Microbiological Process Report

Microbiological Standards and Handling Codes for Chilled and Frozen Foods. A Review

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ABSTRACT

ELLIOTT, R. PAUL (U. S. Department of Agriculture, Albany, Calif.), AND H. DAVID MICHENER. Microbiological standards and handling codes for chilled and frozen foods. A review. Appl. Microbiol. **9**:452–468. 1961.—The usefulness of microbiological standards for frozen foods is now a controversy in the trade and scientific literature. Most reviewers have given arguments both for and against, and have concluded that they should be applied with great caution. Such standards have the advantage of putting questions of safety on a convenient numerical basis. Canadian workers have reported that promulgation of standards has invariably raised the hygienic level of the products controlled.

Bacteriological standards have often been associated with the question of safety to the consumer. Everyone recognizes that food poisoning bacteria are a potential danger in any food. But many have argued that the history of food poisoning outbreaks from frozen foods is excellent and that there is no need for standards; on the other hand, proponents of standards have pointed to the incomplete investigation and reporting of outbreaks, and have argued that there may be more outbreaks than we realize. They have pointed to laboratory studies that have shown grossly mishandled precooked frozen foods to be truly dangerous. Some have proposed that pathogens should be absent from foods; but others have questioned that a microbiological standard can accomplish this end. Some pathogens, such as *Salmonella* or *Staphylococcus* have been shown to be so ubiquitous that their presence in some commercial foods is unavoidable. Also, sampling and analytical methods have been described as inadequate to guarantee that pathogens present will be detected. Some have argued that control at the source is a better way—through inspections of the plant operation, by enforcement of handling codes, or by processing procedures such as pasteurization, which would be more certain to result in a pathogen-free food.

A most important part of any of the proposed standards is a "total count" of viable aerobic bacteria. English workers have found that foods causing poisoning outbreaks usually had total viable counts above 10 million per gram. On the other hand, these same workers found *Salmonella* on meats with very low total viable count. The assumption by many that low total count indicates safety has been shown to be not always true. Furthermore, high counts of nonpathogenic organisms, such as psychrophilic saprophytes would have no public health significance.

The relation between bacterial level and quality is open to less controversy. Some authorities have pointed to bacterial level as a measure of sanitation, adequacy of refrigeration, or speed of handling. Others have indicated that to determine which of these factors caused a high count would be impossible with only a total count on the product as a guide. Some investigators have said a high count affects flavor adversely before actual spoilage is evident, and this may be a factor in competition on today's market. It is well established that initial bacterial level will affect the shelf-life of a chilled product. Methods of analysis are more nearly adequate for counts than for pathogens, but they need improvement, and should be clearly specified as part of any bacteriological standard. Foods with high count could sometimes be brought into compliance merely by storing them for a sufficient period frozen, or by heating them slightly. This has been cited by some authors as a disadvantage of bacteriological standards.

The enterococci and the coliform group (except *Escherichia coli*) have been shown to be ubiquitous and therefore should not be used alone to indicate fecal contamination. Although *E. coli* has greater significance, its source should be determined each time it is found.

Various reviewers have expressed the need for caution in the application of standards. The principal precautionary arguments we have found are as follows:

1) A single set of microbiological standards should not be applied to foods as a miscellaneous group, such as "frozen foods" or "precooked foods."

2) Microbiological standards should be applied first to the more hazardous types of foods on an individual

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basis, after sufficient data are accumulated on expected bacterial levels, with consideration of variations in composition, processing procedures, and time of frozen storage.

3) When standards are chosen, there should be a definite relation between the standard and the hazard against which it is meant to protect the public.

4) Methods of sampling and analysis should be carefully studied for reliability and reproducibility among laboratories, and chosen methods should be specified in detail as part of the standard.

5) Tolerances should be included in the standard to account for inaccuracies of sampling and analysis.

6) At first, the standard should be applied on a tentative basis to allow for voluntary compliance before becoming a strictly enforced regulation.

7) Microbiological standards will be expensive to enforce.

8) If standards are unwisely chosen they will not stand in courts of law.

There is now intense interest in this country and internationally in setting up standards for bacterial numbers in various foods. Pressure for such standards has been building up with the phenomenal growth of frozen precooked foods in the United States, and with this stimulus, similar problems have been seen in other foods. Most of the authors who have discussed the question have given arguments both for and against standards. These are presented separately in the following discussion, but are recombined in the Abstract. Because milk standards are in general use and are not controversial, they will be omitted from discussion.

Advantages of Bacteriological Standards

Bacteriological standards are a convenience and a necessity. Bacteriological standards have the advantage of putting questions of safety and quality in foods on a numerical basis. The administrator finds this a convenient measure for decision as to the acceptability of a food. According to Thatcher (1955), in the absence of definite standards, food control agencies have often been greatly handicapped in efforts to improve quality. Buttiaux and Mossel (1957) have said that, whenever samples are analyzed, bacteriological standards are essential for proper interpretation of results. Thatcher (1955) recognized the value of bacteriological standards set by organizations that have no recourse to factory inspection; that is, he has said that standards are desirable when the results of analysis are the only data available on which to make a decision of suitability. Goods imported from foreign countries would be examples in which a federal agency might logically apply bacteriological standards. Similarly, cities, states, and buying agencies could apply them to goods coming from outside their jurisdiction (Goresline, 1959). A listing of bacterial limits recommended by various authors is given in Table 1.

Bacteriological standards enhance plant sanitation. Many authors have cited the advantage that setting a bacteriological standard results in a cleaner product by bringing bacteriological aspects of production to the fore in the minds of both quality control and production workers (Anonymous, 1960*e*; Heller, 1952; Jones and Pierce, 1947; Mossel, 1953; Nickerson, 1946; Thatcher, 1958; Tressler and Pederson, 1951). To quote Thatcher (1955),

> "Without exception, the introduction in Canada of the few official microbiological standards has marked a positive trend towards improvement in the microbiological quality of the product and in the practice of hygiene by the industries concerned. . . . In the absence of definite standards . . . . the more negligent food firms are more than content to remain 'behind the time' . . . . Experience suggests that they do stimulate backward producers to approach more closely to the achievements of the more progressive ones. Indeed, the latter are not infrequently the strongest supporters of food standards. . . . Enforced standards tend also to mitigate the unfairness that exists when an unethical or unhygienic producer or one operating from inadequate premises and using inferior raw materials, markets his product in the same price range as the progressive producer."

