BOTTLED AND CANNED FRUIT: Studies of Processing Requirements and Fuel Consumptions by Domestic Methods

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The rates at which heat penetrates through fruit during preserving by bottling and canning have been studied by six different domestic methods. Determinations have been made of the processing times and temperatures required to give adequate control both of the spoilage micro-organisms at the different pH levels found, and of the oxidase-enzyme activity in the fruits having light-coloured flesh. The quantities of gas or electricity used in preserving 1 lb., 5 lb. and 10 lb. of fruit, in the higher and lower pH ranges, have been recorded for each method, both for the initial and for the subsequent processes.

Introduction

The investigation was undertaken to determine the minimum processes for fruit bottling required to obtain products that would remain free from spoilage micro-organisms while maintaining a good appearance and texture. Since the survival and growth of bacteria depend largely on the pH of the medium, the distribution of the pH values in the different kinds of fruits is of importance.

Most workers accept foods with a pH value below 4·5 as being safe from spoilage by *Clostridium botulinum*, but foods having a pH value above 4·5 require treatments that ensure the destruction of the spores of this organism.

Cameron & Esty[1] classified foods for preserving purposes into the following pH ranges:

Low acid, pH 5 and higher. Members of this group, containing most meat, fish, milk and some vegetables, are subject to spoilage by mesophilic and thermophilic bacteria.

Medium acid, pH 5 to 4·5, contains principally meat and vegetable mixtures, specialities such as spaghetti and soups that are also subject to spoilage by the bacteria in the low-acid group. In this group the thermophilic anaerobes are of greater importance than the flat-sour group of micro-organisms.

Acid, pH 4·5 to 3·7, containing tomatoes, pears, figs, pineapples and nectarines as well as other fruits. These are subject to spoilage by non-sporing acid-tolerant micro-organisms as well as by spore-forming anaerobes allied to *Clostridium pasteurianum* Winogradsky.

High acid, pH 3·7 and below, contains the more acid fruits. These are subject to spoilage by yeasts, moulds and acid-tolerant bacteria, but are immune from spoilage by spore-forming bacteria.

Since this study is confined to fruit-processing, most of the products would fall into the acid or high-acid groups, but estimations of the pH values have shown that a few fruits fall into the medium-acid group, above. Correct processing times are of particular importance in the medium-acid group, to ensure either destruction or inhibition of any pathogenic organisms.

Considerable spoilage in tomato juice by the organism *Bacillus thermoacidurans* has been reported by Stern, Hegarty & Williams,[2] Becker & Pederson[3] and other workers in the U.S.A., but does not appear to have been noted in this country. Spoilage by similar acid-tolerant bacteria has been noted recently in connexion with these processing tests in tomato products, and further work on the survival of these organisms after processing at different pH levels is in progress.

In the authors' experience, fruit, other than tomatoes, processed in a water bath, method (*a*), has been generally free from microbiological spoilage, and the minimum temperatures obtained were taken as those required for the different kinds of fruit when processed by other methods. Processing temperatures found satisfactory for fruits in the high-acid group were a minimum of 157° F, or over 150° F maintained for 20 minutes. Baumgartner[4] considers most of the spoilage organisms in this group to be destroyed by 30 minutes' heating at 149° F. An exception is the mould *Byssochlamys fulva*, first noted by Olliver & Smith[5] and further tested for the heat resistance of its spores by Gillespy.[6] The heating required for the destruction of the spores of this mould was found to over-cook the fruit for culinary requirements, and since this organism does not seem to be a main cause of spoilage in domestic preserving, its presence has not been considered in the evaluation of processing times.

The discoloration of some bottled pears and plums, processed at temperatures considered sufficient to prevent spoilage by micro-organisms, was found by James & Crang[7] and Crang & Kendall[8] to be due to oxidase-enzyme activity. The temperatures necessary to inactivate the enzyme systems completely may vary considerably from one variety to another in the same kind of fruit. Enzymic discoloration can be prevented either by processing above the maximum temperature of enzyme activity, or by processing for a longer period just below the maximum required for rapid inactivation of the enzyme. When fruit is canned the former method of control usually operates, but the latter method is usually the more satisfactory when fruit is bottled owing to the slow transference of heat through glass in heating and cooling.

In the work described in this paper, the methods of bottling which had been recommended for some years in publications issued by the Ministry of Agriculture were the first to be tested, and modifications were made as required either to improve the colour or texture, or to lessen the risk of spoilage by micro-organisms.

The quantities of gas and electricity used in processing by the different methods were measured, since no information was available on the relative amounts of fuel used in the domestic bottling methods.

Experimental

Methods of testing the pH value

The pH values were tested on freshly pulped fruit at 20° C by means of a glass electrode. Most of the results were obtained during the seasons 1950–1952.

