SOME BACTERIOLOGICAL ASPECTS OF DEHYDRATED FOODS

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(With 2 Figures in the Text)

INTRODUCTION

The advantages of the process of dehydration as applied to foodstuffs may be summarized for present purposes under four headings:

(1) The great saving in 'transport space' (weight and bulk) by the removal of water from the commodity.

(2) The freedom from microbial spoilage secured by reduction of the water content to a level at which microbial growth no longer occurs, even at favourable temperatures.

(3) The preservation of the quality of the product, including its vitamins and mineral salts.

(4) Convenience and avoidance of waste in use by quick rehydration yielding a product all of which is almost immediately available for food.

The bacteriologist is intimately concerned at each stage in the process of dehydration, for no dehydrated food is sterile, and the bacteriology of dehydrated foods is thus essentially different from that of canned foods. Although particular problems arise with specific commodities, in general it may be said that for all dehydrated foods three basic requirements must be met for a bacteriologically satisfactory product:

(1) Conditions of manufacture must be such that, should toxigenic organisms, e.g. *Clostridium botulinum*, staphylococci, and perhaps some other organisms, be present in, or gain access to, the commodity before or during processing, no bacterial toxins are formed.

(2) The dehydrated product should not contain organisms likely to be pathogenic to man by the mouth, e.g. *Salmonella* and dysentery bacteria.

(3) It is desirable that the general bacterial content of the product shall be reasonably low so that no decomposition or development of undesirable flavour occurs over the period of reconstitution. Special problems may arise if the dehydrated product is to be incorporated into some other food whose final water content is high enough for bacterial growth to occur.

The first requirement means in general terms that the product shall be dried at a temperature at which significant bacterial growth is unlikely to occur, and the bacteriologist has therefore to define this temperature. Alternatively, if it is impossible to dry at so elevated a temperature owing to loss of quality in the product, the time of drying at a lower temperature may be so shortened that, even if toxigenic organisms are present, no significant production of toxin can occur. This again requires definition.

The second and third requirements demand the selection for drying of sound, good quality material free from pathogenic organisms, and the observance of reasonable standards of hygiene during all stages of the process. A low viable count may in general be used as an index of reasonable care in manufacture, provided it is known that there are no interfering factors at work, but does not of itself necessarily mean that the product is free from pathogens. For example, some samples of dried foods containing not more than 10,000 organisms per gram have been found infected with small numbers of Salmonellas. Again, a dried food of otherwise satisfactory quality bacteriologically was found to be exposed during the process of dehydration to contamination with coagulase positive *S. aureus* from persons handling the product.

Finally, the limiting water content permissible in the finished product requires definition, and also the conditions of rehydration, since if the latter are unsatisfactory the precautions adopted during manufacture may be largely nullified by the undue proliferation of the residual flora.

To sum up, the bacteriological quality of a dehydrated product has to be assessed on (*a*) freedom from pathogens, potential pathogens, and their toxic products; (*b*) qualitative and quantitative significance of the general bacterial content in relating to the use to which the commodity is to be put.

The known groups of organisms which may in theory be expected to be dangerous in foods under (*a*) include sporing anaerobes of which *Cl. botulinum* is the obvious example, enteric organisms of the typhoid, paratyphoid, dysentery, and *Salmonella* groups, and certain staphylococci and perhaps streptococci. Under (*b*) obvious examples are aerobic sporing organisms which might give rise to 'rope' in bakery products, thermophiles and other organisms capable of causing 'souring', and a variety of bacteria capable of causing spoilage in the reconstituted product.

In general, commodities fall into two groups according to whether they are, or are not, cooked, and therefore more or less sterilized, before drying. The latter group obviously presents greater bacteriological problems. In the former group are dried meat, fish, roller-dried soup, and some potato flours. In the second group are spray-dried egg, spray- and roller-dried milk, carrots, cabbage, and potato strips, and some potato flours, which either are completely uncooked or else receive a short blanching, or a pasteurization, reducing but not eliminating the accompanying flora.

THE TIME AND TEMPERATURE OF DRYING

Ideally, foods undergoing dehydration should be heated at a temperature such that bacterial growth cannot occur, until the water content is sufficiently reduced to inhibit any bacterial action; but with some commodities,

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particularly vegetables of high sugar content, charring may occur under those circumstances and it may therefore be necessary to dry at temperatures at which bacterial growth can in theory occur, the process being examined in detail and a suitable compromise arrived at in which in practice bacterial growth is not found to be significant.

Maximum temperatures of growth

Anaerobes. Of the fifty-one Clostridia listed in the fifth edition of Bergey's *Manual* (Bergey, 1939), ten are stated to be capable of growth at 50° C. or above. The maximum temperature of growth of the most interesting of these in the present connexion, *Cl. botulinum*, does not appear to have been determined. Four strains of *Cl. botulinum* type A, two of English, and two of American origin,' were sown into deep glucose agar shakes and Robertson's medium and incubated at 45° C. No appreciable growth occurred in any of the cultures over a period of 14 days. Similar results were obtained with two strains of type B of American origin. All these strains grew well and produced toxin at 37° C. Six cultures of *Cl. sporogenes* isolated from dried foods and putrid meat all grew well at 45° C. in 24 hr., but not at 50° C. in 9 days. Bergey, on the other hand, states that some strains of this organism can grow at 50° C.

Enteric organisms. Faecal *Bact. coli* is well known to grow at 44° C. Tests with it and the following types of *Salmonella* isolated from a dried food, four cultures of *oranienburg*, two of *bareilly*, and one of *anatum*, were made in nutrient broth immersed in a mercury-toluene regulated water thermostat constant to $\pm 0{\cdot}1°$ C. Good growth of all these organisms was obtained at 45° C. At 47° C. slight growth was obtained with the Salmonellas, but subcultures proved sterile. The maximum for these bacteria appears, therefore, to be near 47° C.

Staphylococcus. A coagulase-positive strain of *S. aureus* isolated from a case of food poisoning failed to grow at 44° C.

Thermophiles. Thermophilic organisms have frequently been isolated from dried vegetables and sometimes from dried meat, in culture at 60° C. The maximum temperature of growth of these organisms appears, from records in the literature, to lie between 65 and 80° C., probably nearer 70° C. in most cases.