Low bacterial counts are attainable. Many investigators have surveyed existing levels of various bacterial groups in commercial foods to evaluate what can be attained commercially. Abrahamson (1960) stated that no new techniques are needed to produce foods that are low in bacterial count on a commercial scale. Attainability under what is considered good commercial practice appears to be an essential basis for any microbiological standard (Anonymous, 1960*e*; Thatcher, 1960). The U. S. Food and Drug Administration has concluded, after an extensive survey, that lower levels of microbial content can be readily attained by the precooked frozen food industry (Shelton et al., 1961).

Low bacterial counts are associated with safe foods. Advocates of standards have often stressed that low bacterial counts tend to parallel safety from food poisoning pathogens (Anonymous, 1960*e*; Mossel, 1953). Hobbs (1953) has said, "In general those foods suspected of causing food poisoning gave counts of greater than 1 million per gram and usually greater than 10 million per gram . . . . The counts for the majority of 'normal' foodstuffs were approximately 10,000 per gram or less." Thatcher (1955) stated that microbial control of milk showed a coincident reduction in the incidence of milkborne epidemics. Heller (1951) suggested that in most cases where counts were very high in a food, the process of manufacture was such that it would permit the entry into the food of both spoilage types and food poisoning types. Goresline (1959) said that, if a standard aerobic plate count of 100,000 per gram and a coliform level of 10 per gram were enforced

TABLE 1. *Suggested microbial limits in chilled and frozen foods, per gram, except as indicated*

Reference	Total viable aerobes	Coliforms	Other organisms, comments
FROZEN PRECOOKED FOODS			
Fitzgerald, 1947*b*	100,000	1	
Heller, 1952	2,000		Pathogens absent; designate methods
Goresline, 1959; Huber et al., 1958; Johnson, 1960; Kereluk and Gunderson, 1959; U. S. Quartermaster Food and Container Institute, 1955	100,000	10	Quartermaster purchases (U. S. A.)
Gunderson, 1960; Litsky, Fagerson, and Fellers, 1957; Rayman, Huber, and Zaborowski, 1955	100,000		
International Association of Milk and Food Sanitarians, 1957		0	
Abrahamson, 1958	100,000	100	*Staphylococcus* 1,000; enterococci 1,000
Abrahamson et al., 1959	100,000		*Staphylococcus* absent; New York City tolerance
Hobbs, 1959	100,000	0.1 g*	*Staphylococcus* 1 g*; *Salmonella* 50 g*; 37 C count
Hobbs, 1959	500,000		22 C count
Nickerson, Proctor, and Robertson, 1959	100,000		5,000,000 direct count
Massachusetts Department of Public Health, 1959 (1960)	50,000	10	*Staphylococcus*, *Salmonella*, *Shigella* absent; Massachusetts law
Abrahamson and Clinton, 1960	100,000	100	*Staphylococcus* 100; enterococci 1,000; attainable in good practice
Robertson, 1960	50,000 to 100,000	100	*Staphylococcus* 100; under AFDOUS consideration
PRECOOKED MEATS			
Heller, 1952	10,000		Sausage. Pathogens absent; designate methods
Heller, 1952		0.1 g*	Pressed meats. Designate methods
Goldenberg, Sheppey, and Robson, 1955	10		Canned hams. Enterococci, *Clostridium perfringens*, *Escherichia coli:* 1 g*; pathogens absent. Spores 10
Anonymous, 1960*e*	10,000		Canned hams. Gram-negative rods, fungi, and *Clostridium* absent
RAW MEATS			
LeFevre, 1917; Marxer, 1903	1,000,000		Hamburger
Bates and Highlands, 1934; Brekenfeld, 1934; Elford, 1936; Geer, Murray, and Smith, 1933; Weinzirl and Newton, 1914, 1915	10,000,000		Hamburger. Recommended; Portland, Oregon, law 1936
Fitzgerald, 1947*a*	250,000		Hamburger, sausage
Nickerson et al., 1959	5,000,000		Hamburger
Fitzgerald, 1947*a*	100,000		Meats, poultry
Ayres, 1955	10,000 to 100,000/cm²		Anaerobes 5,000 to 50,000/g
Nickerson et al., 1959	5,000/cm²		Poultry
Nickerson et al., 1959	10,000/cm²		Cut meats
Hobbs, 1959	2,000,000	0.01 g*	Unfrozen meats. *Salmonella* 50 g*; *Staphylococcus* 0.01 g*; 37 C count
Hobbs, 1959	5,000,000		Unfrozen meats. 22 C count
Hobbs, 1959	500,000	0.1 g*	Frozen meats. *Salmonella* 50 g*; *Staphylococcus* 0.1 g*; 37 C count
Hobbs, 1959	2,000,000		Frozen meats. 22 C count
FROZEN WHOLE EGGS			
Lepper et al., 1944, 1956	5,000,000		Direct microscopic count
Fletcher and Johns, 1951	10,000,000		Canadian regulations, 1947
Fletcher and Johns, 1951	2,500,000		Canadian regulations, 1948
Nickerson et al., 1959	200,000		

