurizing shell eggs which have been adjusted to room temperature (70-75° F.) before immersing and rotating them in oil. Coagulation of the albumen occurs if either or both time or temperature are increased. The point at which coagulation begins establishes the maximum limit beyond which pasteurization may not proceed without interfering with market quality.

Bacteriological Examination of Eggs

After the eggs had been held at room temperature from 4 to 6 days after treatment, they were examined for bacterial growth. The area surrounding the point of inoculation was swabbed with tincture of iodine. An opening was made at the point of inoculation with sterile forceps. Two cubic centimeters of albumen were removed with a pipette. One cc. of this albumen was placed in 5 cc. of nutrient broth and one cc. of albumen was placed on a sterile petri dish. Nutrient agar at (107°-111° F.) was poured over the albumen in the petri dish and mixed as thoroughly as possible. The tubes of broth and the

petri plates were incubated for 48 hours at room temperature. More abundant growth was obtained at room temperature than at 100° F. Since it was only necessary to determine the presence or absence of bacterial growth broth was adopted as the media because it was less expensive and much easier to handle than agar.

For determining the presence or absence of bacteria on the shell or shell membranes, portions of these parts of the eggs were removed aseptically and grown in nutrient broth.

Cultural characteristics of the different bacteria were studied and identification was made by referring to the Fifth Edition of Bergey's Manual of Determinative Bacteriology.

RESULTS

The results obtained show that by pasteurization many of the bacteria which normally cause spoilage in shell eggs may be destroyed when on or in the shell, shell membranes or albumen of whole eggs. In most cases pure cultures of specific bacteria were used but some tests involved mixtures of organisms. The results obtained with specific species of bacteria are presented and discussed.

Aerobacter aerogenes.—This organism is widely distributed in nature and is normally found on plants but it is also found in the intestinal tract of humans and animals. Winter (1942) reported finding this organism in several spoiled eggs and used it to produce black rot in eggs. The strain used in this investigation was obtained from the Department of Pathology and Medical Bacteriology. Black rot was produced within one week by inoculating fresh eggs with this organism.

Table 2 shows the results obtained by pasteurizing shell eggs which had been inoculated by injecting 0.2 cc. of a 24-hour broth culture of these bacteria into the albumen. From these results it is

TABLE 2.—PASTEURIZATION OF SHELL EGGS INOCULATED BY INJECTING INTO THE ALBUMEN 0.2 CC. OF A 24 HOUR BROTH CULTURE OF AEROBACTER AEROGENES.

Date	No. Eggs	Treatment	Bacterial growth found when grown at room temperature for 48 hours.
2- 8-43	5	Eggs rotated for 10 minutes in oil held at 140° F	None
2- 8-43	5	Inoculated but not treated.	Growth from all eggs.
2- 8-43	5	Negative controls.	None
2-10-43	4	Eggs rotated for 10 minutes in oil held at 140° F.	None
2-10-43	2	Inoculated but not treated.	Growth from both eggs.

evident that shell eggs may be so pasteurized that this organism is destroyed even though it may have penetrated into the albumen of such eggs.

Achromobacter lipolyticum.—This is a fat dissolving bacterium found in milk which produced a rancid odor and bitter taste. The strain used in this investigation was obtained from the University Dairy Department. When inoculated into the albumen of shell eggs black rots and crusty yolks were formed.

Table 3 shows the results obtained when shell eggs were pasteurized after this organism had been injected into the albumen of such eggs. The heat treatment did not completely destroy this organism in all eggs, since three eggs of the twenty-two eggs treated contained organisms. All of the eggs used as positive controls which were inoculated but not treated contained the organism.

TABLE 3.—PASTEURIZATION OF SHELL EGGS WHICH WERE INOCULATED BY INJECTING INTO THE ALBUMEN 0.2 CC. OF A 24 HOUR BROTH CULTURE OF ACHROMOBACTER LIPOLYTICUM.

Date	No. Eggs	Treatment	Bacterial growth found when grown at room temperature for 48 hours.
2- 3-43	10	Eggs rotated for 10 minutes in oil held at 140° F.	One egg
2- 3-43	5	Inoculated but not treated.	Growth from all eggs.
2- 3-43	5	Negative controls.	None
2-10-43	4	Eggs rotated for 10 minutes in oil held at 140° F.	One egg
2-10-43	2	Inoculated but not treated.	Growth from both eggs.
3- 1-43	4	Eggs rotated for 10 minutes in oil held at 140° F.	None
3- 1-43	2	Inoculated but not treated.	Growth from both eggs.

Alcaligenes bookeri.—Haines (1938) found *Alcaligenes* in eggs which contained black rot. Winter (1942) reported that he had isolated *Alcaligenes bookeri* from black rot eggs and used the organism isolated to produce black rot in fresh eggs. The strain used in this investigation was obtained from Winter.

Table 4 shows the results obtained when pasteurizing shell eggs which had been inoculated by injecting broth cultures of this organism into the albumen. From these results it is apparent that shell eggs may be pasteurized so that *Alcaligenes bookeri* is destroyed in the albumen of such eggs.

Alcaligenes faecalis.—The strain of this organism used in this investigation was isolated from spoiled eggs removed from a cold stor-

TABLE 4.—PASTEURIZATION OF SHELL EGGS WHICH WERE INOCULATED BY INJECTING INTO THE ALBUMEN 0.2. CC. OF A 24 HOUR BROTH CULTURE OF ALCALIGENES BOOKERI.

Date	No. Eggs	Treatment	Bacterial growth found when grown at room temperature for 48 hours.
2-17-43	4	Eggs rotated for 10 minutes in oil held at 140° F.	None
2-17-43	2	Inoculated but not treated.	Growth from both eggs.
2-27-43	4	Eggs rotated for 10 minutes in oil held at 140° F.	None
2-27-43	2	Inoculated but not treated.	Growth from both eggs.

age warehouse after about eight months storage.

Table 5 shows the results of pasteurizing shell eggs which had been inoculated by injecting broth cultures of this organism into the albumen. From these results it may be concluded that *Alcaligenes faecalis* can be destroyed in the albumen of shell eggs by pasteurization.