The general conclusion from considerations of this type is that where thermophilic growth may be important, and it is practicable to maintain so high a temperature, foods should be processed above 80° C. When thermophilic growth can be neglected, little danger or spoilage is to be expected if the product is not allowed to remain below 50° C. for periods greater than 1–2 hr. Tests on a commercial scale over a period of some months have shown that these limits do, in fact, work in practice, the first for roller-dried soup, the second for dried meat.

Rate of toxin production

Whether *Cl. botulinum* can multiply in the conditions under which foodstuffs are dehydrated is not known, since in the course of examination of about 3000 various samples of dried foods, prepared here and overseas, this organism has not so far been found to occur. But the theoretical possibility cannot be altogether dismissed, since a layer of wet vegetables or minced meat a few inches thick might provide conditions suitable for its multiplication. It is therefore desirable to form an estimate of the rate of toxin production by this organism. Not much work appears to have been done on this point. Wagner, Meyer & Dozier (1925) give data indicating that a 12 hr. culture of *Cl. botulinum* type A at 37° C. had a mouse minimum lethal dose of 1·0 c.c., rising in 48 hr. to 0·01 c.c. and in 120 hr. to 0·0001 c.c., but the size of the inoculum of the original culture does not appear to be given. Dozier (1924*a*) gives data, using inocula of rather less than 1000 and 10,000 organisms per c.c. of medium, which indicate demonstrable toxin formation in between 12 and 24 hr., and indeed, this author states (Dozier, 1924*b*): 'A demonstrable amount of toxin has never been found in cultures incubated at 37° C. in less than 14 hr.' It seemed desirable to get some further information on this question, and accordingly the following tests were made.

Young vegetative cells have been used, on the assumption that growth and toxin formation will necessarily be more rapid with them than with spores. Cultures of the organism selected were grown in Veillon broth or Robertson's medium for 24 hr. at 37° C., and examined microscopically to ensure that sporulation had not commenced. The cultures were then centrifuged and washed in Veillon broth saturated with hydrogen gas. Comparison of total and viable counts indicated that this procedure did not appreciably diminish the viability of the cells in three washings. It was never found practicable completely to detoxify the cells by washing: a cell suspension after washing four times (10^8 cells per c.c.) had a mouse M.L.D. of 0·01 c.c., but the broth used for the last washing had a mouse M.L.D. of 0·1 c.c., so that it was evident that, by diluting the cellular suspension, inocula of 10^3 c.c. could be made which would give a non-toxic inoculated medium to commence the experiments. In all cases duplicate inoculations into mice of 1·0 c.c. were made at the commencement of the run to check this point. The experiments were made in the vessel shown in Fig. 1. 200 c.c. of Veillon broth *p*H 7·2 were placed over a layer of minced meat about 2 in. deep, the bottle exhausted at the pump, and filled with hydrogen. The desired inoculum was then added from a Pasteur pipette by quickly removing the bung, and culture medium withdrawn from time to time by the siphon for toxicity tests and bacteriological examination, hydrogen being run in at the commencement of the experiment to start the siphon. After some hours of incubation sufficient pressure was generally developed to render further admission of hydrogen unnecessary. From time to time microscopic and cultural tests were made to check the purity of the culture, since it is known that organisms growing in association with *Cl. botulinum* may inhibit toxin production. This was in fact found to be the case in an experiment where the flask became accidentally contaminated with *S. albus*, though the indications here were that the *S. albus* grew rapidly, inhibiting the growth of the *Cl. botulinum*, which subsequently grew and produced toxin, i.e. the effect appeared to be an inhibition of growth rather than an effect on the toxin as such.

The results of some illustrative experiments are given in Table 1. A few comparative tests with other strains did not indicate any great variation except that some

strains of type B apparently did not grow so rapidly as some type A strains. A few tests with inocula of 10^6/c.c. were made, but in two-thirds of these 1·0 c.c. of the original medium was toxic to mice, and there is the further doubt whether the slight increase in toxicity obtained in the first few hours may not have been due to diffusion from the cells of the large inoculum, rather than from fresh growth. It seems from the experiments made that the times required for appreciable quantities of toxin to be produced under optimum conditions at the temperatures stated are approximately as given in Table 2.

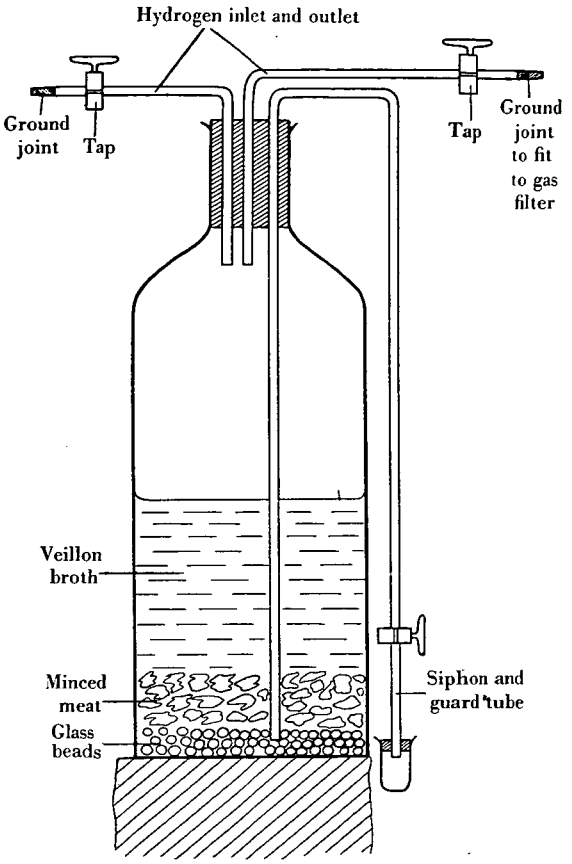

Fig. 1. Apparatus for following the rate of toxin production with *Cl. botulinum*.

It appears from these results that even if actively growing *Cl. botulinum* were present in a food undergoing dehydration, there is little likelihood of appreciable toxin formation in an 8 hr. drying period.

THE POSSIBILITY OF BACTERIAL GROWTH IN THE DEHYDRATED PRODUCT

Two cases have to be considered, namely, (1) possible growth during storage of the dehydrated product; (2) possible growth during or after rehydration.