Microbiological tests

The following kinds of fruit, selected to cover the different pH ranges, were preserved during the 1950 season: blackcurrants, cherries (Frogmore Prolific and morello), damsons, gooseberries, pears, strawberries and tomatoes (whole in brine and 'solid pack'). Twenty to thirty jars or cans were prepared of each kind of fruit. One sample of each process was inoculated with spores of *Byssochlamys fulva*. The samples were stored at 64–77° F for 2–2½ years before examination. The jars or cans were opened under sterile conditions in an inoculation cabinet. All were examined for visible spoilage; in addition a sample of the gooseberries, damsons, pears and tomatoes from each container was inoculated in triplicate on the following media: (i) liver broth, (ii) tomato broth, (iii) glucose/malt/yeast-extract broth, (iv) nutrient broth and (v) potato agar. The inoculated plates and tubes were incubated at 22°, 37° and 57° C, one replicate at each temperature, in order to isolate organisms having different optimum temperatures of growth. Smears (Gram-stained) were prepared from each sample of the bottled and canned fruit and from any sub-cultures that were positive.

Enzyme activity

Two tests for oxidase activity were used: (1) the formation of a red colour on the addition of 1% alcoholic solution of guaiacol to pears, (2) the formation of a blue-black colour on the addition of 1% alcoholic solution of benzidine to plums or apples.

Methods of testing rate of heat-penetration

Throughout the experiments thermocouples of enamelled copper–Eureka wire (22-S.W.G) were used with an extra protection of plastic sheathing. The exposed tips were sprayed with a thin film of Araldite wax and subsequently stoved for 5 hours at 150° C. A Doran thermocouple potentiometer was used with either distilled-water ice kept in a vacuum flask or a Sunvic cold-junction thermostat. Periodic standardizations have been made against standard thermometers.

Glass preserving jars of the screw-band type (1-lb., 2-lb. or 4-lb. sizes), or lacquered cans (1-lb. or A2½ sizes) have been used throughout. The lids were bored to take the thermocouples, held tightly in place with a split rubber bung. The length of the wires was adjusted so that the thermocouple tips penetrated the tissue of the fruit in the coolest part of the container. Fagerson & Esselen[9] showed that the cold spot for convection packs in American 1-lb. glass jars was at the apex of a cone, ¾ in. from the base of the jar. The jars used in the present work were taller than the American ones and the comparable position was found to be 1 in. from the base.

The thermocouple wires were led into the pressure pan through a ¼-in. hole drilled in the lid. A tightly fitting rubber bung, through which the leads were threaded, was held firmly in the hole by a specially designed metal cap. The temperature in the cooker was taken about 1 in. from the top. The oven temperatures were taken by a thermocouple placed about 1 in. from the jar to be tested, with the tip on a level with that inside the jar. A simple key enabled the use of a threefold unit connected to one cold junction.

Processing methods

Fresh, good-quality fruit was prepared in the usual way for preserving. For most packs, 11 oz. of fruit was used per 1-lb. jar and fruits that could be packed more tightly were tested separately. Apple slices were covered with 15°-Brix syrup, and whole tomatoes with 1% brine, but 30°-Brix syrup was used with all other fruits. The solid-pack apples and tomatoes were scalded before packing into jars. Details of preparation and processing may be found elsewhere.[10, 11]

The processing times in methods (*b*), (*c*), (*d*) and (*e*) were varied considerably during the course of the tests in order to find processing values comparable with methods (*a*) or (*f*). The final times that proved satisfactory were as follows:

(*a*) *Bottling: slow water-bath method.*—The jars were filled with fruit and cold syrup, placed on a rack in a pan with cold water just to cover them. The water was raised to 165°, 180° or 190° F in 1½ hours and maintained at these temperatures for 10, 15, 30 or 40 minutes according to the kind of fruit being processed.

(*b*) *Bottling: quick water-bath method.*—The jars were warmed, filled with fruit and with hot syrup (140° F), and placed in a pan as in (*a*) but with warm water (100° F) to cover. The temperature of the water was raised to 190° F in 25 to 30 minutes and maintained for 2, 10, 20, 40 or 50 minutes according to the fruit being processed.

(*c*) *Bottling: pressure-pan method.*—Warmed jars were filled with fruit and with boiling syrup. Domestic pressure pans, large enough to hold 2-lb. preserving jars, had 1 pint to 2 quarts of water added, according to the size of pan, a low trivet put in and the water brought to the boil. The jars were placed on the trivet, the lid fitted on with the exhaust valve open, the pan heated, and the exhaust valve closed when steam began to escape. The heat was regulated to obtain 5 lb. pressure per sq. in. in 5 to 10 minutes from the time of placing the jars in the pan. Pressure was maintained at 5 lb. for 1, 3, 5 or 15 minutes according to the fruit processed. The pan was cooled 10 minutes at room temperature before it was opened to remove the jars.

(*d*) *Bottling: slow-oven method.*—The jars of fruit were placed 2 in. apart on an asbestos mat in the central part of an oven thermostatically controlled to give a temperature of 250° F, after preheating for 15 minutes. The jars were processed for 45 up to 125 minutes, depending on the kind and quantity of fruit, then removed from the oven and immediately filled with boiling syrup.

(*e*) *Bottling: moderate-oven method.*—Warm jars, filled with fruit and with boiling syrup to within 1 in. of the top, were placed 2 in. apart on a baking sheet lined with newspaper. This was placed in the central part of an oven controlled to give a temperature of 300° F, after preheating for 15 minutes, and the jars of fruit were processed for times varying from 30 to 100 minutes, depending on the kind and quantity.

(*f*) *Canning.*—The cans were filled with fruit and with boiling syrup to within ⅜ in. from the top. The lids were sealed on and the cans processed in boiling water for 3 to 45 minutes, depending on the kind of fruit, size of can and time taken for the water to re-boil (see publications[10, 11] for processing times).