TABLE 5.—PASTEURIZATION OF SHELL EGGS WHICH WERE INOCULATED BY INJECTING INTO THE ALBUMEN 0.1 CC. AND 0.2 CC. OF A 24 HOUR BROTH CULTURE OF ALCALIGENES FAECALIS.

Date	No. Eggs	Treatment	Bacterial growth found when grown at room temperature for 48 hours.
1-12-43	5	Eggs rotated for 10 minutes in oil held at 140° F.	None
1-12-43	5	Inoculated but not treated.	Growth from all eggs.
2- 8-43	5	Eggs rotated for 9 minutes in oil held at 142° F.	None
2- 8-43	5	Inoculated but not treated.	Growth from all eggs.
2- 8-43	5	Negative controls.	None
2-22-43	4	Eggs rotated for 10 minutes in oil held at 140° F.	None
2-22-43	2	Inoculated but not treated.	Growth from both eggs.

Alcaligenes viscosum.—This bacterium is found in water and around dairy barns. It produces ropiness in milk. The strain used in this investigation was obtained from the Dairy Department. When injected into the albumen of shell eggs it caused a milky or cloudy condition of the albumen.

Table 6 shows the results of pasteurization of shell eggs the albumen of which had been injected with approximately 100,000,000 organisms of this species. Apparently pasteurization was effective in destroying this organism when present in the albumen of shell eggs.

TABLE 6.—PASTEURIZATION OF SHELL EGGS WHICH WERE INOCULATED BY INJECTING INTO THE ALBUMEN 0.2 CC. OF A 24 HOUR BROTH CULTURE OF ALCALIGENES VISCOSUM.

Date	No. Eggs	Treatment	Bacterial growth found when grown at room temperature for 48 hours.
2- 3-43	5	Eggs rotated for 10 minutes in oil held at 140° F.	None
2- 3-43	5	Inoculated but not treated.	Growth from all eggs.
2- 3-43	5	Negative controls.	None
2-10-43	4	Eggs rotated for 10 minutes in oil held at 140° F.	None
2-10-43	2	Inoculated but not treated.	Growth from both eggs.

Eberthella oedematiens.—The strain of organism used in this investigation was obtained from Winter (Ohio). He isolated it from eggs containing black rot and he was able to produce black rot from 6 to 17 days after inoculating fresh eggs with this organism. In this investigation black rot eggs were produced within one week by inoculating fresh eggs with this organism.

Table 7 shows the results obtained by pasteurizing shell eggs which had been inoculated by injecting 0.2 cc. of a 24-hour broth culture of *Eberthella oedematiens* into the albumen. This organism was also destroyed by such treatment.

TABLE 7.—PASTEURIZATION OF SHELL EGGS WHICH WERE INOCULATED BY INJECTING INTO THE ALBUMEN 0.2 CC. OF A 24 HOUR CULTURE OF EBERTHELLA OEDEMATIENS.

Date	No. Eggs	Treatment	Bacterial growth found when grown at room temperature for 48 hours.
2-17-43	4	Eggs rotated for 10 minutes in oil held at 140° F.	None
2-17-43	2	Inoculated but not treated.	Growth in both eggs.
2-27-43	4	Eggs rotated for 10 minutes in oil held at 140° F.	None
2-27-43	2	Inoculated but not treated.	Growth in both eggs.

Eberthella oxyphila.—The strain of organism used in this investigation was isolated from eggs which had spoiled (black rot) after 8 months in cold storage.

Table 8 gives the results of pasteurizing shell eggs, the albumen of which had been inoculated with this strain of *Eberthella oxyphila.* Rotating eggs for 10 minutes in oil held at 140° F. destroyed this organism in the albumen of shell eggs.

TABLE 8.—PASTEURIZATION OF SHELL EGGS WHICH WERE INOCULATED BY INJECTING INTO THE ALBUMEN 0.1 CC. AND 0.2 CC. OF A 24 HOUR BROTH CULTURE OF EBERTHELLA OXYPHILA.

Date	No. Eggs	Treatment	Bacterial growth found when grown at room temperature for 48 hours.
1-12-43	5	Eggs rotated for 10 minutes in oil held at 140° F.	None
1-12-43	5	Inoculated but not treated.	Growth from all eggs.
2 27 43	4	Eggs rotated for 10 minutes in oil held at 140° F.	None
2-27-43	2	Inoculated but not treated.	Growth from both eggs.

Escherichia coli.—Two strains of this organism were used, one which Winter (Ohio) had isolated from black rot eggs and one isolated at Missouri from spoiled eggs removed from cold storage. Both strains produced black rot when injected into fresh eggs.

Table 9 gives the results of pasteurizing shell eggs which had been inoculated by injecting the organism into the albumen. Shell eggs rotated for 10 minutes in oil held at 140° F. were effectively sterilized with respect to this organism. Twenty-four different eggs which had been inoculated and then pasteurized were cultured without isolating

TABLE 9.—PASTEURIZATION OF SHELL EGGS WHICH WERE INOCULATED BY INJECTING INTO THE ALBUMEN 0.1 CC. OR 0.2 CC. OF A 24 HOUR BROTH CULTURE OF ESCHERICHIA COLI.

Date	No. Eggs	Treatment	Bacterial growth found when grown at room temperature for 48 hours.
1- 7-43	5	Eggs rotated for 10 minutes in oil held at 140° F.	None
1- 7-43	5	Inoculated but not treated.	Growth from 3 eggs.
1- 7-43	5	Negative controls.	None
1-12-43	5	Eggs rotated for 10 minutes in oil held at 140° F.	None
1-12-43	5	Inoculated but not treated.	Growth from all eggs.
2- 3-43	10	Eggs rotated for 10 minutes in oil held at 140° F.	None
2- 3-43	5	Inoculated but not treated.	Growth from all eggs.
2- 3-43	5	Negative Controls.	None
2-22-43	4	Eggs rotated for 10 minutes in oil held at 140° F.	None
2-22-43	2	Inoculated but not treated.	Growth from both eggs.

the organism, whereas of 15 eggs used as positive controls the organism was isolated from 13 of the eggs.

