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A vegetable oiling agent for dried fruits

S. P. KOCHHAR AND J. B. ROSSELL

Summary

The suitability of an exceptionally stable vegetable oil blend, Durkex 500, for coating sultanas (at a level of 0.5%) was examined over a storage period of 1 month at 25°C and of 16 weeks at 37°C. During the early stages of storage at 25°C, the flavour of sultanas, either uncoated or coated with food grade paraffin, was slightly superior to that of sultanas coated with Durkex 500, or with a 50 : 50 blend of it with paraffin. Flavours such as musty, cardboardy, stale, etc. were reported in the coated sultanas, while sharp and acidic flavours were described in the non-oiled control sultanas. After 8 months at 25°C the uncoated sultanas appeared dull and dried up, and started clumping. However, the average flavour score of all the samples of sultanas were not significantly different (at a 5% level) from the acceptable flavour score of 5 at the end of the 25°C storage tests. The accelerated storage test study on the sultanas at 37°C gave generally similar, but somewhat erratic results.

Induction period data at 100°C were found to correlate well with the organoleptic acceptance of Durkex 500 and its 50:50 blend with paraffin in the sultanas evaluated in this work. The results show that stable oils such as Durkex 500 are acceptable vegetable coating oils for dried fruits, enabling manufacturers to conform with the Food Additives and Contaminants Committee recommendation that reduced levels of mineral oil should be used in fruit coatings.

Introduction

Dried fruits such as sultanas, currants, raisins and prunes have traditionally been coated with a thin film of mineral oil. This 'oiling' of the dried fruit is necessary for a number of reasons, the background to which, and the reasons for the choice of mineral oil, having been discussed by Goldenberg (1976). The

Authors' address: Leatherhead Food RA, Randalls Road, Leatherhead, Surrey KT22 7RY.

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oiling agent maintains the 'free-running' properties of the fruit and prevents aggregation into large clumps. This is important for industrial concerns which employ modern flow-line washing machinery incapable of cleaning aggregated clumps effectively. Such clumps must therefore be separated by hand or discarded. Oiling also prevents further drying out by loss of moisture which would otherwise result in crystallization of sugars on the suface of the fruit; it retards ageing and degeneration of the fruit, provides sheen and generally improves the appearance. In addition oiling inhibits the development of insect eggs or larvae which may be present on the surface of the fruit.

Liquid paraffin of food grade quality has been widely used for oiling as it satisfies the above needs, it has a low viscosity enabling it to be easily applied in a thin coat, it is inexpensive, and most importantly it is stable toward oxidation and does not give rise to any off-flavours during the average shelf life of the fruit. This shelf life should be at least 1 year as it is normal to store fruit for use between the annual harvests.

In 1975, The U.K. Food Additives and Contaminants Committee (FACC, 1975) reviewed the use of mineral hydrocarbons in foods, and in relationship to the oiling of dried fruit concluded that, on balance, the use of mineral hydrocarbons in dried fruit should continue to be permitted. However they were not satisfied that the permitted level (The Mineral Hydrocarbons in Food Regulations, 1966) of 0.5% is technologically necessary and recommended that it should be reduced to 0.25%.

They further recommended that research should continue with the object of finding an effective alternative to the use of mineral oil.

It is understood that the Food Industry reacted against these recommendations, saying that a level of 0.25% is too low for an effective coating and a compromise was reached in which the new level will be 0.4%. So far, however, no such revised legislation has reached the statute book.

Alternative coating substances such as rape seed oil, cotton seed oil and specially 'tailored' partially hydrogenated vegetable oils have been tested (Goldenberg, 1976) but found to result in off-flavour development during storage. Wisniak (1977) has described the use of hydrogenated jojoba oil for the waxing of fruit, but the oil is not available on a commercial basis and in any case may not be approved for use in food. As this vegetable product is in fact a liquid wax which comprises esters of long chain alcohols with erucic acid, it is unlikely to gain rapid approval in view of the actions taken in food legislation (Erucic Acid in Food Regulations, 1977) and the associated concern about the presence of erucic acid in foodstuffs.

Durkex 500, a high stability liquid vegetable oil blend, has been successfully employed to coat dried fruits in other countries. In Australia, this oil has essentially replaced mineral oil in the commercial production of sultanas (Green, 1981).

In view of its reported use elsewhere and with regard to the FACC recommendation that research should be carried out with the aim of finding an effective alternative to mineral oil, the current study reports on the evaluation of Durkex

500 as a dried fruit coating, when used alone and in combination with mineral oil up to a total level of 0.5% coating oil.

Materials and methods

The fresh, dried, unoiled sultanas, the edible liquid paraffin oil, and the high stability liquid vegetable oil Durkex 500 were supplid by SCM Durkee Industrial Foods, Slough, U.K. Durkex 500 is a mixture of highly stable rancidity resistant oils derived by fractional crystallization of a partially hydrogenated blend of cotton seed and soya bean oils. The product is manufactured by the Durkee Food Division – SCM Corporation, Ohio, U.S.A., under U.S. patent 2972541 (Cochran *et al.*, 1961). Typical properties of Durkex 500 are given in Table 1.

Table 1. Typical properties of Durkex 500

Taste	Bland
Smell	Odourless
Colour (Lovibond) 133.4 mm cell	7.0 Red, 70.0 yellow (max)
Free fatty acids	0.05% (max) as oleic
Iodine value	76.5
Wiley melting point (°C)	21.7
AOM stability (hr)*	355
Solid fat content	
Temperature (°C)	Percentage
10.0	24.9
21.1	5.5
26.7	0.8
33.3	0.0
Fatty acid composition	
Carbon No.	Weight percentage
C8:0	0.2
C10:0	0.1
C12:0	1.2
C14:0	0.7
C16:0	9.2
C16:1	0.7
C17:0	0.1
C18:0	5.7
C18:1	76.0
C18:2	5.9
C18:3	0.1
C20:0	0.1
Total	100.0
Trans acids (%)	42.6

*AOCS (1980).

These data were provided by Durkee Food Division – SCM Corporation.

The oxidative stabilities at 100°C of Durkex 500, liquid paraffin, and a blend of the two, were determined by measurement of the induction period (IP) at 100°C, using the FIRA/Astell apparatus, details of which have been published by Meara & Weir (1976).

The samples of sultanas were prepared by separating clumps of the unoiled sultanas, removing any stalks and other foreign matter. The cleaned fruit was then placed in a dragee pan rotating at a slow speed. The required weight of the coating agent to produce a coating level of 0.5% by weight was sprayed on to the fruit, the tumbling and rotation of the pan being continued for a further 15 min in order to ensure a uniform coating.

The control (cleaned, uncoated) and the coated sultanas were put into a number of plastic bags (size, 12.7×22.9 cm; film thickness, 38×10^{-6} m; each bag containing about 225 g of the fruit). The bags were heat-sealed carefully so that there was a minimum headspace. The separate bags of sultanas from a particular set were then placed in larger plastic bags and stored in the dark at 25 and 37°C respectively.

The samples of sultanas were periodically taken out for organoleptic assessment. The flavour, appearance, clumping, etc. of the sultanas were evaluated by an experienced taste panel, a scoring system of from 1 (very poor) to 9 (very good) being used. The average flavour score of each sample was then calculated as the average value from the total number of panel members giving flavour scores within 2 points of the average score.

Results and discussion

The average flavour scores of the samples of sultanas with time of storage at 25 and 37°C are shown in Figs 1 and 2 respectively.

It can be seen from Fig. 1 that the average flavour scores of all the samples of sultanas decreased significantly after a storage period of 1 month at 25°C. Over a storage period of 14 months, the control sultanas, which were not oiled, had given slightly higher flavour scores than those of the sultanas coated with Durkex 500 and its 50 : 50 blend with paraffin at the comparable time. The paraffin-coated sultanas, with one exception, were scored slightly higher than the sultanas coated with the other oiling agents at any particular time. However, the non-oiled control sultanas were found to clump together after a storage period of 8 months at 25°C. Further, these sultanas appeared to be very dull and dried up.

Over this period of storage, the paraffin-coated sultanas were also slightly stuck together. After a storage period of 12 months at 25°C, the sultanas coated with Durkex 500 and its 50 : 50 blend with paraffin showed slight signs of clumping. Flavours such as cardboardy, musty, stale, etc were reported to be developing in the coated sultanas on storage at 25°C. On the other hand, sharp and acidic flavours were described in the control sultanas. During the early stages of storage, the development of flavours in the Durkex-500-coated

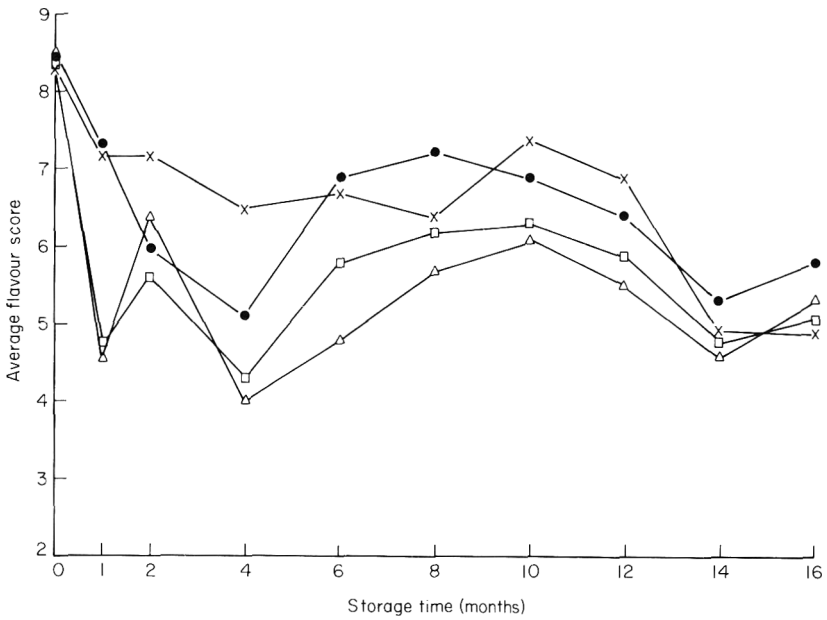

Figure 1. Variation of average flavour scores of sultanas with time of storage at 25°C. ×, Control (no oiling agent); △, Durkex 500; □, Durkex 500 and paraffin; ●, paraffin.

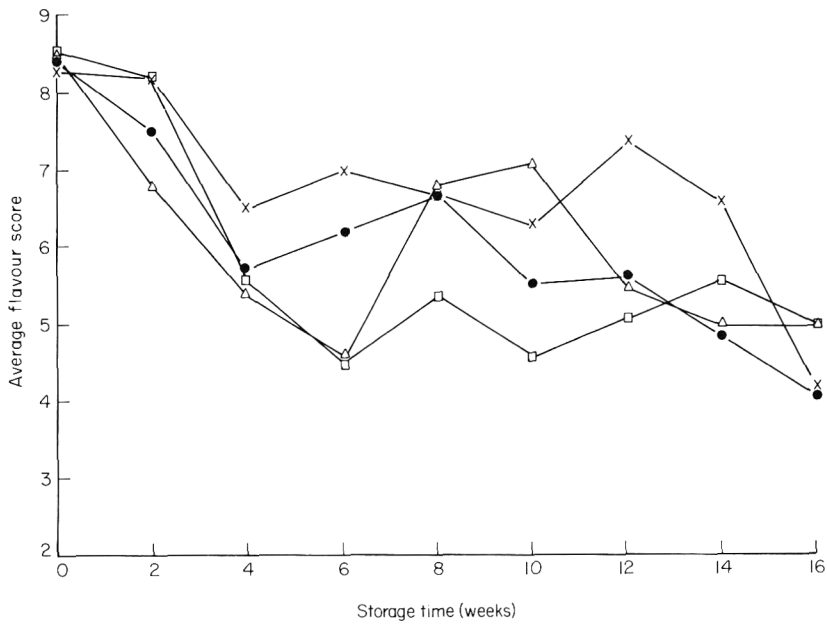

Figure 2. Variation of average flavour scores of sultanas with time of storage at 37°C. Key as for Fig. 1.

sultanas was slightly more pronounced. It is noteworthy that the average flavour scores of all the samples of sultanas were not significantly different (at 5% level) from the acceptable flavour score of 5, after 16 months' storage at 25°C. However, the non-oiled control sultanas, although of acceptable flavour, would have been unacceptable in view of the pronounced clumping and inferior visual appearance.

The storage tests at 37°C (Fig. 2) showed that the control samples of sultanas usually gave the highest scores throughout 16 weeks' storage. The average flavour scores of the sultanas coated with the different oiling agents seemed to be more or less the same up to the storage period of 16 weeks.

During the storage period of 16 weeks at 37°C, all the sultana samples, and particularly the control, were found to be dried up, the latter having started clumping after only 4 weeks' storage at 37°C. The liquid-paraffin-coated samples were the next to clump together after 8 weeks' storage. After 12 weeks' storage, the sultanas coated in Durkex 500 and its 50:50 blend with paraffin were found to be sticking together. The panel members again mentioned that various flavours such as acidic, cardboardy, musty, etc. developed in the samples of sultanas during the later stages of storage tests at 37°C.

The paraffin-coated and uncoated samples were generally better as regards flavour than the samples coated with Durkex 500 and the Durkex/paraffin mixture. This picture was much clearer at 25 than at 37°C when the relative scores were much less consistent. The accelerated test at 37°C was not very good for forecasting what would happen at room temperature. In spite of the relative flavour superiority of the paraffin and control samples, the difference was not significant.

Table 2. Induction period at 100°C of the oiling agents used and of some vegetable oils

Material		Induction period (hr)	
Oiling agents			
Durkex 500		198	
Durkex 500 and liquid paraffin (50:50)		304	
Liquid paraffin		307	
General purpose vegetable oils	*Mean*		*Range*
Sunflower seed oil	9		6–12
Cotton seed oil	6		4–7
Groundnut oil	16		13–21
Maize oil	7.5		5.5–10
Soya bean oil	8.5		7–10.5
Partially hydrogenated soya bean oil (iodine value = 80.6, C18:3 = trace)		49.1	
High erucic rape seed oil		9	
Partially hydrogenated high erucic rape seed oil (iodine value = 80.3; C18:3 = trace)		109	

The IP's at 100°C of Durkex 500, liquid paraffin and the 50 : 50 blend of the two are given in Table 2 together with those of some typical general purpose vegetable oils chosen at random and believed to be representative of the type of processed vegetable oil previously evaluated in this application. It is clear that the IP's of the coating agents employed in this study are very much higher than those of the general purpose vegetable oils including those which had been partially hydrogenated. These oxidative stability data obtained on the oils provided a rationale for the poor flavour stability reported by Goldenberg (1976) for vegetable oils and partially hydrogenated vegetable oils in dried fruit application. These data further explain the reported commercial acceptance of Durkex 500 for dried fruit application. Finally, the IP data correlates well with the organoleptic acceptance of Durkex 500 and blends of Durkex 500/mineral oil in the dried fruit evaluation reported in the current study.

Conclusions

This study on the performance of a high stability oil (Durkex 500) has shown that the flavour of sultanas (stored at 25°C), uncoated or coated with paraffin alone, was slightly superior to that of sultanas coated with a high stability liquid vegetable oil (Durkex 500); or a 50 : 50 blend of this oil with paraffin. However, after 14 months' storage at 25°C the difference was very slight and all samples were scoring close to the 'acceptable' score of 5. During storage at 37°C, the results were generally similar but somewhat more erratic. The sultanas coated with Durkex 500 or a 50 : 50 blend with liquid paraffin resisted clumping and had a more attractive visual appearance for much longer than those coated with paraffin alone or left uncoated. This aspect of clumping was more significant at 37°C, contrary to expectation, but may become even more pronounced at temperatures 20°C below when the oils crystallize.

Oxidative stability data obtained on the oils provide a rationale for the poor flavour stability reported by Goldenberg (1976) for vegetable oils and partially hydrogenated vegetable oils in dried fruit application. These data further explain the reported commercial acceptance of Durkex 500 for dried fruit application. Finally, the IP data correlates well with the organoleptic acceptance of Durkex 500 and blends of Durkex 500/mineral oil in the dried fruit evaluation reported in the current study. It is therefore our view that the recommendation (FACC, 1975) that the limit of 0.25% maximum inclusion of mineral hydrocarbons in dried fruits can be met without encountering the technical problems feared by the industry, and that this can be achieved by the use of suitable blends of food grade liquid paraffin oil with a high stability liquid vegetable oil of the Durkex 500 type at a total coating level of 0.5%. Where the very longest shelf lives of 12–18 months are not likely to be demanded then high stability liquid vegetable oils such as Durkex 500 will be found to be satisfactory in their own right when used at the 0.5% level.

Acknowledgments

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The preparation of quick-cooking dehydrated vegetables by high temperature short time pneumatic drying

K. S. JAYARAMAN, V. K. GOPINATHAN, P. PITCHAMUTHU AND P. K. VIJAYARAGHAVAN

Summary

The technique of high temperature short time (HTST) pneumatic drying, when applied to a variety of vegetables as a pre-treatment prior to conventional modes of hot air drying, brought about porosity in the products and resulted in considerable reduction in their drying and rehydration times with improvements in texture and other rehydration characteristics. The HTST dried vegetables had lower bulk density and superior rehydration characteristics. A starchy cell structure was essential for satisfactory expansion by the technique and low starch vegetables failed to expand.

Introduction

Dehydration of vegetables especially in piece form to low moisture levels by the conventional hot air drying techniques is known to result in irreversible textural changes in the products mainly due to shrinkage and diffusion of solutes accompanying the slow drying processes and thereby yield products which do not rehydrate quickly into structures resembling the freshly cooked materials. One approach to solve this problem is to dehydrate to intermediate moisture levels (about 30–50%) by soak infusion (osmosis) using solutions containing salt, sugar and glycerol along with an antimycotic to yield products that can be eaten as such (Karel, 1973) or by soak infusion with additives combined with partial hot air drying yielding products requiring a short rehydration prior to consumption (Jayaraman & Das Gupta, 1978). Such products have, however, relatively less stability as compared to the low moisture ones due to increased lipid oxidation and browning reactions occurring at the higher water activity associated with them.

Authors' address: Defence Food Research Laboratory, Jyothi Nagar, Mysore-570011, India.

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As regards low moisture dehydrated vegetables, attempts made earlier to minimize shrinkage and improve rehydration characteristics included pre-treatments with additives like glycerol prior to drying (Neumann, 1972; Shipmann *et al.*, 1972) and flashing techniques such as explosive puffing (Cording *et al.*, 1963), vacuum puffing (Eapen & Ramanathan, 1966), centrifugal fluidized bed drying (Brown, Farkas & De Marchena, 1972) and deep fat frying. High temperature pneumatic drying was used by Neel *et al.* (1954) to improve redhydration characteristics of dehydrated potato granules and by Harrington and Griffiths (1950) to make potato puffs suitable for direct eating.

Our earlier studies (Jayaraman *et al.*, 1980) showed that a high temperature short time (HTST) pneumatic drying treatment at 170–200°C for 4–6 min when applied to a number of cooked pulses prior to conventional hot air drying brought about porosity in the products and resulted in considerable reduction in their drying and rehydration times with improved rehydration characteristics. In view of its simplicity, applicability of this technique to a number of vegetables to produce quick cooking dehydrated vegetables was studied. Results of these studies are reported in this paper.

Materials and methods

Raw materials

Vegetables of proper maturity and quality suitable for dehydration were procured from the local market and used in the studies. These included potato, green peas, carrot, sweet potato, elephant yam (*Amorphophallus campanolatus*), colocasia (*Colocasia esculenta*) and raw plantains (cooking variety).

Green peas were depodded while all the other vegetables were washed, peeled, trimmed, diced using a mechanical dicer (O'Brien Inc., U.S.A.) to give ¼-in cubes and screened to remove fines.

Blanching

The diced vegetable pieces were blanched in boiling water containing 0.1% potassium metabisulphite (KMS) for a period of 5 min for potato, carrot and yam and for 3 min for colocasia, sweet potato and plantain.

Green peas were soaked in 2% Na_2CO_3 for 30 min, washed free of alkali and then blanched in boiling water containing 0.4% KMS, 0.1% MgO and 0.1% $NaHCO_3$ for 5 min to stabilize the green colour.

Dehydration

The blanched vegetable dice was exposed initially to air at a high temperature for a short time (between 160 to 180°C for 8 min depending upon the vegetable) in a laboratory model HTST pneumatic drier designed and fabricated for the

purpose and used earlier in the treatment of pulses (Jayaraman *et al.*, 1980). The method employed was essentially the same as for pulses using an air velocity of about 1500 ft/min and batchwise drying with a feeding rate of 250 g/batch.

The HTST dried vegetable dice was collected and subsequently dried to 5% moisture in a conventional hot air drier—a cabinet drier at 60–70°C or a fluidized bed drier at 60°C.

Using different time–temperature combinations for each vegetable the optimum conditions for HTST drying were chosen based on maximum puffing effect combined with minimum scorching and rapid rehydration to give a soft product.

Drying times and curves

Samples were drawn at intervals of 2 min during HTST drying and every 15 min during cabinet or fluidized bed drying and their moisture contents were estimated by drying in air oven at 100°C to constant weight. Drying curves were drawn by plotting g moisture/g solids *vs* time of drying in minutes for the various modes of drying, namely, direct tray drying and fluidized bed drying (untreated controls), HTST plus tray drying and HTST plus fluidized bed drying for comparative evaluation and the total time required to dry to 5% moisture calculated.

Bulk density

To assess the extent of porosity imparted to the vegetable pieces by HTST drying, bulk density (g/cm^3) of the dried vegetable dice was determined using rape seed (100 g) by measuring the volume of seed displaced by 50 g vegetable with a 250 ml measuring cylinder.

Cooking time and rehydration characteristics

Cooking time was determined by the time taken for the product to become soft in the core when boiling 5 g material with 100 ml water.

Rehydration ratio was determined by boiling 5 g material with 100 ml water for a period equal to the cooking time as determined above, filtering over a Buchner funnel and weighing immediately. The ratio was calculated as weight of material after cooking to that before cooking.