TABLE 1—*Continued*

Reference	Total viable aerobes	Coliforms	Other organisms, comments
FISH, SHELLFISH, AND WATERS			
Griffiths and Stansby, 1934	1,000,000		Fish, stale and inedible
Fitzgerald, 1947*a*; Fitzgerald and Conway, 1937	100,000		Fish
Nickerson et al., 1959	100,000 500,000		Fish. Direct count, 150,000 Breaded shrimp. Direct count, 2,000,000
U. S. Public Health Service, 1946		2.3	Oysters. U. S. Public Health Service code
Knott, 1951			Oysters. *E. coli* 200/oyster
U. S. Public Health Service, 1954	50,000	160	Oysters. Acceptable; USPHS code
U. S. Public Health Service, 1954	50,000 to 1,000,000	160 to 1,600	Oysters acceptable on condition; USPHS code
U. S. Public Health Service, 1954	over 1,000,000	over 1,600	Oysters. Rejectable; USPHS code
Kelly, 1958	500,000		Oysters. Acceptable on condition
Kachikian, Larken, and Litsky, 1960	100,000		Frozen breaded shrimp
U. S. Public Health Service, 1959		0.7	Shellfish waters. Approved for harvesting; USPHS code
U. S. Public Health Service, 1959		0.7 to 7	Shellfish waters. Restricted for harvesting; USPHS code
U. S. Public Health Service, 1959		over 7	Shellfish waters. Prohibited for harvesting; USPHS code
Anonymous, 1960*e*	100,000	100	Crabmeat. Enterococci 1,000; *Staphylococcus* 100; New York City tolerance
VEGETABLES			
Berry, 1941; Jones and Ferguson, 1957; Tressler, 1938	100,000		
Sanderson, 1941	100,000		*E. coli* absent
Nickerson, 1946	300,000		
Canada, Laws, Statutes, etc., 1954; Matthews and Young, 1957; Jones and Ferguson, 1956	100,000	0.1 g*	Canadian law suspended
Anonymous, 1958*a*; Schmitt, 1958	200,000		By soup manufacturers
Nickerson et al., 1959	100,000 to 500,000		Direct microscopic count, 500,000 to 1,000,000
Anonymous, 1945	400,000		Peas
Hucker, 1950; Hucker, Brooks, and Emery 1952	50,000		Peas. Before freezing
Hucker, 1950; Hucker et al., 1952	100,000		Green beans. Before freezing
Hucker, 1950; Hucker et al., 1952; Obold and Hutchings, 1947	150,000 to 200,000		Corn. Before freezing
ICE CREAM AND FROZEN DESSERTS			
Buchan, 1910	1,000,000	under 0.1 ml*	Enterococci under 0.001 ml*; *Clostridium sporogenes* under 10 ml*
Beckler and Dusossoit, 1911	500,000		Boston law, August 4, 1906
American Public Health Association, 1937; Fabian, 1926*a*, *b*, 1927, 1929, 1932, 1937, 1939; Fay and Olson, 1924; Fisher, 1935; Obold and Hutchings, 1947; Olson and Fay, 1925; Ostertag, 1950; Smith, Newman, and Nielsen, 1928	100,000		Recommended; also laws of California, Connecticut, other states
Fournelle and Macy, 1942		under 10	
Kruse, 1950	100,000		*E. coli* absent
Dahlberg and Adams, 1950	50,000 to 100,000		Laws of 19 states and 20 cities
U. S. Federal Supply Service, 1953	50,000	20	Federal purchases
Anonymous, 1935	5,000 to 500,000		Pathogens absent; laws of various countries
American Public Health Association, 1937; Fabian, 1937	10,000 to 25,000		Some firms could meet
Macy, 1937	100,000 to 500,000		Most states
Macy, 1937	25,000		Certain cities
International Association of Milk Sanitarians, 1939	75,000 to 500,000		12 states
International Association of Milk and Food Sanitarians, 1956		0	1 state

TABLE 1—*Concluded*

Reference	Total viable aerobes	Coliforms	Other organisms, comments
ICE CREAM AND FROZEN DESSERTS—(*Continued*)			
International Association of Milk and Food Sanitarians, 1956; Levowitz, 1939; Thomas, Jenkins, and Evans, 1938	100,000	0.1 ml*	New Jersey law
Buchbinder et al., 1953; International Association of Milk and Food Sanitarians, 1956		10	20 states
International Association of Milk and Food Sanitarians, 1956		1	1 state
International Association of Milk and Food Sanitarians, 1956		30	1 state
International Association of Milk and Food Sanitarians, 1956		200	1 state
U. S. Public Health Service, 1940	50,000		Grade A, USPHS code
U. S. Public Health Service, 1940	100,000		Grade B, USPHS code
Adams, 1954	2,000,000		Milk or cream for
Fabian, 1939	5,000		Ingredients for; after pasteurization
U. S. Public Health Service, 1940	200,000		Ingredients for; Grade A, before pasteurization; USPHS code
U. S. Public Health Service, 1940	800,000		Ingredients for; Grade A, direct count; USPHS code
U. S. Public Health Service, 1940	1,000,000		Ingredients for, Grade B, before pasteurization; USPHS code
U. S. Public Health Service, 1940	4,000,000		Ingredients for, Grade B, direct count; USPHS code
International Association of Milk Sanitarians, 1940	10,000	0	Coloring solutions. Enterococci 0, yeasts and mold 10
International Association of Milk Sanitarians, 1940	100	0	Flavor extracts; Enterococci 0, yeasts and mold 10
International Association of Milk Sanitarians, 1940	1,000	0	Fruits. Enterococci 0, yeasts and mold 10
International Association of Milk Sanitarians, 1940	100	0	Nuts. Enterococci 0, yeasts and mold 10
Rothwell, 1960	25,000 to 300,000	0 to 150	Standards various countries
MISCELLANEOUS FOODS			
Sanderson, 1941	100,000		Frozen foods. *E. coli* 0.1 g.*
Tressler and Pederson, 1951	100,000 to 200,000		Frozen foods
Buttiaux and Mossel, 1957; Mossel, 1956	100,000	1 g*	Fresh and frozen foods. Pathogens, fecal indicators 1 g.*
Fitzgerald, 1947*a*		1	Various foods; Direct count 1,000,000
Fitzgerald, 1947*a*	100,000		Fruits

* Absent from this portion.

for precooked frozen meals, the presence of pathogens was a remote possibility. He stated that no food poisoning had ever occurred from products purchased by the Quartermaster Corps under such contracts. Thatcher (1958) stressed the desirability of setting standards on foods imported from countries that have high disease rates and poor sanitation. Straka and Stokes (1956) considered that foods with large numbers of spoilage organisms were not wholesome, whether or not disease organisms were present.