Flavobacterium aquatile and Flavobacterium aurescens.—These two species of *Flavobacterium* were isolated from shell eggs removed from a cold storage warehouse. When inoculated into the albumen of fresh eggs *Flavobacterium aurescens* produced black rot but *Flavobacterium aquatile* did not produce black rot.

Tables 10 and 11 show the results of pasteurizing shell eggs which had been inoculated with these two species of *Flavobacteria.* Both species of this organism were destroyed in the albumen of shell eggs when such eggs were rotated for 10 minutes in oil held at 140° F.

TABLE 10.—PASTEURIZATION OF SHELL EGGS WHICH WERE INOCULATED BY INJECTING INTO THE ALBUMEN 0.1 CC. OF A 24 HOUR BROTH CULTURE OF FLAVOBACTERIUM AQUATILE.

Date	No. Eggs	Treatment	Bacterial growth found when grown at room temperature for 48 hours.
1-12-43	5	Eggs rotated for 10 minutes in oil held at 140° F.	None
1-12-43	5	Inoculated but not treated.	Growth from all eggs.

TABLE 11.—PASTEURIZATION OF SHELL EGGS WHICH WERE INOCULATED BY INJECTING INTO THE ALBUMEN 0.1 CC. OF A 24 HOUR BROTH CULTURE OF FLAVOBACTERIUM AURESCENS.

Date	No. Eggs	Treatment	Bacterial growth found when grown at room temperature for 48 hours.
1-12-43	5	Eggs rotated for 10 minutes in oil held at 140° F.	None
1-12-43	5	Inoculated but not treated.	Growth from all eggs.

Proteus ichythosmus, Proteus mirabilis and *Proteus vulgaris.*—Two strains of *Proteus ichythosmus* were used, one which Winter (Ohio) had isolated from a mixed rot egg and the other was obtained from the Dairy Department. This organism is known to cause a fishy odor in milk but such an odor was not observed in eggs. It did produce black rot. The species *mirabilis* and *vulgaris* were isolated from spoiled eggs removed from a cold storage warehouse. These three species of *Proteus* when injected into the albumen of fresh eggs produced black rot.

Tables 12, 13 and 14 show the results of pasteurizing eggs which had been inoculated with these three species of Proteus. The treatment was effective in destroying these organisms when several million bacteria were present in the albumen of shell eggs.

TABLE 12.—PASTEURIZATION OF SHELL EGGS WHICH WERE INOCULATED BY INJECTING INTO THE ALBUMEN 0.2 CC. OF A 24 HOUR BROTH CULTURE OF PROTEUS ICHYTHOSMUS.

Date	No. Eggs	Treatment	Bacterial growth found when grown at room temperature for 48 hours.
2- 3-43	10	Eggs rotated for 10 minutes in oil held at 140° F.	None
2- 3-43	5	Inoculated but not treated.	Growth from all eggs.
2- 3-43	5	Negative controls.	None
2-10-43	4	Eggs rotated for 10 minutes in oil held at 140° F.	None
2-10-43	2	Inoculated but not treated.	Growth from both eggs.
2-17-43	4	Eggs rotated for 10 minutes in oil held at 140° F.	None
2-17-43	2	Inoculated but not treated.	Growth from both eggs.
2-27-43	4	Eggs rotated for 10 minutes in oil held at 140° F.	None
2-27-43	2	Inoculated but not treated.	Growth from both eggs.

TABLE 13.—PASTEURIZATION OF SHELL EGGS WHICH WERE INOCULATED BY INJECTING INTO THE ALBUMEN 0.1 CC. OF A 24 HOUR BROTH CULTURE OF PROTEUS MIRABILIS.

Date	No. Eggs	Treatment	Bacterial growth found when grown at room temperature for 48 hours.
12-31-42	5	Eggs rotated for 10 minutes in oil held at 140° F.	None
12-31-42	5	Eggs rotated for 11 minutes in oil held at 140° F.	One contaminated
12-31-42	5	Inoculated but not treated.	Growth from all eggs.
12-31-42	9	Negative controls.	None
1- 7-43	5	Eggs rotated for 10 minutes in oil held at 140° F.	One contaminated
1- 7-43	5	Inoculated but not treated.	Growth from all eggs.
1- 7-43	5	Negative controls.	None

TABLE 14.—PASTEURIZATION OF SHELL EGGS WHICH WERE INOCULATED BY INJECTING INTO THE ALBUMEN 0.1 CC. OF A 24 HOUR BROTH CULTURE OF PROTEUS VULGARIS.

Date	No. Eggs	Treatment	Bacterial growth found when grown at room temperature for 48 hours.
1-12-43	5	Eggs rotated for 10 minutes in oil held at 140° F.	Growth from one egg.
1-12-43	5	Inoculated but not treated.	Growth from all eggs.
2-22-43	4	Eggs rotated for 10 minutes in oil held at 140° F.	None
2-22-43	2	Inoculated but not treated.	Growth from both eggs.

Pseudomonas aeruginosa and *Pseudomonas fluorescens.*—*Pseudomonas aeruginosa* was obtained from the Dairy Department but was not isolated from eggs and *Pseudomonas fluorescens* was isolated from soiled shell eggs which had been washed in water and stored for 8 months. Two strains of *Pseudomonas fluorescens* were found, one producing a green white with a musty odor and the other producing a greenish white without any musty odor. *Pseudomonas aeruginosa* was used to produce black rot and green whites in fresh shell eggs within 9 days.

TABLE 15.—PASTEURIZATION OF SHELL EGGS WHICH WERE INOCULATED BY INJECTING INTO THE ALBUMEN 0.2 CC. OF A 24 HOUR BROTH CULTURE OF PSEUDOMONAS AERUGINOSA.

Date	No. Eggs	Treatment	Bacterial growth found when grown at room temperature for 48 hours.
2- 3-43	20	Eggs rotated for 10 minutes in oil held at 140° F.	Growth from one egg.
2- 3-43	10	Inoculated but not treated.	Growth from all eggs.
2- 3-43	5	Negative controls.	None
2-10-43	4	Eggs rotated for 10 minutes in oil held at 140° F.	Growth from one egg.
2-10- 43	2	Inoculated but not treated.	Growth from both eggs.