Coefficient of rehydration, which is a measure of the degree of return to the original state, was calculated following the formula given by Von Loesecke (1955).

Rehydration curves were drawn by plotting against time of cooking the percentage moisture in the product after boiling 5 g in 100 ml water for varying periods of time.

Texture studies

For an objective assessment and comparison of the texture of the rehydrated products treated by HTST and conventional modes of drying, measurements were made for all vegetables except peas using Warner–Bratzler shear press (The G.K. Electric Mfg. Co., U.S.A.; capacity = 10 kg with 20 g division).In order to eliminate errors due to individual size differences, vegetable strips of ¼-in cross section were obtained using the standard laboratory dicer (O'Brien Inc., U.S.A.) and dried by HTST and conventional modes of drying. Pieces of uniform dimension were selectively rehydrated and used for texture measurement. Softness was expressed in terms of the force (kg) required to cut the strip across (0.6 cm^2 cross section) by the jaws of the instrument, as average of minimum eight measurements using eight different pieces.

Analytical methods

Starch content of raw vegetables was determined by the AOAC (1970) procedure. *Beta* (β)-carotene in carrots and total chlorophyll in green peas at various stages of processing and drying were also determined by the AOAC (1970) methods. The spectrophotometric method was used for the estimation of total chlorophyll.

Results and discussion

Drying characteristics

Moisture contents of the vegetables amenable to HTST drying at various stages of processing are given in Table 1 along with the optimum temperature–time combinations for HTST drying which enabled achievement of optimum

Table 1. Moisture content at various stages of processing and optimum temperature–time for HTST drying of vegetables

	Moisture (%)				Optimum temp. time for HTST drying	
Vegetable	Raw	Blanched	HTST treated	Final dried (tray)	Temp. (°C)	Time (min)
Potato	82.2	83.3	59.3	4.1	170	8
Green peas	71.1	72.5	38.3	3.4	160	8
Carrot	89.3	91.0	52.9	4.2	170	8
Yam	76.6	78.3	50.2	3.9	180	8
Sweet potato	73.6	78.6	53.8	5.3	170	8
Colocasia	80.2	83.3	54.2	4.9	170	8
Plantain (raw)	80.8	83.3	58.8	4.6	170	8

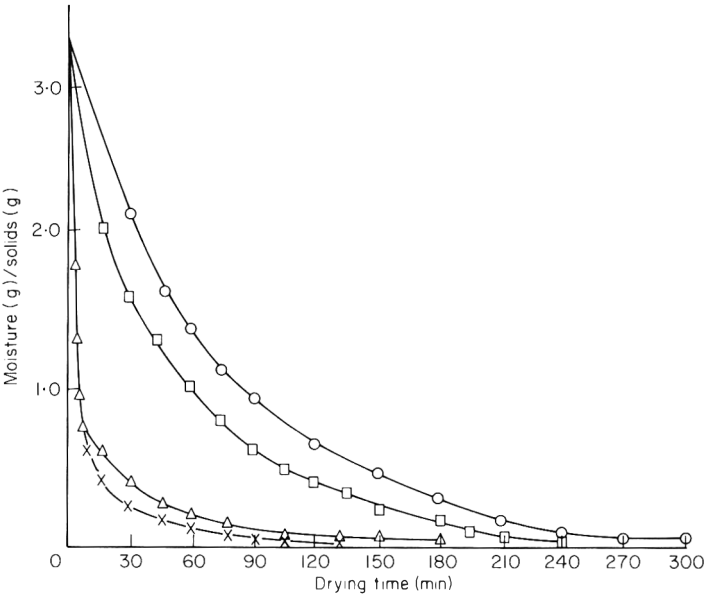

Figure 1. Dehydration curves for HTST drying of green peas as compared to conventional modes of drying. ○, Direct tray drying; □, direct fluidized bed drying; △, HTST plus tray drying; △–×, HTST plus fluidized bed drying.

porosity in the vegetable pieces leading to quicker drying and rehydration without scorching.

Dehydration curves plotted for the HTST drying followed by tray as well as fluidized bed drying for the various vegetables along with those for the direct tray or fluidized bed dried control samples showed that HTST drying brought down their moisture content from about 70–90% in the blanched material to about 40–60% in 8 min thereby drastically cutting down the constant rate drying period and resulting in an expanded structure due to flashing of water vapour which further reduced the time for subsequent finish drying in tray or fluidized bed drier. Typical curves obtained with green peas are shown in Fig. 1. A similar drying behaviour was observed with all the other diced vegetables.

Substantial reduction in the total drying time could be achieved by HTST drying as compared to controls (Table 2). Thus, HTST treatment prior to tray or fluidized bed drying reduced the total drying time by about half for green peas and yam and by one-third for the others. As compared to 5–6 hr required for conventional direct tray drying of the vegetables, drying could be completed in about 2–2½ hr for most of the vegetables by combining HTST drying with fluidized bed drying.

There was considerable decrease in bulk density of the dehydrated vegetables as a consequence of HTST drying treatment indicating puffing effect (Table 2). The decrease was highest in potato and colocasia (55–60%) and lowest in green peas (25%) with the values for others ranging in between (35–45%). This expanded structure was maintained throughout the subsequent drying operation.

Table 2. Drying time, bulk density and rehydration characteristics of HTST dried vegetables as compared to direct hot air dried vegetables

Parameter and mode of drying*	Potato	Green peas	Carrot	Yam	Sweet potato	Colo-casia	Raw plantain
Total drying time (min)							
I	330	300	300	360	300	300	300
II	285	240	225	270	240	240	240
III	210	150	195	180	180	180	180
IV	180	120	165	120	150	150	150
Bulk density (g/cm^3)							
I	0.62	0.51	0.44	0.50	0.69	0.55	0.50
II	0.62	0.51	0.44	0.45	0.62	0.50	0.45
III	0.25	0.38	0.24	0.29	0.45	0.26	0.33
IV	0.25	0.39	0.24	0.29	0.38	0.26	0.33
Reconstitution time (min)							
I	12	12	12	12	6	10	12
II	12	12	12	12	6	10	10
III	5	5	5	6	2	2	4
IV	5	5	5	6	2	2	4
Rehydration ratio†							
I	2.7	2.8	3.8	2.4	2.1	2.3	3.5
	4.1	3.1	4.1	3.2	3.3	3.9	4.5
II	2.8	2.8	3.8	2.4	2.2	2.4	3.6
	4.2	3.2	4.3	3.3	3.5	4.1	4.6
III	5.0	3.5	4.4	4.1	3.8	4.7	4.8
IV	5.1	3.5	4.5	4.1	3.8	4.7	5.0
Coefficient of rehydration†							
I	0.51	0.85	0.43	0.59	0.58	0.48	0.71
	0.77	0.94	0.46	0.79	0.92	0.81	0.91
II	0.52	0.85	0.43	0.59	0.61	0.50	0.73
	0.79	0.97	0.48	0.82	0.97	0.85	0.93
III	0.94	1.06	0.50	1.01	1.06	0.98	0.97
IV	0.96	1.06	0.51	1.01	1.06	0.98	1.01

* Mode of drying: I, direct tray; II, direct fluidized bed; III, HTST plus tray; IV, HTST plus fluidized bed.

† The two values given for I and II correspond to cooking times (a) same as required for the rehydration of HTST dried and (b) as required for their complete rehydration as given under reconstitution time above.

Analysis of the fresh vegetables amenable to HTST drying for starch content gave the figures: potato 11.8 and 66.3%; green peas 7.3 and 25.2%; carrot 2.6 and 24.3%; yam 12.9 and 55.1%; sweet potato 18.8 and 71.2%; colocasia 9.9 and 50.1% and raw plantain 10.6 and 55.0% on wet and dry weight bases respectively. The data showed that all of them had more than 25% starch on moisture-free basis. It was interesting to note that although carrot had a low starch content on fresh weight basis due to its higher moisture content as compared to others, it exhibited satisfactory expansion comparable to others.

Low starch vegetables, namely, horse radish, white radish, turnips, khol-khol, beet root, squash (red pumpkin), bell pepper, french beans, raw papaya and egg plant failed to expand when subjected to various time–temperature combinations between 150–200°C and 4–10 min thereby indicating that a starchy cell structure was essential for good puffing. Similar conclusions were reported earlier by Brown *et al.*, (1972) for centrifugal fluidized bed (CFB) puffing of vegetables.

Initial reduction in moisture content of the blanched vegetables by direct hot air drying to about 30–40% prior to HTST drying at 130–180°C resulted in scorching and failed to bring about satisfactory expansion indicating that the remaining moisture was insufficient to bring about the desired flashing effect by this technique. This is in contrast to explosive, vacuum and CFB puffing where lowering the initial moisture to an optimum level has been reported to be necessary for optimum puffing.

Rehydration characteristics

The HTST dried vegetables reconstituted in boiling water in less than half the time, and in some cases even less, as required for the untreated controls (Table 2).

Typical rehydration curves for HTST plus tray dried and direct tray dried potato dice are given in Fig. 2 which show the superiority of the HTST dried

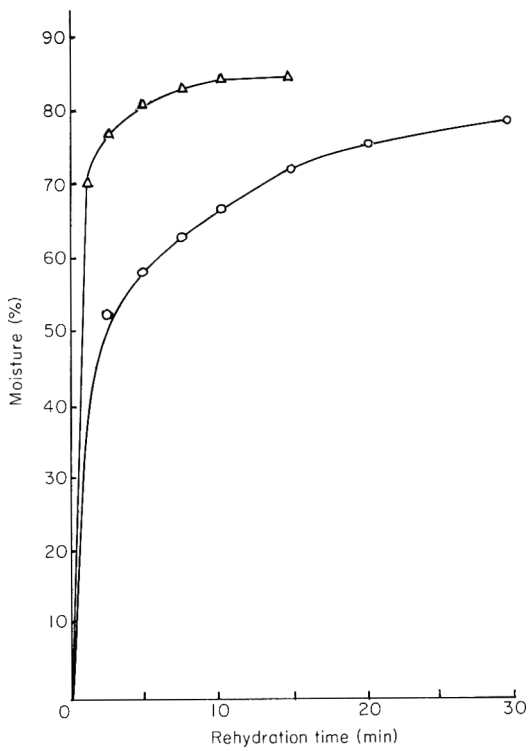

Figure 2. Rehydration curve for HTST plus tray dried as compared to direct tray dried potato. ○, Direct tray dried; △, HTST plus tray dried.

Table 3. Shear press readings* (kg) on raw, blanched and rehydrated HTST dried vegetables as compared to readings on rehydrated untreated controls

			Dried and rehydrated			
Vegetable	Raw	Blanched	Direct tray	Direct FB	HTST + tray	HTST + FB
Potato	0.99 (± 0.16)	0.40 (± 0.11)	0.56 (±0.90) [5]† 0.27 (± 0.07) [12]	0.44 (± 0.12) [5] 0.29 (± 0.07) [12]	0.16 (± 0.04) [5]	0.05 (± 0.05) [5]
Carrot	2.19 (± 0.22)	0.79 (± 0.22)	0.55 (± 0.15) [15] 0.34 (± 0.14) [12]	0.54 (± 0.18) [5] 0.40 (± 0.10) [12]	0.28 (± 0.13) [5]	0.21 (± 0.09) [5]
Yam	1.41 (± 0.28)	0.61 (± 0.07)	0.60 (±0.14) [6] 0.30 (± 0.11) [12]	0.59 (± 0.20) [6] 0.34 (± 0.07) [12]	0.27 (± 0.09) [6]	0.26 (± 0.08) [6]
Sweet potato	2.14 (± 0.32)	0.21 (±0.08)	1.90 (± 0.37) [2] 0.44 (± 0.13) [6]	1.60 (± 0.32) [2] 0.23 (± 0.09) [6]	0.11 (± 0.05) [2]	0.10 (± 0.04) [2]
Colocasia	1.05 (±0.14)	0.19 (±0.05)	0.63 (± 0.17) [2] 0.21 (± 0.08) [10]	0.85 (± 0.30) [2] 0.20 (± 0.05) [10]	0.03 (± 0.03) [2]	0.06 (± 0.03) [2]
Raw plantain	0.42 (± 0.03)	0.14 (± 0.06)	0.61 (± 0.18) [4] 0.20 (± 0.03) [12]	0.36 (± 0.10) [4] 0.19 (± 0.02) [12]	0.17 (± 0.08) [4]	0.12 (± 0.04) [4]

* Values given (mean ± s.d.) are based on measurements using minimum eight pieces (strips) of uniform cross section (¼ in.).

† Figures in square brackets represent cooking time in minutes.

product over the untreated control with regard to per cent water uptake and reconstitution time. Similar rehydration trends were seen with the other diced vegetables.

Rehydration ratios and coefficients of rehydration given in Table 2 for the different vegetables processed by the HTST technique along with those for the directly dried controls reconstituted for the same time as for the HTST treated products as well as for the period of their complete cooking again show the superiority of the HTST dried samples as regards water uptake. The control samples even when cooked to completion showed inferior rehydration ratios and coefficients as compared to rehydrated HTST dried samples.

These results are further supported by the texturometer readings given in Table 3. As seen from the data, the rehydrated HTST treated samples showed uniformly the lowest readings and therefore were softest as compared to the untreated controls rehydrated for the same period as for HTST treated products as well as for the period of their complete cooking.

Changes in β-carotene in carrots and total chlorophyll in green peas during drying

As the acceptability of dehydrated carrot and green peas is influenced to a large extent by their colour which is directly related to the concentration of β-carotene in the former and total chlorophyll in the latter, concentration of these two pigments was determined at various stages of processing from raw to finish dried in HTST treated samples as well as the untreated controls in order to assess comparatively the extent of loss occurring as a result of HTST treatment.

Results given in Table 4 show that the loss of β-carotene was about 5–8% more in HTST dried carrots as compared to the corresponding untreated controls but this was negligible and the final dried products retained their colour

Table 4. β-Carotene content in carrots and total chlorophyll content in green peas at various stages during processing and after HTST and direct hot air drying

	β-carotene in carrots		Total chlorophyll in green peas	
Stage	(mg/100 g)*	%	(mg/100 g)*	%
Raw	126.00	100.0	30.9	100.0
Blanched	135.90	107.8	30.1	97.3
After HTST treatment	94.92	75.4	27.9	90.3
HTST + FB dried	90.28	71.7	27.7	88.5
HTST + tray dried	82.64	65.6	26.1	84.5
Direct FB dried	100.60	79.8	27.0	87.3
Direct tray dried	89.02	70.7	25.7	82.9

* Moisture-free basis.

and visual appeal. Similarly the loss in total chorophyll in green peas in HTST dried samples was almost the same as in untreated controls and the HTST dried products retained their attractive green colour. These results clearly indicate that the HTST drying did not adversely affect the natural pigments to any significant extent.

Storage stability

HTST dried carrot and green peas when packed under nitrogen and other vegetables packed under air in paper–aluminium foil–polythene laminate pouches retained their acceptability up to 1 year under ambient conditions of storage (25–30°C) and showed negligible changes in rehydration characteristics.

Conclusions

A short time high temperature drying treatment in air at 160–180°C for 8 min applied to a number of piece-form vegetables prior to conventional tray or fluidized bed drying at 60–70°C results in an expanded structure in the products and brings about considerable reduction in their drying and rehydration times and improvements in rehydration characteristics. Only vegetables with a starchy cell structure are amenable to the process. The HTST treatment results in negligible loss of natural pigments such as carotenoids and chlorophyll and does not adversely affect shelf stability of the products. Being simple, the technique can be adopted for preparation of a number of quick cooking dehydrated vegetables for use as such and in convenience mixes.

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Drying kinetics of rough rice grain

R. AGUERRE, C. SUAREZ AND P. E. VIOLLAZ

Summary

It is shown that thin layer drying of rewetted rough rice grain in air flow may be interpreted in terms of Fick's law solution for diffusion from a sphere. Diffusion coefficients were calculated by non-linear regression analysis comparing actual and predicted values of grain moisture content. The activation energy of rough rice was calculated assuming an Arrhenius type equation for moisture diffusivity dependence on the inverse of the absolute temperature.

Introduction

The drying of cereal grains has been studied by several researchers (Becker & Sallans, 1955; Fan, Chung & Shellenberger, 1961) among others. Empirical correlations for the prediction of drying rates have been performed with more or less success, to predict drying behaviour and the variables which control the dehydration of thin layer (monolayer) grains.

It is generally agreed that the mechanism of moisture movement in grain drying may be interpreted in terms of Fick's law. Mathematical analysis of non-stationary-state diffusion in solids, was used by Becker & Sallans (1955) to analyse experimental wheat drying data using a Fick's law solution for short times. Liquid diffusion models have been presented for corn (Chu & Hustrulid, 1968) and peanuts (Young & Whitaker, 1971). More recently, an accurate description of moisture movement within sorghum grain have been conducted by Suarez, Viollaz & Chirife (1980).

Most research in rice grain drying, was conducted to determine the cause of broken grains (Kunze & Hall, 1965; Sharma, Tolley & Kunze, 1979; Kunze, 1979). But up to now, the information available in the literature about some fundamental aspects of rice drying, shows that different criteria were used to

Authors' address: Departamento de Industrias, Facultad de Ciencias Exactas y Naturales, Ciudad Universitaria, 1428 Buenos Aires, Argentina.

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interpret the experimental drying data of this material. Sharma *et al.* (1979) have used semi-theoretical equations in their analysis of rice drying to calculate the drying constants of the model. However, Steffe & Singh (1980) have reported that rough rice must be viewed as a composite body from the point of view of drying. Assuming that moisture migration may be interpreted in terms of Fick's law, the authors calculated the liquid diffusivity of the starchy endosperm, bran and hull separately.

It was the purpose of this work to study some fundamental aspects of rough rice dehydration in air flow with constant temperature and humidity content. Unlike reports in previous works, it was assumed in our analysis that diffusion resistance is distributed uniformly throughout the grain. Based on this assumption, the diffusion coefficients at four temperatures and the corresponding activation energy of the rough rice were calculated.

Materials and methods

Laboratory drier

This consisted of a centrifugal fan which blows air over six 2 kW electric bar elements (shielded) into a chamber and then upwards through a vertical duct. The inlet of the chamber is connected to a steam line; in this way air humidity was increased by blending heated air in the chamber with steam. Steam flow was carefully regulated to avoid the presence of water drops in the air at the outlet of the chamber. A flow meter was used to measure the air velocities during runs.

The inlet air dry bulb temperature was regulated (± 0.2°C) by an electronic proportional controller; wet and dry bulb thermometers were fitted in the duct to measure the relative humidity of the drying air.

A metal cup with screened bottom and lid served as drying chamber and was placed on the outlet of the duct.

Air velocities in the range of 12–18 m/sec were used in all drying experiments in order to minimize external resistances to moisture loss. In each drying experiment samples of about 10 g grains were used. The progress of the drying process was followed by weighing the sample at regular intervals of time on a precision balance (± 0.0001 g).

Materials

An Argentine variety of rice (Itapé, medium grain) was used during experiments; it was received with an average moisture content of about 14%. (All moisture contents are reported on a dry basis). Previous to drying the grains were humidifed. This was done by placing the grain in evacuated vacuum dessicators over a cup of pure water which provides a saturation humidity. The system was kept at 5°C until equilibrium was attained. The moisture content of the grains was increased by this process from about 14 to 22%.

Suarez *et al.* (1980) have found that this method of humidification gave better results than the usual procedure of adding liquid water to the grains (Becker & Sallans, 1955; Steffe & Singh, 1980).

Before humidification the grains were screened to obtain samples of more uniform size; a size distribution in the range of 3.3 and 2.8 mm was used for the experiments. For a better characterization a dial micrometer was used to measure the minor and major axis of sixty grains; average values were 2.19 and 8.81 mm respectively.

Besides this size characterization of the grain volumetric tests were undertaken to obtain estimates of the radii of the rice grains. By means of a pycnometer, using chlorobenzene as a fluid, the volume of twenty grains was measured, from which the equivalent spherical radius was easily calculated.

The moisture content of the grain was determined gravimetrically using a vacuum oven method at 70°C over magnesium perchlorate.

Determination of equilibrium moisture content

Measurements corresponding to the desorption branch of the isotherm were made. The details of the experimental technique have been published by Iglesias *et al.* (1975).

Results and discussion

Drying runs were conducted at different air velocities, in order to establish drying conditions under internal moisture diffusion into the grain. The results are shown in Fig. 1, in terms of m^* *versus* time, where $m^* = (\bar{m} - m_i)/(m_0 - m_i)$ with $\bar{m}$, m_i and m_0 being defined as the average moisture content, the equilibrium moisture content and the initial moisture content respectively. It can be seen that an increase of the air velocity from 12 to 18 m/sec, at a temperature of 70°C, does not modify the drying rate of grain. Hence it can be concluded that the total mass transfer resistance in all the drying experiments are due to the internal moisture diffusion within the grain, because the diffusivity is an increasing function of the temperature.

Reproducibility of drying runs, conducted at analogous experimental conditions of temperature, air velocity and relative humidity, are also shown in Fig. 1, which shows a very good agreement between pairs of drying runs.