As an argument against citing the excellent history of safety in years of consuming frozen precooked foods, Abrahamson (1960) and Slocum (1960) commented that the reporting of food illness in the United States is known to be incomplete and not a valid basis for judging the sanitary quality of these foods. Ross and Thatcher (1958) agreed that, even though the history of these foods is good, the high levels of pathogens sometimes found in commercial precooked frozen foods indicated enteric infections to be likely. Several investigators have demonstrated the potential danger of mishandling. Straka and Combes (1952) grew staphylococci in creamed chicken held at elevated temperatures. Proctor and Phillips (1948) succeeded in growing α-type streptococci and *Salmonella enteritidis* in four types of precooked foods held at 86 F. Saleh and Ordal (1955) grew *Clostridium botulinum* in chicken à la king at 86 F. A recent outbreak of botulism from a frozen chicken pie mishandled by the consumer was reported by the U. S. Public Health Service (1960).

Bacterial counts reflect sanitation level. Several authors have shown the value of total viable counts in reflecting the hygienic conditions that occurred during processing (Abrahamson, 1960; Dack et al., 1960; Huber, Zaborowski, and Rayman, 1958; Thatcher, 1955; Shelton et al., 1961; Thatcher, 1960). However, others (Berry, 1946; Heller, 1951; Mossel, 1953; Proctor and Nickerson, 1948) have suggested that direct microscopic counts give a better picture of the sanitary history of a product than do viable counts. Processing procedures such as freezing, heating, or drying will often reduce the viable count, whereas the dead cells remain, will stain, and can be counted under the microscope to reflect evidence of insanitation which had occurred before the procedure which killed them.

Bacterial counts reflect degree of decomposition. Many authors have considered a bacterial count as one of the best indicators of degree of decomposition. Most such studies have shown that by the time decomposition has reached the point where it is detectable as such to human senses, bacterial levels are 10^6 or 10^7 per gram or, if a surface test, per square centimeter. This is clearly shown in Table 2. A notable exception is the work of Peterson and Gunderson (1960) on chicken pies. They found 10^4 psychrophilic bacteria per gram to give detectable off flavors and 10^5 to make the pies definitely unacceptable. This is well within the range of counts found in commercial pies on todays market (Canale-Parole and Ordal, 1957; Huber et al., 1958; Fanelli and Ayres, 1959; Thatcher, 1960; Shelton et al., 1961). Thatcher (1955) expressed as an argument for standards the probably greater consumer acceptance of controlled foods because of their better quality and flavor. Flavor as affected by bacterial level has been suggested to be a factor in the survival or failure of producers of precooked foods in today's highly competitive market (Burr and Elliott, 1960).

In some instances, bacterial counts have been used to represent the degree of adulteration by decomposed material. Redfield's (1920) early work showed a relation between odor of whole egg and its bacterial level, as follows:

Odor	*Bacteria per gram*
Good	2,800,000
Strong	4,300,000
Sour	284,500,000
Bad	250,000,000

Lepper, Bartram, and Hillig (1944, 1956) found that direct microscopic counts of over 5,000,000 per gram in frozen eggs indicate either that decomposed shell eggs were used, or that the liquid egg magma was held unfrozen long enough for some decomposition to occur. Various workers have recommended bacterial limits in fish and in ground meats on the basis that counts exceeding the limit represented decomposition (Table 1).

Low bacterial counts will enhance shelf-life. The shelf-life of a food held at a temperature permitting growth decreases markedly if the numbers of bacteria present at the beginning of the growth period are high. This factor has been stressed as an argument for imposing bacteriological standards (Thatcher, 1955, 1958). Jones and Pierce (1947) recommended that low bacterial levels on frozen fruits and vegetables were desirable for this reason. Lepper et al. (1944) made a similar recommendation for eggs.

Disadvantages and Precautions

There is no need for bacteriological standards; present control is adequate. Several investigators have pointed

TABLE 2. *Bacterial level at odor or slime point for protein foods*

Food	Logarithm of no. of bacteria/cm²		Reference
	Odor	Slime	
Poultry meat	6.5		Lochhead and Landerkin, 1935
	8	8 to 9	Ayres, Ogilvy, and Stewart, 1950
	7	7.5	Walker and Ayres, 1956
	6.9		Brooks, 1958
	5.2		McVicker et al., 1959
	7 to 8*		Meyer, Winter, and Weiser, 1959
Beef		7.7 to 8	Schmid, 1931
		7.7	Empey and Vickery, 1933
		7.5	Haines, 1933
		6.5	Moran, 1935
		7 to 8	Schwartz and Zeiser, 1939
	7.7 to 8		Jepsen, 1945
	8.7*		Kirsch et al., 1952
	6.3 to 7	8	Kraft and Ayres, 1952
	8*, †		Barnes, 1957
	7	7.8	Ayres, 1960
Processed meats		7 to 8*	Allen and Foster, 1960
Frankfurters	8 to 8.5	8.5	Kraft and Ayres, 1952
Wiltshire bacon		6.7 to 8	Gibbons, 1940
Wiltshire bacon		7	Gibbons, Rose, and Hopkins, 1951
Fish	6 to 6.6*		Birdseye, 1929
Haddock	6*		Griffiths and Stansby, 1934
Fish	7 to 8.5		Schwartz and Zeiser, 1939
Fish	6.5*		Shewan, 1949
Oysters	4 to 5.7*		Boyd and Tarr, 1956
Crabmeat	8*		Alford, Tobin, and McCleskey, 1942
Shell eggs	7*		Miller, 1954
Frozen eggs	6.7*		Lepper, Bartram, and Hillig, 1944, 1956
Liquid eggs	7*		Elliott, 1954
Chicken pies	5‡		Peterson and Gunderson, 1960

* Per gram.
† Yeasts, 6.
‡ Unacceptable flavor.

to the excellent public health record of frozen foods as an argument against imposing bacteriological standards (Anonymous, 1960*b*; Dack et al., 1960; Fitzgerald, 1947*a*; Humphrey, 1950; Jones and Pierce, 1947).

