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The pasteurization of liquid whole egg and the evaluation of the baking properties of frozen whole egg

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INTRODUCTION

The potential dangers associated with the large-scale commercial use by the bakery trade of untreated bulk supplies of liquid whole-egg products have long been recognized. The size of the problem may be judged by the fact that some 35,000 tons per annum of these egg products are used by the bakery trade in this country. Home production is insufficient to cope with this demand and a not insignificant proportion of the supplies are imported, at present, from other countries. The difficulties surrounding adequate bacteriological sampling of consignments, the limited value of such procedures and the possible commercial problems arising out of the delays over bacteriological examination are equally well recognized; whatever the source of the eggs, the potential danger of salmonella contamination exists and it seems most unlikely, at any rate in practice, however much the standards of hygiene in production were improved, that this hazard could be eliminated.

For some years now, applied bacteriologists have been studying the possibility of devising a method of treatment for whole-egg products which would be effective in killing any salmonellae that might be present without altering the baking qualities of the product. Hannan, Brooks & Hobbs (1957), Ingram, Rhodes & Ley (1961), have shown that gamma-irradiation will destroy salmonellae in frozen egg, but the application of irradiation methods to foods for human consumption is not an approved procedure. Heat treatment has been studied experimentally by many workers and it would seem that pasteurization of liquid whole egg prior to the production of frozen whole egg, bulk liquid whole egg or dried whole egg offers a practical solution to the problem. There is now a considerable literature on the subject and Murdock, Crossley, Robb, Smith & Hobbs (1960) set out the present position with regard to the pasteurization of liquid whole egg and reviewed the earlier literature. At the end of 1959, although there was a good deal

of laboratory and pilot-plant experience of whole-egg pasteurization, there was no general agreement about the temperatures to be used or the holding times, there was also a certain amount of reluctance by some sections of the bakery trade to accept the pasteurized product and, because there was no simple, rapid and reliable method for assessing the efficiency of the procedure, it could not be accepted for legislation purposes. There were several reasons for the reluctance of the bakery trade to accept the experimental products offered to them: the poor quality of some of the raw material, the application of unduly severe heat treatment which was sometimes applied and the use of excessively high homogenization pressures which reduced considerably the viscosity of the finished product.

In December 1959 the British Egg Marketing Board, with the same aim as previous groups of workers, began a series of investigations on the pasteurization

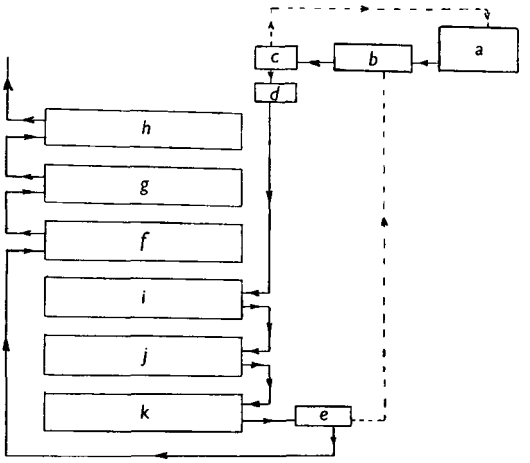

Fig. 1. Diagram of pasteurization plant. *a*, storage tank; *b*, balance tank; *c*, centrifugal pump; *d*, homogenizer; *e*, flow diversion valve; *f*, regeneration cooling section; *g*, cooling section; *h*, chilling section; *i*, regeneration heating section; *j*, heating section; *k*, holding section.

of liquid whole egg prior to freezing; they commenced with critical laboratory and baking studies on egg pasteurized in an existing commercial plant. The results obtained were sufficiently encouraging to warrant the planning of large-scale pasteurization tests and baking trials. These tests and the bakery trials form the subject of the present communication.