In the analysis of dehydration of rough rice the following assumptions will be made: (1) At a given temperature, the diffusion coefficient is independent of moisture content. This fact has been observed by different authors (Becker & Sallans, 1955; Steffe & Singh, 1980; Suarez *et al.* 1980) in the range of practical moisture concentrations. (2) Equilibrium moisture content is constant with time. Given the high Biot number usually found for air drying of foods (Alzamora, Chirife & Viollaz, 1979) it seems quite reasonable to assume a

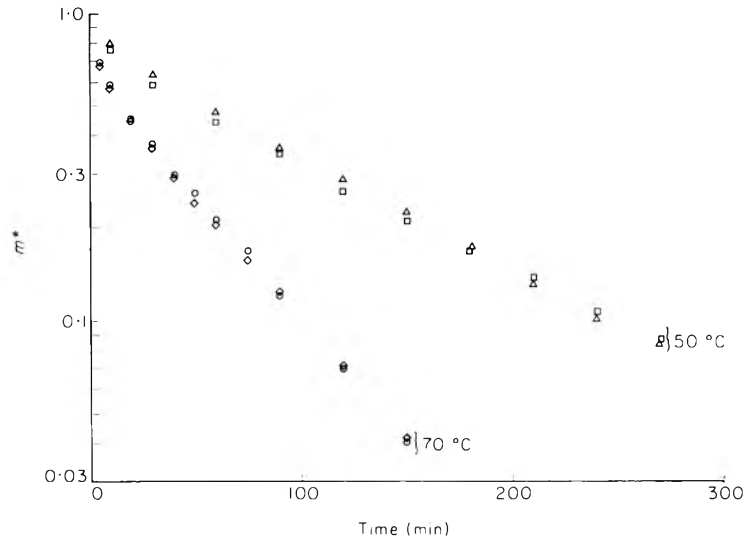

Figure 1. Effect of air velocity on drying curves. Reproducibility of drying experiments. △, □, 15 m/sec air velocity; ○, 12 m/sec air velocity; ◇, 18 m/sec air velocity.

constant value of the boundary conditions. (3) Grain temperature is constant during drying. Although the drying phenomenon is a simultaneous process of heat and mass transfer, dehydration may be analysed as a mass transfer process, without taking into account the internal grain resistance to heat transfer, when the moisture content is low. This assumption was used by Suarez *et al.* (1980) in the analysis of sorghum dehydration with accurate results. Becker & Sallans (1955) have found that during wheat drying, the temperature of the grain rapidly

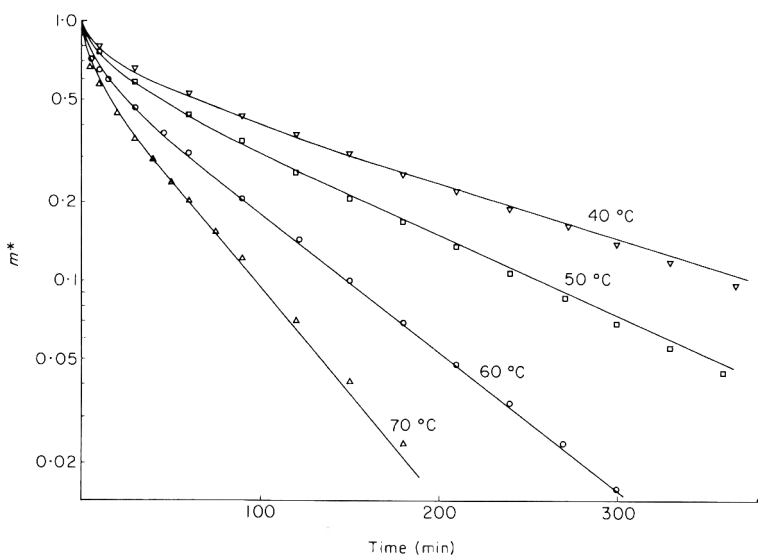

Figure 2. Comparison of predicted and experimental drying curves for rough rice grain. —, Predicted; ▽, □, ○, △, experimental.

reaches the air dry bulb temperature. Similar results have been observed by Fortes, Okos & Barret (1981) in wheat air dehydration. Further, as the Biot number for heat transfer usually found in food dehydration is very low, (Vaccarezza, Lombardi & Chirife, 1975; Alzamora *et al.* 1979), it is possible to neglect temperature gradients within the grain. (4) The effect of shrinkage on the rate of diffusion is neglected. This assumption is quite acceptable given the small difference in the grain size measured at the beginning and at the end of each run (which in all cases was less than 4%).

Drying curves for experiments conducted at four different temperatures, are shown in Fig. 2. The values of equilibrium moisture content for each set of drying conditions (temperature, relative humidity) were experimentally determined, as described in the Materials and methods section, and are given in Table 1. Those values were used as surface moisture content in calculation of m^*.

Table 1. Equilibrium moisture content

Air temperature (°C)	Relative humidity (%)	m_i (dry basis)
40.0	44.0	0.090
50.0	59.0	0.107
60.0	43.0	0.066
70.0	57.0	0.070

Calculation of the diffusion coefficient

From the hypothesis given previously the analytical solution to the moisture diffusion equation for a sphere was used to correlate the experimental drying data of rough rice.

Fick's second law solution in terms of dry basis moisture content may be written as follows (Luikov, 1968):

$$m^* = \frac{6}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{n^2} \exp\left(-\frac{n^2 \cdot \pi^2 \cdot D_{\text{eff}} \cdot \theta}{r^2}\right), \tag{1}$$

where D_{eff} is the moisture diffusivity (cm²/sec), r is the radius of sphere (cm) and θ is the time (sec).

Diffusion coefficients for rough rice were calculated by comparing actual and predicted values. With this object Equation (1) was programmed on a digital computer to simulate drying. For each set of drying conditions the diffusion coefficients were allowed to vary until the sum of the squared deviation between experimental and theoretical curves was a minimum.

The comparison of predicted and experimental drying curves, are shown in

Table 2. Regression values of the experimental drying curves

Temperature (°C)	Standard deviation	Intercept*
40.0	0.53×10^{-2}	0.661
50.0	0.31×10^{-2}	0.631
60.0	0.32×10^{-2}	0.624
70.0	0.39×10^{-2}	0.624

* Average value of intercept: 0.636.

Fig. 2. To estimate the accuracy of the curve fitting the standard deviation (s.d.), defined as

$$\text{s.d.} = \sum \left(\frac{(\text{OBS} - \text{PRE})^2}{(n-1)} \right)^{1/2}, \tag{2}$$

was calculated for each drying experiment and the results are given in Table 2 (OBS and PRE are the observed and predicted mean moisture contents, n being the number of experimental values).

Another criterion was used to confirm the validity of Equation (1) to predict the drying behaviour of rice grain. From Fig. 2 it can be seen that for $m^* < 0.3$, Equation (1) reduced to a straight line equation:

$$\log m^* = \log(6/\pi^2) - \frac{\pi^2 \cdot D_{\text{eff}} \cdot \theta}{2.3\, r^2} \tag{3}$$

From Equation (3) the theoretical intercept should be $6/\pi^2 = 0.608$. The intercept of various experimental drying curves, representing log m *versus* time for $m^* \leq 0.3$, were calculated and are given in Table 2. From this table it can be seen that the average value of the intercept is slightly greater than the theoretical one. This difference is due principally to the fact that rice grain does not have a conventional shape.

Assuming an Arrhenius type dependency of the diffusion coefficient with temperature

$$D_{\text{eff}} = A \exp(-E_a/RT)$$

the activation energy E_a, was calculated. The dependence of D_{eff} with temperature is shown in Fig. 3, and the activation energy calculated by linear regression analysis is 9.9 kcal/mol.

For rice grain the literature does not report activation energy values for the whole grain., Steffe & Singh (1980) obtained values of the activation energy for

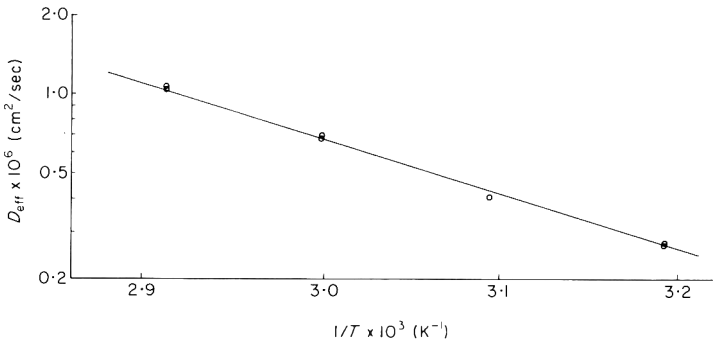

Figure 3. Effect of temperature on the diffusion coefficients of water in rough rice grain.

starchy endosperm, bran and hull which are 5.7, 10.2 and 14.7 kcal/mol respectively, but did not give any information for the whole grain. Sharma *et al.* (1979) used an empirical model to interpret rice drying data and found that the kinetic drying constants of the model satisfy the Arrhenius equation. However, the activation energy which results from their analysis, cannot be interpreted in terms of a diffusional drying process. In their drying experiments, Sharma *et al.* (1979) used air velocities in the range 0.5–1.0 m/sec, which are very different from the values reported in this work (over 12 m/sec) and those shown in Fig. 1, have made it possible to operate without external control of moisture loss. Therefore it must be expected that under the drying conditions in which Sharma *et al.* (1979) have conducted the experiments the drying rate is controlled by the air velocity and not by moisture diffusion within the grain.

Conclusions

It has been shown that rice dehydration in air flow may be interpreted in terms of Fick's law based on moisture concentration, given the accurate agreement between experimental and predicted runs. This model assumes that the diffusional resistance is distributed uniformly throughout the grain. As rough rice is a heterogeneous material as it is constituted by three different components, hull, bran and starchy endosperm, it is reasonable to think that the moisture adsorption capacity will be different for each of the respective constituents. However, from the point of view of drying kinetic analysis, it seems that this non-homogeneity of the body need not be considered; taking into account the results obtained in this work.

On the other hand, it appears that no difference in the values of diffusion coefficients of cereal grains obtained using rewetted materials instead of harvested ones, may be expected. Steffe & Singh (1980), performing statistical tests, concluded that the diffusion coefficients of fresh and rewetted starchy endosperm and bran were equal.

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Scanning electronmicroscopy studies of limed corn kernels for tortilla making

O. PAREDES-LÓPEZ* AND M. E. SAHARÓPULOS

Summary

Scanning elecronmicroscopy (SEM) was used to study changes in corn kernel structure during the lime treatment of the tortilla making process. The outside surface of the alkali-treated kernels (nixtamal) showed substantial structural alteration, which facilitate its separation. The aleurone and some pericarp layers are retained in nixtamal. Most of the germ remains attached to the starchy endosperm, and greatly contributes to the nutritional quality of the product. The cell walls of the horny and floury endosperm appeared noticeably affected in the preparation of nixtamal. The functional and nutritional properties acquired by nixtamal might be related to the structural modification as shown by SEM.

Introduction

Studies carried out in Mexico and Central America have paid particular attention to the nutritional properties of tortillas, a food made from corn boiled with lime, as the major staple diet of the population (Cravioto *et al.*, 1945). In the rural areas of this geographic region the consumption of corn provides about 70% of the calories and about one half of the proteins in the daily diet (Paredes-López & Gallardo, 1981). The importance of tortillas in Mexico may be appreciated by noting that the average annual *per capita* consumption is of the order of 120 kg. It is noteworthy that in some southern regions of the U.S.A., the tortilla making process is also quite popular (Martínez-Herrera & Lachance, 1979). Research studies have shown that during the liming of corn losses of some of the nutrients take place, but what is most interesting is the increase in amino acid availability and in general the noticeable improvement of the overall quality of

Authors' address: Depto. de Alimentos, ENCB, Instituto Politécnico Nal., Apdo. P. 42–186, México 4, D. F., México.

*Present address: CIEA del Instituto Politécnico, Unidad Irapuato, Apdo. P. 629, 36500 Irapuato, Gto., México.

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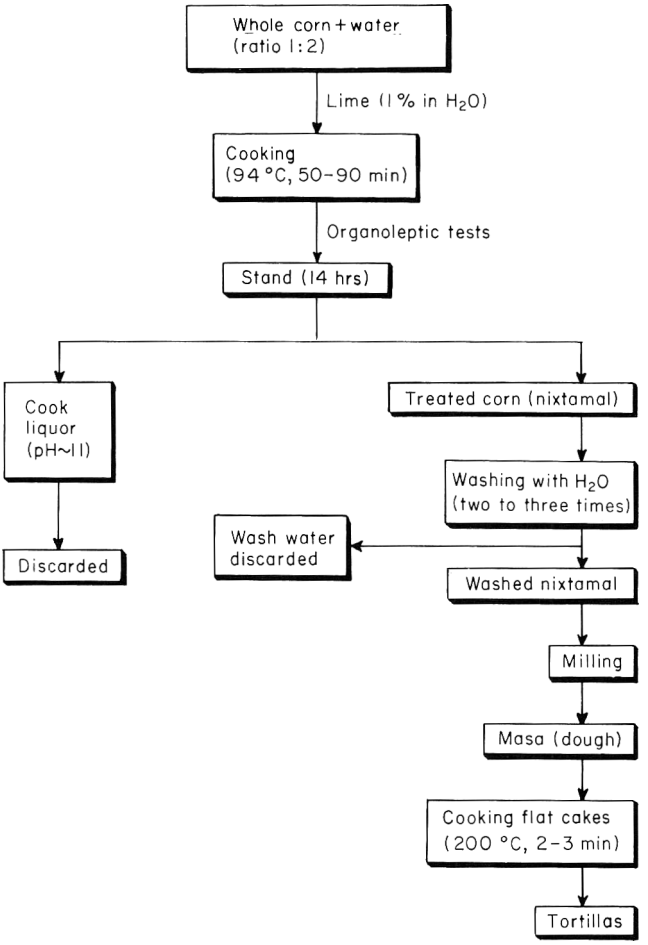

Figure 1. Process for tortilla preparation.

corn (Bressani, Paz y Paz & Scrimshaw, 1958; Cravioto *et al.*, 1945). Figure 1 shows the process used in Mexico and Central America for tortilla making.

Morphological structure is often a key to the functionality of a food material. This is one of the reasons why scanning electronmicroscopy (SEM) is becoming more important, specially in recent years, to understand structural changes during food processing. Although numerous studies have been reported on the changes of nutritional properties of corn during the alkaline treatment process, it seems that no studies have been published on the microstructure of nixtamal (alkali-cooked, soaked corn) and tortillas. In this investigation, SEM has been employed to examine structural changes in lime-treated corn.

Materials and methods

Preparation of samples

A commercial hybrid corn (*Zea mays* L.), Pride 1108, was grown during 1979

and harvested at maturity. Pride 1108 is a yellow, dent-type corn. Kernels were removed from cobs, and stored in sealed containers at 4°C before use.

The corn kernels were treated in 500 ml Erlenmeyer flasks. One part of corn and two parts of 1% lime solution in distilled water were boiled for 60 min in flasks equipped with water condensers. The treated kernels were then soaked overnight (about 14 hr) at room temperature (Fig. 1). The cooking liquor was decanted and discarded and nixtamal was freeze dried at − 80°C during 48 hr and fractured, when it was required, to expose inner surfaces. Before freezing, kernel samples for aleurone studies were washed three times with distilled water, as is commonly done in the process for tortilla preparation (Fig. 1). Control kernels of corn were freeze dried in the same way as already described.

Scanning electronmicroscopy

Specimens were attached to stubs with silver conducting paint and were coated with a layer of gold approximately 30 nm thick in a Balzers sputter coater. The coated samples were scanned with a Cambridge Stereoscan Mark 2A scanning electronmicroscope at an accelerating voltage of 10 kV, and a representative area was photographed on 35 mm Kodak Panatomic X film (A.S.A. 32).

Results and discussion

The alkaline processing of corn resulted in a considerable change in the structure of the outside surface (compare Fig. 2a and Figs 2b, c). Figure 2a, for the control kernels, shows a somewhat continuous cuticular surface of the pericarp. Figures 2b, c represent the microscopic structure of the outside surface most commonly found in nixtamal. Figure 2b demonstrates that boiling and liming of corn produced alterations of the outermost layer of the pericarp; in this photomicrograph the outside surface presents a corrugated-like structure. The corn processing also produced partial dissolution of surface materials as shown in Fig. 2c; numerous holes were observed in many regions of the outside surface of the nixtamal. The structural damage brought about by the liming of corn, facilitates the outermost layer separation during washing in the tortilla making process. The amount of pericarp represents about 5–6% of the kernel weight (Wolf *et al.*, 1952a). Some of it is lost in the preparation of nixtamal. The loss of pericarp was observed in the pioneer studies of Cravioto *et al.* (1945).

Figure 2d shows that after the lime treatment the aleurone layer remains attached to the endosperm. Figure 2d (upper right corner) also shows that some of the innermost layers of the pericarp are not removed during the washing of nixtamal. Thus, the alkaline treatment contributes to the outside surface removal while the aleurone layer keeps enclosing the endosperm. In view of the aleurone's semi-permeable properties, this is a very important functional and nutritional characteristic in the alkaline processing of corn. The aleurone layer is rich in proteins and minerals (Simmonds, 1978). Wolf *et al.* (1952b) found that

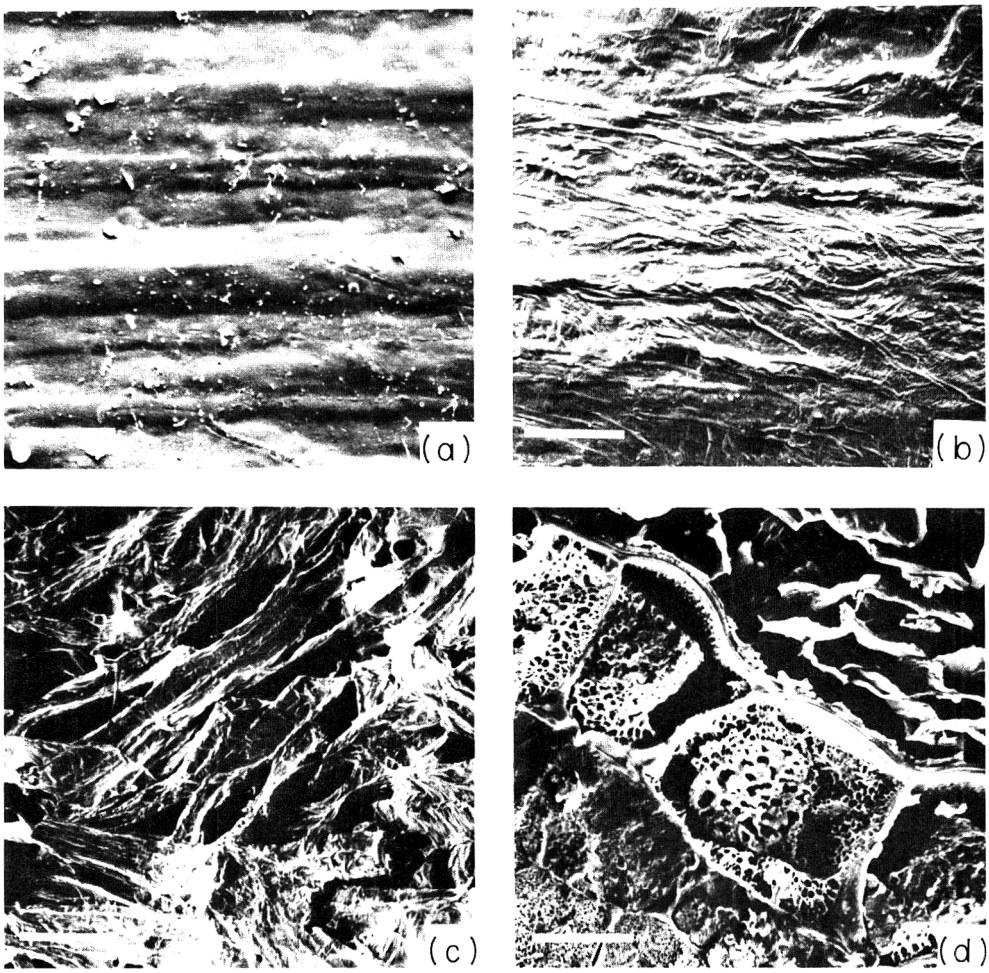

Figure 2. Scanning electronphotomicrographs of outside surface and aleurone layer of corn caryopsis: (a) outside surface, non-limed; scale bar = 50 μm; (b) outside surface, limed; scale bar = 50 μm; (c) outside surface, limed; scale bar = 100 μm. (d) aleurone layer, limed; scale bar = 20 μm.

the aleurone layer forms a covering that encloses the germ and endosperm and it is interrupted only over the hilar layer at the base of the kernel. These authors indicated that the particular structure of aleurone allows it to behave as a semi-permeable envelope. Thus, the presence of the aleurone layer might contribute to reduction of protein losses, since almost no protein is lost from the endosperm during the alkaline cooking and soaking (Paredes-López, 1980). Moreover, most of the proteins leached away due to over-cooking and over-liming of corn seems to consist of albumins and globulins of low molecular weight (Paredes-López & Saharópulos, 1981).