Table 15 shows the results of pasteurization of shell eggs into the albumen of which several million bacteria of this species were injected. This organism showed more resistance than most others investigated, bacterial growth being obtained from two eggs out of twenty-four pasteurized. Since the optimum temperature for the growth of this organism is about 98° F. it is not likely this species of *Pseudomonas*

would survive in eggs held in cold storage and to the author's knowledge it has not been isolated.

TABLE 16.—PASTEURIZATION OF SHELL EGGS WHICH WERE INOCULATED BY INJECTING INTO THE ALBUMEN 0.2 CC. OF A 24 HOUR BROTH CULTURE OF PSEUDOMONAS FLUORESCENS (STRAIN PRODUCING MUSTY ODOR).

Date	No. Eggs	Treatment	Bacterial growth found when grown at room temperature for 48 hours.
2- 8-43	5	Eggs rotated for 10 minutes in oil held at 140° F.	None
2- 8-43	5	Inoculated but not treated.	Growth from all eggs.
2- 8-43	5	Negative controls.	None
2-27-43	4	Eggs rotated for 10 minutes in oil held at 140° F.	None
2-27-43	2	Inoculated but not treated.	Growth from both eggs.

Table 16 shows the results obtained by pasteurizing shell eggs into which had been injected a strain of *Pseudomonas fluorescens* which was isolated from an egg which gave off a musty odor. The eggs which were used as positive controls gave off a very decided musty odor when opened. Evidently this organism was destroyed by pasteurization even though several million bacteria were present in the albumen of the eggs at the time of treatment. Table 16 shows the results of two trials in which this strain of *Pseudomonas fluorescens* when present in the albumen of shell eggs was completely destroyed by rotating such eggs for 10 minutes in oil held at 140° F.

TABLE 17.—PASTEURIZATION OF SHELL EGGS WHICH WERE INOCULATED BY INJECTING INTO THE ALBUMEN A 24 HOUR BROTH CULTURE OF PSEUDOMONAS FLUORESCENS. AUGUST, 1942.

No. Eggs	Treatment	Bacterial growth found when grown at room temperature for 72 hours.	
		Injected 1 cc.	Injected .1 cc.
12	Inoculated and treated for 12 minutes in still water at 140° F.	None	None
12	Inoculated but not treated	Growth from all eggs.	Growth from all eggs.

Having observed heavy losses from greenish whites when breaking eggs which had been improperly washed and stored, this investigation was first concerned with *Pseudomonas fluorescens* which was observed to be the causative agent of most spoilage in shell eggs which were improperly washed. Therefore an effort was made to pasteurize eggs which had been inoculated by injecting cultures of *Pseudomonas*

fluorescens into the albumen of such eggs. This first attempt was successful and indicated the possibility of pasteurizing shell eggs and thereby destroying this and other bacteria which cause spoilage in shell eggs.

TABLE 18.—PASTEURIZATION OF EGGS WHICH WERE INOCULATED BY IMMERSING SHELL EGGS AT 100° F. IN A BROTH CULTURE OF PSEUDOMONAS FLUORESCENS FOR ONE HOUR AT 46° F. 12-16-42 TO 12-31-42.

No. eggs	Treatment	Organisms recovered from: Surface of shell	Shell	Shell membranes	Albumen
5	Eggs rotated for 10 minutes in oil held at 138° F.	—	—	—	—
		—	—	—	—
		—	—	—	—
		—	—	—	—
		—	1 contaminated	—	—
6	Eggs rotated for 10 minutes in oil held at 140° F.	—	—	—	—
		—	—	—	—
		—	—	—	—
		—	—	—	—
		—	—	—	—
		—	—	—	—
4	Inoculated and treated in circulating oil for 10 minuate at 142.5° F.	—	—	—	—
		—	—	—	—
		—	—	—	—
		—	—	—	—
6	Inoculated but not treated	+	+	+	—
		+	+	+	—
		+	+	+	—
		+	+	+	—
		+	+	+	—
		+	+	+	—
6	Negative controls	—	—	—	—
		—	—	—	—
		—	—	—	—
		—	—	—	—
		—	—	—	—
		—	—	—	—

Table 18 shows that when warm eggs (100° F.) were immersed in a cold (46° F.) broth culture of *Pseudomonas fluorescens* these organisms were drawn through the shell and were isolated from the shell membranes of such eggs. This phenomenon explains why warm soiled shell eggs washed in cold water show such heavy losses when stored, while cold soiled shell eggs washed in warm water keep exceedingly well.

Pasteurization was effective in destroying this organism on and in the shell and on the shell membranes. Since *Pseudomona fluorescens* does cause heavy losses in storage eggs and much of this loss cannot be detected by candling but only by breaking, it was deemed advisable to investigate rather thoroughly the possibility of pasteurizing to destroy this organism.

Table 19 shows the results of three trials in which 40 eggs were rotated for 10 minutes in oil held at 140° F. The organism could be

TABLE 19.—PASTEURIZATION OF SHELL EGGS WHICH WERE INOCULATED BY INJECTING INTO THE ALBUMEN 0.1 CC. AND 0.2 CC. OF A 24 HOUR BROTH CULTURE OF PSEUDOMONAS FLUORESCENS.

Date	No. Eggs	Treatment	Bacterial growth found when grown at room temperature for 48 hours.
12-31-42	5	Eggs rotated for 10 minutes in oil held at 140° F.	None
12-31-42	5	Eggs rotated for 11 minutes in oil held at 140° F.	None
12-31-42	5	Inoculated but not treated.	Growth from all eggs.
12-31-42	9	Negative controls.	None
1- 7-43	5	Eggs rotated for 8 minutes in oil held at 140° F.	Growth from 4 eggs.
1- 7-43	5	Eggs rotated for 9 minutes in oil held at 140° F.	Growth from 1 egg.
1- 7-43	5	Eggs rotated for 10 minutes in oil held at 140° F.	None
1- 7-43	5	Inoculated but not treated.	Growth from all eggs.
1- 8-43	30	Eggs rotated for 10 minutes in oil held at 140° F.	Growth from 1 egg.
1- 8-43	20	Inoculated but not treated.	Growth from all eggs.
1- 8-43	10	Negative controls.	None

isolated from the albumen of only one of these eggs. Thirty positive controls which were inoculated but not treated all produced bacterial growth.