(1) *Possible growth during storage of the dehydrated product*

Theoretically, bacterial growth under equilibrium conditions is not in general expected below about 95 % relative humidity, and fungal growth below about 80–85 % relative humidity (Haines, 1937). Apparent deviations to the extent of about 5 % relative humidity occur, however, in practice, and it is desirable to determine the vapour-pressure isotherm together with bacterial analyses at the appropriate humidities for some representative commodities. The vapour-pressure isotherm for spray-dried egg, together with some readings for dried meat, is given in Fig. 2. This is a composite curve taken in part from Gane's data (Gane, 1941) and in part from our own observations, the latter in particular being made at higher humidities than Gane's measurements, so as to include the range over which microbial growth can occur. It may be seen that where our measurements duplicate Gane's, they are almost identical with his, and not with those of Stuart, Hall & Dicks (1942). No great accuracy can be claimed at humidities at which microbial growth is occurring for obvious reasons, but the readings appear to be capable of reasonable replication. In the case of dried meat, the vapour-pressure isotherm should, strictly speaking, be determined on the fat-free product, since fat can have no water relations, but that method introduces assumptions which may not be valid on bacteriological grounds, and for practical purposes we have therefore considered the system meat containing 40 % fat as a whole. In making the measurements, care was taken to equilibrate the system as far as possible by using a thin layer spread in a 15 cm. diameter Petri dish enclosed in a vessel containing the required sulphuric acid solution, until successive moisture determinations agreed. The latter were made by drying in thin layers in an air oven at 100° C. for 6 hr.

A summary of typical experiments with dried egg, dried meat and dried cabbage is given in Table 3. It appears from these results that bacterial growth is unlikely below 90 % relative humidity and mould growth below about 80 % relative humidity, which in the case of dried egg and meat containing 40 % fat is tantamount to saying that bacterial growth is unlikely below about 15 % moisture content and mould growth below about 10 % moisture content. These are the two commodities in which the moisture content is most likely to approach the limits permissible. With dried milk and dried vegetables considerations other than bacteriological ones set the limiting water content well below that at which microbial growth is probable.

So far we have been considering bacterial growth when the uptake of water is permitted. Bacterial death takes place in dehydrated products stored at humidities below 90 %, the rate of death appearing to vary with a number of factors such as the water content, the temperature, and the nature of the organisms. Some illustrative experiments with dried meat, and dried egg in which the death of a coagulase-positive strain of *S. aureus* was followed, are given in Table 4. The dried meat experiments suggested that the death-rate was slower in nitrogen than in air, and more rapid at 37° C. than at 15° C. In this particular instance no significant difference was found between the rate of death at 2·0 and 4·5 % water contents in air at 15° C., but some other experi-

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Table 1. *Rate of production of toxin by* Cl. botulinum *type A growing under anaerobic conditions at* 35 *and* 25° C. *Tested by intraperitoneal inoculation into mice.*

Inoculum (number of organisms per c.c. of original culture) ...	10^3/c.c.						10/c.c.					10^3/c.c.				10/c.c.				
Temp. ...	35° C.						35° C.					25° C.				25° C.				
Volume of culture inoculated, in c.c., into mice ...	1	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	1	10^{-1}	10^{-2}	10^{-3}	10^{-4}	1	10^{-1}	10^{-2}	10^{-3}	1	10^{-1}	10^{-2}	10^{-3}	10^{-4}
Time in hours of incubation of culture																				
0	−	−	.	.	.	.	−	−	.	.	.	−	−	.	.	−	−	.	.	.
2	−	−	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
4	−	−	−	−	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
6	−	−	−	−	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
8	−	−	−	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
9	−	−	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
11	+	*s*	−	.	.	.	−	−	.	.	.	.	.	.	.	.	.	.	.	.
13	+	+	+	−	.	.	−	−	.	.	.	−	−	.	.	.	.	.	.	.
15	+	+	−	−	.	.	*s*	−	.	.	.	.	.	.	.	.	.	.	.	.
18	+	+	+	+	.	.	+	*s*	−	−	.	−	−	.	.	.	.	.	.	.
20	.	.	.	.	.	.	.	.	.	.	.	−	−	.	.	−	−	.	.	.
22	+	+	+	+	.	.	.	.	.	.	.	*s*	−	.	.	.	.	.	.	.
23	.	.	.	.	.	.	.	.	.	.	.	+	−	.	.	−	−	.	.	.
24	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
26	.	.	.	.	.	.	.	.	.	.	.	*s*	*s*	*s*	−	−	−	.	.	.
30	+	+	+	+	+	−	.	.	.	.	.	+	+	*s*	−	−	−	.	.	.
33	+	+	+	+	+	+	+	+	+	+	+	+	+	+	−	.	.	.	.	.
38	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	−	−	−	.
40	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	*s*	*s*	*s*	.
42	.	.	.	.	.	.	.	.	.	.	.	.	,	.	.	+	+	.	.	.
45	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	*s*	−

− = no reaction, + = death of the animal with characteristic signs of botulism, *s* = signs of botulism but animal recovered.

Table 2. *Time required for appreciable toxin production by* Cl. botulinum *type A growing under optimum conditions in meat broth at* 35 *and* 25° C.

Inoculum (organisms/c.c. of culture)	10^6/c.c.	10^3/c.c.	10/c.c.
Temp. 35° C.	(4–5 hr.?)	12 hr.	18 hr.
,, 25° C.	—	24 hr.	40 hr.

In the case where the culture was contaminated with *S. albus* no toxin was detected until after about 40 hr. at 37° C., 10^3/c.c. inoculum *Cl. botulinum*.

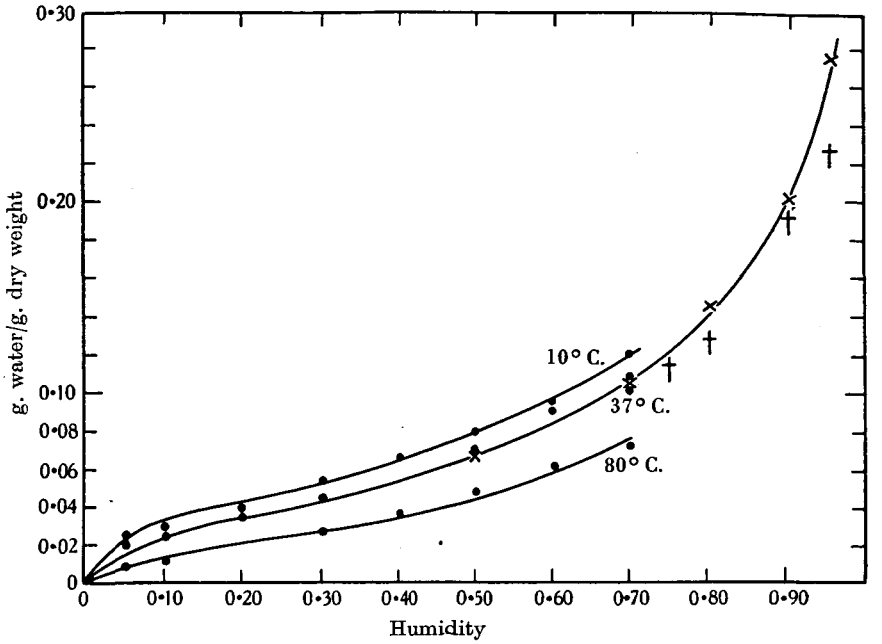

Fig. 2. Water relations of dried egg and dried beef. • = Gane's data, spray dried egg at temperature stated. × = own data, spray dried egg at 25° C. † = own data, dried beef (40% fat) at 15–20° C.