THE PLANT

The A.P.V. installation used for the pasteurization tests is illustrated diagrammatically in Fig. 1; it was designed to operate at the nominal rate of 500 gal./hr. with a 2·5 min. minimum holding time. During normal operations, a centrifugal pump delivered liquid whole egg from the 1000 gal. storage tank via a float balance tank to a homogenizer operating at 500 lb. p.s.i. The homogenized liquid egg passed through the various sections of the A.P.V. plate pasteurizer as follows: regeneration heating section, hot water heating section, plate holding section, and

chilling section. Provision was made for inadequately heated egg to be diverted back to the float balance tank, although during the experiments described there was no occasion for this to be done.

EXPERIMENTS WITH INOCULATED EGG

For these experiments the plant was modified to permit the safe preparation of a large volume of liquid whole egg heavily inoculated with *Salmonella typhimurium* and to enable samples to be taken at various points. The mercury-in-glass thermometer at the outlet of the holding section to the automatic flow diversion valve was checked against an N.P.L. thermometer and the minimum holding time of 2·5 min. was confirmed by the nitrite injection method (Murdock *et al.* 1960).

Freshly prepared liquid whole egg was collected in the storage tank and when 1000 gal. had been collected it was thoroughly mixed by pumping out from the bottom of the storage tank via the float balance tank and back to the top of the storage tank. An inoculum of *Salm. gallinarum* (later *Salm. typhimurium*) was added to the storage tank through a level gauge connexion at the top of the tank and mixed with the liquid egg by recirculation. The valve from the storage tank was closed, the centrifugal pump was connected to the homogenizer, and the previously sterilized pasteurizer was brought to steady operating conditions on water introduced to the balance tank. The pipe from the automatic flow diversion valve to the regeneration cooling section was broken as a precaution against accidental contamination of the cooling and chilling sections, but it should be noted that this procedure was a special safeguard for the purpose of this experiment and, normally, contamination of the cooling and chilling sections is prevented by the automatic flow diversion valve which does not change into the forward flow position until the correct pasteurization temperature has been reached. A steady temperature of 65·5° C. (150° F.) was reached by passage of water as follows: float balance tank, centrifugal pump, homogenizer, regeneration heating section, heating section, holding section, automatic flow diversion valve, balance tank. The automatic flow diversion valve was then reconnected to the regeneration cooling section and the water was run through the cooling and chilling sections. The storage tank was connected to the balance tank and pasteurization runs were made over a range of temperatures decreasing from 66·1° in 1·1° C. steps to 65·0° C. (151° F. in 2° F. steps to 143° F.), with a minimum holding time of 2·5 min. To ensure that the new temperature remained constant after each temperature adjustment, the pasteurizer was allowed to run for 30 min. before samples were taken at that temperature. In all cases the holding time was standardized at 2·5 min.

After preliminary runs with *Salm. gallinarum* and with *Salm. typhimurium*, a final run was made with *Salm. typhimurium* in a concentration of 200,000 viable organisms per ml. This serotype was chosen as it is the most frequently encountered salmonella organism in the U.K., it is often present in frozen whole egg samples; in addition, it has been shown that it is less sensitive to heat than some other serotypes of salmonellae (Anellis, Lubas & Rayman, 1954; Osborne, Straka & Lineweaver, 1954).

Holding time

In a commercial pasteurizing plant the product is subjected to a heat treatment which is additional to that applied in the holding section. When the pasteurizer used in the above experiments is operated to give a minimum holding time of 2·5 min. at 64·4° C. (148° F.) the product is additionally heated as follows:

Section of plant	Temperature range C.	Temperature range F.	Time (sec.)
Regeneration heating section	18·3–45·6	65–114	18·4
Heating section	45·6–64·4	114–148	23·6
Regeneration cooling section	64·4–92·8	148–99	18·4

It was therefore necessary to confirm the results obtained with the commercial plant on small laboratory apparatus in which the additional heating effect on either side of the holding section could be virtually eliminated and which would be insignificant compared with the additional heating effect that would be obtained in any commercial plant. Such experiments are reported by Shrimpton, Monsey, Hobbs & Smith (1962). It need only be stated here that the effectiveness of all treatments from 61·7° to 65·0° C. (143°–149° F.) for a minimum holding time of 2·5 min. was confirmed.