Many authors believe that present controls are adequate protection for the public. The U. S. Food and Drug Administration and most state food enforcement agencies rely on factory inspection for domestic products (Anonymous, 1960*e*; Price-Davies, 1952; Slocum, 1960). This "control at the source" was thought by Thatcher (1958), Buttiaux and Mossel (1957), Slocum (1960), and Brandly (1960) to be a better safeguard than sampling, particularly if used in conjunction with strict food handling codes and a strong educational program that would instruct both the industry and the consuming public in proper food handling methods.

Ingram (1961) and Rowlands (1952) recommended that we rely on appropriate procedures for freeing foods of bacteria, rather than on specified bacteriological standards particularly where factory inspection is difficult or impossible. For example, Ingram suggested pasteurization of milk, egg products, and feeding stuffs to rid them of *Salmonella* and other similar pathogens.

Bacteriological standards will not free foods of danger from pathogens. Most persons have agreed that the complete absence of pathogens from foods is desirable but some have added that complete freedom from pathogens is not always necessary. Many authors have argued that a set of standards will not accomplish this end, anyway.

There are some who have said that small numbers of food poisoning organisms in foods are not harmful. It is generally well known that spores of *Clostridium botulinum* are safely ingested, and become harmful only if they germinate and grow in a food. For this to happen, anaerobic conditions, absence or near absence of other organisms, and suitable pH and nutrients are required. Therefore their presence in foods in which they cannot grow is not significant (Dack, 1956). Hobbs (1953), Dack et al. (1960) and many others have shown that, before potentially toxigenic staphylococci can cause illness, they must grow to many millions per gram; therefore a few thousand per gram are of no significance and the food is perfectly wholesome. Similarly, McCullough and Eisele (1951*a*, *b*, *c*, *d*), in feeding tests to adult human volunteers, found that high levels of *Salmonella* were required for infection to occur. Ross and Thatcher (1958), and Thatcher (1955) pointed to the fact that, although pathogens such as staphylococci and salmonellae and fecal indicators such as coliforms and enterococci are regularly present in small numbers in many precooked frozen foods, the records of illness from these foods are infrequent. For this reason, they have questioned that establishment of a zero standard for these bacterial groups would give any noticeable improvement in public health protection. Thatcher (1958) has said that, where very low levels of pathogens caused outbreaks, microbiological standards would have limited prophylactic value. He also found it difficult to specify the precise number of cells of specific pathogens present on factory surfaces or in food that would warrant condemnation of the food (Thatcher, 1955).

A fecal indicator standard has limitations. Various intestinal organisms, such as the coliform group, *Escherichia coli*, or enterococci, have long been used to indicate the presence of fecal matter, and thus the potential presence of pathogens. The coliform group (except *E. coli*) and enterococci, however, have been found to be widely distributed, so their presence alone is not conclusive evidence of fecal contamination (Anonymous, 1960*e*; Dack, 1955; Fabian, 1932; Johns, 1959; Thatcher, 1955). *E. coli* has more significance, but its source should be determined (Herrick, 1948). Its presence is unavoidable in vegetables from heavily manured soils or in animal products such as eggs, poultry, or red meats. Furthermore, it grows in some foods (Harris, 1932).

The survival of these organisms has been found to differ when they are subjected to adverse conditions such as frozen storage. *E. coli* dies quickly, other members of the coliform group somewhat less so, and the enterococci are highly resistant. Berry (1946) considered *E. coli* of doubtful value because of its rapid freezer death. Similarly, Appleman (1955) considered that in citrus juices, if coliforms or enterococci are equally indicative of pollution, the enterococci should be used because of their greater longevity. On the other hand, others have stressed that the organisms that die off rapidly are the more valuable because they indicate recent contamination and therefore a greater potential hazard from pathogens. Thus, Ingram (1961) questioned the use of the resistant enterococci to measure a potential hazard, when the coliform group dies out at a rate more nearly comparable with that of the salmonellae.

Total count is unrelated to danger or to spoilage. Many authors have said that total numbers of organisms are often unrelated to the presence or absence of pathogens. Hobbs and Greenwood Wilson (1959) found *Salmonella* on meats where there were low counts and no fecal organisms. Thatcher (1958) reported that outbreaks of salmonellosis in babies occurred from dried egg yolk, although the total bacterial count was strictly controlled at a very low level. Similarly, he stated that powdered milk containing no viable staphylococci has given rise to food poisoning due to enterotoxin formed before the drying process killed the organisms responsible. He believed standards specifying absence of pathogens would be of little value in such an instance.

On the other hand, spoilage at refrigeration temperatures is accompanied by growth of bacteria to tremendous numbers, but no food poisoning bacteria can grow at such temperatures (Burr and Elliott, 1960; Dykstra, 1956). Obviously, a total count standard in such an instance would be unrelated to the question of public health. There are some who have argued that bacterial count is not necessarily related to the degree of spoilage (Brandly, 1960; Castell, Anderson, and Pivnick, 1948; Green, 1949*a*; Jones and Pierce, 1947; Tressler and Pederson, 1951). A correlation with spoilage would not be valid, of course, if the high bacterial numbers were due to heavy contamination; but where very high numbers are due to growth, alteration of the food is inevitable. Whether this alteration represents improvement (fermented or cured foods) or deterioration (fresh meats, vegetables, etc.) depends on the nature of the food product.