Table 3. *Microbial growth in typical dehydrated foods equilibrated at various humidities. Organisms per gram of material 'wet weight' viable at* 37° C.

		Spray-dried egg, 25° C.			
Humidity ...	95	90	80	70	50
Water content at equilibrium (%) ...	22	17	13	10	7
Time in days					
0	$5{\cdot}0\times10^{3}$	$5{\cdot}0\times10^{3}$	$5{\cdot}0\times10^{3}$	$5{\cdot}0\times10^{3}$	$5{\cdot}0\times10^{3}$
4	$3{\cdot}9\times10^{3}$	$2{\cdot}8\times10^{3}$	$2{\cdot}5\times10^{3}$	$1{\cdot}8\times10^{3}$	$2{\cdot}6\times10^{3}$
7	$5{\cdot}3\times10^{6}$	$6{\cdot}7\times10^{3}$	$2{\cdot}0\times10^{3}$	$7{\cdot}0\times10^{3}$	$7{\cdot}7\times10^{3}$
11	$7{\cdot}6\times10^{6}$	$3{\cdot}9\times10^{4}$	$1{\cdot}3\times10^{3}$	$2{\cdot}0\times10^{3}$	$1{\cdot}3\times10^{3}$
14	$1{\cdot}0\times10^{6}$*	$8{\cdot}0\times10^{4}$*	$1{\cdot}1\times10^{3}$	$1{\cdot}5\times10^{3}$	$6{\cdot}4\times10^{3}$
22	$7{\cdot}2\times10^{5}$*	$3{\cdot}9\times10^{4}$*	$1{\cdot}4\times10^{3}$	$3{\cdot}1\times10^{3}$	$2{\cdot}0\times10^{3}$
35	*M*	*M*	*M*	$1{\cdot}3\times10^{3}$	$1{\cdot}3\times10^{3}$
126	*M*	*M*	*M*	780	520
		Tray-dried minced beef, 40 % *fat at room temperature* (15–20° C.)			
Humidity ...	95	90	80	75	70
Water content at equilibrium (%) ...	18	16	11	10	9
Time in days					
0	$3{\cdot}0\times10^{6}$	$3{\cdot}0\times10^{6}$	$3{\cdot}0\times10^{6}$	$3{\cdot}0\times10^{6}$	$3{\cdot}0\times10^{6}$
5	4×10^{5}*	5×10^{4}	6×10^{4}	2×10^{5}	$1{\cdot}8\times10^{5}$
11	*M*	*M*	—	—	—
22	*M*	*M*	—	—	—
36	*M*	*M*	*M*	—	—
64	*M*	*M*	*M*	$1{\cdot}4\times10^{4}$	$1{\cdot}5\times10^{5}$
		Dried shredded cabbage, 37° C.			
Humidity ...	95	90	80	75	70
Time in days					
0	$5{\cdot}2\times10^{5}$	$5{\cdot}2\times10^{5}$	$5{\cdot}2\times10^{5}$	$5{\cdot}2\times10^{5}$	$5{\cdot}2\times10^{5}$
2	$2{\cdot}6\times10^{4}$	$1{\cdot}1\times10^{5}$	$2{\cdot}5\times10^{5}$	$8{\cdot}7\times10^{5}$	$5{\cdot}7\times10^{4}$
4	$2{\cdot}6\times10^{4}$	—	—	—	$6{\cdot}2\times10^{4}$
7	*M*	*M*	—	—	—
15	*M*	*M*	$1{\cdot}1\times10^{4}$	$5{\cdot}4\times10^{4}$	$1{\cdot}7\times10^{3}$

* Visible mould growth appearing. *M* = Heavy mould growth making further bacterial counts impossible.

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ments with other commodities have suggested that in air the death-rate tends to be slower with low water contents. The experiment with *S. aureus* indicated that this organism died out slowly at room temperature in dried egg.

(2) *Possible growth during or after rehydration*

The ideal dehydrated food should reconstitute instantaneously on immersion in water. In practice, many commodities do so within a few minutes. Nevertheless, in some quarters a 24 hr. period of reconstitution has been recommended, and in this country, despite propaganda to the contrary, cases of overnight reconstitution have been brought to our notice. Clearly this state of affairs is undesirable on two grounds:

(1) Should Salmonellas or staphylococci be present in small numbers, insufficient in themselves to constitute an infective or toxigenic dose, they might multiply during rehydration to such an extent as to render the food highly toxic.

(2) Even in the absence of potential pathogens, general bacterial multiplication may make the food unpalatable and is almost certain to lead to some loss of quality.

Table 4. *Rate of death of bacteria in stored dehydrated products. Organisms per gram viable at* 37° C.

Dried meat

Stored at 15° C. in air

Time (weeks)	4·5 % water content	2·0 % water content
0	700,000	2,000,000
2	52,000	200,000
4	36,000	43,000
6	27,000	37,000
10	9,400	—

Effect of storage in nitrogen and in air at 15° C.

Time (months)	Air at 15° C.	Nitrogen at 15° C.
0	24,000,000	2,400,000
4	81,400	555,000
7	29,300	854,000
12	—	669,000

Effect of temperature

Time (months)	Nitrogen at 15° C.	Nitrogen at 37° C.
0	1,020,000	1,020,000
3	432,000	51,000
6	436,000	—
11	278,000	11,000

(The count after three months' storage in air at 15° C. was 23,100.)

Rate of death of S. aureus *in dried egg powder stored in a packet at room temperature. Organisms per gram of powder at* 37° C.