Gas and electricity measurements

The gas and electricity used in processing by each method was noted on meters fitted for the purpose. In order to facilitate comparisons, the quantities of fuel needed when processing 1 × 1-lb., 5 × 1-lb. and 5 × 2-lb. containers were recorded, and expressed as the quantity needed per 1-lb. jar or can. Several different pans, ovens and cookers were used for each test but the figures given are those for the equipment that proved to be the most economical for the quantity of fruit processed.

Since a considerable amount of fuel was used in preheating the water or ovens in methods (*b*) to (*f*), this has been deducted in calculating fuel requirements for the subsequent processes (Table V).

Results

Range of pH values

The range and distribution of pH values found in fresh fruit are given in Table I.

It will be seen that figs and pears were the only fruits found to have pH values above 4·5, but most of the tomatoes and some of the sweet cherries and plums had pH values in the 4·0–4·4 range.

Since it is realized that comparatively few fruits were tested, a comparison with the

Table I

Range and distribution of pH values in fresh fruit

Fruit	No. of samples	Range	No. of samples in each pH range: Below 3·0	3·0 to 3·4	3·5 to 3·9	4·0 to 4·4	4·5 and above
Apples	51	2·9–3·8	4	40	7		
Blackberries (cultivated)	6	2·8–3·1	5	1			
Blackcurrants	25	2·7–3·3	15	10			
Cherries (acid)	3	2·9–3·6	2		1		
,, (sweet) ..	10	3·7–4·3			3	7	
Damsons	2	3·1–3·4		2			
Figs	2	4·5–5·3					2
Gooseberries	9	2·9–3·2	1	8			
Greengages and 'Gage' plums	20	3·0–4·2		16	3	1	
Loganberries	1	2·9	1				
Medlars	2	3·4–3·7		1	1		
Peaches	1	3·7			1		
Pears	15	3·7–4·6			4	8	3
Pineapple	1	3·4		1			
Plums (red or purple)	22	2·9–4·3	4	13	1	4	
,, (Victoria type) ..	14	2·9–3·6	1	11	2		
,, (yellow)	8	2·8–3·5	2	5	1		
Quince	1	3·2		1			
Raspberries	3	3·0–3·1		3			
Redcurrants	1	3·0		1			
Rhubarb	14	3·0–3·6		11	3		
Strawberries	10	3·1–3·6		9	1		
Tomatoes*	219	3·9–4·4			14	205	

* Tomato figures obtained from Miss M. E. Kieser (private communication)

pH ranges in fruit found by other workers would be of value. Goldmann[12] reported a range of pH values found in fruit juices in the U.S.A. The results were generally similar for the fruits mentioned in Table I although she reported the range for apples (30 samples) to be 3·00–5·00 and oranges (18 samples) to be 3·55–4·90, but pears (12 samples) only 3·2–3·90. Figures for tomatoes were not included. The high figures for apples and oranges are not likely to be found in fruit used for preserving in this country.

The distribution of pH values in canned fruit reported by Adam[13] is also similar for most fruits given in Table I, with figs having a pH range 4·4 to 5·2, pears 3·9 to 4·7, and sweet cherries 3·7 to 4·4. The chief differences were in the plums and tomatoes, the highest pH values reported by Adam for canned plums and greengages being 3·3 and 3·5 respectively, and the range for canned tomatoes being from 4·1 to 4·7. The pH of the plums can easily be accounted for, as those with the higher pH values listed in Table I were in varieties not recommended for commercial canning. The higher tomato figures may be due to growth in warmer climatic conditions, since the figures supplied in Table I were all on different tomato varieties grown under glass and outdoors at Long Ashton Research Station, whereas canned tomatoes are often from imported fruit.

Microbiological spoilage

The results of examination of the containers after storage are given in Table II. As will be seen, no microbiological spoilage occurred in the blackcurrants, cherries or damsons. The mould *Byssochlamys fulva* was recovered from one of the inoculated jars of gooseberries, and from three of the jars of strawberries.

Anaerobic organisms were isolated from four bottles of pears, but had apparently remained dormant in the fruit itself. The processes for the solid-pack tomatoes, by methods (*c*) and (*d*), were inadequate. The times of processing this pack by methods (*a*) to (*e*) were subsequently increased to give minimum temperatures comparable with those found in canning.

Enzyme inactivation

The maximum temperatures at which oxidase-enzyme activity was found in the fruits tested were as follows: apples 150–165° F, plums 150–185° F and pears 180–195° F. In these tests the pulp was heated and cooled rapidly. Since enzyme inactivation bears a time–temperature relationship, oxidase activity ceased at several degrees below these figures when the slower heating–cooling curves normally used in fruit bottling were followed.