Methods of sampling and analysis are inadequate. Sampling and analytical procedures are the greatest problems in the enforcement of bacteriological standards (Anonymous, 1960*e*; Appleman, 1957). Ingram (1961) has said that absence of pathogens cannot be guaranteed by a negative test obtained by analysis of a sample, even of a relatively easily sampled product such as liquid or frozen egg, for the sample analyzed may even under the best of conditions amount to only 1% of the entire lot, and is usually much less than this. Difficulties in sampling products such as raw meats (Heller, 1952) or stuffed turkeys (Thatcher, 1958) are much greater because infection and growth will often be highly localized. For direct microscopic counts, the amount of sample actually examined under the microscope is exceedingly small, so that sampling procedures and homogeneity of the sample taken are very important (Heller, 1951). Hartman and Huntsberger (1960) have found hourly, daily, and seasonal fluctuations in bacterial count on products from a given plant.

Bacterial analyses are only rough estimates. Ingram (1961) cited the coliform dilution technique as an example of a method with great inherent inaccuracies. Similar unavoidable errors occurred in the usual plating techniques (Nickerson, 1946). Tressler and Pederson (1951) have emphasized that sometimes the breaking of bacterial clumps will affect results seriously, so that preparation for plating must be carefully standardized. Hartman and Huntsberger (1961) have demonstrated that subtle differences in plating procedures can affect results significantly.

As a result of sampling and analytical errors, various investigators have found great differences in bacterial level among samples one might expect to be homogeneous replicates. For example, even among packages of peas obtained from a commercial line at nearly the same time, Michener, Thompson, and Dietrich (1960) found variations of 20-fold or more in plate count. Green (1949 *a*, *b*) and Gunderson and Rose (1948) reported similar results on shrimp and chow mein, respectively.

To minimize such errors, and to evaluate their importance, Buttiaux and Mossel (1957) have recommended that collaborative studies such as those conducted for chemical analyses by the Association of Official Agricultural Chemists should be undertaken. In interpreting the results of a given analysis or series of analyses, the expected variation must be considered and standards should include recognition of the existence of variations (Anonymous, 1960*e*; Ingram, 1961; Mossel, 1956; Nickerson, 1946; Shelton et al., 1961).

Bacteria, especially pathogens, may be difficult to grow. Those surviving heating, freezing, or other adverse conditions of processing or storage may be incapable of growth on ordinary media or on selective media on which they are known to grow ordinarily (Ingram, 1961). Thus to measure total viable numbers, or to measure viable indicator organisms or pathogens, especially designed techniques may be needed. For example, *Brucella* in dairy products is a distinct danger, but very hard to isolate (Thatcher, 1958).

The nature of the inoculum may also affect isolation of bacteria or interpretation of results. Wolford (1955) found the coliform test in orange juice by usual methods to be unreliable because sugars in the juice are carried into the lactose broth medium. Hurley and Ayres (1953) and others, in analyzing eggs, found that the inoculum affected selectivity of enrichment media and therefore recoveries of salmonellae.

The only fully reliable method for demonstrating the toxicity of foods infected with staphylococci or of cultures from such foods is by animal or human feeding or animal inoculation tests, which are laborious. Serological tests are not fully developed yet, and the coagulase test does not always parallel toxin formation. Thus, the significance of the usual tests is somewhat doubtful because most laboratories do not conduct animal tests.

Regulations that include standards must necessarily always designate with great exactitude the method by which foods should be sampled and analyzed (Anonymous, 1960*e*; World Health Organization, 1959). This must include sample preparation (Tressler and Pederson, 1951), diluent, medium, and time and temperature of incubation (Berry, 1946; Heller, 1951). Several authors have listed and discussed such methods as applying to recommended standards or to plant sanitation evaluation (Buttiaux and Mossel, 1957; Mossel, 1956; Thatcher, 1955). Methods used by the Association of Food and Drug Officials of the United States for obtaining background information for discussions of bacteriological standards have also been described (Anonymous, 1958*b*; Shelton et al., 1961).

Methods for bacteriological analysis are widely scattered in the scientific literature. Basic sources, *specifically for foods*, are as follows: *Foods in general:* American Public Health Association, 1958; Frazier, 1958; Frazier and Foster, 1959; Tanner, 1944, 1950. *Frozen foods, in particular:* American Public Health Association, 1953, 1958; Anonymous, 1958*b*; Shelton et al., 1961; Zaborowski, Huber, and Rayman, 1958. *Canned foods:* American Public Health Association, 1958; Townsend et al., 1956. *Spices, fermented foods, and fruit juices:* American Public Health Association, 1943, 1958. *Shellfish:* American Public Health Association, 1947. *Dairy products, frozen desserts:* American Public Health Association, 1953; Foster and Frazier, 1957. *Eggs:* American Public Health Association, 1953, 1958; Association of Official Agricultural Chemists, 1960; Schneiter, 1940. *Meats:* American Public Health Association, 1958; Evans and Deibel, 1960; Jensen, 1954; Jepsen, 1957. *Water:* American Public Health Association, 1955.

Existing laboratory facilities and personnel are inadequate. Thatcher (1955) has said that a standard is justifiable only to the degree to which it is enforced, and that because of the complexity and cost of such examinations and enforcement, standards should be devised only to meet a strongly indicated need. Heller (1952) and Thatcher (1958) stated that laboratory staffs and facilities of government agencies would have to be enlarged greatly if adequate enforcement of bacteriological standards were to be undertaken. With existing personnel, the U. S. Food and Drug Administration was able to analyze the products of only 63 of the estimated total of 300 firms producing frozen precooked foods in the United States in a survey conducted in 1958 and 1959 (Shelton et al., 1961).

Processing and storage influence viable counts. Weinzirl and Newton (1915) pointed to difficulties of enforcement on frozen products in view of the drop in viable count during freezing and storage. Also, Ingram and Brooks (1952) and others have suggested that the increase in bacterial level during thawing of frozen egg will increase enforcement problems.

Excessive sanitation will introduce a food poisoning hazard. It is well established that most foods decompose before they become a hazard from food poisoning microorganisms. This serves to warn the user if frozen or chilled foods are allowed to stand too long at room temperature (Fitzgerald, 1947*a*). It has been shown that *Clostridium botulinum* fails to grow and produce toxin in the presence of the more rapidly growing spoilage flora (Perry et al., 1948). Whereas Logan, Harp, and Dove (1951) recommended that chicken à la king be filled into the carton hot to reduce contamination, Saleh and Ordal (1955) reported *C. botulinum* can grow and produce toxin in this product when few spoilage organisms are present. Gunderson (1960) has recommended that frozen precooked foods be permitted to retain their proper proportion of natural flora so they will spoil before food poisoning organisms can grow.