The germ comprises 10–14% of the caryopsis weight in the different varieties of corn. On a dry basis, the germ contains: 34.5% lipids; 18.8% proteins; 19%

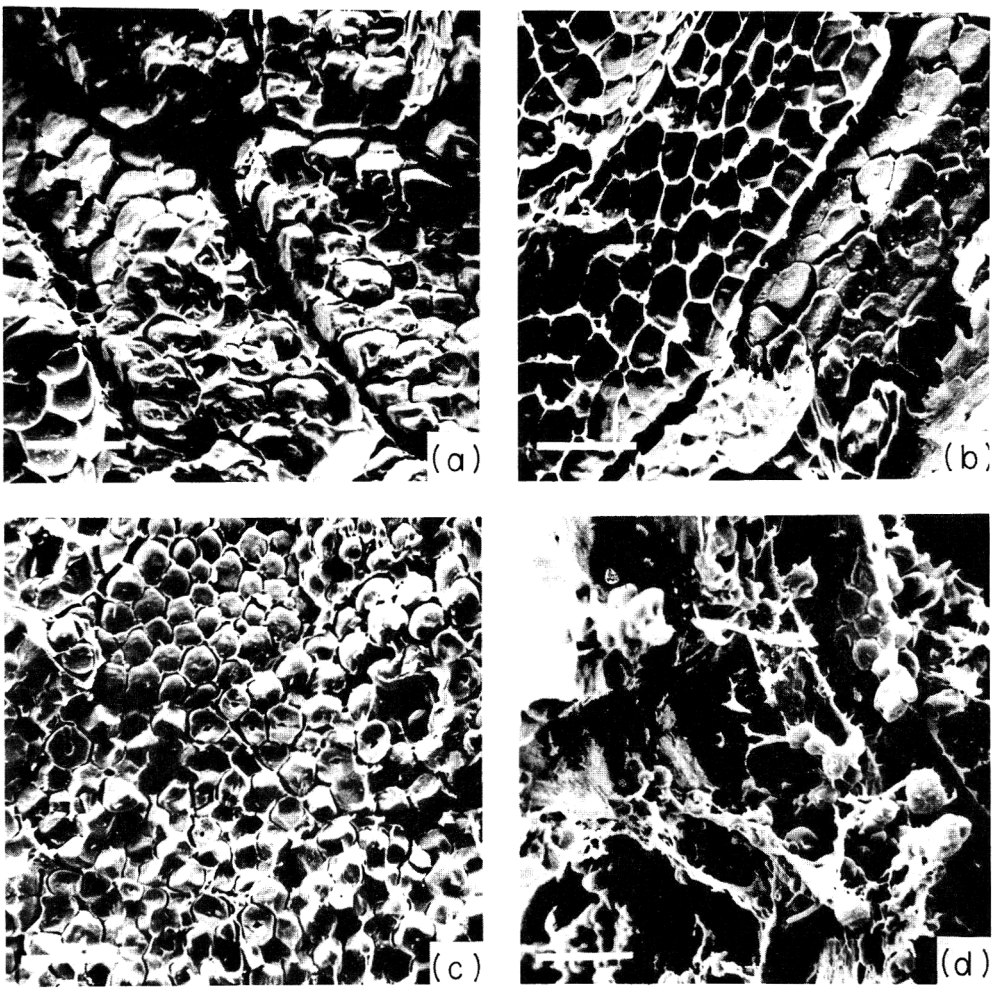

Figure 3. Scanning electronphotomicrographs of endosperm: (a) horny, non-limed; (b) horny, limed; (c) floury, non-limed; (d) floury, limed. Scale bars = 40 μm.

sugars and starch; and 10.1% ash (Earle, Curtis & Hubbard, 1946; Wolf *et al.*, 1952a). About 60% of the total proteins in the germ consists of equal amounts of albumins and globulins (Paulis & Wall, 1969; Paulis, James & Wall, 1969). For nutritional purposes, these protein fractions are of relatively high quality. It should be noted that most of the germ is retained in the tortilla making process, which greatly contributes to the overall nutritional properties of the final product.

The alkaline treatment modified the horny endosperm (Figs 3a, b) and the floury endosperm (Figs 3c, d). Figure 3a (control sample) presents a uniform arrangement of the starch granules of the hard (outer) endosperm; and as can be appreciated in Fig. 3b, the boiling and liming of corn produced a noticeable

removal of starch granules from this endosperm region. It has to be pointed out that Fig. 3b represents an extreme case of the modifications observed in the horny endosperm; the other SEM observations were not included here for space reasons. The microstructure of the soft (inner) endosperm of the untreated kernels (Fig. 3c) exhibited remarkable alterations after the liming (Fig. 3d). The regular starch arrangement (Fig. 3c) changed to a quite irregular one (Fig. 3d). Figure 3d also presents some sort of fibrils connecting the dispersed starch granules. The alterations of the floury endosperm appear to be more dramatic than those of the horny endosperm.

The structural properties of the horny and floury endosperms have been studied by several workers (Benett, 1950; Wolf *et al.*, 1952a; Wolf *et al.*, 1952b). The endosperm comprises about 80–84% of the caryopsis weight and the ratio of horny to floury endosperm averages about 2 : 1 in dent corn. The starch granules of the floury endosperm are more loosely packed and more uniformly spherical in shape. The calcium that can go through the aleurone layer seems to migrate at a slower rate in the horny endosperm; probably the loose arrangement of the floury endosperm facilitates the calcium diffusion (Paredes-López, 1980). The differences in structure and in calcium uptake in the endosperm regions are very likely responsible for the different alterations shown by the endosperm (Figs 3a–d). The pH of the cooking liquor usually reaches the value of 12.4, then, disruption of cell walls and modification of the protein matrix were expected.

Sodium dodecyl sulphate-polyacrylamide gel electrophoretic (SDS-PAGE) results (Paredes-López & Saharópulos, 1981) have shown important protein structural alterations during the tortilla preparation process of Fig. 1. SDS-PAGE studies of alcohol-extracted zein from limed corn, exhibited some new components of higher molecular weights as compared to the zein extracted from raw corn. Reduced glutelin from alkali-treated corn showed subunits of higher and lower molecular weight as determined by SDS-PAGE. It is likely that the appearance of components of higher molecular weight might be caused by a combined effect of heat denaturation of proteins, and cross-linkages produced by unusual amino acids (De Groot & Slump, 1969; Sanderson *et al.*, 1978). The alkaline treatment might also disrupt any tertiary structure due to –S–S– bonds and non-covalent attractive forces, producing a more extensive unfolding of the proteins. In summary, the alkaline cooking of corn seems to be producing noticeable structural alterations of starch and proteins.

The functional and nutritional properties given to the corn kernels by the alkaline cooking, might be closely related to the changes in the morphological structure as observed by SEM. These SEM findings are probably in accord with the observations of Wall & Paulis (1978), who suggested that the improved digestibility by enzymes of tortilla proteins, as reported by Bressani & Scrimshaw (1958), might be due to a better accessibility to the proteins caused by starch gelatinization and changes in the protein matrix. The starch–protein relationships in the endosperm cells and the role of $Ca(OH)_2$ in modifying the matrix requires further study.

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The microbial flora of vacuum packed smoked herring fillets

H. MAGNÚSSON* AND K. TRAUSTADÓTTIR

Summary

The quantitative and qualitative changes in the microbial flora of vacuum packed smoked herring fillets, held at 10°C over a period of 18 weeks, were examined. Samples were periodically tested by a sensory panel for taste and smell. Initial total counts were in the order of 10^4/g. After 7 weeks' storage the counts reached 10^8/g. No significant changes were recorded thereafter. Initially, the incidence of yeasts was high (64%). After 9 weeks of storage these were no longer detected. Homofermentative *Lactobacillus* sp(p). increased during the keeping period, reaching 84% of the total flora after 12 weeks' storage. Sensory data indicated a keeping quality of at least 3 months at 10°C. No correlation was observed between sensory scores and total microbial counts. It appears that total plate counts have a minor significance in quality assessment of vacuum packed smoked herring fillets.

Introduction

Smoking of food is a common practice in Iceland and has been so for a long time. A wide variety of smoked fish products are available commercially and one of these is vacuum packed, cold, smoked herring fillets.

Being a semi-preserved product, the estimated keeping time under refrigeration is at least 3 months.

Limited work has been carried out on the microbiological changes during processing and subsequent storage of smoked herring fillets. According to Shewan & Hobbs (1967) the overall effect of the brining treatment, which is applied prior to smoking, is to reduce the proportion of Gram-negative bacteria and increase the proportion of Gram-positive types, particularly micrococci and

* To whom correspondence should be addressed.

Authors' address: Icelandic Fisheries Laboratories, Department of Bacteriology, Skúlagata 4, 101 Reykjavik, Iceland.

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coryneforms. Light brining has generally no marked effect on the numbers of bacteria present on the fish (Shewan, 1961). Factors like the age of the brine, the type and quality of salt used, the strength of the salt solution and immersion time of the fish in the brine are probably of importance here.

During the smoking process a considerable decrease in total numbers of bacteria has been reported. Thus Shewan (1961) stated that in the case of 'kippers' and 'finnans' the aerobic plate count at 20°C showed a 75–100% reduction and 25–70% at 37°C. The same author considered that the cold smoking process did not affect the composition of the flora in the fish.

During subsequent storage of cold smoked fish a typical pseudomonad spoilage flora develops according to Liston (1979). These results were obtained by examining smoked fish where vacuum packing was apparently not applied. Moulds are commonly present in smoked fish (Shewan, 1961).The sawdust used for the smoke production was considered the main source.

Information on quantitative changes during storage of smoked herring fillets was not available.

The purpose of this work was to investigate quantitative and qualitative changes in the microbial flora of vacuum packed smoked herring fillets, held at 10°C, over a period of 18 weeks. Sensory assessment was carried out over that period for comparison.

Material and methods

Production and treatment of samples

Samples were obtained from a producer in the Reykjavik area. According to the producer's information, frozen fillets with skin are defrosted in running water and then immersed in a brine solution (18° Baumé) for 1 hr after which the fillets are arranged on the trolleys and left to dry for 2 hr. The actual smoking time is 6–7 hr and the temperature of the fish reaches about 30°C. Beech wood sawdust is used for smoke production. The smoked fillets are trimmed, vacuum packed (PAE 20–70 μm) and kept in a cold store until distribution. Each package usually contains two fillets, the average net weight being 100 g. The final product contains about 5.4% water phase salt (3.5% for whole fillet).

The keeping quality of this product was examined over a period of 18 weeks. The storage temperature was 10(± 1)°C. On each date of examination five packages were randomly selected from the original lot and these were combined in one sample. Approximately one half of the flesh was removed from each fillet and after mincing, 25 g were weighed into a Waring blender and mixed with 225 ml Butterfield's buffer solution (pH 7.2) (Speck, 1976). Blending time was 2 min at 8000 rev/min. The resulting 1 : 10 dilution was used for subsequent microbiological examination. The remaining flesh was used for sensory assessment of taste and smell.

Microbial counts

Microbial counts were carried out over a period of 18 weeks, weekly for the first 9 weeks but every 3 weeks for the remaining period. The following counts (pour plate) were performed: Total counts on plate count agar (PCA), total counts on PCA containing 3.5% (w/v) NaCl, counts of acid-producing micro-organisms on APT agar containing bromcresol purple and counts of *Bacillus* spores on PCA (sample held at 80°C for 15 min prior to plating). The plates were incubated at 22°C for 5 days except those for *Bacillus* counts which were incubated at 35°C for 3 days.

This examination also included counts for faecal coliforms by the MPN technique, sulphite-reducing clostridia in differential reinforced clostridial medium (DRCM) by the MPN technique, *Clostridium perfringens* on tryptose-sulphite cycloserine (TSC) agar and finally coagulase-positive staphylococci on Baird–Parker (BP) medium. For more information on methods see Speck (1976).

The composition of the microbial flora

The composition of the flora was examined after 0, 3, 9, 12 and 15 weeks' storage. On each occasion, twenty-five randomly selected colonies were picked off the PCA plates containing NaCl. Purified strains were classified to a generic level by examining for morphology, Gram reaction (Hucker's modification), motility, production of oxidase and catalase, oxidation–fermentation reactions and production of gas from glucose. Identification of Gram-negative bacteria was based on the determinative scheme of Shewan, Hobbs & Hodgkiss (1960) but updated in accordance with *Bergey's Manual* (Buchanan & Gibbons, 1974). Gram-positive strains were classified according to *Bergey's Manual* (Buchanan & Gibbons, 1974).

Sensory assessment

Sensory assessment was made periodically throughout the experiment, weekly for the first 9 weeks but every 3 weeks for the remaining period. The sensory panel consisted of seven or eight judges. Scores were given for taste and smell by the following scoring system: 5 (very good), 4 (good), 3 (fair), 2 (slightly off), 1 (off).

pH measurements

During the storage period, pH was measured in the minced flesh which was mixed with equal amount of distilled water.

Results

Microbial counts

The results from microbial counts on PCA, PCA + 3.5% NaCl and APT agar are shown on Fig. 1. Similar counts were obtained on PCA and PCA + 3.5% NaCl throughout the storage period. Initially, counts on APT agar were approximately one log cycle lower than on other media but no significant difference was observed during the remaining period. Initial total counts were in the order of 10^4/g. After 7 weeks' storage, maximum plate counts were reached, exceeding 10^8/g. These high counts were more or less sustained for the remaining period.

The results obtained from other microbial counts are shown in Table 1. Values of pH are included for convenience. Faecal coliforms, coagulase-

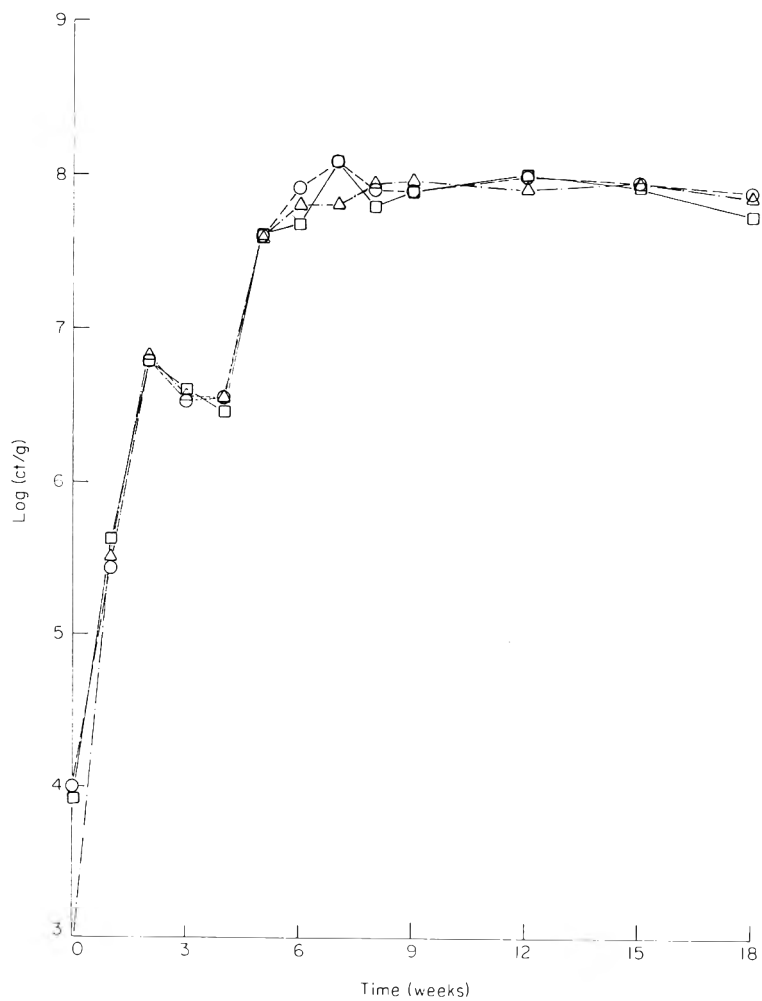

Figure 1. Microbial counts in vacuum packed smoked herring fillets. ○- - -○, PCA; □———□, PCA + 3.5% NaCl; △—·—·—△, APT.

Table 1. Counts of *Bacillus* and sulphite-reducing clostridia in smoked herring fillets along with pH measurements

Keeping time (weeks)	*Bacillus* (log no./g)	Sulphite-reducing clostridia (log MPN/g)	pH
0	0.70	0.00	6.6
1	0.00	0.00	6.6
2	0.00	1.04	6.5
3	0.70	1.04	6.4
4	0.00	0.96	6.3
5	1.95	3.04	6.4
6	2.45	0.56	6.3
7	3.76	0.56	6.5
8	2.95	1.18	6.5
9	2.77	2.66	6.5
12	2.18	3.04	6.2
15	3.38	1.45	6.2
18	3.32	3.04	6.1

positive staphylococci and *Cl. perfringens* were not detected and are thus excluded from Table 1. Also, the numbers of *Bacillus* sp(p). and sulphite-reducing clostridia were relatively low. It is evident from Table 1 that these counts were somewhat variable especially the *Clostridium* counts.

The pH values showed a drop from 6.6 to 6.1 during the 18 weeks' storage.

The composition of the microbial flora

The percentage composition of the microbial flora on each date of examination is shown in Table 2. Initially the incidence of yeasts was high or 64% of the

Table 2. Percentage composition of the microbial flora of smoked herring fillets (no. of isolates on each occasion = 25)

	Storage time (weeks)				
Group	0	3	9	12	15
Yeasts	64	4	0	0	0
Homofermentative *Lactobacillus*	8	60	76	84	72
Coryneforms	0	12	4	4	0
Micrococcus	24	4	4	4	12
Acinetobacter	0	8	8	0	8
Moraxella	4	4	0	0	0
Streptococcus	0	4	0	0	0
Unidentified	0	4	4	4	4
Lost	0	0	4	4	4

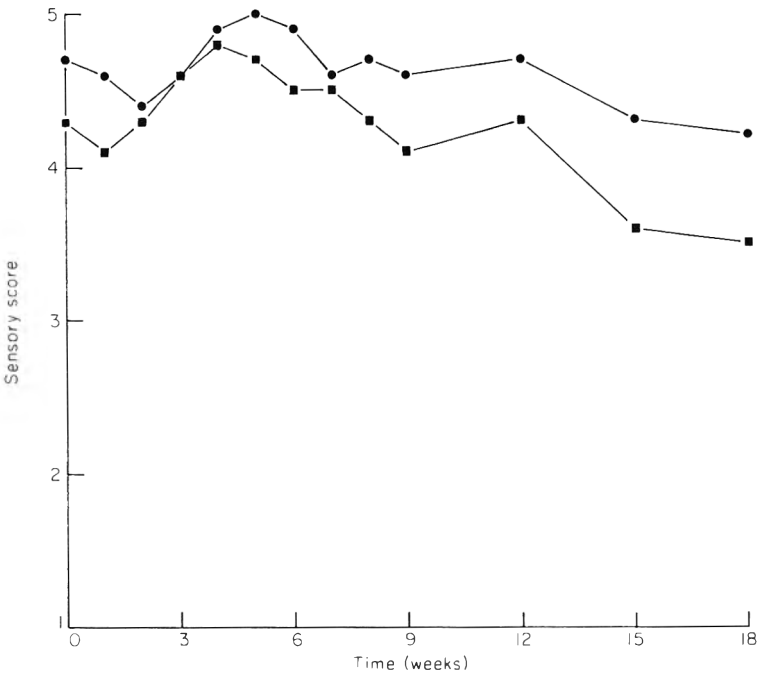

Figure 2. Sensory scores for taste and smell in vacuum packed smoked herring fillets. ●——●, smell; ■——■. taste. Scoring system: 5 (very good), 4 (good), 3 (fair), 2 (slightly off), 1 (off).

total flora. After 9 weeks' storage, these were no longer detected. Homofermentative *Lactobacillus* sp(p). were initially present in small numbers (8% of the total flora) but after 12 weeks' storage, the proportion of these strains reached a peak level of 84%. In addition, *Micrococcus, Streptococcus, Moraxella, Acinetobacter* and coryneforms sp(p). were isolated during the storage period.

Sensory assessment

The sensory scores for taste and smell are shown on Fig. 2. After 12 weeks' storage the herring fillets were still of high quality according to the sensory panel. All samples examined during the first 12 weeks received scores for taste and smell between 4 and 5 (good and very good). During the remaining period slightly lower scores were given, especially for taste.

According to these results, the vacuum packed herring fillets can be kept at 10°C for at least 18 weeks without any obvious signs of spoilage provided that the initial product is of similar quality as used in this experiment.

Discussion and conclusions

The results of this study indicated that the rapid increase of microbes in the fillets during the first few weeks of the storage period had little effect on the sensory

quality of the product. After 18 weeks' storage at 10°C the product was still in good condition according to the sensory panel despite the high microbial counts. It is concluded that total plate counts have a minor significance in quality assessment of vacuum packed smoked herring fillets.

The results from the compositional studies of the microbial flora showed that homofermentative *Lactobacillus* sp(p). increased during the storage period at the expense of other genera, reaching a peak level of 84% after 12 weeks' storage. These results are not in accordance with results obtained from related studies (Liston, 1979; Shewan & Hobbs, 1967) where a typical pseudomonad spoilage flora was considered to develop during subsequent storage. These latter results were obtained by studying the microbial flora of unpackaged product. In correspondence with one of the authors of the earlier papers we have ascertained that some of the storage temperatures and all of the salt concentrations were lower than in the present work. Different methods of processing and handling might indeed affect the initial flora on the product and changes in the flora during storage. The use of vacuum package is probably of most importance in this respect since carbon dioxide which increases in the gasphase of the package during storage (Silliker & Wolfe, 1980) inhibits Gram-negative bacteria such as *Pseudomonas* whereas lactic acid bacteria are favoured (Clark & Takács, 1980).

The relatively long shelf life of vacuum packed smoked herring fillets is due to many factors like salt content, smoking, vacuum package and low storage temperature. It is tempting to speculate whether lactic acid bacteria might also play a part in this respect. Production of acid(s) resulted in a pH drop of 6.6 to 6.1 during the storage period. This decrease in pH can hardly affect the keeping quality significantly. However, it is known that lactobacilli can inhibit growth of bacteria by producing hydrogen peroxide and by antibiotics (Schrøder *et al.*, 1980). These workers described a psychrotrophic *Lactobacillus plantarum,* isolated from saithe, which produced antibacterial principles other than acid. Further experiments are required before it can seriously be suggested that such laws are operating in lactobacilli-containing food products like smoked herring fillets.

Acknowledgments

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Nitrosodimethylamine levels in fish cooked by natural gas and by electricity

PAULINE E. KEY, JACQUELINE M. BAYLY, R. C. MASSEY AND D. J. McWEENY

Summary

The nitrosodimethylamine (NDMA) content of fish has been measured in raw fish and after baking in pre-heated and not pre-heated ovens and after grilling using electrical and natural gas heated domestic cookers. In many cases there is an increase in NDMA levels with natural gas heated cookers but the increase is not great in comparison to variations observed in levels in raw fish obtained on different occasions. There is no significant increase in NDMA levels with electric cookers.

Introduction

Recent work (Spiegelhalder, Eisenbrand & Preussman, 1980) has implicated nitrogen oxides (NO_x) arising from nitrogen fixation during combustion of natural gas as nitrosating agents leading to the formation of volatile nitrosamines, particularly nitrosodimethylamine (NDMA) during the kilning of malt. Palliative measures include (1) re-design of gas burners to give a cooler flame more comparable to that from oil or town gas (2) raising the SO_2 content of the combustion gases (Spiegelhalder *et al.*, 1980; Wainwright, 1981). Domestic gas cookers also produce NO_x and this raises the question as to whether nitrosamine formation is significant in food cooked by natural gas of the low sulphur type used throughout mainland Britain. Data is now presented on a limited investigation of NDMA levels in fish in the raw state and after cooking with gas or electrically heated domestic cookers. The findings are discussed in relation to results recently reported for fish in Japan (Kawabata *et al.*, 1980) and Hong Kong (Huang *et al.*, 1981).