Table II

Microbiological results of different processes

Fruit, variety and pH of fresh fruit	Method of processing *	Number of samples	Maximum temperature in coolest part of container, ° F	Results after storage for 2–2½ years
Blackcurrants: Seabrook, pH 2·97	(a) Water bath: 180° F in 1½ h., held 15 min.	5†	169° Over 160° for 22 min.	No spoilage apparent
	*(c) Pressure: 5 lb. for 4 min.	6	185° ,, ,, ,, 46 ,,	,, ,, ,,
	*(d) Oven: 250° F for 1 h.	4†	156°	,, ,, ,,
	(f) Canning: 10 min. to re-boil, held 18 min.	7†	195° ,, ,, ,, 22 ,,	No microbiological spoilage but 3 cans developed hydrogen swells
Cherries: Frogmore Prolific, pH 4·08 and morello, pH 3·55	*(a) Water bath: 165° F in 1½ h., held 10 min.	7†	156°	No spoilage apparent in either variety
	(a) 180° F in 1½ h., held 15 min.	12†	171° Over 160° for 32 min.	
	*(c) Pressure: 5 lb. for 4 min.	9	167° ,, ,, ,, 20 ,,	
	*(c) ,, 5 lb. for 7 min.	3†		
	*(d) Oven: 250° F for 100 min.	10†	181° ,, ,, ,, 34 ,,	
	(f) Canning: 5 min. to re-boil, held 15 min.	12†	208° ,, ,, ,, 18 ,,	No microbiological spoilage but all cans developed hydrogen swells
Damsons: Shropshire Prune, pH 3·35	*(a) Water bath: 165° F in 1½ h., held 10 min.	4	156° Over 150° for 20 min.	Smears negative; no growth in liver broth, tomato broth, glucose/malt/yeast-extract broth, nutrient broth or potato agar
	*(c) Pressure: 5 lb. for 4 min.	6†		
	*(d) Oven: 250° F for 45 min.	6†	160° ,, ,, ,, 22 ,,	
	(f) Canning: 6 min. to re-boil, held 10 min.	5†	202° ,, ,, ,, 20 ,,	
Gooseberries: Keepsake, pH 3·12	(a) Water bath: 165° F in 1½ h., held 10 min.	5†	160° Over 150° for 25 min.	*Byssochlamys fulva* recovered from inoculated jars in potato agar but no apparent breakdown of fruit; all other cultures and smears negative
	*(d) Oven: 250° F for 45 min.	5†	163° ,, ,, ,, 36 ,,	All cultures and smears negative
	*(c) Pressure: 5 lb. for 2½ min.	6†	173° ,, ,, ,, 46 ,,	
	(f) Canning: 3 min. to re-boil, held 16 min.	5	204° ,, ,, ,, 23 ,,	
Pears: Bristol Cross, pH 4·47	(a) Water bath: 190° F in 1½ h., held 30 min.	5†	187° Over 180° for 34 min.	*Byssochlamys fulva* recovered in potato agar from 1 inoculated jar; anaerobes isolated in liver broth from 1 jar; other cultures negative
	(c) Pressure: 5 lb. for 5 min.	6†	204° ,, ,, ,, 32 ,,	All cultures and smears negative
	*(d) Oven: 250° F for 1½ h.	5†	188° ,, ,, ,, 16 ,,	Anaerobes isolated in liver broth from 3 jars; other cultures negative
	(f) Canning: 6 min. to re-boil, held 15 min.	5†	196° ,, ,, ,, 11 ,,	All cultures and smears negative
Strawberries: Royal Sovereign, pH 3·38	(a) Water bath: 165° F in 1½ h., held 10 min.	7†	154° Over 150° for 10 min.	Slight breakdown due to *Byssochlamys fulva* in inoculated jar; no other apparent spoilage
	*(c) Pressure: 5 lb. for 3 min.	6†	— —	No apparent spoilage
	*(d) Oven: 250° F for 45 min.	5†	140° —	2 jars (1 inoculated) showed breakdown due to *Byssochlamys fulva*; no other apparent spoilage
	(f) Canning: 3 min. to re-boil, held 16 min.	7†	— —	No apparent spoilage

* Processes subsequently altered (see Table IV)
† One sample inoculated with spores of *Byssochlamys fulva*

Table II (*contd.*)

Fruit, variety and pH of fresh fruit	Method of processing *	Number of samples	Maximum temperature in coolest part of container, ° F	Results after storage for 2–2½ years
Tomatoes: whole in brine, pH 4·27	(*a*) Water bath: 190° F in 1½ h., held 30 min.	5†	188° Over 180° for 28 min.	All cultures amd smears negative
	*(*c*) Pressure: 5 lb. for 7 min.	6†	204° ,, ,, ,, 39 ,,	
	*(*d*) Oven: 250° F for 1½ h.	5†	177° —	1 jar unsealed, *Endomyces* sp. isolated
	(*f*) Canning: 5 min. to re-boil, held 27 min.	5†	204° ,, ,, ,, 27 ,,	All cultures and smears negative
Tomatoes: solid-pack, pH 4·26	*(*a*) Water bath: 190° F in 1½ h., held 30 min.	5†	172°	Inoculated jar unsealed and obvious spoilage; cultures and smears from other jars negative
	*(*c*) Pressure: 5 lb. for 7 min.	6†	158°	Obvious spoilage in 5 jars, 4 of which were unsealed and contained mixture of moulds, yeasts, and bacteria, including *Endomyces* sp. and lactobacilli
	*(*d*) Oven: 250° F for 1½ h.	5†	155°	1 jar unsealed, *Endomyces* and yeasts isolated; cultures from other jars negative
	(*f*) Canning: 3 min. to re-boil, held 38 min.	5†	184° Over 180° for 8 min.	All cultures and smears negative

* Processes subsequently altered (see Table IV)
† One sample inoculated with spores of *Byssochlamys fulva*

There is also a considerable reduction of enzyme activity as the temperature approaches the maximum at which it can be demonstrated. In several processes discoloration due to enzyme activity was therefore very slight, even though the fruit was not heated sufficiently to inactivate the oxidase system completely.