Foods will be overcooked or preservatives will be introduced to meet a standard. Parker (1940) has stated that with milk, flavor is often sacrificed to produce an unnecessarily low bacterial count. Overcooking may sometimes occur if standards are enforced on other food products, and some producers will be tempted to use preservatives (Brandly, 1960). Shelton et al. (1961) demonstrated that a terminal cook before packaging will often destroy evidence of earlier insanitary practice.

More background information is needed. Various authors have said that, where a standard is essential, one must establish an objective foundation by demonstrating a relation between the standard and the hazard against which it is meant to protect the public. To do this, each individual food for which a standard is to be set, and all the various types of processing procedures that might affect the bacterial content, must be studied (Anonymous, 1960*b*, *e*; Appleman, 1955; Ingram, 1961; Proctor and Nickerson, 1948; Shelton et al., 1961; Slocum, 1960; Thatcher, 1955).

Bacterial standards will be hard to defend in court. Insanitary conditions and inadequate refrigeration leading to high bacterial content have been shown to be related to disease in milk (American Public Health Association, 1953). However, this has not been shown in frozen foods (Anonymous, 1960*e*) due in part, no doubt, to the less favorable environment the latter foods offer to pathogens. If total viable bacterial count reflects spoilage, quality, or grade, and not public health hazard, there may be a doubt in the minds of many people that food enforcement agencies whose primary responsibility is the protection of public health have the legal right to enforce such a bacteriological standard (Hillery, 1960; Anonymous, 1961). Certainly, unless the laws under which the agency operates clearly state that standards relating to quality may be enforced, a legal contest may be decided in favor of the owner of the food.

According to Ingram (1961) one may hesitate to impose, all at once, a standard which would expose most of an industry to legal proceedings. If one takes the stand that the "average" level of bacteria in foods being marketed becomes the standard, half the foods in commerce would exceed it. With a more strict standard the proportion would be higher.

Ingram (1961) has stated that the exact level at which a hazard begins to exist would be hard to establish. The level of bacteria would be an indefinite and ambiguous figure and have only a general correlation with the actual condition of the food. Repeated analyses would not agree, especially after time has elapsed. Ingram (1961) has also stated that because the standard is likely to be to some degree arbitrary it seems wise to introduce it on a tentative basis allowing for modification in the light of experience. The level ultimately adopted is then likely to have gained wide acceptance, and the improvement which follows the introduction of the standard will provide the best possible justification for giving it the final force of law.

Obviously, standards may have their most successful use where they can be set empirically and where their legality will not be questioned (Anonymous, 1960*e*), as for example, for foods being brought into a country or community, or being purchased by a firm or agency for its own use. Goresline (1959) has said that where the armed forces is the purchaser and user it has the privilege of exerting a certain supervision that is not possible in the commercial field.

Choose wisely the type of food. Where a food is particularly hazardous, especially as applied to public health, a meaningful bacteriological standard is warranted (Thatcher, 1955, 1958). But for foods not likely to cause illness, such as citrus juices, standards would be unwise (Thatcher, 1958). Furthermore, when standards are applied, each food must be considered separately, taking into account method of preparation, storage, and treatment by the consumer (Anonymous, 1960*b*; Heller, 1951, 1952; Humphrey, 1950; Proctor and Nickerson, 1948; Vaughn, Murdock, and Brokaw, 1957); otherwise inequitable or unattainable tolerances will be established. For example, a precooked food to which raw cheese or raw egg is added just before freezing would not meet a standard applied to the precooked foods in general (Dack et al., 1960; Slocum, 1960). Similarly, a count of 100,000 is high for pasteurized milk, but not for bacon or other cured products (Ingram, 1961). The U. S. Food and Drug Administra-

TABLE 3. *Partial list of codes and recommended procedures for storage and handling of chilled and frozen foods*

Chilled or frozen	Product	Organization regulating or recommending	Comments	Reference
Frozen	Ice cream	American Public Health Association	Survey of state laws	APHA, 1937
Frozen	Foods	States	Survey, 22 state locker laws	Anonymous, 1947*b*
Frozen	Foods	Oakland, Calif.	Maximum 5 F in distribution	Anonymous, 1956
Chilled	Foods	Illinois		Anonymous, 1956
Frozen	Foods	Indiana	Maximum 10 F	Anonymous, 1956
Frozen	Foods	Maryland	Storage limited to 24 months	Anonymous, 1956
Frozen	Foods	New Jersey	Storage limited to 24 months	Anonymous, 1956
Frozen	Foods	New Hampshire	Display 0–5 F, storage 0 F; transportation 10 F	Anonymous, 1956
Frozen	Foods	U. S. Dept. of Agriculture	Recommends 0 F or lower, tolerance for short periods	Copley, 1957
Chilled	Shellfish	U. S. Public Health Service	Recommended practice	USPHS, 1946, 1959
Frozen	Desserts	U. S. Public Health Service	Recommended practice	USPHS, 1940, 1941
Frozen	Foods	Massachusetts Dept. Public Health	Law, storage temperature, bacteriological standards	Massachusetts DPH, 1960
Frozen or chilled	Foods	Am. Soc. of Refrig. Engineers	Storage recommendations	Rose et al., 1952
Chilled	Foods	U. S. Public Health Service	Recommended storage temperatures	Adams, 1946
Frozen	Foods	Association of Food and Drug Officials of the U. S.	Storage at 0 F; sanitary equipment	AFDOUS, 1959, 1960
Frozen	Fish	Iceland	Quality requirements, handling methods	Anonymous, 1947*a*; Nielsen, 1949
Chilled or frozen	Fish	Denmark	Sanitation and quality inspection	Jensen, 1958
Chilled or frozen	Fish	Food and Agriculture Organization of the UN	Review of regulations and codes	Hess, 1953
Frozen	Fish	United Kingdom	Processing and handling laws	Anonymous, 1953
Chilled	Milk	U. S. Public Health Service	Basis for state and local codes	USPHS, 1955
Chilled or frozen	Fish	U. S. Dept. of Interior	Review. Standards and inspection	Anonymous, 1960*c*
Frozen	Fruits and vegetables	General Foods		Dykstra, 1956
Frozen	Poultry and eggs	Wilson and Company		Loy, 1956
Frozen	Citrus foods	U. S. Department of Agriculture		Allegri, 1956
Chilled or Frozen	Foods	International Institute of Refrigeration	Recommended conditions	International Institute of Refrigeration, 1959
Frozen	Ice cream		Review of codes	Rothwell, 1960