Time (days)	Viable count	*S. aureus* count
0	400,000	2,000
25	—	500
70	90,000	20

To get data on the first point, some tests have been made on the growth of small numbers of Salmonellas in rehydrated egg powder. It is known that hens are liable to be infected with several members of this group, and it is to be expected that Salmonellas may occur in dried egg powder during large-scale manufacture (Savage *et al.* 1940; Mallmann, Ryff & Matthews, 1942).

The rehydrated powder containing the *Salmonella* chosen was incubated at the selected temperature, and an estimate of the numbers of Salmonellas present was made by making serial dilutions into tetrathionate broth (double strength for the heavier inocula) and plating on MacConkey's medium. The dilutions were made in sets of five tubes each after the manner of the determination of *Bact. coli* in water, so that McCrady's probability tables could be used for estimating the numbers of organisms originally present. The method is tedious because there are present in dried egg numbers of late-lactose fermenting organisms which grow on MacConkey's medium and form colonies that are indistinguishable by the eye from some Salmonellas, e.g. *oranienburg*, and furthermore, cross-agglutinate on a slide with some of the standard *Salmonella* sera. It was essential, therefore, in all cases of doubt, to pick off a number of colonies and carry out both agglutination and biochemical tests. Experiments have been made with *Salmonella* types *bareilly*, *oranienburg*, and *montevideo* at various temperatures. For convenience, in general 10 g. of the egg powder were added to 90 c.c. water, but some comparative tests with 10 g. added to 30 c.c. water, the normal rehydration procedure, were made, and showed no significant difference from the first method. The results are summarized in Table 5. It may be seen that in only one test out of thirteen did the Salmonellas fail to multiply, at all temperatures from 15 to 45° C., i.e. in general, the rehydrated egg provides a good medium for their growth. At room temperatures the rate of growth is comparatively slow, but at blood heat considerable multiplication occurs in between 4 and 6 hr., and in 24 hr. a count of 10^6 per c.c. or more may be obtained.

Considerations of this kind lead to the conclusion, therefore, that the period of rehydration should not exceed 4 hr.

GENERAL BACTERIOLOGY OF THE PROCESS OF DEHYDRATION IN THE FACTORY

A considerable mass of data has been accumulated on the general bacterial changes during dehydration which it is not possible to present in detail, but a few typical processes may be considered as illustrative of the type of result obtained.

Roller-dried soup

The results of examinations of rather more than 100 batches of commercially produced rolled-dried soup from two factories, operating over a period of some 6 months, together with some observations made at the factory, are summarized in Table 6.

The chief points arising from these examinations are as follows:

(*a*) The commercially produced soup containing

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added herbs carried an aerobic flora of the order of 10^3–10^4 organisms per g., the chief constituents of which were sporing aerobes, coliform organisms, *B. fluorescens* [*Pseudomonas fluorescens*] and *B. pyocyaneus* [*Pseudomonas aeraginosa*]. Some of the sporing aerobes were haemolytic and pathogenic to mice, and some of the positive and facultative, fermenting dextrose and other sugars, in these tubes. These organisms were probably not thermophiles, but they have not been studied in detail. Occasionally Clostridia, probably *Sporogenes*, were found in small numbers. The heated glucose agar shake is, therefore, not by itself a reliable criterion for

Table 5. *Rate of growth of* Salmonella *types in rehydrated egg. Organisms per* 10 *c.c. of fluid, taking* 10 *g. egg powder to varying volumes of water from* 30 *to* 90 *c.c.*

Temp. °C.	Type of *Salmonella*	Time hr.	Estimated no. Salmonellas	Viable count yeastrel agar 37° C.
45	*bareilly*	0	3·5	—
		4	70	—
		6	1,600	—
		8	> 18,000	—
		24	$> 1{\cdot}3 \times 10^6 < 4{\cdot}5 \times 10^6$	9×10^8 sporing aerobes, Gram-negative rods, enterococci
37	*bareilly*	0	60	2×10^4 enterococci
		2	90	—
		4	600	—
		6	> 18,000	—
		8	> 180,000	—
		24	17,500,000	$1{\cdot}3 \times 10^9$ sporing aerobes and enterococci
Room 15–20	*bareilly*	0	< 2	—
		24	< 2	—
		48	25	—
		72	5	—
		96	5	5×10^9 micrococci, enterococci, sporing aerobes, Gram-negative rods
25	*bareilly*	0	25	—
		24	> 180	—
		48	> 18,000	—
		72	$> 1{\cdot}8 \times 10^6$	10^7 Salmonellas obtained directly here, micrococci
20	*bareilly*	0	8	—
		24	> 1,800	—
		48	> 180,000	—
37	*oranienburg*	0	2·5	$3{\cdot}5 \times 10^5$
		8	160,000	$2{\cdot}8 \times 10^7$
		24	$3{\cdot}5 \times 10^6$	7×10^8
37	*montevideo*	0	1·1	—
		4	17	—
		8	13,000	—
		25	350,000	—
15	*montevideo*	0	0·1	—
		30	0·8	—
		56	25	—
		96	> 1,800	—

Essentially similar results were obtained in a number of other experiments not quoted, including some with *typhimurium*.

coliform organisms were pathogenic to mice. Heated glucose agar shakes (½ hr. 80° C.) usually gave gas in dilutions corresponding from one-tenth to one-thousandth of a gram inoculation, but the gas production was seldom due to Clostridia. There appeared to be at least two, possibly three, species of sporing organisms, Gram-

the presence of Clostridia in the soups. Thermophiles (growing at 60° C.) were present in considerable numbers in most of the samples. No appreciable number of staphylococci, nor any organisms of the typhoid-dysentery group, have so far been found.

(*b*) Examination of the process at factory *X* indicated

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that the liquid soup from the holding tank and the dried soup coming off the roller appeared to contain a small number of organisms (10–400/g.) including a few sporing aerobes and thermophiles. In other words the soup as it left the roller contained a very small number of organisms and the higher counts recorded above under (*a*) must therefore be due to subsequent infection. Examination of the dried herbs being added to the dried soup at the end of the process implicated them as a likely source of infection.