The method of heating the fruit in an oven and adding the boiling liquid after processing, method (*d*), is, of course, one that gives no protection against oxidation, and any fruits with light-coloured flesh were very discoloured before the liquid was added. On this account the method cannot be recommended when processing such fruits.

Peroxidase activity remained in pears at temperatures considerably above that required to inactivate the oxidase system, but did not appear to have any adverse effect on the colour of preserved fruit.

Rates of heat-penetration

Typical heating–cooling curves obtained when stone-fruits were processed by the six different methods of bottling or canning studied are given in Figs. 1 and 2. Fig. 2 also shows the effect of the quantity of fruit processed when oven methods are used.

In order to simplify processing, fruits were grouped according to their pH values, density of pack, maximum temperatures permitting oxidase activity and the minimum temperatures of processing required. The tightness of the pack made a considerable difference to the rate of heat-penetration, and different processing times had to be considered for 'average' packs (approximately 11 oz. of fruit and 5 fl. oz. of liquid per 1-lb. jar), and tight packs in which the ratio of fruit to liquid was greater than this.

The time taken for the heat to penetrate to the 'cold spot' in a 2-lb. container was longer than in a 1-lb. jar under the same conditions, but as the larger jar also maintained its heat longer, increases in the processing times were not essential for the water-bath methods. Longer times were required for jars larger than the 2-lb. size.

In addition to satisfactory keeping quality, the texture of the product is of importance. Some fruits are bottled chiefly for pies, and so are re-cooked after they are taken from the jars. Rhubarb (included as a fruit for preserving) and gooseberries, when processed sufficiently for use in pies, were tough when required for immediate use, and alternative processing times are given for pie or for dessert use.

The way in which the fruits were grouped when processing requirements were calculated are given in Table III. The minimum internal process temperature of the fruits had to be sufficient to prevent survival of micro-organisms at the different pH levels, and to control

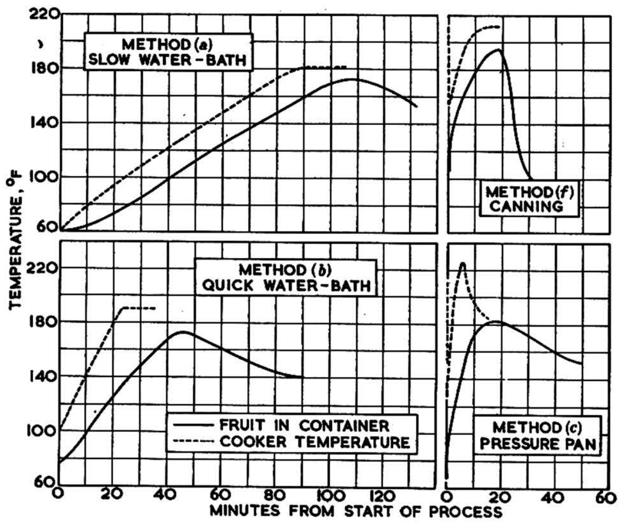

Fig. 1.—*Heating–cooling curves for stone-fruit in 1-lb. containers*

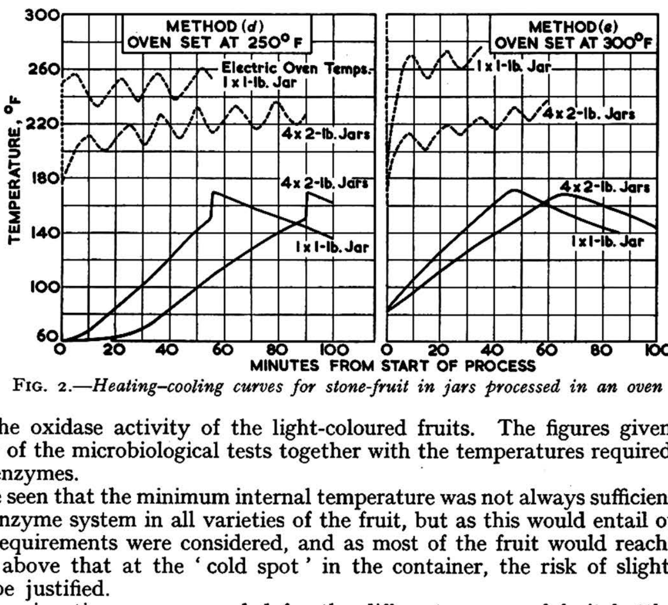

Fig. 2.—*Heating–cooling curves for stone-fruit in jars processed in an oven*

sufficiently the oxidase activity of the light-coloured fruits. The figures given were derived from a study of the microbiological tests together with the temperatures required for inactivation of the enzymes.

It will be seen that the minimum internal temperature was not always sufficient to inactivate the oxidase-enzyme system in all varieties of the fruit, but as this would entail over-processing when other requirements were considered, and as most of the fruit would reach temperatures considerably above that at the 'cold spot' in the container, the risk of slight discoloration was felt to be justified.