tion has based its interpretation of bacteriological analyses on the timing and degree of cooking the product receives in the food plant and on the amount of subsequent heating required by the consumer (Shelton et al., 1961).

Choose wisely the bacterial group. The type of organism, or group chosen as a basis for the standard must reflect the hazard against which the standard is meant to protect the consumer. Coliforms could not be used for indicating fecal pollution of southern oysters (Kelly, 1958), orange juice (Johns, 1959; Vaughn et al., 1957), fermented products (Johns, 1959), or egg whites (Ingram and Brooks, 1952) because of their natural occurrence in the raw product, or their use in fermentation. Where the coliform group, enterococci, or *E. coli* are present in a frozen food, the choice of organism for the standard must include a consideration of whether the standard should measure potential hazard from fecal pathogens that die out rapidly, or measure esthetics insofar as original contamination is concerned (Burton, 1949; Ingram, 1961; Johns, 1959).

For products stored near the freezing point, a count of bacteria viable at 37 C would be valueless to measure quality or future shelf-life, but a count of cold-tolerant pseudomonads would have some meaning (Ingram, 1961). Similarly, in foods causing *Clostridium perfringens* (*welchii*) poisoning, aerobes may be present in very small numbers, whereas anaerobes may be very high (Hobbs, 1953).

Current Status of Standards and Handling Codes

Food-handling codes are being developed. A partial list of food-handling codes that have been mentioned in the scientific literature is shown in Table 3. The code being discussed most generally now is the Frozen Food Handling Code published by the Association of Food and Drug Officials of the United States (AFDOUS) (Association of Food and Drug Officials of the United States, 1959, 1960). This was promulgated by AFDOUS with cooperation of the National Association of Frozen Food Packers (Humphrey, 1959), not as a regulation, but as a guide for state and local legislation. The code has recommended that frozen foods be held at or below 0 F, except for brief periods, from the time of original freezing until sold to the consumer. It also has made recommendations for design and construction of frozen food processing equipment. The State of Massachusetts recently passed legislation closely following the AFDOUS code, to take effect August 1, 1960 (Massachusetts Department of Public Health, 1959 (published, 1960)), but this was postponed (Anonymous, 1960*h*; Hillery, 1960). A total of 29 states may eventually adopt the code in one form or another (Anonymous, 1960*d*).

In June 1960, ten major frozen food associations requested jointly that AFDOUS suggest to its members deferment of any statutory or regulatory action on the code for 1 year, thus giving industry an opportunity to demonstrate its ability to comply voluntarily. The frozen food associations have given this job to a Frozen Foods All-Industry Coordinating Committee (Anonymous, 1960*a*, *f*, *g*; Milleville, 1960).

The codes that recommend storage temperatures for frozen foods are concerned less with microbial growth than with quality loss. Microbial growth usually ceases at about 14 F (Ingraham and Stokes, 1959), whereas quality loss of nonmicrobial origin continues at much lower temperatures. One principal problem of enforcement of these handling codes is that there are few objective tools that can be used to determine time-temperature histories. Several authors have suggested "thaw" indicators, some of which can integrate the time-temperature experience of a package, but an evaluation of their applicability is outside the scope of this review.

A few microbiological standards are now in use. Most states and localities have official bacteriological standards for fluid milk. This product is outside the coverage of this review. In Canada, official federal microbiological standards have been adopted for ice cream, flavored milk, milk powder, frozen and dried eggs, tomato products, shellfish, dehydrated vegetables, and gelatin (Gibbons, 1953; Thatcher, 1955). In 1959 the Canadians replaced a coliform standard in eggs by the direct count, and eliminated standards on blanched frozen vegetables (Johns, 1959). Surprisingly enough, only 38 states and only 24 of 87 cities surveyed in the United States in 1950 had any sanitary ice cream laws. The laws of only 19 states and the ordinances of 20 cities established bacterial count standards for ice cream. Only 40% of the states and cities regulated counter freezers (Dahlberg and Adams, 1950). As late as 1954 bacteriological standards for cream used in ice cream were reported to be lacking in most areas of the United States (Adams, 1954). Information on recommended and existing bacteriological standards in ice cream is found in Table 1 (*see also* Rothwell (1960) for a review on this subject).

A section requiring bacteriological standards for frozen precooked foods is being considered for inclusion in the AFDOUS food handling code (Association of Food and Drug Officials of the United States, 1959, 1960). A survey of plant sanitation and bacterial levels was to be completed by June 1960 (Anonymous, 1960*g*) (*see also* Table 1). Shelton et al. (1961) have reported the results of the survey conducted by the U. S. Food and Drug Administration in 1958 and 1959, designed to correlate plant operations and microbial content of these foods.

The city of New York (Abrahamson et al., 1959), and the U. S. Quartermaster Corps (Goresline, 1959; Huber et al., 1958; U. S. Quartermaster Food and Container Institute, 1955) have announced tolerances and the state of Massachusetts (Massachusetts Department of Public Health, 1959 (1960)) has promulgated official bacteriological standards for precooked frozen foods (Table 1); other governmental agencies in the United States have not. Self-imposed industry standards and empirical administrative tolerances set by enforcement agencies are not usually mentioned in the scientific literature.

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