Eggs are very frequently cleaned by washing on the farm or in a local dealer's plant before the eggs reach the packing plant or cold storage warehouse. Table 20 shows the results of an experiment designed to determine the possibility of pasteurizing shell eggs which had been inoculated with approximately one hundred million *Pseudomonas fluorescens* from three hours to four days before they were treated. From these results it appears that shell eggs which have been improperly washed or otherwise inoculated with *Pseudomonas fluorescens* can be pasteurized and such organisms destroyed. Storage experiments of eggs improperly washed and then pasteurized at various intervals after treatment have been initiated at this station.

Sarcina lutea and Sarcina rosea.—Haines (1938) reported that he found *Sarcina* on the surface of the shells of eggs in two per cent of the eggs examined. However, he did not find them inside the egg. Since Haines had reported this genus present on the surface of shell eggs, two species of this organism were obtained from the Botany Department and used to test their resistance to pasteurization. These

organisms (*Sarcina lutea* and *Sarcina rosea*) were injected into the albumen of shell eggs. The effects of pasteurization on these two organisms are shown in Tables 21 and 22. Pasteurization was effective in destroying both species of *Sarcinae* used.

TABLE 20.—EFFECT OF TIME BETWEEN INOCULATION AND TREATMENT ON THE EFFECTIVENESS OF PASTEURIZATION OF SHELL EGGS INOCULATED BY INJECTING INTO THE ALBUMEN 0.2 CC. OF A 24 HOUR BROTH CULTURE OF PSEUDOMONAS FLUORESCENS. INOCULATED 2-17-43 AT 4:30 P. M. EGGS ROTATED FOR 10 MINUTES IN OIL HELD AT 140° F.

		Pseudomonas fluorescens found when grown at room temperature for 48 hours.	
Date treated	No. eggs	Point of inoculation	Opposite side of egg
7:30 p.m. 2-17-43	4	None	None
8:30 a.m. 2-18-43	4	One	One
7:30 p.m. 2-18-43	4	None	None
8:30 a.m. 2-19-43	4	One	One
7:30 p.m. 2-19-43	4	None	None
8:30 a.m. 2-20-43	4	None	None
7:30 p.m. 2-20-43	4	None	None
8:30 a.m. 2-21-43	4	None	None
7:30 p.m. 2-21-43	3	None	None

TABLE 21.—PASTEURIZATION OF SHELL EGGS WHICH WERE INOCULATED BY INJECTING INTO THE ALBUMEN 0.2 CC. OF A 24 HOUR BROTH CULTURE OF SARCINA LUTEA.

Date	No. Eggs	Treatment	Bacterial growth found when grown at room temperature for 48 hours.
2- 3-43	5	Eggs rotated for 10 minutes in oil held at 140° F.	None
2- 3-43	5	Inoculated but not treated.	Growth from all eggs.
2- 3-43	5	Negative controls.	None
2-10-43	4	Eggs rotated for 10 minutes in oil held at 140° F.	None
2-10-43	2	Inoculated but not treated.	Growth from both eggs.

Sarcina lutea produced one black rot egg and *Sarcina rosea* produced an offensive odor and cloudy albumen.

From these results, it appears these organisms, if they should gain entrance to the egg, would cause spoilage. Pasteurization of shell eggs could be used to destroy these organisms, even though they had penetrated the albumen.

TABLE 22.—PASTEURIZATION OF SHELL EGGS WHICH WERE INOCULATED BY INJECTING INTO THE ALBUMEN 0.2 CC. OF A 24 HOUR BROTH CULTURE OF SARCINA ROSEA.

Date	No. Eggs	Treatment	Bacterial growth found when grown at room temperature for 48 hours.
2- 3-43	5	Eggs rotated for 10 minutes in oil held at 140° F	None
2- 3-43	5	Inoculated but not treated.	Growth from all eggs.
2- 3-43	5	Negative controls.	None
2-10-43	4	Eggs rotated for 10 minutes in oil held at 140° F.	None
2-10-43	2	Inoculated but not treated.	Growth from both eggs.

TABLE 23.—PASTEURIZATION OF SHELL EGGS WHICH WERE INOCULATED BY INJECTING INTO THE ALBUMEN 0.2 CC. OF A 24 HOUR BROTH CULTURE OF SERRATIA MARCESENS. THE STRAIN USED 2-3-43 AND 2-10-43 WAS OBTAINED FROM THE DEPARTMENT OF BOTANY, UNIVERSITY OF MISSOURI AND THE STRAIN USED 2-17, 3-1 AND 3-8-43 WAS OBTAINED FROM DR. A. R. WINTER, OHIO STATE UNIVERSITY.

Date	No. Eggs	Treatment	Bacterial growth found when grown at room temperature for 48 hours.
2- 3-43	10	Eggs rotated for 10 minutes in oil held at 140° F.	None
2- 3-43	5	Inoculated but not treated.	Growth from all eggs.
2- 3-43	5	Negative controls.	None
2-10-43	4	Eggs rotated for 10 minutes in oil held at 140° F.	None
2-10-43	2	Inoculated but not treated.	Growth from both eggs.
2-17-43	4	Eggs rotated for 10 minutes in oil held at 140° F.	Growth from one egg.
2-17-43	2	Inoculated but not treated.	Growth from both eggs.
3- 1-43	4	Eggs rotated for 10 minutes in oil held at 140° F.	Growth from one egg.
3- 1-43	2	Inoculated but not treated.	Growth from both eggs.
3- 1-43	5	Negative controls.	None
3- 8-43	4	Eggs rotated for 10 minutes in oil held at 140° F.	None
3- 8-43	4	Inoculated but not treated.	Growth from all eggs.