(*c*) Samples of dried soup powder from the factories without the addition of any flavouring materials after drying, contained a small number of organisms, often less than 100/g. It is not certain whether these organisms survived the cooking process, or were chance factory

Dehydrated minced beef

The results of two typical runs on a semi-commercial scale are shown in Table 7, from which the following chief points emerge:

(*a*) The raw meat carried a flora of the order of 10^4–10^7/g., consisting chiefly of *Achromobacter*, cocci, coliform and *Proteus* organisms, and aerobic sporing organisms. Sporing anaerobes occasionally occurred in small numbers, seldom detected in amounts less than 5 or 1 g., and thermophilic organisms were rarely present in 1 g. samples. After cooking, the meat was almost sterile.

(*b*) During the operations of mincing and loading the trays for drying, which in this particular case involved a fair amount of operation by hand, the count rose again,

Table 7. *Bacteriological examination of the preparation of dehydrated minced beef, tray dried in 5 hr. or less, the temperature of the meat being raised to 50° C. within the first half hour of drying and subsequently maintained at above that temperature. Counts per gram of material at 37° C.*

Thermophiles were absent from all samples of 5 g.

Material	Viable count 37° C.	Viable count 25° C.	Aerobic spores	Anaerobic spores + (g.)	Anaerobic spores − (g.)	Organisms
		First experiment				
Sliced meat packed on trays	$1{\cdot}3\times10^4$	$1{\cdot}8\times10^5$	20	1	1/10	*Achromobacter*, cocci, coliform *Proteus*, sporing aerobes
Meat after ½ hr. cooking at 100° C.	45	35	10	.	5	
Meat after ¾ hr. cooking at 100° C.	85	20	10	. .	5	
Cooked meat after mincing and reincorporation of cooking liquors	$9{\cdot}0\times10^3$	$7{\cdot}5\times10^4$	10	.	5	(1)
Dried meat emerging from drier	450	900	10	.	5	(2)
Dried meat pressed into tins	500	$1{\cdot}2\times10^3$	10	.	5	

(1) At 25° C. 75 % cocci, 20 % Gram-positive rods, 5 % Gram-negative rods; at 37° C. 100 % cocci, some coagulase positive *S. aureus*.
(2) At 25° C. 70 % cocci, 10 % Gram-positive rods, 20 % Gram-negative rods; at 37° C. 100 % cocci.

In this run a fair amount of handling was involved in the mincing of the meat and the loading on to trays, and some infection with *S. aureus* occurred at this stage, which, however, largely died out during drying. In the second experiment quoted below an attempt was made to reduce this infection.

		Second experiment				
Sliced raw meat	$1{\cdot}3\times10^6$	5×10^6	5	5	1	
Meat after ¾ hr. boiling	150	200	10	.	5	
Meat after 40 min. 100° C. retort	20	50	10	.	5	
Meat after mincing, loading on trays and reincorporation of cooking liquors	110	100	10	.	5	
Dried meat	25	200	10	.	5	Some *Pseudomonas* at 25° C. probably from spray used to humidify drier

contaminants after cooking, but the consistent presence of thermophiles in the liquid soup at the factory suggests that these may have survived the cooking.

(*d*) The dried herbs in use were heavily infected (10^4–10^7 organisms/g.) containing sporing aerobes (several species), *B. fluorescens*, *B. pyocyaneus*, coliform organisms, thermophiles, and some Clostridia. Onion powder appeared to be less heavily infected than most of the herbs.

(*e*) Aqueous extracts of the soup containing herbs were occasionally lethal to mice by intraperitoneal inoculation, due to infection. There was no evidence of any preformed toxin in the soup nor of the growth or survival of Clostridia under the conditions of cooking and drying adopted.

(*f*) Changes in *p*H of some samples of the reconstituted soup (containing herbs) of the following order occurred: from about 6 to 4·7 in 6 hr. at 60° C., approaching *p*H 4 subsequently, and from *p*H 5·8 to 5·2 in 10 hr. at 37° C., approaching *p*H 4 in 24 hr.

and some coagulase-positive *S. aureus* gained access to the meat.

(*c*) No evidence of bacterial multiplication during drying was obtained, and the final product carried a small load of bacteria of the order of 25–900 per g. No pathogenic anaerobes were found nor was *S. aureus* detected in the dried product. There was some evidence that there might be a small infection from the air currents set up by the fans in the drier in some cases.

Dried carrot, cabbage, and potato

Vegetables are liable to be contaminated with micro-organisms derived from the soil, in addition to infection from human sources during handling. It is clear that the essence of good vegetable drying is that all the pre-drying processes should be carried through rapidly and smoothly, so that no opportunity is offered for bacterial development. In addition, the drying process itself must be such that uneven drying, in which wet patches of material pass right through the drier and emerge with very high

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Table 6. *Bacteriology of roller-dried soup*

		Viable count per g.		
		37° C.	25° C.	Aerobic spores
20 samples factory *X* (herbs added) as received from factory	Arithmetic mean	8,000	7,000	3,000
	Most common value	10^3	10^3	10^3
	Range	10^2–10^5	10^2–10^5	10^2–10^4
20 samples factory *X* without added herbs as received from factory	Arithmetic mean	200	270	96
	Most common value	10^2	10^2	10
	Range	10–700	10–100	10–600
21 samples factory *Y* (herbs added) as received from factory	Arithmetic mean	24,000	52,000	8,000
	Most common value	10^4	104	10^3
	Range	10^2–10^5	103–10^5	10^2–10^4
10 samples factory *Y* without added herbs as received from factory	Arithmetic mean	34	50	10
	Most common value	20	50	< 10
	Range	< 10–150	10–120	< 10–15
15 samples factory *Y* with onion powder cooked in	Arithmetic mean	80	100	10
	Most common value	10	100	< 10
	Range	< 10–180	10–300	< 10–40
7 samples factory *X* 0·2 % onion powder incorporated at end	Arithmetic mean	240	180	80
	Range	60–1,000	10–700	20–200
7 samples factory *Y* 0·2 % onion powder incorporated at end	Arithmetic mean	70	70	20
	Range	20–180	50–150	< 10–30
Samples taken at factory *X* (1)	Liquid soup from inlet to holding tank batch 27	150	10	20
	Dry soup from roller	200	400	40
	Dry soup from brush sieve	200	1,000	30
	Mixed herbs	10^6	5×10^6	2×10^3
(2)	Liquid soup from holding tank	30	10	30
	Dry soup from roller	30	< 10	30
	Before brush sieve	50	< 10	40
	After brush sieve	10	< 10	< 10
Dried herbs, etc., factory *X*	Sage	$7{\cdot}5 \times 10^6$	6×10^6	$2{\cdot}7 \times 10^6$
	Celery seed	$1{\cdot}3 \times 10^7$	$1{\cdot}6 \times 10^7$	6×10^6
	Cloves	5×10^4	5×10^4	2×10^3
	Pimento	10^6	$1{\cdot}4 \times 10^6$	4×10^5
	Lemon thyme	$2{\cdot}6 \times 10^6$	3×10^6	$8{\cdot}7 \times 10^5$
	Coriander	9×10^3	$1{\cdot}2 \times 10^4$	10^3
	Soya bean	$1{\cdot}6 \times 10^5$	$1{\cdot}7 \times 10^5$	$3{\cdot}7 \times 10^4$
	Oatmeal	7×10^4	9×10^4	2×10^4
	Yeastrel	$1{\cdot}3 \times 10^5$	$1{\cdot}2 \times 10^4$	10^5
	Onion powder	$3{\cdot}5 \times 10^3$	$1{\cdot}1 \times 10^4$	3×10^3
Dried herbs, etc., factory *Y*	Lemon thyme	5×10^6	10^7	3×10^6
	Mint	$4{\cdot}5 \times 10^7$	10^9	$1{\cdot}3 \times 10^7$
	Celery powder	$2{\cdot}5 \times 10^5$	4×10^5	$1{\cdot}4 \times 10^5$
	Pimento	10^6	10^6	4×10^5
	Sage	4×10^5	$1{\cdot}3 \times 10^6$	6×10^4
	Coriander	6×10^4	$1{\cdot}2 \times 10^5$	10^4
	Curry	8×10^5	$1{\cdot}3 \times 10^6$	7×10^5
	Cloves	2×10^4	3×10^4	10^3
	White pepper	10^5	8×10^4	2×10^4
	Onion powder	2×10^4	2×10^4	2×10^4