Authors' address: Food Science Laboratory, Ministry of Agriculture, Fisheries & Food, Queen Street, Norwich NR2 4SX.

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Materials and methods

Fish

Samples of fish were purchased from local retail outlets as required; materials used in Tables 1a, 1b and 2 were purchased on separate occasions.

Standard oven-cooking procedure

Approximately 700 g fish was divided into three roughly equal parts; one portion was reserved for analysis in the raw state. The other two portions were cooked separately in open oven-proof glass dishes with 75 g butter. Cooking was for 20 min, one portion in an electric oven at 180°C, the other portion in a natural gas oven at regulo 4. The cooked portions were allowed to cool but before becoming cold the excess fat and butter was drained and absorbed on a paper towel. Since the aim was to measure NDMA in the fish as normally consumed this excess fat was not analysed.

Cold start procedure

Fish was prepared for cooking as in the standard procedure but the ovens were not pre-heated and the cooking time was increased to 40 min.

Grilling procedure (frozen fish)

After removing a sample for analysis, frozen cod steaks were cooked according to the processor's instructions (5 min on each side) under a pre-heated gas or electric grill.

Analysis

Work-up procedure. Samples of raw or cooked fish were minced and 50 g portions taken for analysis. Nitrosodipropylamine (1 ml of 250 ng/ml solution in ethanol) was added as internal standard; 5% aqueous solution of sulphamic acid (100 ml) was added to destroy nitrosating species and methylethylamine (1 mg/ml in water, 1 ml) was added to provide an indicator of artefact formation. After 10 min at room temperature, 1% DLα-tocopherol in liquid paraffin (100 ml) was added to the flask along with dihexylamine (1 mg/ml in liquid paraffin, 1 ml). The mixture was then vacuum distilled, collecting the distillate in two cold traps (the first at 0°C, the second cooled in liquid nitrogen), until the flask contents reached 100°C. The contents of the traps were combined in a separating funnel and extracted with dichloromethane (DCM, 6 × 16 ml). The extracts were combined, dried by percolation through a column of anhydrous sodium sulphate (5 g pre-washed with 8 ml DCM) and the column washed through with a further 8 ml DCM. The combined DCM solutions were concentrated to

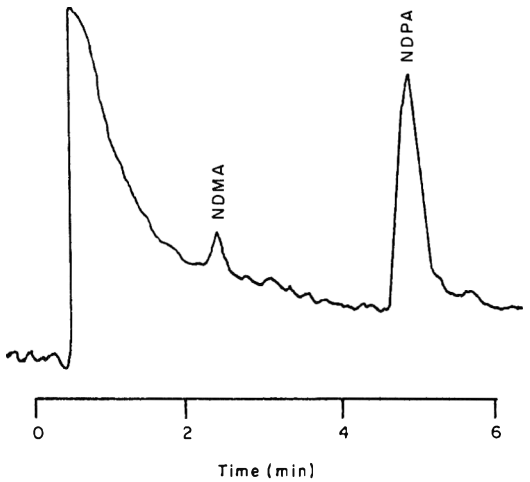

Figure 1. A GC/TEA chromatogram of an electrically cooked cod fillet containing 0.3 μg/kg nitrosodimethylamine (NDMA); nitrosodipropylamine (NDPA) added as internal standard.

1 ml ± 0.1 ml on a Kuderna Danish evaporator in a water bath at 60°C. The concentrate volume was measured (by syringe) prior to storage at − 20°C pending analysis.

Measurement. A Pye GCD chromatograph was used with a thermal energy analyser (TEA) (ThermoElectron Corp., U.S.A.) as detector. Column parameters were: glass column (2 m) packed with 20% Carbowax 20 M + 2% KOH on Chromosorb WAW; oven temperature 190°C, injection block 220°C; 5 μl injections; retention times NDMA 2.4 min, NDPA 4.9 min. Recovery of NDMA averaged 60%, limit of detection 0.1 μg/kg (after correction for recovery). Results for all samples were expressed in terms of concentration in the raw fish, i.e. values for cooked fish were corrected for the 10–20% weight loss during cooking.

Results

Nine types of fish (including three smoked products) were cooked according to the standard procedure. Data corrected for recovery is presented in Table 1a. NDMA concentrations in raw fish ranged from < 0.1 to 1.0 μg/kg; after cooking by gas the levels were 0.2 to 2.0 μg/kg as compared to 0.1 to 1.6 μg/kg after cooking by electricity. In most samples the level in fish cooked in a gas oven was somewhat higher than that in the raw or electric-oven-cooked fish but in only one case (kippers) did the difference between gas and electric cooking amount to more than 1 μg/kg.

Three types of fish were cooked in ovens not pre-heated; some increase in NDMA level was noted in each case (Table 1b). In two samples the gas-cooked

Table 1. NDMA (μg/kg) in fish cooked by gas and electricity

Fish	Raw	Cooked by gas*	Cooked by electricity*
(a) *Pre-heated oven*			
Cod	NA	0.3	0.3
Smoked haddock	1.0	0.9	0.5
Dog fish (rock eel)	0.1	0.5	0.2
Plaice	0.4	0.3	0.3
Skate	ND	0.2	0.1
Coley fillet	ND	0.2	0.1
Dover sole	0.1	0.4	0.2
Smoked cod fillets	0.9	1.1	1.6
Kippers	0.3	2.0	0.3
(b) *Non-pre-heated oven*			
Skate	ND	0.1	0.1
Smoked haddock	0.3	0.8	0.3
Smoked cod fillets	0.2	0.5	0.3
(c) *Pre-heated grill*			
Cod steak (frozen)	0.2	0.3	0.1

* Expressed on fresh weight basis, i.e. after correction for 10–20% weight loss during cooking.

ND = None detected, subject to limit of 0.1 μg/kg.

NA = Not analysed.

sample was higher than the electrically cooked one; there was no difference in the third case.

A single type of fish (cod steak) was cooked from the frozen state under pre-heated grills (Table 1c).

In view of the small differences observed, a supplementary experiment was carried out to assess the reproducibility of the NDMA levels and their measurement. Nine samples of cod fillet purchased on a single occasion were

Table 2. NDMA (μg/kg) in duplicate samples from individual cod fillets*

Sample	Raw fish	Sample	Electrically cooked	Sample	Gas cooked
1a	0.4	4a	0.2	7a	0.2
1b	0.3	4b	0.3	7b	0.8
2a	0.3	5a	NA	8a	0.3
2b	0.3	5b	0.3	8b	0.4
3a	0.2	6a	0.3	9a	0.3
3b	0.2	6b	0.2	9b	0.3

*Each fillet divided into two portions and NDMA measured in each portion; in the cooked samples the two portions from each fillet were cooked on separate occasions, i.e. Samples 4a, 5a and 6a were cooked simultaneously as were Samples 4b, 5b and 6b, Samples 7a, 8a and 9a and Samples 7b, 8b and 9b.

studied by taking each fillet, dividing it lengthwise into two parts (designated 'a' and 'b') along the mid-section and measuring the NDMA levels separately in each portion. Three samples were measured in the raw state, three after cooking the two portions consecutively in a gas oven and three after cooking them consecutively in an electric oven. The data is presented in Table 2.

Discussion and conclusions

Reproducibility of NDMA levels as measured in raw fish was good but after cooking there was more variation in the extent to which levels within paired-halves agreed. This indicates that the initial levels in the two halves of a raw fillet were comparable and could be measured satisfactorily, but that there were variations during cooking in the extent to which NDMA was formed and perhaps subsequently lost by volatilization or by partition into the fat used for cooking.

These variations are comparable to those recently reported by Huang *et al.* (1981) in studies on NDMA levels in several batches of salted yellow croaker in the raw state and after frying or steaming.

The results suggest that the use of a gas cooker may cause some small increase in the natural NDMA level. The size of this increase is not markedly affected by the cooking procedure *viz.* the increase when frozen fish is grilled close to a natural-gas flame is no greater than that when fresh fish is cooked in a pre-heated oven; similarly placing the fish in an initially cold oven did not cause a markedly greater increase in NDMA levels despite the higher NOx levels which might be expected with the burners full on during the oven 'warm-up' period. The increases during cooking exceeded 1.0 μg/kg on only one occasion and were usually in the region 0–0.4 μg/kg. The differences between levels in samples of the same species purchased on different occasions (i.e. cod 0.2–0.4, smoked cod 0.2–0.9, smoked haddock 0.3–1.0 μg/kg) were at least as great as those attributable to cooking.

Earlier work by Kawabata *et al.* (1980) reports that coal-gas broiling of Japanese dried fish results in significantly higher levels of NDMA (up to 300 μg/kg). In a similar study Maki *et al.* (1980) have reported that the NDMA content of Japanese dried fish increased by a factor of thirty after coal-gas broiling, the effect being attributed to participation by nitrogen oxides. In contrast to these findings the results of our preliminary investigation show that nitrogen oxides produced in domestic natural-gas ovens in the U.K. have little significant effect in raising NDMA levels during cooking of types of fish which are popular in this country.

The known effect of SO_2 in retarding nitrosamine formation during malt kilning (Wainwright, 1981) suggests that the NO_x in coal-gas combustion products (which contain SO_2) should produce less NDMA than is formed from the NO_x in combustion products of relatively sulphur-free natural gas. If the mechanisms of NDMA formation in malt and fish are similar it would be

expected that NDMA levels in fish cooked by natural gas would be higher than when coal gas is used.

This hypothesis is not supported by the observations that in the present work the increase in levels encountered when natural gas is used are barely significant whilst substantial increases occur with coal gas in the Japanese work (Kawabata *et al.*, 1980). In the latter case NDMA levels are relatively high in the raw fish and this indicates the availability of substantial amounts of amines as precursors for the formation of additional NDMA during gas cooking. There is no evidence from the Japanese work that the presence of SO_2 inhibits this NDMA formation or that its absence in the present work encourages NDMA formation. It therefore seems likely that the nitrosation mechanisms in malt and in fish differ significantly in so far as there is no SO_2-sensitive stage in fish.

Where initial NDMA levels are low the lack of SO_2 in combustion products from natural gas does not seem likely to be associated with significant increases in NDMA levels during cooking of the types of fish commonly consumed in the U.K.

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Moisture mobility in meat emulsion during cooking

I. Slab moisture history

G. S. MITTAL, J. L. BLAISDELL* AND F. L. HERUM*

Summary

Mobility of moisture in meat emulsion sausage during cooking was simulated. The model was verified for low temperature processing using slab geometry of the product for different processing conditions and formulations. The moisture diffusivities were described in terms of product temperature and fat : protein ratio.

Introduction

This paper presents the observed and simulated moisture content of meat emulsion slab as a function of its composition, relative humidity and temperature of the environment. Eyring's absolute reaction rate theory was applied to define the moisture diffusivity in meat emulsion.

With the growing importance on industrial and institutional food preparation, heat and mass transfer data is necessary for the development of optimal cooking procedures, equipment and installations. A few studies have been undertaken to collect the transport properties during sausage cooking. Agrawal (1976) measured and simulated simultaneous heat and mass transfer for the cooking of sausage emulsion of one composition in various temperature environments. In a related study (Igbeka, Blaisdell & Herum, 1976), the moisture isotherms of a commercial bologna product were found to be sigmoid in shape. Monagle, Toledo & Saffle (1974) determined experimentally the effects of temperature, humidity and air velocity on weight changes and temperature profiles in frankfurters during thermal processing. However, no mathematical models were developed.

Authors' address: School of Engineering, University of Guelph, Guelph, Ontario, Canada N1G 2W1, and *Department of Agricultural Engineering, Ohio State University, Columbus, OH 43210, U.S.A.

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Materials and methods

The experimental design chosen was a central rotatable composite design (Cochran & Cox, 1957). For three factors this design consisted of twenty experiments i.e. eight vertices of a cube (2^3 factorial), six centre points for replication and six star points to give the design the property of being rotatable. Table 1 presents the variables and their levels chosen for investigations. The order of experiments was completely randomized.

Fresh emulsion was prepared before starting each experiment in the laboratory using a modified Waring blender (Mittal, 1979). The formulation included non-fat dry milk (3%), salt (2.5%), sucrose (0.5%), corn syrup solids (2%), spices and curing agents. Protein, fat and water were added according to the desired fat : protein ratio (*FP*). Most of the fat was taken from the pork meat and protein from the lean beef. The viscosity of the emulsion was used as an index of the extent of chop.

A closed wind tunnel was used to provide the controlled environment. The wind tunnel consisted of a fan, a heating and cooling section, steam injection system, drying column and a test section (Mittal, Blaisdell & Herum, 1979). The temperature was controlled by proportional rate and integral modes to within ± 1°C. The humidity was controlled to within $\pm 1\%$ by injecting steam and venting the circulating air. The air flow was controlled within ± 0.01 m/sec with an orifice, a pressure transmitter and a flow recorder controller to regulate a butter-fly valve.

Meat emulsion slabs of 10.2 cm in diameter and 1.9 cm thick were employed. The emulsion was placed on an aluminium disc fitted to an aluminium ring with the help of a rubber O-ring. The side and bottom of the slab were coated with 'Castolite-AP' clear casting plastic, to insure that the moisture loss was purely uni-directional from the upper surface of the slab.

Weight losses of these slabs were recorded as a function of time during cooking. One meat slab was used for the measurement of temperature. Six copper constantan thermocouples were inserted radially up to the centre through the holes on the side of the aluminium ring. Temperatures were recorded at 1 min intervals. The details were given elsewhere (Mittal, 1979; Mittal *et al.*, 1979).

Table 1. Variables and their levels for experiments

	Variable levels				
Variable	−1.68	−1.0	0.0	1.0	1.68
Temperature (°C)	42	45	50	55	58
Relative humidity (%)	41	48	60	75	87
Fat:protein ratio	1.2	1.4	1.9	2.5	3.0

Mathematical analysis

One dimensional moisture diffusion through a slab of thickness L can be represented by the Fick's second law:

$$\frac{\delta m}{\delta t} = \frac{\delta}{\delta x}\left(D_m \frac{\delta m}{\delta x}\right). \tag{1}$$

The symbols are defined in the Appendix. The following assumptions related to initial and boundary conditions were made:

(a) The initial moisture content was uniform through the slab. This seems to be reasonable since the meat emulsion was prepared about 1 hr before the experiment and the emulsion was well mixed before putting in the aluminium ring.
(b) There was no significant film layer just above the surface of the product to impede moisture flow from the product surface. For this purpose, a minimum air velocity of 1.67 m/sec was used in the test section to provide mass transfer Biot number $>> 10$.
(c) The moisture gradient at the bottom of the slab was zero due to the moisture barrier.
(d) The dimensional changes were negligible. The maximum observed change was 1.5% of the original dimension.

Mathematically, the initial and boundary conditions can be expressed as follows:

$$\begin{aligned} m(x,0) &= m_0 \\ m(L,t) &= m_e \\ \left.\frac{\delta m}{\delta x}\right|_{x=0} &= 0 \end{aligned} \tag{2}$$

Defining a non-dimensional moisture, C, and thickness, ψ :

$$C = \frac{m - m_e}{m_0 - m_e} \quad \text{and} \quad \Psi = x/L \tag{3}$$

and considering the D_m independent of concentration, the Equations (1) and (2) can be written as:

$$\frac{\delta C}{\delta t} = \frac{D_m}{L^2}\frac{\delta^2 C}{\delta \Psi^2} \tag{4}$$

$$\begin{aligned} C(\Psi,0) &= 1 \\ C(1,t) &= 0 \\ \left.\frac{\delta C}{\delta \Psi}\right|_{\Psi=0} &= 0. \end{aligned} \tag{5}$$

To solve these equations on a digital computer, utilizing the Continuous System Modelling Program (CSMP), the space co-ordinate was eliminated as a variable by dividing the slab into ten equal slices. The node location for mean concentration was assumed to be at the centre of each slice. The method of Hamdy & Barre (1969) was used to approximate the moisture ratio profiles within each slice by a parabola.

The following equations were obtained for the ten nodes and the average moisture ratio:

$$\frac{dC_1}{dt} = 100\,\frac{D_m}{L^2}\,(C_2 - C_1) \tag{6}$$

$$\left.\frac{dC_i}{dt}\right|_{i=2-9} = 100\,\frac{D_m}{L^2}\,(C_{i+1} - 2C_i + C_{i+1}) \tag{7}$$

$$\frac{dC_{10}}{dt} = \frac{400\,D_m}{3L^2}\,(-3\,C_{10} + C_9) \tag{8}$$

$$\bar{C} = (C_1 + C_2 + C_3 + C_4 + C_5 + C_6 + C_7 + C_8 + C_9 + C_{10})/10. \tag{9}$$

To determine the moisture diffusivity giving the best fit of the model to observed data, the criterion was arbitrarily taken as the minimum sum of normalized standard deviation, δ_H, between computed and observed values of moisture history. This was calculated by

$$\begin{aligned}\delta_H &= \frac{1}{t}\int_0^t \frac{\bar{m}_c - \bar{m}}{m_0 - m_e}\,dt \\ &= \frac{1}{t}\int_0^t (C_c - \bar{C})\,dt.\end{aligned} \tag{10}$$

To minimize, δ_H, a combination of golden section search and successive parabolic interpolation was used (Brent, 1973).

Results and discussion

Temperature history in non-dimensional form is shown in Fig. 1 for 50°C, 60% *RH* and *FP* of 3.0. The non-dimensional temperature ratio and Fourier number, the non-dimensional time are defined as follows:

$$TR = \frac{T - T_a}{T_0 - T_a},\quad N_{FO} = \frac{\alpha t}{L^2}. \tag{11}$$

The value of thermal diffusivity was taken to be 5.76E-4 m²/hr (Agarwal, 1976).

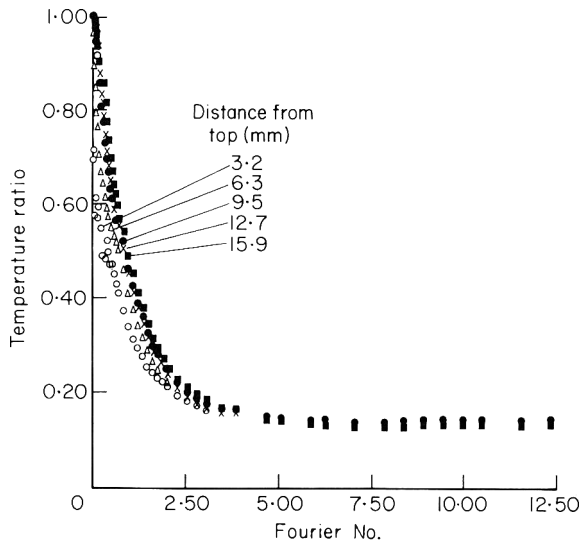

Figure 1. Temperature ratio as a function of Fourier number at different locations in a meat emulsion slab of 3.0 *FP* during cooking at 50°C and 60% *RH*.

In the initial period of cooking, there was condensation on the slab surface because the product temperature was below the dew point temperature of air. During this period, a temperature gradient of 5–9°C existed between the top and lower parts of the slab. The slab temperature increased very little (only 3–6°C) after evaporation of the condensed moisture and plateaued below the air temperature.

During this latter period, the temperature difference between the top and bottom nodes was about 0.5–2.0°C, a gradient of 0.03–0.10°C/mm slab thickness. According to Keey (1972) a temperature gradient below 1°C/mm indicates that the diffusion is under isothermal condition and the moisture under such conditions moves entirely in liquid phase. Therefore, moisture transport after removal of condensed moisture was assumed to be under isothermal conditions. Further, the data was analysed from the time the product attained its initial weight. It was assumed that the initial moisture profile was not significantly disturbed during the condensation and condensed moisture removal period.

Moisture history analysis

Figure 2 illustrates the typical moisture removal behaviour. It is the plot of log $(\Delta C/\Delta t)$ *versus* log $(m - m_e)$. The equilibrium moisture contents were taken from Igbeka *et al.* (1976). This figure shows scatter induced by taking small differences in weights over short times, no constant water removal rate period, and non-linear behaviour requiring two linear segments. The moisture loss rate *versus* time plot is shown in Fig. 3. These rates are not constant but decrease with the time of cooking. Two falling rate periods are also visible in this plot.

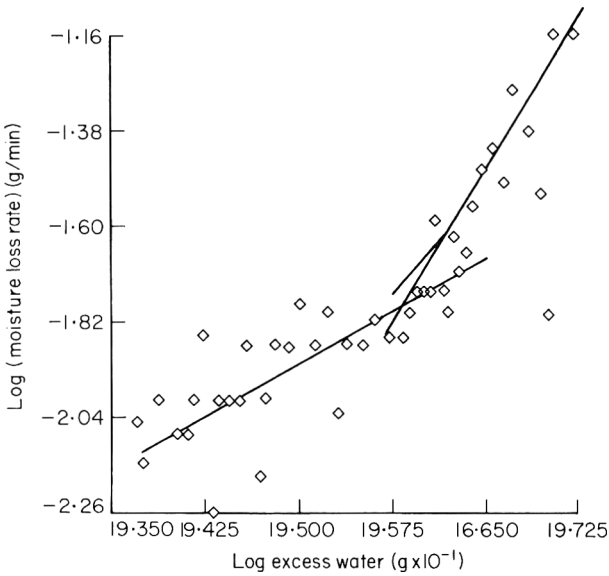

Figure 2. Moisture loss rate *versus* excess water on log-log scale for cooking of a meat emulsion slab of 2.5 *FP* at 45°C and 48% *RH*.

These plots of temperature and moisture histories indicate that there is no constant water removal rate period during cooking of meat emulsion. The surface temperature rises continuously and approaches the dry bulb temperature of air. Thus, the internal water movement was the controlling mechanism from the beginning of the cooking process. The two linear segments in Fig. 2 suggest the applicability of diffusion flow (Perry & Chilton, 1975).