Staphylococcus albus, Staphylococcus aureus and *Staphylococcus citreus.*—Haines (1938) reported that he found Staphylococci on the surface of the shell of 5 per cent of the eggs he examined. He did not find these organisms inside the egg. Rettger (1913) found *Staphylococcus albus* and *Staphylococcus aureus* in fresh and incubated eggs. Since this organism had been reported present in eggs and on the surface of the shell of eggs, it was deemed advisable to test the resistance of several species to pasteurization and to note the effect of the organism upon the contents of whole shell eggs when inoculated into such eggs. Cultures of *Staphylococcus albus* and *Staphylococcus aureus* were obtained from the Department of Pathology and Medical Bacteriology and *Staphylococcus citreus* was obtained from the Botany Department.

When these species of *Staphylococci* were injected into the albumen of shell eggs and allowed to grow at room temperature for one week or longer *Staphylococcus aureus* produced black rot, *Staphylococcus albus* produced a cloudy condition of the albumen but *Staphylococcus citreus* did not produce any deleterious effect.

TABLE 24.—PASTEURIZATION OF SHELL EGGS WHICH WERE INOCULATED BY INJECTING INTO THE ALBUMEN 0.2 CC. OF A 24 HOUR BROTH CULTURE OF STAPHYLOCOCCUS ALBUS, AUREUS AND CITREUS.

Date	Species	No. eggs	Treatment	Bacterial growth found when grown at room temperature for 48 hours.
2- 8-43	albus	5	Eggs rotated for 10 minutes in oil held at 140° F.	None
2- 8-43	albus	5	Inoculated but not treated.	Growth from all eggs.
2- 8-43	albus	5	Negative controls.	None
2-10-43	albus	4	Eggs rotated for 10 minutes in oil held at 140° F.	None
2-10-43	albus	2	Inoculated but not treated.	Growth from both eggs.
2- 8-43	aureus	5	Eggs rotated for 10 minutes in oil held at 140° F.	None
2- 8-43	aureus	5	Inoculated but not treated.	Growth from all eggs.
2-10-43	aureus	4	Eggs rotated for 10 minutes in oil held at 140° F.	None
2-10-43	aureus	2	Inoculated but not treated.	Growth from all eggs.
2- 3-43	citreus	5	Eggs rotated for 10 minutes in oil held at 140° F.	None
2- 3-43	citreus	5	Inoculated but not treated.	Growth from all eggs.

Table 24 shows the results obtained when shell eggs which had been inoculated with these species of bacteria were pasteurized. Apparently these species of *Staphylococci* were destroyed by the pas-

teurization of shell eggs, even though they were present in the albumen of such eggs.

Serratia marcesens.—Two strains of this organism were used, one strain was isolated from a black rot egg by Winter (Ohio) and the other was obtained from a stock culture of the Botany Department. The Ohio strain was more resistant to heat than the strain obtained from the Botany Department. Table 23 shows the results of four attempts to pasteurize shell eggs which were inoculated with *Serratia marcesens*. Fourteen eggs inoculated with the strain obtained from the Botany Department which were pasteurized were found to be free of this organism. However, *Serratia marcesens* was isolated from two eggs out of twelve treated eggs which were inoculated with the Ohio strain.

This organism produced a very brilliant red pigment in shell eggs. Figure 1 shows how this organism penetrated through the shell.

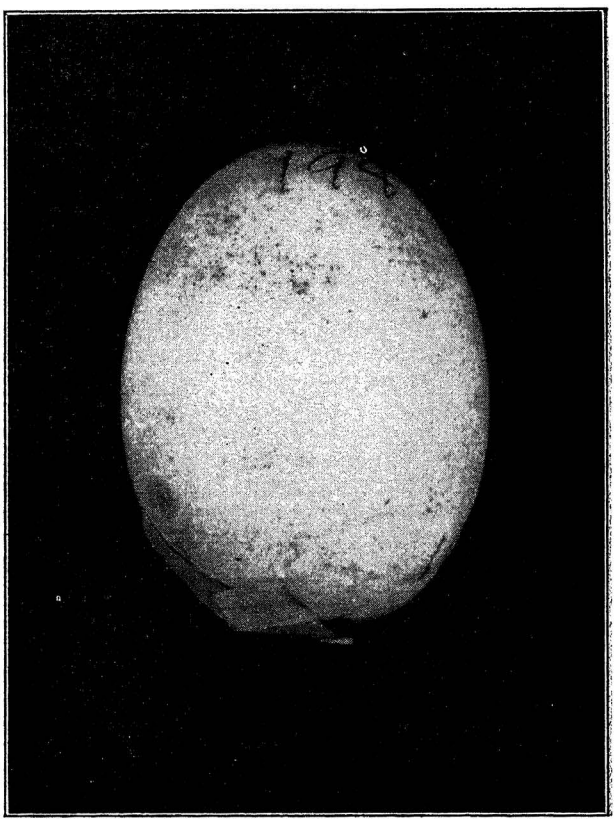

Fig. 1.—Illustration of bacteria (*Serratia marcesens*) penetrating the egg shell from the inside. Pores in the shell were very definitely marked by red areas.

of the egg from growth initiated in the albumen by inoculating such eggs with *Serratia marcesens*. The shell pores are very definitely marked by red colored areas which appear as dark spots in Figure 1. This photograph illustrates how bacteria penetrate through the pores of the shell of an egg.

Mixed Cultures.—In some of the tests made, cultures of several organisms were mixed and inoculated into shell eggs while in others unknown mixtures were used. Table 25 shows the results of pasteurizing shell eggs which were inoculated by immersing warm (100° F.) eggs in a cold mixture of albumen from 20 spoiled eggs. Bacteria pene-

TABLE 25.—PASTEURIZATION OF EGGS WHICH WERE INOCULATED BY IMMERSING SHELL EGGS AT 100° F. FOR ONE HOUR IN A MIXTURE OF ALBUMEN FROM 20 ROTS AT 46° F.