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Table 6 (*continued*)

Minimum concentration (g.) giving gas in heated glucose agar shake (no. of samples)					Thermophiles Minimum concentration (g.) giving growth at 60° C. (no. of samples)				Notes on organisms
1 g.	$\frac{1}{10}$ g.	$\frac{1}{100}$ g.	$\frac{1}{1000}$ g.	$\frac{1}{10000}$ g.	1 g.	$\frac{1}{10}$ g.	$\frac{1}{100}$ g.	$\frac{1}{1000}$ g.	
2	9	2	5	0	0	1	1	13	—
	2 negative in 1 g.					5 negative in 1 g.			
7	1	0	0	0	2	2	2	2	Sporing rod 2 × 0·5 μ subterminal spores in heated glucose agar; cylindrical spores
	12 negative in 1 g.					12 negative in 1 g.			
3	11	5	2	0	3	10	6	2	Sporing aerobes, *B. fluorescens* and *B. pyocyaneus* coliform organisms. Clostridia occasionally present
3	0	0	0	0	2	2	0	0	
	7 negative in 1 g.					6 negative in 1 g.			
11	2	0	0	0	8	1	0	0	—
	2 negative in 1 g.					6 negative in 1 g.			
2	0	0	0	0	1	0	1	0	—
	5 negative in 1 g.					5 negative in 1 g.			
5	0	0	0	0	3	0	0	0	Rod about 2 × 0·6 μ with terminal spores in heated glucose agar shake; spherical spores
	2 negative in 1 g.					4 negative in 1 g.			
−	5 c.c.		.	. .	+	+	−	−	—
+	−	−	.	.	+	+	−	−	
+	−	−	.	.	+	+	−	−	
	+ down to 10^{-5} g.					+ down to 10^{-5} g.			
−	−	−	−	.	−	−	−	−	—
−	−	−	−	.	−	−	−	−	
+	−	−	−	.	−	−	−	−	
−	−	−	−	.	−	−	−	−	
+	+	+	+	+	−	.	.	.	*B. fluorescens* and *B. pyocyaneus*, sporing aerobes
+	+	+	+	+	−	.	.	.	
+	+	+	−	−	−	.	.	.	
−	.	.	.	.	−	.	.	.	
+	+	+	+	−	−	.	.	.	*B. pyocyaneus*
+	+	−	−	−	−	.	.	.	
+	+	+	−	.	−	.	.	.	*Actinomyces*, Clostridia
+	−	.	.	.	−	.	.	.	
+	+	+	+	−	−	.	.	.	
+	+	+	+	−	.	.	.	.	Sporing aerobes
+	+	+	+	−	+	+	+	−	Sporing aerobes, *Cl. sporogenes*.
+	+	+	+	−	+	−	−	.	Coliform organisms pathogenic
+	+	+	+	−	−	.	.	.	to mice
+	+	+	+	−	−	.	.	.	
−	.	.	.	.	+	−	.	.	
+	+	+	+	−	+	+	−	.	
+	+	−	.	.	+	−	.	.	
−	.	.	.	.	−	.	.	.	
−	.	.	.	.	−	.	.	.	
+	+	+	−	−	−	.	.	.	Haemolysing sporing aerobes pathogenic to mice

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bacterial populations, does not occur. The most frequent causes of the high bacterial counts often encountered in dried vegetables are: (1) the standing of wet vegetables for some hours at temperatures between 15 and 60° C. before entry into the drier; (2) patchy drying.

Dried carrot

Of some hundred samples, about a third gave plate counts of 1000 organisms/g. or less and may be taken to illustrate the result obtainable when operations are satisfactory and no 'wet patches' occur in transit through the conveyor or tunnel. The remainder varied from 10^3 to 10^8/g. The flora consisted chiefly of micrococci, a small white non-haemolytic coccus not growing on bile which seems to be present in most dried carrot, sporing aerobes, moulds, actinomyces, and coliform organisms in considerable numbers. The coliform organisms were chiefly of the *aerogenes* type, but occasionally faecal coli was found in quantity. Clostridia and thermophiles were not usually present, but occasionally both were found in bad samples. *Cl. botulinum* has not so far been found. No organisms of particular pathogenic significance have so far been found in the carrot, and up to the present no toxin formation has been demonstrated in the limited number of samples of 'soured' material obtained from 'wet patches'.

Detailed examination of the process at the factory indicated the following main points:

(1) Washed, hand-trimmed carrots may carry a load of 10^4–10^6 organisms/g. superficial tissue (wet weight).

(2) Areas of necrotic tissue from poor-quality washed carrots gave counts of 10^7/g.

(3) Blanching does not sterilize the carrot, the nett result of pre-drying operations being that carrot strips enter the drier with a load of about 10^4 organisms/g.