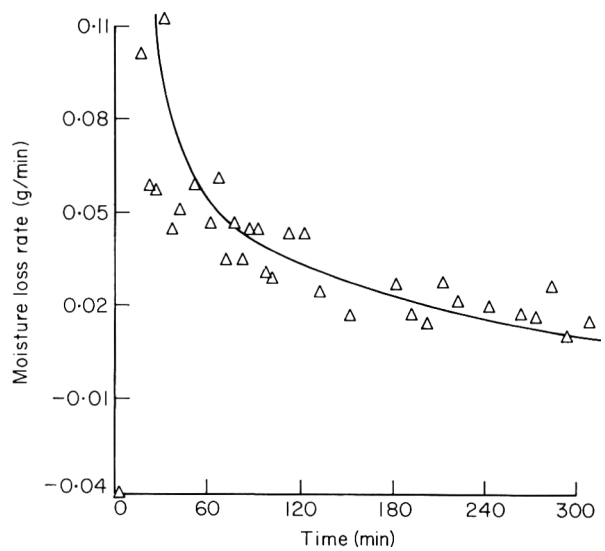

Figure 3. Moisture loss rate *versus* time for cooking of a meat emulsion slab of 1.4 *FP* at 55°C and 48% *RH*.

Therefore, the diffusion-controlled falling rate was considered to begin almost immediately after cooking starts.

Equilibrium moisture content

The equilibrium moisture content values were taken from Igbeka *et al.* (1976). The following model found to define these values, which is similar to the model suggested by Chung & Pfost (1967). The coefficient of determination of 0.97 was found for these models:

for $RH < 75\%$,

$$m_e = -0.067 \ln(-R_g[T + 8.495] \cdot \ln[RH]/[1.096E6]), \quad (12)$$

and

for $RH > 75\%$,

$$m_e = -0.483 \ln(-R_g[T + 44.532] \cdot \ln[RH]/[4.584E5]). \quad (13)$$

Moisture diffusivity

The moisture diffusivity values giving least deviation between observed and computed moisture histories were determined. The values of δ_H vary between 0.0007 to 0.0066 for different experiments.

The predicted and observed moisture histories are illustrated in Figs 4 and 5.

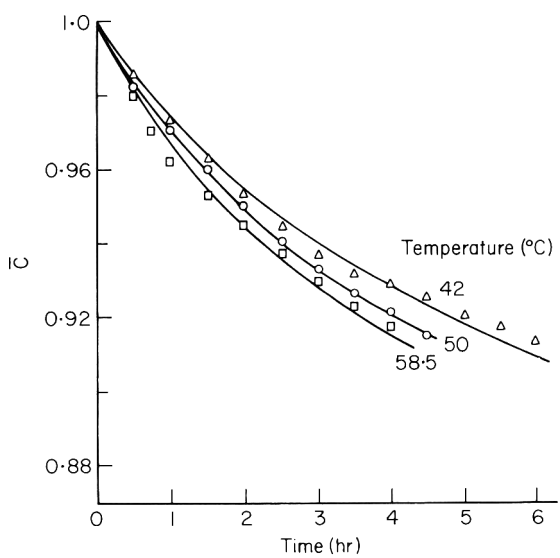

Figure 4. Predicted and observed moisture history of meat emulsion slab of 1.9 *FP* during cooking at various temperatures and 60% *RH*.

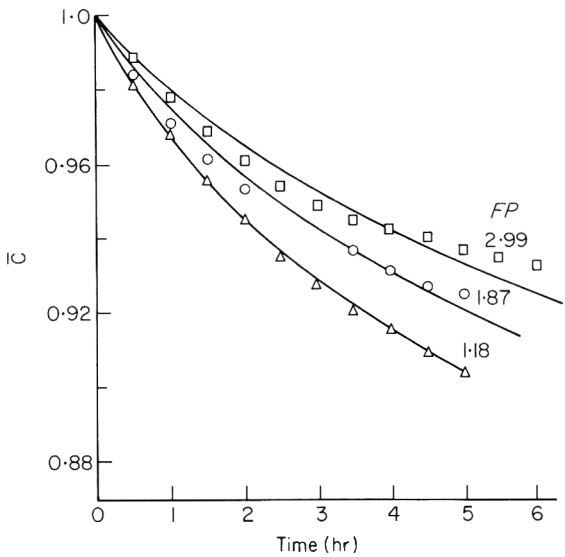

Figure 5. Predicted and observed moisture history of meat emulsion slab of different *FP* during cooking at 50°C and 60% *RH*.

These are for maximum, average and minimum air temperatures (Fig. 4) and FP (Fig. 5). These plots show that the diffusion model with constant diffusivity predicts the average moisture histories satisfactorily.

The stepwise regression procedure of the statistical analysis system (SAS) (Barr *et al.*, 1979) was used to find a suitable model. A quadratic model was tried with the logarithmic values of T_{ab} and *RH* as dependent variables. On the basis of maximum R^2 value, it was found that D_m is the exponential functions of *FP* and $1/T_{ab}$. To find a meaningful model, the moisture removal process was considered to be a rate process and D_m was considered as if this was specific reaction rate. A specific reaction rate can be modelled employing absolute reaction rate theory (Aiba, Humphery & Millis, 1973). Based on this, the following model was found appropriate, with R^2 value of 0.991:

$$D_m = 0.3224(10^{-4})\,T_{ab} \cdot \exp(-0.3302\,FP - 3060.37/T_{ab}). \quad (14)$$

The moisture diffusivity values obtained in this study vary in the range of 0.21 (10^{-6}) to 0.58 (10^{-6}) m²/hr.

It is felt that these values of diffusivity should give better understanding of the moisture movement in the meat emulsion slab during cooking. The techniques developed here can be used to analyse the moisture migration behaviour in other food materials during thermal processing.

Appendix

C	Concentration of moisture (dimensionless)
$\bar{C}$	Average C
D_m	Moisture diffusivity (m²/hr)

FP	Fat : protein ratio
L	Slab thickness (m)
N_{FO}	Fourier number
R_g	Gas constant (8310 J/[kg-mole. K])
RH	Relative humidity (%)
R^2	Coefficient of determination
T	Temperature (°C)
TR	Temperature ratio
m	Moisture content (decimal dry basis)
m	Average m
t	Time (hr)
x	Linear distance (m)
α	Thermal diffusivity (m^2/hr)
ΔC	Small increment of C
Δt	Small increment of t
δ_{Ti}	Normalized standard deviation
Ψ	Non-dimensional distance

Sub-script

a	Air
ab	Absolute (K)
c	Computed
e	Equilibrium
o	Initial

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Moisture mobility in meat emulsion during cooking

II. Frankfurter moisture history

G. S. MITTAL, J. L. BLAISDELL* AND F. L. HERUM*

Summary

Mobility of moisture in meat emulsion sausage during cooking was simulated for cylindrical geometry. The model was verified for high temperature (> 55°C) processing and various processing conditions and formulations. The moisture diffusivity were described in terms of product temperature and fat : protein ratio.

Introduction

In the first part of this series, the mobility of moisture in meat emulsion was reported for low temperatures (< 58°C) and a slab geometry. It was not possible to investigate the movement of moisture during cooking at high temperatures because of the substantial amount of moisture loss from the bottom and middle of the slab in addition to that at the top surface. This was due to heat-associated changes and shrinkage of the product in contact with the aluminium ring. Therefore, a cylindrical shape (frankfurter), in which the flux of moisture would be uni-directional radially outward, was used to study moisture mobility at higher temperatures.

The objective of this work was to assess weight loss and the distribution of temperature in frankfurter as a function of composition, relative humidity and air temperature above 55°C.

Materials and methods

The experimental design chosen was a central rotatable composite design. Table 1 presents the variables and their levels chosen for investigations. Other experimental details are described in the first part of this series.

Authors' address: School of Engineering, University of Guelph, Guelph, Ontario, Canada N1G 2W1, and *Department of Agricultural Engineering, Ohio State University, Columbus, OH 43210, U.S.A.

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Table 1. Variables and their levels for experiments

	Variable levels				
Variable	−1.68	−1.0	0.0	1.0	1.68
Temperature (°C)	58	63	69	76	81
Relative humidity (%)	41	48	60	75	87
Fat:protein ratio	1.2	1.4	1.9	2.5	3.0

Meat emulsion was stuffed into polyethylene casing of 2.54 cm in diameter with the help of a hand operated stuffer. Two nearly identical test frankfurters of about 15.2 cm length and of same weight were suspended in the test section with a frame of galvanized wires. One of the frankfurters was used to record weight at intervals. Processing was stopped when product had lost about 13% of the initial weight. Into another frankfurter, four copper constantan thermocouple probes were inserted axially at different locations. The probes were extended 7.6 cm through a plastic stopper which was inserted at the top of the casing as a thermocouple position guide. To prevent moisture losses from the sides of the plastic stopper, the sides and holes were coated with a high vacuum grease.

The equilibrium moisture contents of the meat emulsion were recorded for different processing conditions and formulations. The emulsion was spread in thin aluminium foil discs for this purpose.

Mathematical modelling

Assumptions:

(1) An infinitely long ($L/D > 5.5$) (see Appendix for symbol definitions), homogeneous cylinder.

(2) Uniform initial temperature and moisture distributions.

(3) An infinite mass transfer coefficient was assumed. For this purpose, a minimum air velocity of 1.67 m/sec was used in the test section to provide mass transfer Biot number >> 10.

(4) Negligible dimensional shrinkage—the changes in length were 0–5% and the changes in diameter were ± 7% (the negative sign denotes the expansion).

(5) Moisture diffusivity independent of concentration and isotherm conditions in the product. These are not unconditionally true (Mittal, Blaisdell & Herum, 1981).

One dimensional moisture diffusion through a cylinder of radius R can be represented by

$$\frac{\delta m}{\delta t} = \frac{1}{r}\frac{\delta}{\delta r}\left(D_m \cdot r \frac{\delta m}{\delta r}\right) \tag{1}$$

for the following initial and boundary conditions:

$$m(r, 0) = m_0$$

$$\left.\frac{\delta m}{\delta r}\right|_{r=0} = 0 \tag{2}$$

$$m(R, t) = m_e.$$

Taking as non-dimensional variables

$$C = \frac{m - m_e}{m_0 - m_e} \tag{3}$$

$$\Psi = r/R.$$

and substituting in Equations (1) and (2) with constant moisture diffusivity, the following equations can be written:

$$\frac{\delta C}{\delta t} = \frac{D_m}{R^2}\left(\frac{1}{\Psi}\frac{\delta C}{\delta \Psi} + \frac{\delta^2 C}{\delta \Psi^2}\right) \tag{4}$$

$$C(r, 0) = 1$$

$$\left.\frac{\delta C}{\delta \Psi}\right|_{\Psi=0} = 0 \tag{5}$$

$$C(1, t) = 0.$$

To solve these equations on a digital computer using Continuous System Modelling Program (CSMP), the space co-ordinate was eliminated as a variable by dividing the cylinder into ten concentric shells. The moisture ratio profiles within each shell were approximated by a parabola (Hamdy & Barre, 1969). Taking equal thickness of shells, the following equations can be obtained for different shells and average moisture ratio:

$$\frac{dC_1}{dt} = \frac{200 D_m}{R^2}(C_2 - C_1) \tag{6}$$

$$\left.\frac{dC_i}{dt}\right|_{i=2-9} = \frac{100 D_m}{R^2}\left(\frac{2i}{2i-1} C_{i+1} - 2C_i + \frac{2i-2}{2i-1} C_{i-1}\right) \tag{7}$$

$$\frac{dC_{10}}{dt} = \frac{100 D_m}{R^2}(-4.105C_{10} + 1.298C_9) \tag{8}$$

$$\bar{C} = \frac{1}{2400}(22C_1 + 72C_2 + 120C_3 + 168C_4 + 216C_5 + 264C_6 + 312C_7 + 360C_8 + 391C_9 + 475C_{10}) \tag{9}$$

To determine the moisture diffusivity giving the best fit of the model to observed data, the criterion was taken as the minimum sum of normalized standard deviation σ_H between computed and observed values of moisture history.

Results and discussion

Temperature history in non-dimensional form is shown in Fig. 1 for 69°C, 60% *RH* and 1.9 *FP*. The non-dimensional temperature ratio and Fourier number, the non-dimensional time are defined as follows:

$$TR = \frac{T - T_a}{T_0 - T_a} \qquad N_{FO} = \alpha t / L^2. \tag{10}$$

The value of the thermal diffusivity was taken to be $5.76\,(10^{-4})\,m^2/hr$ (Agrawal, 1976).

The temperature increased at a rapid rate in the beginning at all the four locations. After a step rise during the course of the experiment, the temperatures increased very little, and plateaued above the wet bulb temperature, but below the air dry bulb temperature. This plot also indicates that there is a negligible temperature gradient inside the frankfurter after the steep rise in temperature. The temperature gradient existed for a very short time. As discussed in the first part of this series, it was decided to simulate the moisture history assuming isothermal conditions after removal of condensed water.

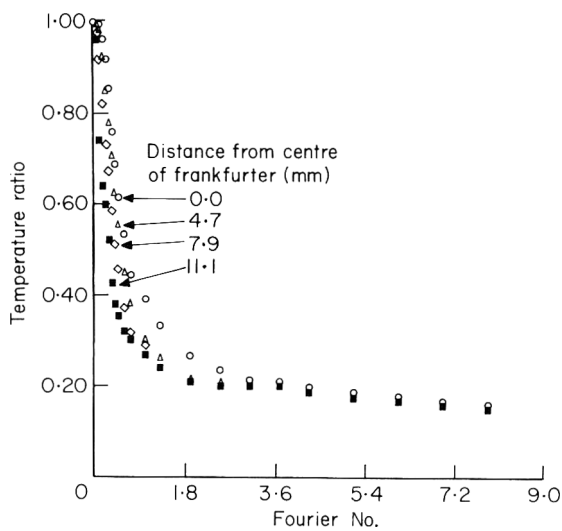

Figure 1. Non-dimensional temperature distribution and changes during cooking of frankfurter of 1.9 *FP* at 69°C and 60% *RH*.

Equilibrium moisture content

Equlibrium moisture contents of the meat emulsion at various processing conditions and compositions were recorded. These values were used to calculate moisture ratios from average moisture contents. The Chung & Pfost (1967) equation with a term for the *FP* gave the best fit. The following model was obtained with the Non-linear Regression Analysis of the Statistical Analysis System (SAS) (Barr *et al.*, 1976), giving R^2 value of 0.965:

$$m_e = -0.102 \ln(-R_g \cdot FP \cdot [T + 5.665] \cdot \ln[RH]/[1.132E7]) \quad (11)$$

Moisture history

A typical moisture loss rate *versus* time plot is shown in Fig. 2 for the central point of the experimental design. The moisture loss rate was continuously decreased at a constant rate from the start of the cooking process. Thus, there is no constant drying rate period evident.

A drying rate curve, which is the plot of drying rate measured by the weight of moisture per unit surface area leaving the wet solids *versus* the instantaneous weight of moisture in the solid expressed as a function of the weight of the dry solid, is shown in Fig. 3. Two linear segments are distinctly indicated in this plot. The drying rate curve is concave upward, which implies that the diffusion laws are applicable here (Perry & Chilton, 1975).

The typical plots of the predicted *versus* observed moisture histories are illustrated in Figs 4 and 5. These are for maximum, average and minimum air

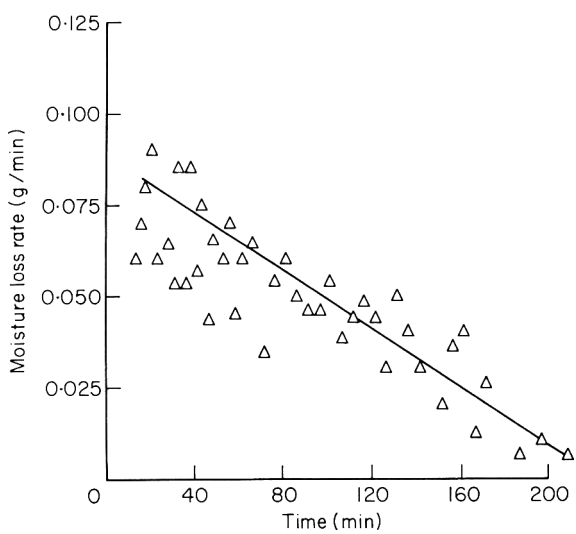

Figure 2. Moisture loss rate *versus* time during cooking of frankfurter of 1.9 *FP* at 69°C and 60% *RH*.

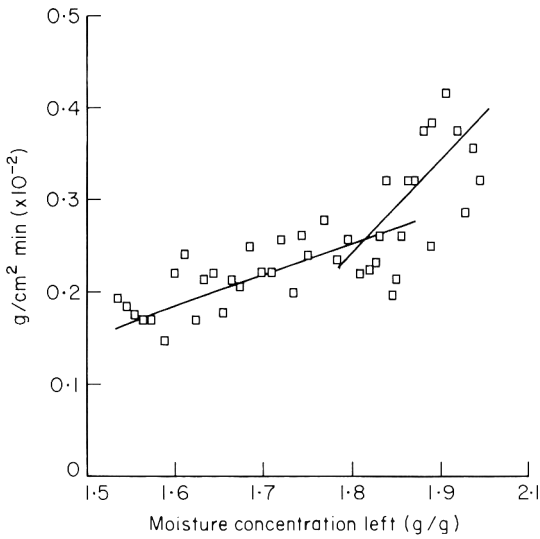

Figure 3. Moisture loss rate per unit surface area *versus* moisture concentration left during cooking of frankfurter of 2.5 *FP* at 76°C and 75% *RH*.

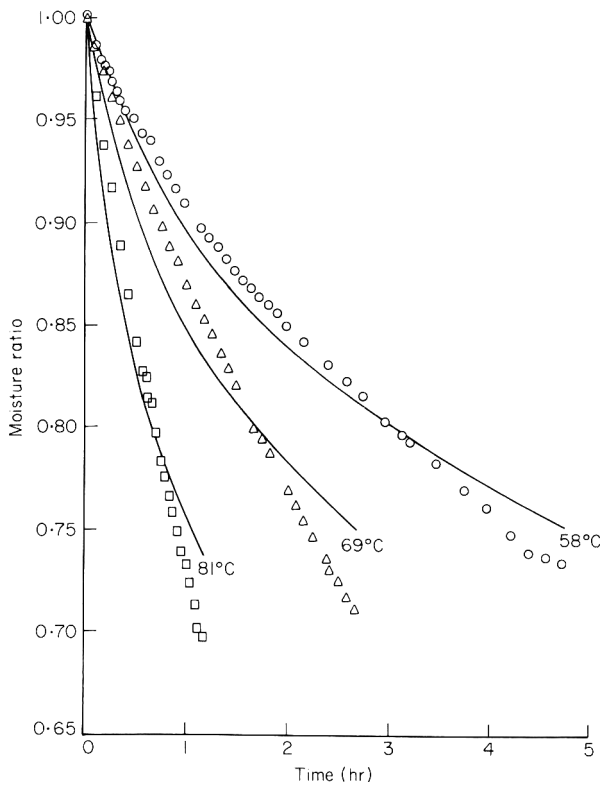

Figure 4. Predicted and observed moisture histories of frankfurters of 1.9 *FP* during cooking at different temperatures and 60% *RH*.

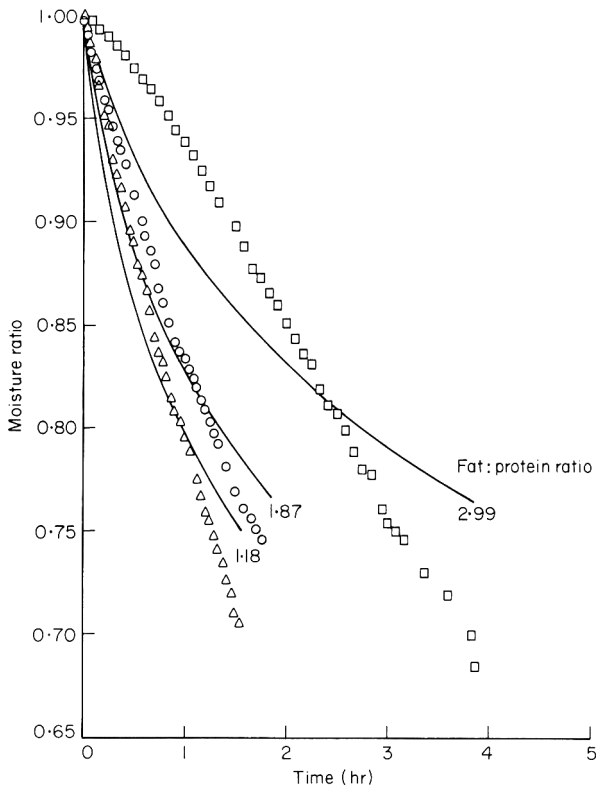

Figure 5. Predicted and observed moisture histories of frankfurters of various *FP* during cooking at 69°C and 60% *RH*.

temperatures (Fig. 4) and fat : protein ratios (Fig. 5). The values of the standard deviations between observed and predicted moisture histories vary between 0.0075 and 0.0391. The diffusion model with constant diffusivity does not predict the moisture histories for some of the experimental conditions. These deviations are due to the assumptions of diffusivity independent of concentration and isothermal conditions.

Moisture diffusivity

The diffusivity values obtained are in the range of $0.403\,(10^{-6})$ to $2.121\,(10^{-6})\,m^2/hr$ for various processing conditions and compositions of the emulsion. These values are in agreement with the values obtained by Agrawal (1976) using a similar approach. His values are between $1.22\,(10^{-6})$ and $3.5\,(10^{-6})\,m^2/hr$ for one fat : protein ratio (1.25), constant relative humidity (73–80%) and air temperatures of 34–72°C.

The Eyring's absolute reaction rate theory (Aiba, Humphery & Millis, 1973) was used to fit model for diffusivity. Based on this theory, the following model was found suitable, giving R^2 value of 0.92:

$$D_m = 0.232\,T_{ab} \cdot \exp(-0.0414\,FP - 6246.6/T_{ab}). \quad (12)$$

The moisture diffusivity values can be calculated from this model for different product temperatures and fat:protein ratios. After calculation of moisture diffusivity, the moisture mobility in the emulsion can be predicted reasonably well.