BACTERIOLOGICAL TECHNIQUE

In a preliminary experiment, *Salm. gallinarum*, SRL stock culture 74-416 was used as the test organism. Six 500 ml. quantities of 48 hr. nutrient broth cultures, each containing the washings from two 48 hr. agar slope cultures in 500 ml. bottles, were poured into the tank containing 1000 gal. of liquid whole egg. The general colony count, salmonella and coliform counts before and after pasteurization at various temperatures are given in Table 1.

Table 1. *Pasteurization of liquid whole egg inoculated with salmonellae*

Count per ml. (37° C.)	*Salmonella gallinarum* inoculated egg: Unpasteurized	*Salmonella gallinarum* inoculated egg: Pasteurized 66·1°–62·8° C. (151°–145° F.)	*Salmonella typhimurium* inoculated egg: Unpasteurized	*Salmonella typhimurium* inoculated egg: Pasteurized 65·0–61·7° C. (149°–143° F.)
General	700,000	Less than 500	70 million*	Less than 500
Salmonella	400,000	Not found in 50 ml.	200,000	Not found in 50 ml.
Coliform bacilli	Present in 0·001 ml. (faecal)	Not found in 0·1 ml.	Present in 0·001 ml. (faecal)	Not found in 0·1 ml.

* High count may be due to delay in transporting sample.

Another experiment was carried out using a streptomycin-resistant (S^R) strain of *Salm. typhimurium*, MM 2871 belonging to phage type 14 (Callow, 1959) as the test organism. The strain was chosen as a marker organism because its characteris-

tics would be likely to differ from natural contamination with *Salm. typhimurium* (*Salm. typhimurium* phage type 14 is the organism commonly found in egg products). The inoculum for the 1000 gal. tank of liquid whole egg consisted of two 500 ml. quantities of overnight nutrient broth cultures and the washings from six agar slope cultures in 500 ml. bottles. Table 1 shows the counts obtained in the second experiment before and after pasteurization. The salmonella count before pasteurization was obtained from an average of two control samples.

Samples were taken after pasteurization at 66·1°, 65·0°, 63·9° and 62·8° C. (151°, 149°, 147° and 145° F.) for 2·5 min. for *Salm. gallinarum*, and at 65·0°, 63·9°, 62·8° and 61·7° C. (149°, 147°, 145° and 143° F.) for 2·5 min. for *Salm. typhimurium*. General colony counts of samples taken after pasteurization at all temperatures were less than 500 per ml. and salmonellae were not isolated from 50 ml. of any of the treated samples after incubation for 3 days at 37° C. in enrichment cultures as shown in Table 1.

For direct counts, 0·02 ml. quantities of duplicate dilutions of the egg were dropped on the surface of deoxycholate citrate and MacConkey agar plates; the drops were not spread but allowed to dry and the colonies developing at 37° C. were counted after 2 days. The counts given are those obtained from the MacConkey plates unless these were overgrown with contaminants.

For liquid enrichment cultures, selenite and tetrathionate media were used; 25 ml. of liquid whole egg plus 25 ml. quarter-strength Ringer's solution and 50 ml. double-strength enrichment medium were subcultured on to deoxycholate citrate and Wilson & Blair agar plates after 24 hr. and again after 3 days' incubation at 37° C.

Salmonella colonies were confirmed by serological and fermentation reactions. General colony counts were carried out on the surface of blood agar, and for coliform organisms, dilutions of liquid whole egg were incubated in MacConkey broth at 37° C., and subcultured if necessary into brilliant green bile broth and peptone water at 44° C. for *Escherichia coli*.

BACTERIOLOGICAL RESULTS

The results using liquid whole egg, inoculated with either *Salm. gallinarum* or *Salm. typhimurium*, in the commercial pasteurization plant are given in Table 1.