The processing times recommended for the different groups of fruit bottled by the five methods finally adopted are given in Table IV. The canning times have not been included, as they have not been altered from those previously published.

Fuel consumptions

The quantities of gas or electricity used when different loads of fruit in Groups I and IV were processed for the times given in Table IV are shown in Table V. Since there was a great variation depending on the type of equipment used, these figures are the minimum obtained for each process. As would be expected, it is usually more economical to preserve 8–10 lb. of fruit at a time than smaller quantities, but if it necessitates the use of a large container this may not be so, e.g. the large pressure-pans are more wasteful of fuel than the smaller ones.

Table III

Fruit	pH range	Maximum temp. permitting oxidase activity, °F	Minimum internal process temp., °F
Group I	2·7–3·8		
Soft fruit, average packs, including gooseberries and rhubarb for pies		—	157° or maintained over 150° for 20 min.
Apple slices		150–165°	
Group II	2·8–4·3		
Soft fruit, tight packs		—	as Group I
Gooseberries and rhubarb for dessert		—	165° or maintained over 160° for 20 min.
Most whole stone-fruit		163–185°	
Group III	2·8–4·3		
Apples, solid-pack		150–165°	as Group I
Strawberries, soaked		—	
Nectarines		—	165° or maintained over 160° for 20 min.
Peaches		—	
Plums, halved		163–185°	
Group IV	3·7–4·6		
Figs, in acidified syrup		—	183° or maintained over 180° for 15 min.
Pears		181–188°	
Tomatoes, whole in brine		—	
Group V	3·9–4·4		
Tomatoes, solid-pack		—	as Group IV

Table IV

Fruit processing times: method of processing

Fruit group (see Table III)	(a) Slow water-bath	(b) Quick water-bath	(c) Pressure pan
I	Cold to 165° F in $1\frac{1}{2}$ h. Maintain 10 min.	Warm to 190° F. 25–30 min. Maintain 2 min.	5 lb. pressure in 5–10 min. Maintain 1 min.
II	Cold to 180° F in $1\frac{1}{2}$ h. Maintain 15 min.	,, 10 min.	,, 1 min.
III	,, ,, ,,	,, 20 min.	,, 3–4 min.
IV	Cold to 190° F in $1\frac{1}{2}$ h. Maintain 30 min.	,, 40 min.	,, 5 min.
V	,, 40 min.	,, 50 min.	,, 15 min.

Fruit group (see Table III)	(d) Slow-oven		(e) Moderate-oven	
	Quantity processed		Quantity processed	
	1–4 lb.	5–10 lb.	1–4 lb	5–10 lb.
I	45–55 min.	60–75 min.	30–40 min.	45–60 min.
II	55–70 min.	75–90 min.	40–50 min.	55–70 min.
III	Not recommended		50–60 min.	65–80 min.
IV	80–100 min.	105–125 min.	60–70 min.	75–90 min.
V	Not recommended		70–80 min.	85–100 min.

The quantities of fuel used in heating the jars, lids, syrup, etc. have been included when these have to be applied hot. Since most methods of processing entail preliminary heating of water or an oven before the jars of fruit are put in, there will be saving on fuel if a second batch is processed immediately after the first. The saving will be found when the amounts of fuel used in the initial and subsequent processes in Table V are compared.

The order in which the processes are placed for fuel economy depends partly on the quantity of fruit being preserved. When the three 'loads' in Table V are averaged, the processes may be placed in the following order:

Single process		*Subsequent processes*	
Electricity	Gas	Electricity	Gas
Slow water-bath	Pressure pan	Canning	Canning
Pressure pan	Slow water-bath	Pressure pan	Pressure pan
Quick water-bath	Slow oven	Slow oven	Slow oven
Slow oven	Quick water-bath	Quick water-bath	Quick water-bath
Canning	Canning	Moderate oven	Slow water-bath
Moderate oven	Moderate oven	Slow water-bath	Moderate oven

It will be seen from Table V that the oven methods (*d*) and (*e*) are more extravagant on fuel than the other processes if only one jar of fruit is being bottled, but this is not necessarily so when larger quantities are processed.