Appendix

C	Concentration of moisture (dimensionless)
D	Diameter of frankfurter (m)
D_m	Moisture diffusivity (m^2/hr)
FP	Fat:protein ratio
L	Length of frankfurter (m)
N_{FO}	Fourier number
R	Radius of frankfurter (m)
RH	Relative humidity (%)
R_g	Gas constant (8310 J/[kg-mole. K])
R^2	Coefficient of determination
T	Temperature (C)
TR	Temperature ratio
m	Moisture content (decimal dry basis)
r	Radial distance (m)
t	Time (hr)
α	Thermal diffusivity (m^2/hr)
δ_H	Normalized standard deviation
Ψ	Non-dimensional radial distance

Sub-script

$_a$	Air
$_{ab}$	Absolute
$_e$	Equilibrium

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Factors controlling the growth of *Clostridium botulinum* types A and B in pasteurized, cured meats

V. Prediction of toxin production: Non-linear effects of storage temperature and salt concentration

A. ROBINSON, ANGELA M. GIBSON* AND T. A. ROBERTS*

Summary

While investigating the effects of potassium sorbate and pig breed, cut and batch of pork in a pork slurry system, non-linear effects of storage temperature and salt concentration on toxin production by *Clostridium botulinum* were detected. Predicted probabilities of toxin production after analysis by logistic regression, published previously, were re-examined and similar effects detected. Improved formulae for the probability of toxin production in a model pork slurry system are given and the implications of the non-linearity of storage temperature and salt concentration on the predicted probability of toxin production are discussed.

Introduction

Roberts, Gibson & Robinson (1981c) used logistic regression to predict the probability of formation of toxin by *Clostridium botulinum* types A and B under various conditions in a pasteurized cured pork slurry model system. The initial purpose was to identify the relative contributions of the factors and interactions most important in controlling toxin production to facilitate the modification of commercial cured meat product formulations without reduction of bacteriological safety (Roberts, Gibson & Robinson, 1981a). In subsequent investigations on the effect of sorbate (Roberts, Gibson & Robinson, 1982) and the possible effect of pig breed, cut and batch of meat (Gibson, Roberts & Robinson, 1982) the fit of the regression model to the data was much improved if non-linear terms in storage temperature and salt concentration were included. This led us to examine more closely the relatively massive data bank on toxin production in 'low' and 'high' pH pork slurries published previously (Roberts *et al.*, 1981a, b, c). Similar quadratic effects were confirmed. The resulting

Authors' addresses: School of Mathematics, University of Bath, Claverton Down, Bath BA2 7AY, and *Agricultural Research Council, Meat Research Institute, Langford, Bristol BS18 7DY.

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improved formulae for the probability of toxin production are given below and supersede those published previously (Roberts *et al.*, 1981c). The nature and significance of the non-linear effects are discussed.

Non-linear effect of storage temperature

The nature of the non-linearity is the same in all cases, and may be accommodated into the model by the inclusion of a quadratic term in storage temperature. This is illustrated in Fig. 1 for two treatment combinations when the difference between the non-linear and quadratic predictions is relatively large (in other treatment combinations the difference was much less marked). The probability of toxin production at first increases with rising storage temperature, but subsequently decreases.

Calculated T_{pmax}

A consequence of the quadratic fit is that the temperature at which the probability of toxin production is maximal (T_{pmax}) can be calculated. T_{pmax} is not

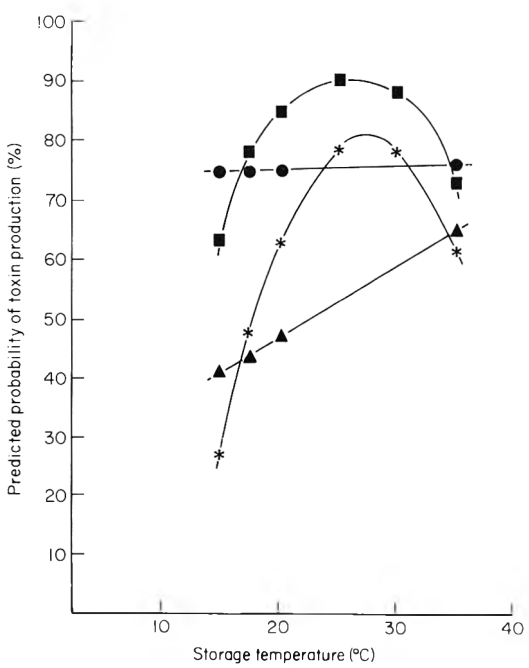

Figure 1. Comparison of predicted probabilities of toxin production obtained using original (linear) and revised (quadratic) formulae. Probabilities (%) plotted against storage temperature for two combinations of conditions. Data obtained at 15, 17.5, 20 and 35°C only. 2.5% salt, 100 μg/g nitrite, LOW heat: non-linear, ■———■; linear, ●———●. 2.5% salt, 100 μg/g nitrite LOW heat + polyphosphate + nitrate: non-linear, *———*; linear, ▲———▲.

constant, but depends upon the other factors with which storage temperature interacts. These experiments were not designed to determine T_{pmax} and incubation temperatures between 20 and 35°C were consciously omitted, because the former simulated indifferent food storage temperatures and the latter simulated accelerated abuse tests. Nevertheless, from the available data the calculated T_{pmax} is in the region 25–30°C. The variation in T_{pmax} is illustrated below using by way of example data testing the effect of sorbate on toxin production (Roberts *et al.*, 1982).

The probability of toxin production *(p)*, defined by the formula

$$p = \frac{1}{1 + e^{-\mu}}$$

increases or decreases with the linear predictor (μ) and so maximizing μ with respect to temperature is equivalent to finding T_{pmax}. In the sorbate study, storage temperature interacted with salt concentration, pH and inoculum level and these are taken into account when calculating T_{pmax}. The point of maximum probability occurs when the slope of μ is zero. With a low inoculum level (10 spores per replicate) this occurs when

$$\begin{aligned}\frac{d\mu}{dt} &= 0.292 - 2\,(0.0238) \times \text{storage temperature} \\ &\quad + 0.0507 \times \text{salt concentration} \\ &\quad + 0.1427 \times \text{pH level} \\ &= 0\end{aligned}$$

whence

$$T_{pmax} = 6.13 + 1.06 \times \text{salt concentration (\%)} + 2.99 \times \text{pH value}$$

Examples of calculated values are given in Table 1. It is important to emphasise that T_{pmax} is the temperature at which maximum probability of toxin production occurs. It does not necessarily coincide with the temperature at which the maximum amount of toxin is produced, or the temperature at which the greatest rate of toxin production occurs, neither of which can be calculated from these data.

Table 1. Some calculated values of T_{pmax}

	NaCl (% w/v)		
T_{pmax}*	2.5	3.5	4.5
pH 5.5	25.26	26.33	27.39
5.8	26.16	27.23	28.29
6.1	27.06	28.13	29.19

* T_{pmax} calculated from Roberts *et al.*, (1982) (10^1 spores/bottle) for high inoculum add 1.3°C to T_{pmax}).

The maximum growth rate of *Cl. botulinum* type A and B has been variously reported to be within the range 37–42.5°C (Ohye & Scott, 1953) and greater at 37 than at 35 or 48°C (Bonventre & Kempe, 1959). The optimum growth temperature was reported by Ohye & Scott (1967) to be 40°C. Toxin synthesis was greatest at 37°C (Bonventre & Kempe, 1959). However all these studies were in laboratory media where growth inhibitors, such as salt and nitrite, were absent, and conditions therefore differed considerably from those in our pork slurry.

Although, by definition, the T_{pmax} is not the same as the temperature for maximum toxin production, they would be expected to be similar. The fact that the calculated T_{pmax} in the slurry system lies between 25–30°C and considerably below that published for studies in laboratory media is probably the consequence of the several differences between the slurry system and laboratory media. The meat slurry system was not sterile initially, and during storage at 35°C there would have been competition from those bacteria surviving the relatively low heat treatments. These survivors are likely to have differed in different batches of pork. Although the spoilage pattern of *Cl. botulinum* growth in pork slurry is distinctive, some samples may have spoiled from growth of organisms other than *Cl. botulinum,* and would therefore have been removed for toxin testing. Although obviously spoiled, these could have contained no toxin. The possibility that at 35°C some toxin may have been denatured by proteolysis before testing seemed remote because limited experiments to estimate the rate of toxin production in several pork slurries showed that although toxin production occurred at 35°C within a few days, the proportion of samples containing toxin remained essentially the same over *c.* 60 days' storage at 35°C. Either of the above would have effectively reduced the proportion of replicates containing toxin at 35°C causing the predicted probability of toxin production at 35°C to be spuriously low.

Non-linear effect of salt concentration

The non-linear effect of salt concentration reported in the studies on sorbate (Roberts *et al.*, 1982) and pig breed, cut and batch of pork (Gibson *et al.*, 1982) was much less pronounced than that of storage temperature. After re-examination of the 'low' and 'high' pH data, the quadratic effect of salt, unlike storage temperature, was not the same in all cases, and was not detected in the 'low' pH data (Roberts *et al.*, 1981a).

Pig breed, cut and batch slurries (Gibson et al., *1982) and 'high' pH slurries (Roberts* et al., *1981a)*

In both these studies the reduction in the probability of toxin production tended to accelerate with increasing salt concentration (Fig. 2).

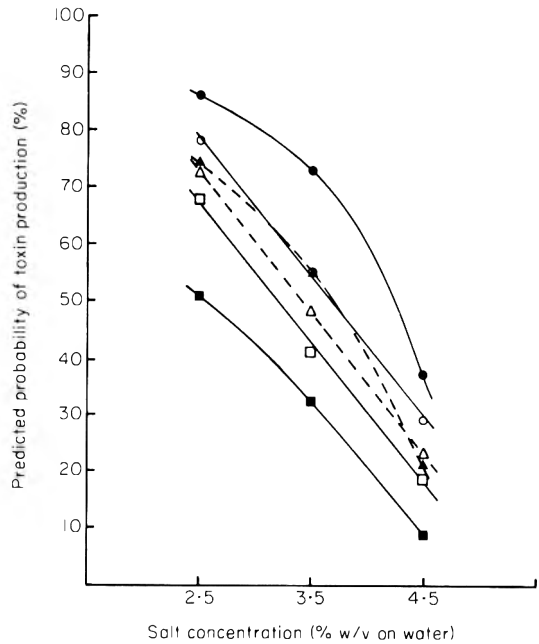

Figure 2. Comparison of linear and non-linear formulae for the prediction of toxin production (% probability): The effect of salt concentration. (All slurries contain 100 μg/g nitrite, subjected to the HIGH heat treatment. ○———○, 20°C linear formula; ●———●, 20°C non-linear formula; △– – –△, 17.5°C linear formula; ▲– – –▲, 17.5°C non-linear formula; □———□, 15°C linear formula; ■———■, 15°C non-linear formula.

Sorbate slurries (Roberts et al., *1982)*

The non-linear effect of salt was first noticed in the sorbate study but differed from that above. Increasing the salt to 3.5% reduced the probability of toxin production but no further significant reduction occurred as salt concentration was increased to 4.5% (Fig. 3). This is difficult to interpret since there was no significant interaction between salt and sorbate when spoilage or toxin data were analysed.

Improved formulae for predicting the probability of toxin production

Appended below are improved formulae for the prediction of the probability of toxin production by *Cl. botulinum* types A and B in 'low' and 'high' pH slurries. These formulae supersede those given in Roberts *et al.* (1981c).

The probability of toxin production is given by

$$p = \frac{1}{1 + e^{-\mu}}$$

where μ is the linear predictor.

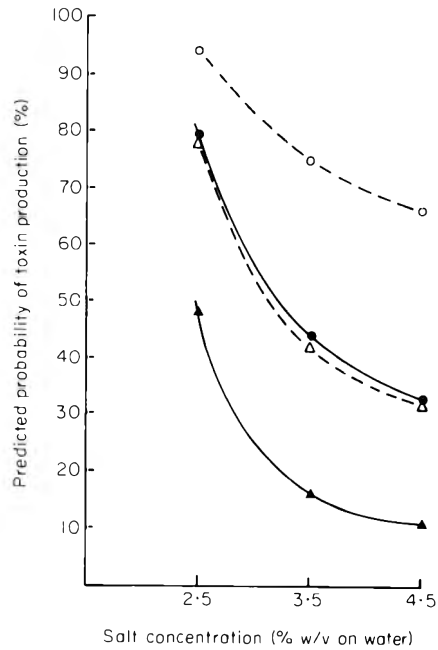

Figure 3. Non-linear effect of salt concentration: Comparison of slurries with and without added sorbate at two extremes of pH. ○– – –○, pH 6.6 sorbate *not* added; ●———●, pH 6.6 sorbate added; △– – –△, pH 5.7 sorbate *not* added; ▲———▲, pH 5.7 sorbate added.

For 'low' pH slurries without heating (unheated), or after LOW or HIGH heat treatment the improved model is:

$\mu = -2.809$	
$-(3.346 \times N)$	where N = $NaNO_2$ ($\mu g/g \times 10^2$)
$+(0.8194 \times T)$	where T = storage temperature (°C)
$-(1.926 \times S)$	where S = NaCl (% w/v on the water)
$+(1.915)$	if inoculum 1000 spores/bottle
$+(2.360)$	if heat treatment LOW
$-(0.08305)$	if heat treatment HIGH
$-(2.322)$	if 1000 μg/g isoascorbate added
$+(2.672)$	if 0.3% w/v *polyphosphate added
$-(4.307)$	if 500 μg/g $NaNO_3$ added
$-(4.329 \times N \times S)$	
$-(0.01493 \times T^2)$	
$-(0.05057 \times T)$	if heat treatment LOW
$-(0.02103 \times T)$	if heat treatment HIGH
$-(0.2765 \times S)$	if heat treatment LOW
$+(0.1413 \times S)$	if heat treatment HIGH
$-(0.5543)$	if heat treatment LOW *and* isoascorbate added

*Curaphos 700, Fibrisol Service Ltd., Colville Road, London W3 8TE.

+ (0.05577)	if heat treatment HIGH *and* isoascorbate added
− (0.4831)	if heat treatment LOW *and* polyphosphate added
− (1.597)	if heat treatment HIGH *and* polyphosphate added
+ (1.07)	if heat treatment LOW *and* $NaNO_3$ added
− (1.073)	if heat treatment HIGH *and* $NaNO_3$ added
+ (1.275 × N)	if $NaNO_3$ added
+ (0.3755 × N)	if isoascorbate added
+ (0.3320 × S)	if isoascorbate added
− (0.3745 × S)	if polyphosphate added
+ (0.5218 × S)	if $NaNO_3$ added

For 'high' pH slurries, after LOW or HIGH heat treatment, the improved model is:

μ = − 7.647	
− (1.603 × N)	where N = $NaNO_2$ (μg/g × 10^2)
+ (1.336 × S)	where S = NaCl (% w/v on the water)
+ (0.8748 × T)	where T = storage temperature (°C)
− (2.134)	if 500 μg/g $NaNO_3$ added
− (6.468)	if 1000 μg/g isoascorbate added
− (1.789)	if 0.3% w/v polyphosphate added
− (1.839)	if heat treatment HIGH
− (0.01692 × N × T)	
− (0.01439 × T^2)	
− (0.3599 × S^2)	
+ (0.6981 × N)	if 500 μg/g $NaNO_3$ added
+ (0.4289 × N)	if 0.3% w/v polyphosphate added
− (1.295)	if $NaNO_3$ *and* polyphosphate added
+ (0.8782 × S)	if isoascorbate added
+ (0.4192 × N)	if heat treatment HIGH
+ (1.02)	if heat treatment HIGH *and* $NaNO_3$ added

The question arises whether the fitted models could be improved still further, e.g. by the inclusion of terms in higher powers of factors (e.g. in salt and storage temperature) and/or interactions of three or more factors. In the cases of salt and storage temperature there is no evidence of any non-linearity not explained by the inclusion of second order terms. Interactions of up to three factors were fitted in the above models, and some three-factor interactions were statistically significant. However, their influence on the probability of toxin production was very small compared with other factors and interactions, and they may be excluded for ease of interpretation. Fourth and higher order interactions may be present, but are likely to be even less important, and, in any case, we are unlikely to be able to estimate their qualitative behaviour with confidence in a system with such inherent errors.

To illustrate the difference between the original and revised formulae Table 2 shows the predicted probabilities of toxin production calculated from both

Table 2. Comparison of predicted probabilities of toxin production calculated using original and revised formulae, in 'LOW' pH slurries, containing 2.5% salt, 100 μg/g nitrite, and an inoculum of 10 spores/bottles.

	Polyphosphate (0.3% w/v)	Isoascorbate (1000 μg/g)	$NaNO_3$ (500 μg/g)	Unheated				LOW heat				HIGH heat			
				15	17.5	20	35	*15	17.5	20	35	15	17.5	20	35
A	−	−	−	27	47	62	62	48	66	76	59	27	44	59	50
B				41	44	47	65	62	62	62	63	41	42	44	54
C				−14	3	15	−3	−14	4	14	−4	−14	2	15	−4
A	−	−	+	6	13	23	22	33	50	62	43	2	5	8	6
B				12	13	15	26	47	47	47	59	4	5	5	7
C				−6	0	8	−4	−14	3	15	−6	−2	0	3	−1
A	−	+	−	11	22	35	35	15	26	38	22	11	21	33	26
B				19	21	23	39	25	25	25	26	20	21	22	30
C				−8	1	12	−4	−10	1	13	−4	−9	0	11	−4
A	−	+	+	2	5	9	9	8	16	24	13	1	2	3	2
B				4	5	6	11	15	15	15	16	2	2	3	3
C				−2	0	3	−2	−7	1	9	−3	−1	0	1	−1
A	+	−	−	68	83	90	90	77	87	92	84	29	48	62	54
B				78	81	83	91	85	85	85	85	44	46	47	57
C				−10	2	7	−1	−8	2	7	−1	−15	2	15	−3
A	+	−	+	28	47	63	62	63	78	85	73	2	5	9	7
B				42	45	48	66	75	75	75	76	5	5	6	8
C				−14	2	15	−4	−12	3	10	−3	−3	0	3	−1
A	+	+	−	41	62	76	75	38	56	68	49	13	24	36	29
B				56	59	62	77	52	52	53	54	22	23	24	32
C				−15	3	14	−2	−14	4	15	−5	−9	1	12	−3
A	+	+	+	11	22	35	35	24	39	52	33	1	2	3	2
B				20	22	24	40	37	37	38	39	2	2	2	3
C				−9	0	11	−5	−13	2	14	−6	−1	0	1	−1
D				−9.75	1.4	10.6	−3.1	−11.5	2.5	12.1	−4	−6.75	0.6	7.6	−2.25

* Storage temperatures (°).

A = Probabilities (%) calculated using revised formula (i.e. including a quadratic term for temperature).

B = Probabilities (%) calculated using original formula (i.e. a linear term for temperature, Roberts *et al.*, 1981c).

C = Difference between probabilities.

D = Mean difference between probabilities for each treatment combination.

formulae for 'low' pH slurries, with an inoculum of 10 spores per bottle and 2.5% salt and 100 μg/g nitrite added. All values are rounded to the nearest whole number (e.g. 0.5 becomes 1, 0.4 becomes 0).

The positive or negative values of the mean difference (line 'D', Table 2) indicate that the original formula (i.e. containing a linear term for storage

Table 3. Probability (%) of toxin production by *Cl. botulinum* type A and B*, in pork slurry† prepared from 'low' pH meat, inoculum 10 spores/bottle

NaCl (% on water)	$NaNO_2$ (μg/g)	Polyphosphate‡ (0.3% w/v)	Sodium isoascorbate (1000 μg/g)	$NaNO_3$ (500 μg/g)	Unheated				LOW heat§				HIGH heat§			
					15¶	17.5	20	35	15	17.5	20	35	15	17.5	20	35
2.5	100	−	−	−	27	47	62	62	48	66	76	59	27	44	59	50
2.5	100	−	−	+	6	13	23	22	33	50	62	43	2	5	8	6
2.5	100	−	+	−	11	22	35	35	15	26	38	22	11	21	33	26
2.5	100	−	+	+	2	5	9	9	8	16	24	13	1	2	3	2
2.5	100	+	−	−	68	83	90	90	77	87	92	84	29	48	62	54
2.5	100	+	−	+	28	47	63	62	63	78	85	73	2	5	9	7
2.5	100	+	+	−	41	62	76	75	38	56	68	49	13	24	36	29
2.5	100	+	+	+	11	22	35	35	24	39	52	33	1	2	3	2
2.5	200	−	−	−	4	8	15	14	9	16	25	13	4	7	13	9
2.5	200	−	−	+	2	5	10	10	15	27	38	22	1	2	3	2
2.5	200	−	+	−	2	4	7	7	3	5	8	4	2	4	7	5
2.5	200	−	+	+	1	3	5	5	5	9	14	7	0	1	2	1
2.5	200	+	−	−	18	34	49	48	25	41	53	34	4	8	14	11
2.5	200	+	−	+	12	24	38	37	38	56	68	49	1	2	4	3
2.5	200	+	+	−	9	19	32	31	8	16	24	13	2	4	8	6
2.5	200	+	+	+	6	13	23	22	15	26	37	21	0	1	2	1
2.5	300	−	−	−	0	1	2	2	1	2	3	2	0	1	1	1
2.5	300	−	−	+	1	2	4	4	6	12	18	9	0	1	1	1
2.5	300	−	+	−	0	1	1	1	0	1	1	1	0	1	1	1
2.5	300	−	+	+	1	1	3	3	3	5	8	4	0	0	1	1
2.5	300	+	−	−	2	5	9	9	3	7	10	5	0	1	2	1
2.5	300	+	−	+	5	10	18	18	19	32	44	26	0	1	1	1
2.5	300	+	+	−	2	3	6	6	1	3	4	2	0	1	1	1
2.5	300	+	+	+	3	8	13	13	8	16	24	12	0	1	1	1

* Inoculum consists of a mixed suspension of equal numbers of spores of five strains of *Cl. botulinum* type A and B.