BAKING TRIALS

It was essential to ensure that pasteurization would not adversely affect the baking properties of the product and that baking trials should be carefully carried out in commercial bakeries. In arranging for these trials, consideration was given for the need to include the newer, larger bakeries and to cover a reasonably wide range of bakery products. Supplies of shell eggs were randomly selected and two batches of frozen whole egg were produced, raw and pasteurized, which were code-marked. For the raw batch, the procedures normally used for Lion Brand Frozen Whole Egg were employed and it was not homogenized. The pasteurized batch was homogenized at 500 lb. p.s.i. and pasteurized at 64·4° C. (148° F.) for a

minimum holding time of 2·5 min. The bakers were asked to prepare their normal products from these two batches without changing their processes. There were several considerations which led to the choice of a pasteurization temperature at 64·4° C. (148° F.) for the large-scale commercial trials. At this temperature there is an adequate margin of safety; practical commercial pasteurization runs can be maintained at this temperature and small-scale trials had already indicated that

Table 2. *Results of baking tests*

Bakery	Bakery products	Did both batches give acceptable products?	Baker's comments
A	Madeira cake, sultana cake, cherry slab	Yes	Little or no difference between batches
B	Swiss roll various, genoese slabs and bars, Swiss fingers, Swiss gateaux, trifles	Yes	Normal standard maintained with both batches
C	Swiss roll, sponge bar, butter madeira, cherry madeira	Yes	The raw batch gave a visibly better volume
D	Dundee slab, cherry slab, other slab, other fruit cake, fairy cake, various rolls, sponge sandwiches, sponge cakes	Yes	Any differences between batches were minute
E	Swiss roll, sponge sandwich, madeira (low egg content)	Yes	Pasteurized batch preferred for Swiss roll and sponge sandwich
F	Fruit slabs, sponges	Yes	Pasteurized batch best for whipping
	Layer bases, madeira slabs	Yes	Pasteurized batch gave slightly less volume
	Walnut Genoese	No	Raw batch fairly good, pasteurized batch poor volume
	Choux pastry (see results at Bakery H)	Yes	Pasteurized batch gave results as good as, or better than standard and better than raw batch
G	Madeira, madeira sandwich, dundee, sultana, sponge drops, orange bars, sponge bars, gateaux base	Yes	No significant differences
H	Cherry slab, sponge, Genoa slab, Genoese, high-ratio almond cake	Yes	A definite preference for the raw batch. Use of pasteurized only for last 18 months requires changes in methods and recipes. Weight of some cakes increased to obtain size
	Choux pastry (see results at Bakery F)	No	Pasteurized batch gave an unsaleable product—poor volume, weak cases. Raw batch very good
I	Cakes (various)	Yes	Pasteurized batch was reputed to have given a little more volume which in some cases only is preferred. No great differences between the two batches

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bakery performance was unlikely to be affected. Furthermore, as described by Shrimpton, *et al.* (1962), heating at 64·4° C. (148° F.) has a special significance with regard to the destruction of α-amylase and these authors have found that this temperature maintained for 2·5 min. in whole egg is also lethal for *Salm. senftenberg* N.C.T.C. 9959 (775 W) which has so far been found to be the most heat resistant salmonella. The results of the baking trials are given in Table 2.

DISCUSSION

Although much information has been accumulated from the very large numbers of bacteriological examinations made on samples of frozen whole egg, the variation in the results from container to container of the same consignment, and even from different parts of the same container, makes 'Bacteriological clearance' procedures unreliable guides of the safety of the product, irrespective of the fact that such methods are, in addition, uneconomical. It is generally known that bulked whole-egg supplies from certain sources tend to be more heavily contaminated with salmonellae than those from other sources, but the fact is that the freedom from salmonella contamination of any one consignment of bulked whole egg can only be assured if the whole of that consignment were expended in innumerable bacteriological examination, clearly an impracticable procedure.