Table V

Electricity and gas consumptions per 1 lb. jar or can of fruit

Method of processing	Load per batch, lb.	Single process: Group I fruits, Electricity, kwh.	Single process: Group I fruits, Gas, cu. ft.	Single process: Group IV fruits, Electricity, kwh.	Single process: Group IV fruits, Gas, cu. ft.	Subsequent processes: Group I fruits, Electricity, kwh.	Subsequent processes: Group I fruits, Gas, cu. ft.	Subsequent processes: Group IV fruits, Electricity, kwh.	Subsequent processes: Group IV fruits, Gas, cu. ft.
(*a*) Slow water-bath	1	0.57	4.3	0.91	6.2	0.57	4.3	0.91	6.2
(*b*) Quick water-bath	,,	0.83	5.7	1.03	6.8	0.54	4.3	0.73	5.4
(*c*) Pressure pan	,,	0.63	3.6	0.67	4.1	0.43	2.4	0.47	2.9
(*d*) Slow oven	,,	0.98	6.9	1.19	9.3	0.53	4.0	0.74	6.4
(*e*) Moderate oven	,,	1.09	7.4	1.31	10.0	0.44	3.4	0.76	6.0
(*f*) Canning	,,	0.45	3.6	0.52	4.5	0.21	1.9	0.28	2.8
(*a*) Slow water-bath	5	0.15	1.3	0.22	1.8	0.15	1.3	0.22	1.8
(*b*) Quick water-bath	,,	0.19	1.6	0.25	2.1	0.14	1.3	0.18	1.8
(*c*) Pressure pan	,,	0.25	1.2	0.26	1.4	0.19	0.9	0.20	1.1
(*d*) Slow oven	,,	0.26	1.9	0.31	2.6	0.15	1.3	0.22	2.0
(*e*) Moderate oven	,,	0.27	2.4	0.36	3.2	0.16	1.6	0.25	2.4
(*f*) Canning	,,	0.31	3.0	0.34	3.4	0.10	1.1	0.13	1.5
(*a*) Slow water-bath	8 to 10	0.13	1.2	0.19	1.5	0.13	1.2	0.19	1.5
(*b*) Quick water-bath	,,	0.17	1.5	0.21	1.8	0.13	1.1	0.17	1.4
(*c*) Pressure pan	,,	0.17	1.3	0.18	1.6	0.11	0.9	0.12	1.2
(*d*) Slow oven	,,	0.17	1.2	0.21	1.6	0.11	0.9	0.15	1.3
(*e*) Moderate oven	,,	0.20	1.6	0.24	2.0	0.13	1.2	0.17	1.6
(*f*) Canning	,,	0.20	1.7	0.23	2.0	0.09	0.9	0.11	1.2

Discussion

These studies have shown the complexity of giving recommendations for processing fruit. In arriving at the processing times recommended in Table IV, 640 heating–cooling curves were plotted for different kinds of fruit. The fruits in Group I (Table III) are all in the high-acid group, and the oxidase-enzyme systems of the apples are inactivated at comparatively low temperatures. A relatively high ratio of liquid to solid is necessary if the heat is to penetrate adequately in the times given. The texture of gooseberries and rhubarb, processed as recommended for this Group, will be firm, so that they will tolerate further cooking without undue breakdown. The fruits in Group II comprise the soft fruits, which are packed with a higher fruit/liquid ratio, but not 'solid packs', also the gooseberries and rhubarb, cooked sufficiently for serving without further heating, and most whole stone-fruit. The temperatures required to inactivate the oxidase-enzyme systems in the plums vary so considerably from one variety to another that it has been thought desirable to risk the possibility of slight discoloration in a few varieties for the sake of retaining a reasonably whole attractive product.

The fruits in Group III are those acid kinds that can be packed very tightly into the jars, as well as halved stone-fruit, and whole nectarines and peaches. The nectarines and peaches are not so acid as some fruits and also have oxidase-enzyme systems that are not readily inactivated by heat.

Group IV comprises figs, pears and whole tomatoes, all of which are in the higher pH ranges for fruits. In addition, the pears are very liable to enzymic discoloration. For this reason, more stringent processing conditions are necessary. Even so, the figs should be packed in acidified syrup, otherwise there is a risk that pathogenic organisms, if present, might develop.

No spoilage has been noted in whole tomatoes when processed for the times given for the Group IV fruits (Table IV), but very occasionally spoilage has been noted in the solid-pack tomatoes, processed for the times given for Group V. Further investigations are being continued on the resistance of the spores of anaerobic organisms allied to *Bacillus thermoacidurans* at different pH levels in tomato pulp. It appears at present that the spores are not destroyed, but only inhibited, by the lower pH levels of the tomatoes, even if processed for a short while at 212° F.

The advantages and disadvantages of the different methods of processing may be summarized as follows:

Method (a): slow water-bath.—This is recommended as the most reliable method to use if the appearance of the fruit is of paramount importance, but it does necessitate the use of a thermometer if it is to be followed accurately. It is one of the most economical in fuel when only one batch of fruit is to be processed.

Method (b): quick water-bath.—This method was evolved for those people requiring a quicker process than method (*a*). The appearance of the fruit is nearly as good as that obtained by method (*a*), and the quick water-bath method does not require a thermometer (as 190° F can be taken as the approximate simmering point) and needs a considerably shorter total processing time. It is intermediate in fuel consumption for either single or subsequent processes.

Method (c): pressure pan.—Careful timing is required to avoid either under-processing or over-cooking of the fruit when this method of processing is used, therefore the minimum and maximum times in which the 5 lb. pressure should be reached have been defined. As 5 lb. is the minimum pressure recorded by many types of pressure pans this was used but even so, some breakdown of over-mature fruit may occur. Since insufficient time is given to remove all the air in the cooker, the 5 lb. pressure per sq. in. is usually a mixture of air and steam pressure, registering about 225° F, and 1 minute at this pressure is sufficient for the more acid fruits. Owing to the great differences in the temperatures of the fruit and cooker in this short time of heating, a cooling period of 10 minutes before the pan is opened is, however, essential. This point requires stressing as the instructions given by some of the manufacturers of the cookers recommend cooling the cooker quickly and removing the jars as soon as atmospheric pressure has been reached, which is often after only a few minutes. If this were carried out, the maximum temperature of the fruit in the jar would frequently be below 150° F and spoilage would be almost inevitable. This method of processing is one of the most economical in fuel, especially when using gas.