(4) Under good conditions of drying such material may emerge with a bacterial count of the order of 10^2/g., under bad, 10^7 organisms/g.

Dried cabbage

Dried cabbage is bacteriologically the least satisfactory of the dried vegetables. The viable count on rather more than one hundred samples was usually in the range 10^3–10^6/g. and was seldom below 10^3/g. The flora consisted of micrococci, coliform organisms (aerogenes and faecal), sporing aerobes, enterococci, *viridans* streptococci, and small Gram-positive rods. *Viridans* streptococci were present in some samples in large numbers, up to 10^5/g. Clostridia and thermophiles were sometimes present. *Cl. botulinum* has so far been absent, and aqueous extracts injected intraperitoneally into mice as a matter of routine from all samples have been uniformly negative.

Dried potato strips

The distribution of the plate count at 37° C. on 136 samples of dried potato strips from one factory is given in Table 8.

In other words, the majority of the samples carried less than 10^3 organisms/g., and dried potato strips were therefore the most satisfactory in this respect of the dried vegetables examined. The flora included sporing aerobes present in most samples, sometimes up to about 500/g. but usually less than 100/g., white and yellow micrococci, coliform organisms (chiefly *aerogenes*) diphtheroids, Gram-negative white cocci, *Actinomyces* and moulds. Clostridia were sometimes present in small numbers and thermophiles occasionally. No organisms of pathogenic significance were found.

Investigation of the process at the factory led to the same general conclusion as in the case of carrot, e.g. very high counts when 'patchy drying' accompanied by 'souring' occurred (up to 10^{10} organisms/g.; the predominating organisms appeared to be a short Gram-negative rod growing in pairs and producing acid in dextrose). On the other hand, with an efficient pre-drying technique and adequate drying a satisfactory product was obtained.

Another point investigated was the efficacy of the washing process. It appears essential, if the aerobic spore content is to be low, for some kind of cleaning process to be used.

Table 8. *Plate count at* 37° C. *on* 136 *samples of potato strips from one factory. Organisms per gram*

Organisms/g.	<100	$>100<10^3$	10^3	10^4	10^5	10^6
No. of samples	15	66	25	19	5	1

Roller-dried potato flour

Examination of a number of samples of this product, carried out in the main by a technique similar to that recently described by Barton-Wright (1943), to whom we are indebted for the loan of his manuscript, indicated that it may contain from 10–10^4/g. heat-resistant aerobic spores, i.e. organisms that might lead to 'rope' in bakery products. Detailed investigation at the factory showed that the aerobic spore content could be considerably reduced by using a short-pressure cooking instead of the steaming in use. Other organisms present included micrococci, *Achromobacter*, Clostridia and thermophiles occasionally in small numbers. No organisms of pathogenic significance have so far been found.

COMMENT

The problems likely to confront the epidemiologist by the large-scale consumption of dehydrated foods appear to be not dissimilar to those involved in the large-scale distribution of other kinds of food in so far as, with foods of animal origin, e.g. milk and eggs, there is the possibility that these foods may contain pathogens with which the animals are infected or which they harbour as carriers. With the setting up of efficiently controlled dehydration plants, however, means can be taken to counteract this potential danger, i.e. milk can be pasteurized before drying, and once dried there is probably less risk of reinfection during distribution than with the fresh commodity. Essentially, the two points requiring special care in the preparation and use of dehydrated foods, apart from the usual standards of hygiene that should be adopted in any well-regulated food factory, are the selection of drying conditions such that bacterial multiplication cannot occur, and the instruction of the public in the correct methods of rehydration.

In defining the temperature of drying, 50° C. would seem to be the minimum below which the material must not be held for any appreciable period. There is, with

many commodities, no difficulty in this. For example, the specification for the preparation of dried minced meat by the process developed at the Low Temperature Research Station, Cambridge, includes the demand that the temperature of all the meat shall rise to above 125° F. (52° C.) within the first hour, and shall thereafter remain above that temperature until the moisture content is sufficiently reduced to prevent any bacterial growth. It seems unlikely that significant toxin formation by *Cl. botulinum* could occur in an 8 hr. drying period, whatever the temperature, but small inocula of organisms of the *Salmonella* group can commence multiplication after about 4 hr. at suitable temperatures, and in 6–8 hr. at 37–45° C. may have reached the level of some thousands or more per gram of the material. This constitutes an argument for, first, shortening the period of holding of commodities which must commence drying below 50° C. to within 4 hr., and secondly, of limiting the time of rehydration to this period. Since coliform and other similar organisms can survive in the dried product, it is unlikely, should significant multiplication of a *Salmonella* occur before drying, that it would be necessarily destroyed in the conveyor- or tunnel-drying process, and it would certainly not in the spray-drying process where the heating is but momentary.

Provided the moisture content is reduced to 10 %, there seems to be little likelihood of microbial growth in the dehydrated product, and, in practice, the moisture content is below this level in many products for reasons other than bacteriological ones. Actually, microbial death occurs in dehydrated materials of water-contents, below 10 % and the fact that the rate of death is influenced by a variety of factors makes it difficult always to assess the quality of a dehydrated product in the bacteriological sense when there is a significant and probably unknown interval between preparation and examination, by making plate counts. If it is desired to set standards in terms of the plate count, it will probably be necessary, especially in the case of commodities produced overseas, to have a 'production standard' to be reached at the time of manufacture, and a 'consumption standard' not to be exceeded at utilization. In practice, it seems likely, that the plate count, or perhaps a total microscopic count, may be more useful in controlling production, while routine examination for the absence of certain groups of organisms likely to be of pathogenic significance is probably more useful where the product is examined before being released for consumption.

SUMMARY

1. Data on the maximum temperatures of growth of certain organisms, on the rate of toxin production by *Cl. botulinum* and the rate of multiplication of certain Salmonellas, is given, as a basis on which to define the time and temperature of dehydration in the preparation of dehydrated foods.

2. It is concluded that 50° C. is the minimum temperature below which dehydration should not be carried out. Where some heating below this temperature is unavoidable, the period of such heating should not exceed 4 hr.

3. Data on the microbial changes in dehydrated foods equilibrated at various humidities indicate that bacterial growth is not expected below about 15 % water content. Some experiments on the death of bacteria at water levels below this are discussed.

4. Details are given of the general bacteriological examination of the process of dehydration on a commercial scale for dried soup, dried minced beef, dried carrot, cabbage and potato.

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