Date	No. Eggs	Treatment	Organisms recovered by growing in nutrient broth for 48 hours.	
			Shell	Shell membranes
1- 5-43	4	Eggs rotated for 10 minutes in oil held at 140° F.	−	−
			−	−
			−	−
			−	−
1- 5-43	5	Inoculated but not treated.	+	+
			+	+
			+	+
			+	+
			+	+
1- 5-43	5	Negative controls.	−	−
			−	−
			−	−
			−	−
			−	−

trated the shell and were found on the shell membranes but pasteurization was effective in destroying all organisms in this mixture. Table 26 shows the results of pasteurizing shell eggs which had been inoculated by injecting into albumen a broth culture prepared from 36 spoiled

TABLE 26.—PASTEURIZATION OF SHELL EGGS WHICH WERE INOCULATED BY INJECTING 0.1. CC. BROTH CULTURE OF A MIXTURE OF ORGANISMS FROM 36 SPOILED EGGS INTO THE ALBUMEN OF EACH EGG.

Date	No. Eggs	Treatment	Bacterial growth found when grown at room temperature for 48 hours.
1- 8-43	10	Eggs rotated for 10 minutes in oil held at 140° F.	Growth from one egg.
1- 8-43	10	Inoculated but not treated.	Growth from all eggs.

eggs. Pasteurizing was effective in destroying the organisms in 9 out of 10 eggs treated. Table 27 shows that pasteurization was effective

TABLE 27.—PASTEURIZATION OF SHELL EGGS WHICH WERE INOCULATED BY INJECTING INTO THE ALBUMEN OF EACH EGG 0.1 CC. OF A 24 HOUR BROTH CULTURE OF PSEUDOMONAS FLUORESCENS, PROTEUS MIRABILIS, PROTEUS VULGARIS, FLAVOBACTERIUM AURESCENS, FLAVOBACTERIUM AQUATILE, ALCALIGENES FAECALIS, EBERTHELLA OXYPHILA, AND ESCHERICHIA COLI.

Date	No. Eggs	Treatment	Bacterial growth found when grown at room temperature for 48 hours.
1-11-43	5	Eggs rotated for 8 minutes in oil held at 140° F.	Growth from two eggs.
1-11-43	5	Eggs rotated for 9 minutes in oil held at 140° F.	None
1-11-43	5	Eggs rotated for 10 minutes in oil held at 140° F.	None
1-11-43	15	Inoculated but not treated.	Growth from all eggs.

TABLE 28.—PASTEURIZATION OF SOILED SHELL EGGS WHICH WERE CLEANED BY WASHING WITH WATER HELD AT DIFFERENT TEMPERATURES. EGGS ROTATED FOR 10 MINUTES IN OIL HELD AT 140° F.

Temperature of water	Bacterial growth found when grown at room temperature for 48 hours.							
	Untreated eggs				Pasteurized eggs			
	Shell membrane		Albumen		Shell membrane		Albumen	
	No. eggs	Growth	No. eggs	Growth	No. eggs	Growth	No. eggs	Growth
Clean controls, unwashed	5	none	5	none	5	none	5	none
Soiled controls, unwashed	5	none	5	none	5	none	5	none
140° F.	5	1	5	none	5	none	5	none
130° F.	5	1	5	none	5	none	5	none
120° F.	5	none	5	none	5	none	5	none
110° F.	5	1	5	none	5	none	5	none
100° F.	5	2	5	1	5	none	5	none
60° F.	5	2	5	none	5	none	5	none
47° F.	5	1	5	none	5	none	5	none
47° F. treated 4 days after washing.	5	3	5	2	5	none	5	none
47° F. treated 6 days after washing.	5	3	5	1	5	none	5	none
47° F. treated 9 days after washing.	6	4	6	1	6	none	6	none

in destroying eight different species of bacteria when used as a mixture for inoculating the albumen of shell eggs.

Since it was known that washing shell eggs in water may lead to

serious bacterial contamination of such eggs, an effort was made to apply pasteurization to such eggs to determine its effectiveness under practical operating conditions. Several cases of dirty eggs were obtained and case lots were washed at the temperatures indicated in Table 28. Sample lots of 10 eggs each were removed from each case and five eggs were pasteurized and five were used for controls. From the results it was evident that bacteria did penetrate the shells of hens eggs when they were washed but that pasteurization was effectively used to destroy the bacteria which were present in these eggs. Pasteurization was not only effective in destroying bacteria present in shell eggs soon after washing but eggs held for as long as 9 days at room temperature were freed of living bacteria.

Temperature of Eggs During Pasteurization

In order to determine the actual temperature of the contents of shell eggs during the process of pasteurization, thermocouples using 20 gauge iron and constantan wire connected with a Leeds Northrup Micromax Recorder were used to record at one minute intervals on graph paper the temperature just beneath the shell and near the center of eggs being pasteurized.

Figure 2 shows the rate at which eggs are heated during the process of pasteurization employed in this investigation, i.e., rotating eggs adjusted to 70 to 75° F. in egg processing oil for 10 minutes with the temperature of the oil held at 140° F. and then cooling the eggs at room temperature. From Figure 2 it is evident that bacteria which have penetrated the egg shell and are on the shell membranes or in the outer albumen are subjected by this process of pasteurization to a temperature of 130 to 136° F. for about 8 minutes. Bacteria on the surface of the shell or in the shell would be exposed to higher temperatures and for a longer period of time. But the temperature of the center of the egg only goes to 120 to 122° F. for about 8 minutes. This method of heating shell eggs is not effective in raising the temperature of the center of the egg sufficiently high to be effective in destroying bacteria which are in the yolk of eggs.

Figure 2 shows that the temperature of the center of the egg continues to rise for several minutes after the egg is removed from the oil but that portion of the egg next to the shell cools quite rapidly when the egg is exposed to room temperature. For most desirable pasteurizing effects it would appear that the eggs should be cooled slowly. However, it is true that the time of treatment may be extended somewhat if the eggs are cooled rapidly when removed from the oil.