Method (d): slow oven, 250° F.—Oven processing of bottled fruit is not so reliable as the water-bath methods but often more convenient for the housewife. In the past, the processing time for this method was left largely to the experience of the preserver, who kept the jars in the oven 'until the fruit looked cooked'. It was found that the temperature of the fruit in the centre of the jar at this stage was far below the desired minimum, but when the jar was filled with boiling syrup or water there was a rapid rise in temperature and, provided that the jars were not tightly packed, this might be sufficient to prevent spoilage. The difficulty remained in judging when the fruit was sufficiently cooked.

The cooling effect of the different loads in the oven is very marked in thermostatically controlled gas or electric ovens, and in some of the heat-storage cookers this problem is so serious that oven bottling cannot be recommended. The effect can be offset in the gas and electric and some solid-fuel ovens by varying the process time according to the quantity of fruit being processed; but such variations do not overcome the difficulty of uneven heating throughout the oven, so that the fruit in tall jars tends to be overcooked at the top before that at the bottom has reached a sufficiently high temperature. The method cannot be recommended when processing fruits with light-coloured flesh, as the warm, dry atmosphere encourages enzyme activity, and the fruit is spoilt in appearance and flavour before the boiling liquid is added at the end of the process. The amount of fuel needed is very similar to that required in method (*b*).

Method (e): moderate oven, 300° F.—This method was adapted from that recommended by one of the firms supplying gas cookers. It overcomes the difficulties of processing fruits with light-coloured flesh found in method (*d*), since the boiling syrup or water is poured on the fruit before being processed in the oven. This also gives a more even penetration of heat, can be used for 'solid-pack' fruits, and the time required in the oven is less than in method (*d*).

In the early experiments with this method, the jars were put on an asbestos mat on the oven shelves, but it was difficult to allow the exact amount of headspace for the expansion of the liquid to ensure that at the end of processing the jars were full but had not overflowed. Standing the jars in trays with deep sides was shown to be undesirable, but a flat baking-sheet, lined with newspaper to absorb any liquid, had no effect on the rate of processing, and was adopted as the most convenient procedure.

This method is the most extravagant of those studied from the point of view of fuel consumption, particularly if only one batch of jars is to be processed, but it has advantages over method (*d*) in ease of manipulation, and it can be used for all fruits.

Method (*f*) : *canning*.—The advantages of canning over bottling are the rapid heat-transference possible through the metal container, so that comparatively short processing times followed by rapid cooling are used. The fruit is raised to a higher temperature than in the bottling methods, but, owing to the rapid cooling, the fruit is not broken down. The 1-lb. cans may safely be processed for 5 minutes less than the time recommended for the same fruit in an A2½ can, but if the full time is given, no over-cooking is apparent. It is the most economical method for fuel consumption if several batches of cans are to be processed, but not for a single process.

Conclusions

Studies of the pH values of different kinds of fruit, the temperatures required to inactivate the oxidase enzymes and to kill the micro-organisms likely to cause spoilage, and the rates at which the heat penetrates to the coolest part of the container have been made. Based on the results, new quick water-bath and steam-pressure processes have been developed and some of the processing times recommended for bottling fruit have been amended when the slow water-bath method is used. It was shown that the oven methods of bottling cannot be controlled as accurately as the water-bath methods, and the times of processing in the oven must be varied according to the quantity of fruit being processed. Recommended times are given for one process in a domestic oven controlled at 250° F, in which the jars of fruit are filled with boiling syrup or water after heating, and in another in which the jars are filled with fruit and boiling liquid before being processed in an oven controlled at 300° F.

The amounts of gas and electricity used in processing different quantities of fruit in the low and higher pH ranges have shown that the slow water-bath and steam-pressure methods are the most economical on fuel for a single batch of fruit, whereas canning is the best if several batches of fruit are to be processed consecutively. The oven method, controlled at 300° F, was generally the most extravagant of those tested.

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References

[1] Cameron, E. J. & Esty, J. R., *Food Res.*, 1940, **5**, 549
[2] Stern, R. N., Hegarty, C. P. & Williams, O. B., *Food Res.*, 1942, **7**, 186
[3] Becker, M. E. & Pederson, C. S., *J. Bact.*, 1950, **59**, 717
[4] Baumgartner, J. G., 'Canned Foods', 1943, p. 24 (London: Churchill Ltd.)
[5] Olliver, M. & Smith, G., *Ann. Bot.*, 1933, **71**, 196
[6] Gillespy, T. G., *Rep. Fruit Veg. Pres. Sta. Campden*, 1946, p. 61
[7] James, D. P. & Crang, A., *Rep. agric. hort. Res. Sta. Bristol*, 1948, p. 234
[8] Crang, A. & Kendall, L., *Rep. agric. hort. Res. Sta. Bristol*, 1949, p. 163
[9] Fagerson, I. S. & Esselen, W. B., junr., *Food Tech., Champaign*, 1950, **4**, 411
[10] 'The A.B.C. of Preserving', 2nd edn. (London: H.M.S.O.)
[11] Crang, A., 'Preserves for All Occasions', 1953, p. 24, 4th edn. (London: Penguin Books Ltd.)
[12] Goldmann, M. E., *Food Res.*, 1949, **14**, 275
[13] Adam, W. B., *Food*, 1950, p. 4

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