Since the extent of salmonella contamination of any batch of frozen whole egg is unpredictable, some form of heat treatment, which would kill any salmonellae that might be present in the raw bulked whole-egg supplies without altering the baking qualities of the product, would offer a simple solution to the problem. Pasteurization methods had been well examined by various workers over a period of some years on an experimental basis, but because of the failure to make firm recommendations about the optimum temperature and holding time for the production of safe materials which were acceptable to the baking trade, and because of the absence, at that time, of a simple and reliable efficiency test of the pasteurization procedure no large-scale trials on a commercial basis could be satisfactorily undertaken.

The large-scale trials described in this paper were planned to overcome previous objections by utilizing an existing commercial plant for the production of pasteurized whole egg which in its raw state was known to contain salmonellae in a concentration well above that likely to be found in any natural product. At the same time a simple, rapid and reliable test, on the lines of the phosphatase test for checking the pasteurization of milk, had been developed; this test is described in accompanying papers (Brooks, 1962 (see p. 145); Shrimpton *et al.* 1962 (see p. 153). The final laboratory trials on this test confirmed that 64·4° C. (148° F.) for 2·5 min. could be relied upon to kill salmonellae including *Salm. senftenberg* and that a similar time-temperature combination destroyed the enzyme, α-amylase.

The baking trials may be criticized on the grounds that the bakers were offered two products to test which were visibly different, the pasteurized sample being 'thinner' than the raw whole-egg sample. This was unfortunate because homogenization, which appeared to be largely responsible for the 'thinness', was sub-

sequently found to be an unnecessary procedure and is no longer used. In spite of this oversight in the planning, the results indicated that the opinion of the bakery trade was generally favourable towards the pasteurized product. One or two unfavourable reports would be expected in any large series of commercial baking trials, and since it could be known, from its appearance, which was the pasteurized product, bias might play some small part against it. Yet the bakers do not appear to have been influenced by the obvious difference between the two samples when assessing their baking properties, and two only of the nine bakeries cooking plain and fruit cakes, Swiss rolls, Genoese slabs, sponge sandwiches and Choux pastry gave unfavourable reports for certain confectionery made with the thinner samples. Thus, it may be safely concluded that the pasteurized whole-egg products frozen whole egg and bulk liquid whole egg, are generally acceptable to the bakery trade although some adjustment of one or two of the recipes may be desirable, but since the homogenization process is now omitted the product should be more acceptable than at the time of the bakery trials. Support for this conclusion comes from the development during 1961 of an increasing demand from bakeries in the U.K. for whole-egg products (frozen whole egg, bulk liquid whole egg and dried whole egg) which had been pasteurized at 64·4° C. (148° F.) for 2·5 min.

In the U.K. there are now seven pasteurization plants. These plants have been using a variety of heat treatments arrived at empirically, and the resulting product was tested bacteriologically by the local authority. Now, however, procedures are being standardized in accordance with the recommendations made on the results obtained in the present experiments. All liquid whole egg in the U.K. intended for spray drying and all British Egg Marketing Board bulk liquid whole egg distributed by tanker or churn is pasteurized at 64·4° C. (148° F.) for 2·5 min. Home production of whole-egg products is not able to supply the U.K. demand completely, and it is therefore relevant to consider the pasteurization facilities which exist in exporting countries in the event of the passage of U.K. legislation requiring all whole-egg products to be pasteurized. Pasteurization is already compulsory in Denmark, and West German legislation requires the pasteurization of imported egg products. There are pasteurization plants ready for use in Australia, China, Israel, Japan, Mexico, Poland, Rumania, South Africa and the United States of America.

SUMMARY

Experiments carried out by the British Egg Marketing Board in order to establish a heat treatment which would effectively pasteurize liquid whole egg are described.

The results of large scale bakery trials and subsequent trade demands indicate that the recommended pasteurization treatment gives a product of a satisfactory baking performance.

It is recommended that for the adequate pasteurization of whole-egg products, a temperature of 64·4° C. (148° F.) for the minimum holding time of 2·5 min. should be used.

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