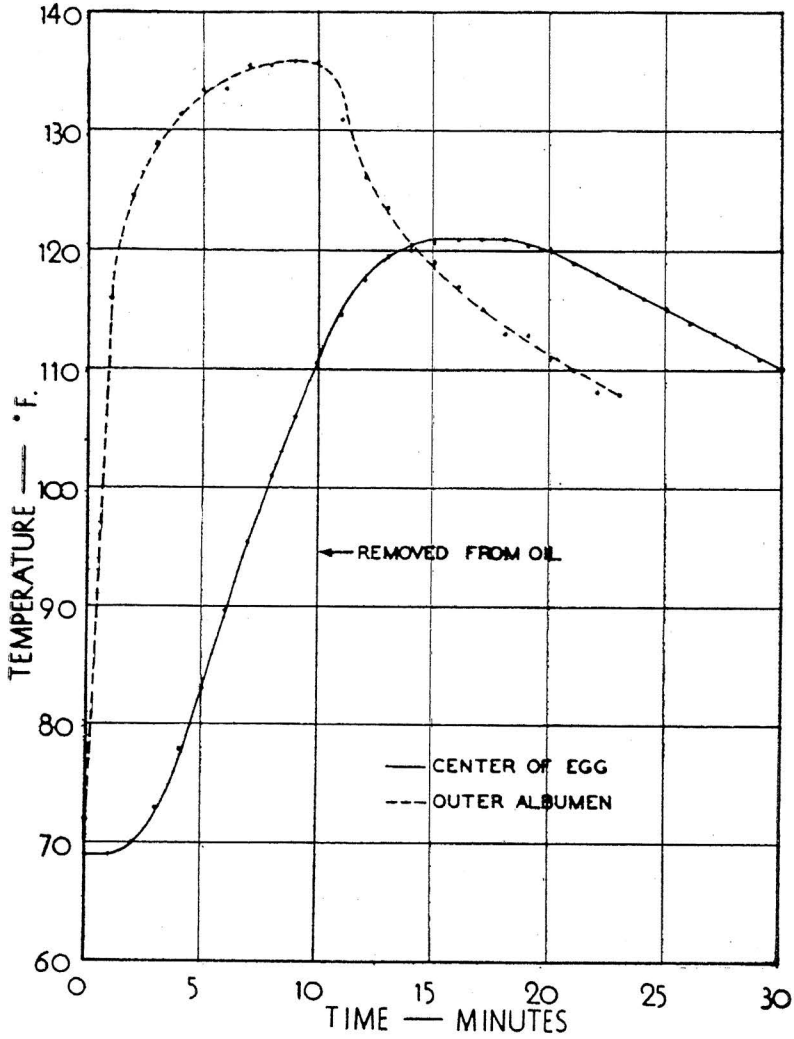

Fig. 2.—The temperature of the contents of whole shell eggs during the process of pasteurization.

Possible Applications

The application of the pasteurization process to shell eggs may prove of great value to the poultry industry and our national food economy. If the process can be applied to eggs as they pass through the regular marketing channels much waste in eggs may be prevented.

If storage tests confirm the laboratory work, it will be possible to pasteurize shell eggs going into storage and thereby eliminate most if not all of the spoilage which results from bacterial contamination

of such eggs before they are stored. Since this process also stabilizes the keeping quality of shell eggs, loss due to deterioration in quality as well as waste may be minimized by pasteurization.

The pasteurization of shell eggs before they are broken for freezing or drying should reduce materially the bacterial content of such products.

Limitations

It is not the intention of the author to claim that a perfect method for the pasteurization of shell eggs has been developed, but it is believed that this approach to the problem of egg spoilage may have possibilities for preventing waste and loss of quality in eggs. There may be much more effective methods for pasteurizing shell eggs than those used in this investigation. In fact, this station has determined that circulating air may be used to stabilize egg quality in shell eggs and therefore pasteurization of eggs may be effected in the same manner.

Nor is there any intention of claiming that all organisms which cause spoilage in shell eggs are destroyed by pasteurization, but the same limitations exist in pasteurization of dairy products. However, it does appear that most and possibly all of the bacteria which cause spoilage in shell eggs held in cold storage may be destroyed by pasteurization even though they have penetrated into the albumen of shell eggs. This process has not been effective against molds.

TABLE 29.—BACTERIAL GROWTH IN SHELL EGGS WHICH WERE INOCULATED BY INJECTING 0.1 CC. OF A 24 HOUR BROTH CULTURE INTO BOTH THE ALBUMEN AND YOLK AND HELD 30 HOURS AFTER INOCULATION BEFORE TREATING BY ROTATING THE EGGS FOR 10 MINUTES IN OIL HELD AT 140° F. 3-24-43.

Organisms	Positive controls	Treated eggs	Candling appearance
Aerobacter aerogenes	+	+	.....
Alcaligenes bookeri	+	+	Black rot
Alcaligenes fecalis	+	+	Black rot
Alcaligenes viscosum	+	+	Black rot
Eberthella oedematiens	+	+	Black rot
Escherichia coli	+	+	Black rot
Flavobacterium aquatile	+	+	Black rot
Flavobacterium aureus	+	+	Black rot
Proteus mirabilis	+	+	Black rot
Proteus vulgaris	+	+	Black rot
Pseudomonas aeruginosa	+	+	Black rot
Pseudomonas fluorescens	+	+	Black rot
Pseudomonas fluorescens (musty strain)	+	+	.....
Sarcina lutea	+	+	Black rot
Sarcina rosea	+	+	.....
Serratia marcesens	+	+	Black rot
Staphlococcus aureus	+	+	Black rot
Staphlococcus albus	+	+	.....

To test the limitations of pasteurization, shell eggs were inoculated by injecting 0.1 cc. of a 24-hour broth culture of each of the organisms

shown in Table 29 into both the albumen and yolk of each egg. The eggs were then divided into two groups, one lot remaining untreated and the other lot, after holding for 30 hours at room temperature, was treated by rotating the eggs for 10 minutes in oil held at 140° F. By the time these eggs were treated, the number of organisms per cc. of albumen or yolk near the point of inoculation was no doubt several billion, since the estimated number injected 30 hours previously was 50,000,000 per 0.1 cc.

Table 29 shows that under these conditions bacterial growth was obtained from most eggs and that pasteurization was not effective under such adverse conditions. Possibly it is fortunate that eggs heavily infected with bacteria and therefore approaching an inedible state cannot be rendered sterile without cooking the eggs and thus making them unmarketable as shell eggs.

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