† Slurries prepared from pork of 'low' pH (range 5.34–6.36) were mixed with water (ratio meat : water 1 : 1.5). Those prepared from pork of 'high' pH (range 6.3–6.72) were mixed in the ratio meat : water 1 : 1.8.

‡ The polyphosphate used in the slurries was Curaphos 700 (Fibrisol Service Ltd, Colville Road, London W3 8TE).

§ LOW heat = heated in water at 80° for 7 min which raised the centre temperature to 70°C; HIGH heat = heated at 80° for 7 min plus 70°C for 1 hr.

¶ Storage temperatures (°C).

The percentage probabilities are rounded to the nearest whole number.

Table 4. Probability (%) of toxin production by *Cl. botulinum* type A and B*, in pork slurry† prepared from 'low' pH meat, inoculum 10 spores/bottle

NaCl (% on water)	$NaNO_2$ (μg/g)	Polyphosphate‡ (0.3% w/v)	Sodium isoascorbate (1000 μg/g)	$NaNO_3$ (500 μg/g)	Unheated				LOW heat§				HIGH heat§			
					15¶	17.5	20	35	15	17.5	20	35	15	17.5	20	35
3.5	100	−	−	−	8	16	27	27	14	25	35	20	9	17	27	21
3.5	100	−	−	+	2	6	10	10	12	22	32	18	1	2	4	3
3.5	100	−	+	−	4	8	15	14	4	8	13	6	4	9	15	11
3.5	100	−	+	+	1	3	5	5	4	7	11	5	0	1	2	1
3.5	100	+	−	−	25	43	59	59	28	44	57	38	7	14	23	17
3.5	100	+	−	+	9	19	30	30	25	41	54	34	1	2	3	2
3.5	100	+	+	−	13	26	40	39	9	17	26	14	3	7	12	9
3.5	100	+	+	+	4	9	17	16	8	15	23	12	0	1	1	1
3.5	200	−	−	−	1	3	6	5	2	5	8	4	1	3	6	4
3.5	200	−	−	+	1	3	6	6	7	14	21	11	1	1	2	1
3.5	200	−	+	−	1	2	4	4	1	2	3	1	1	2	4	3
3.5	200	−	+	+	1	2	4	4	3	6	9	4	0	1	1	1
3.5	200	+	−	−	5	11	19	18	6	11	17	9	1	2	4	3
3.5	200	+	−	+	5	11	20	19	16	28	39	23	0	1	2	1
3.5	200	+	+	−	3	7	13	13	2	4	7	3	1	2	3	2
3.5	200	+	+	+	4	8	14	14	7	13	20	10	0	1	1	1
3.5	300	−	−	−	0	0	1	1	0	1	1	1	0	1	1	1
3.5	300	−	−	+	1	2	3	3	4	8	13	6	0	1	1	1
3.5	300	−	+	−	0	0	1	1	0	0	1	0	0	1	1	1
3.5	300	−	+	+	1	2	3	3	2	5	8	4	0	1	1	1
3.5	300	+	−	−	1	2	3	3	1	2	3	1	0	0	1	1
3.5	300	+	−	+	3	7	12	12	10	18	27	14	0	1	1	1
3.5	300	+	+	−	1	2	3	3	1	1	2	1	0	0	1	1
3.5	300	+	+	+	3	7	12	12	6	11	17	8	0	1	1	1

Key as for Table 3.

temperature) effectively overestimated the likelihood of toxin production at 15 and 35°C and underestimated it at 17.5 and 20°C. The greatest differences between the two formulae occurred at 15 and 20°C (line 'D', Table 2) and is apparent over all combinations of additives tested and irrespective of heat treatment. Tables 3–11 show the revised calculated probabilities for toxin production (expressed as a percentage for clarity) for every combination of factors tested. The difference between the original and revised predicted probabilities at any given combination of factors is greatest over the intermediate

Table 5. Probability (%) of toxin production by *Cl. botulinum* type A and B*, in pork slurry† prepared from 'low' pH meat, inoculum 10 spores/bottle

NaCl (% on water)	$NaNO_2$ (μg/g)	Polyphosphate‡ (0.3% w/v)	Sodium isoascorbate (1000 μg/g)	$NaNO_3$ (500 μg/g)	Unheated				LOW heat§				HIGH heat§			
					15¶	17.5	20	35	15	17.5	20	35	15	17.5	20	35
4.5	100	−	−	−	2	4	8	8	3	5	9	4	2	5	9	6
4.5	100	−	−	+	1	2	4	4	4	8	12	6	0	1	2	1
4.5	100	−	+	−	1	3	5	5	1	2	3	2	2	3	6	4
4.5	100	−	+	+	1	1	3	3	1	3	5	2	0	1	1	1
4.5	100	+	−	−	5	11	18	18	4	8	13	7	1	3	5	4
4.5	100	+	−	+	3	6	10	10	6	12	19	9	0	0	1	1
4.5	100	+	+	−	3	7	13	12	2	3	5	3	1	2	3	2
4.5	100	+	+	+	2	4	7	7	2	5	8	4	0	0	1	0
4.5	200	−	−	−	0	1	2	2	1	1	2	1	1	1	2	2
4.5	200	−	−	+	1	2	4	3	3	7	11	5	0	1	1	1
4.5	200	−	+	−	0	1	2	2	0	1	1	1	1	1	2	2
4.5	200	−	+	+	1	2	3	3	2	4	6	3	0	1	1	1
4.5	200	+	−	−	1	3	5	5	1	2	4	2	0	1	1	1
4.5	200	+	−	+	2	5	9	9	5	10	16	8	0	0	1	1
4.5	200	+	+	−	1	3	5	5	1	1	2	1	0	1	1	1
4.5	200	+	+	+	2	5	8	8	3	6	9	5	0	0	1	1
4.5	300	−	−	−	0	0	0	0	0	0	1	0	0	0	1	0
4.5	300	−	−	+	1	2	3	3	3	6	9	5	0	1	1	1
4.5	300	−	+	−	0	0	1	1	0	0	0	0	0	0	1	1
4.5	300	−	+	+	1	2	4	4	2	5	7	4	0	1	2	1
4.5	300	+	−	−	0	1	1	1	0	1	1	0	0	0	0	0
4.5	300	+	−	+	2	4	8	8	5	9	15	7	0	0	1	0
4.5	300	+	+	−	0	1	2	2	0	0	1	0	0	0	0	0
4.5	300	+	+	+	3	6	10	10	4	7	12	6	0	1	1	1

Key as for Table 3.

range of probabilities of toxin production. Where probabilities of toxin production are very low (e.g. slurries containing 2.5% salt, 100 μg/g nitrite, plus polyphosphate with zero heat treatment) the new predicted probability differs little from the original value.

The difference in predicted values obtained by using the two formulae is also illustrated in Figs 1 and 2. In Fig. 1, the probabilities of toxin production are plotted against storage temperature for two treatment combinations: (1) 2.5% salt, 100 μg/g nitrite, zero heat treatment, and (2) 2.5% salt, 100 μg/g nitrite

Table 6. Probability (%) of toxin production by *Cl. botulinum* type A and B*, in pork slurry† prepared from 'low' pH meat, inoculum 1000 spores/bottle.

NaCl (% on water)	$NaNO_2$ (μg/g)	Polyphosphate‡ (0.3% w/v)	Sodium isoascorbate (1000 μg/g)	$NaNO_3$ (500 μg/g)	Unheated				LOW heat§				HIGH heat§			
					15¶	17.5	20	35	15	17.5	20	35	15	17.5	20	35
2.5	100	−	−	−	72	86	92	92	86	93	96	91	71	84	91	87
2.5	100	−	−	+	31	51	67	66	77	87	92	84	13	25	37	30
2.5	100	−	+	−	46	66	79	78	54	71	80	65	46	65	77	71
2.5	100	−	+	+	13	26	40	39	38	56	68	49	5	10	17	13
2.5	100	+	−	−	94	97	98	98	96	98	99	97	74	86	92	89
2.5	100	+	−	+	72	86	92	92	92	96	98	95	15	27	40	33
2.5	100	+	+	−	83	92	95	95	81	89	93	87	49	68	79	73
2.5	100	+	+	+	46	66	79	78	68	82	88	77	6	11	19	14
2.5	200	−	−	−	21	38	54	53	39	57	69	50	20	35	50	41
2.5	200	−	−	+	14	28	42	42	55	71	81	65	5	11	18	13
2.5	200	−	+	−	11	22	35	35	15	27	38	22	11	22	33	26
2.5	200	−	+	+	7	15	26	25	25	40	53	34	3	6	10	7
2.5	200	+	−	−	60	77	87	86	69	82	89	78	22	39	53	45
2.5	200	+	−	+	49	69	81	80	81	90	94	87	6	12	20	15
2.5	200	+	+	−	41	62	76	75	38	56	68	49	13	24	37	29
2.5	200	+	+	+	31	51	67	66	54	70	80	64	3	6	11	8
2.5	300	−	−	−	3	6	11	10	6	12	19	9	2	5	9	7
2.5	300	−	−	+	6	12	21	21	31	47	60	41	2	4	7	5
2.5	300	−	+	−	2	4	8	7	3	5	8	4	2	4	7	5
2.5	300	−	+	+	4	9	16	15	15	26	38	22	1	3	5	4
2.5	300	+	−	−	13	26	40	39	19	32	44	27	3	6	10	8
2.5	300	+	−	+	26	44	60	60	61	76	84	71	2	5	8	6
2.5	300	+	+	−	10	20	32	31	8	16	24	13	2	4	8	6
2.5	300	+	+	+	19	36	51	51	38	56	68	49	2	4	6	5

Key as for Table 3.

Table 7. Probability (%) of toxin production by *Cl. botulinum* type A and B*, in pork/slurry† prepared from 'low' pH meat, inoculum 1000 spores/bottle.

NaCl (% on water)	$NaNO_2$ (μg/g)	Polyphosphate‡ (0.3% w/v)	Sodium isoascorbate (1000 μg/g)	$NaNO_3$ (500 μg/g)	Unheated				LOW heat§				HIGH heat§			
					15¶	17.5	20	35	15	17.5	20	35	15	17.5	20	35
3.5	100	–	–	–	37	57	72	71	52	69	79	63	39	58	72	64
3.5	100	–	–	+	15	28	43	43	49	66	76	60	6	12	20	15
3.5	100	–	+	–	21	38	54	53	22	37	49	31	23	40	55	46
3.5	100	–	+	+	7	15	26	25	20	34	46	28	3	6	11	8
3.5	100	+	–	–	69	84	91	91	72	84	90	80	33	52	67	59
3.5	100	+	–	+	40	61	75	74	70	82	89	78	5	10	17	13
3.5	100	+	+	–	51	70	82	81	41	58	70	52	19	35	49	41
3.5	100	+	+	+	23	41	58	57	37	55	67	48	2	5	9	7
3.5	200	–	–	–	8	17	29	28	15	26	37	21	9	18	28	22
3.5	200	–	–	+	9	18	30	29	35	52	65	45	4	7	13	9
3.5	200	–	+	–	6	12	21	21	6	12	18	9	7	13	22	17
3.5	200	–	+	+	6	13	22	22	17	29	41	24	3	5	9	7
3.5	200	+	–	–	26	45	61	60	29	46	58	39	7	15	24	18
3.5	200	+	–	+	27	47	63	62	56	72	81	67	3	6	10	8
3.5	200	+	+	–	19	35	51	50	14	24	35	20	5	11	18	14
3.5	200	+	+	+	20	37	53	52	33	50	63	43	2	4	7	5
3.5	300	–	–	–	1	3	6	6	3	5	8	4	2	3	6	4
3.5	300	–	–	+	5	11	19	19	23	38	51	32	2	4	8	5
3.5	300	–	+	–	1	3	6	6	1	3	5	2	2	3	6	4
3.5	300	–	+	+	5	11	19	19	14	25	36	21	2	4	8	6
3.5	300	+	–	–	5	11	20	19	6	12	18	9	1	3	5	3
3.5	300	+	–	+	18	33	49	48	42	60	71	53	2	3	6	4
3.5	300	+	+	–	5	11	19	19	3	7	11	5	1	3	5	3
3.5	300	+	+	+	17	32	48	47	29	45	58	39	2	4	6	4

Key as for Table 3.

Table 8. Probability (%) of toxin production by *Cl. botulinum* type A and B*, in pork slurry† prepared from 'low' pH meat, inoculum 1000 spores/bottle.

NaCl (% on water)	$NaNO_2$ (μg/g)	Polyphosphate‡ (0.3% w/v)	Sodium isoascorbate (1000 μg/g)	$NaNO_3$ (500 μg/g)	Unheated				LOW heat§				HIGH heat§			
					15¶	17.5	20	35	15	17.5	20	35	15	17.5	20	35
4.5	100	−	−	−	11	23	36	36	16	27	39	22	14	26	39	32
4.5	100	−	−	+	6	13	22	22	21	36	48	30	3	6	10	7
4.5	100	−	+	−	8	16	27	26	6	12	19	10	10	19	30	24
4.5	100	−	+	+	4	9	15	15	9	17	25	13	2	4	7	5
4.5	100	+	−	−	26	44	60	60	23	38	51	32	8	16	26	20
4.5	100	+	−	+	15	29	44	43	31	48	61	41	2	3	6	4
4.5	100	+	+	−	18	34	49	49	10	19	28	15	6	12	19	14
4.5	100	+	+	+	10	20	33	32	14	25	36	20	1	2	4	3
4.5	200	−	−	−	3	7	12	12	4	8	13	7	4	8	14	10
4.5	200	−	−	+	5	12	20	20	19	32	45	27	2	5	9	6
4.5	200	−	+	−	3	6	11	11	2	5	8	4	4	8	13	10
4.5	200	−	+	+	5	11	19	18	11	20	30	16	2	5	9	6
4.5	200	+	−	−	8	16	27	27	7	13	20	10	2	5	8	6
4.5	200	+	−	+	13	26	40	40	28	44	57	38	1	3	5	4
4.5	200	+	+	−	7	15	26	25	4	7	12	6	2	4	8	6
4.5	200	+	+	+	12	25	38	38	17	30	42	25	1	3	5	4
4.5	300	−	−	−	1	2	3	3	1	2	4	2	1	2	4	3
4.5	300	−	−	+	5	10	18	17	17	29	41	24	2	4	8	6
4.5	300	−	+	−	1	2	4	4	1	2	3	1	1	3	5	4
4.5	300	−	+	+	6	13	23	22	14	24	35	20	3	6	11	8
4.5	300	+	−	−	2	5	8	8	2	4	6	3	1	1	2	1
4.5	300	+	−	+	12	23	37	36	25	41	54	35	1	2	4	3
4.5	300	+	+	−	3	6	11	11	1	3	5	2	1	2	3	2
4.5	300	+	+	+	15	29	44	43	21	35	47	29	2	3	6	4

Key as for Table 3.

Table 9. Probability (%) of toxin production by *Cl. botulinum* type A and B*, in pork slurry† prepared from 'high' pH meat, inoculum 10 spores/bottle.

NaCl (% on water)	$NaNO_2$ (μg/g)	Polyphosphate‡ (0.3% w/v)	Sodium isoascorbate (1000 μg/g)	$NaNO_3$ (500 μg/g)	LOW heat§				HIGH heat§			
					15¶	17.5	20	35	15	17.5	20	35
2.5	100	−	−	−	81	92	96	99	51	74	86	94
2.5	100	−	−	+	51	73	86	94	41	65	80	92
2.5	100	−	+	−	6	14	26	49	1	4	8	19
2.5	100	−	+	+	1	4	8	19	1	3	5	13
2.5	100	+	−	−	53	75	87	95	21	42	61	81
2.5	100	+	−	+	7	16	30	54	5	11	22	44
2.5	100	+	+	−	2	4	8	20	0	1	2	6
2.5	100	+	+	+	0	0	1	2	0	0	0	1
2.5	200	−	−	−	40	63	79	89	20	39	57	74
2.5	200	−	−	+	25	45	64	79	25	46	64	79
2.5	200	−	+	−	1	2	5	10	0	1	2	4
2.5	200	−	+	+	0	1	2	5	0	1	2	5
2.5	200	+	−	−	21	41	59	75	9	20	35	53
2.5	200	+	−	+	3	8	16	28	3	8	16	29
2.5	200	+	+	−	0	1	2	4	0	0	1	2
2.5	200	+	+	+	0	0	0	1	0	0	0	1
2.5	300	−	−	−	10	21	35	46	6	13	23	32
2.5	300	−	−	+	9	20	34	45	14	28	44	56
2.5	300	−	+	−	0	0	1	1	0	0	0	1
2.5	300	−	+	+	0	0	1	1	0	1	1	2
2.5	300	+	−	−	6	14	24	34	3	8	15	23
2.5	300	+	−	+	2	4	8	12	3	6	12	18
2.5	300	+	+	−	0	0	0	1	0	0	0	0
2.5	300	+	+	+	0	0	0	0	0	0	0	0

† Key as for Table 3.

Table 10. Probability (%) of toxin production by *Cl. botulinum* type A and B*, in pork slurry† prepared from 'high' pH meat, inoculum 10 spores/bottle.

NaCl (% on water)	$NaNO_2$ (μg/g)	Polyphosphate‡ (0.3% w/v)	Sodium isoascorbate (1000 μg/g)	$NaNO_3$ (500 μg/g)	LOW heat§				HIGH heat§			
					15¶	17.5	20	35	15	17.5	20	35
3.5	100	−	−	−	66	84	92	97	32	55	73	88
3.5	100	−	−	+	31	55	73	88	23	45	64	83
3.5	100	−	+	−	6	15	27	51	2	4	8	20
3.5	100	−	+	+	2	4	8	20	1	3	6	14
3.5	100	+	−	−	33	57	74	89	11	24	41	65
3.5	100	+	−	+	3	8	16	34	2	5	11	25
3.5	100	+	+	−	2	4	9	21	0	1	2	6
3.5	100	+	+	+	0	0	1	2	0	0	0	1
3.5	200	−	−	−	23	43	62	77	10	22	37	55
3.5	200	−	−	+	12	27	44	62	13	27	44	62
3.5	200	−	+	−	1	2	5	10	0	1	2	4
3.5	200	−	+	+	0	1	3	5	0	1	3	5
3.5	200	+	−	−	11	23	39	57	4	10	19	33
3.5	200	+	−	+	2	4	8	15	2	4	8	15
3.5	200	+	+	−	0	1	2	4	0	0	1	2
3.5	200	+	+	+	0	0	0	1	0	0	0	1
3.5	300	−	−	−	4	10	19	27	3	6	11	17
3.5	300	−	−	+	4	10	18	27	6	14	26	36
3.5	300	−	+	−	0	0	1	1	0	0	0	1
3.5	300	−	+	+	0	0	1	1	0	1	1	2
3.5	300	+	−	−	3	6	12	19	2	4	7	11
3.5	300	+	−	+	1	2	4	6	1	3	5	9
3.5	300	+	+	−	0	0	0	1	0	0	0	0
3.5	300	+	+	+	0	0	0	0	0	0	0	0

Key as for Table 3.

Table 11. Probability (%) of toxin production by *Cl. botulinum* type A and B*, in pork slurry† prepared from 'high' pH meat, inoculum 10 spores/bottle.

NaCl (% on water)	$NaNO_2$ (μg/g)	Polyphosphate‡ (0.3% w/v)	Sodium isoascorbate (1000 μg/g)	$NaNO_3$ (500 μg/g)	LOW heat§				HIGH heat§			
					15¶	17.5	20	35	15	17.5	20	35
4.5	100	−	−	−	29	52	71	87	9	21	37	61
4.5	100	−	−	+	9	20	36	61	6	15	28	51
4.5	100	−	+	−	3	8	16	34	1	2	4	11
4.5	100	−	+	+	1	2	4	11	1	1	3	8
4.5	100	+	−	−	9	22	38	63	2	6	13	29
4.5	100	+	−	+	1	2	4	10	0	1	3	7
4.5	100	+	+	−	1	2	5	12	0	1	1	3
4.5	100	+	+	+	0	0	0	1	0	0	0	1
4.5	200	−	−	−	6	14	26	42	2	6	11	21
4.5	200	−	−	+	3	7	14	26	3	7	14	26
4.5	200	−	+	−	1	1	3	6	0	0	1	2
4.5	200	−	+	+	0	1	1	3	0	1	1	3
4.5	200	+	−	−	2	6	12	22	1	2	5	9
4.5	200	+	−	+	0	1	2	4	0	1	2	4
4.5	200	+	+	−	0	1	1	2	0	0	0	1
4.5	200	+	+	+	0	0	0	0	0	0	0	0
4.5	300	−	−	−	1	2	5	7	1	1	3	4
4.5	300	−	−	+	1	2	5	7	1	3	7	11
4.5	300	−	+	−	0	0	0	1	0	0	0	0
4.5	300	−	+	+	0	0	0	1	0	0	1	1
4.5	300	+	−	−	1	1	3	5	0	1	2	3
4.5	300	+	−	+	0	0	1	1	0	1	1	2
4.5	300	+	+	−	0	0	0	0	0	0	0	0
4.5	300	+	+	+	0	0	0	0	0	0	0	0

Key as for Table 3.

plus polyphosphate and nitrate after the LOW heat treatment. The inclusion of a quadratic term for temperature considerably improved the fit of the data in all the logistic regression analyses carried out but the probabilities of toxin production at 35°C were lower than expected, most growth (i.e. spoilage) having occurred after storage at 35°C. Separate statistical analysis of spoilage and toxin data (Roberts *et al.*, 1981a, b) also resulted in factors and interactions being ranked similarly for relative importance, thus confirming a relationship between toxin production and the observed degree of spoilage. Since growth temperatures between 20 and 35°C were not included in the experimental design it is unwise to predict probabilities within that range.

The non-linear effect of salt (Fig. 2) was much less pronounced, and not apparent in the 'low' pH study (Roberts *et al.*, 1981a). Because the effect of storage temperature was considerable the differences between the linear and non-linear plots of salt concentration against the percentage probability of toxin production vary (Fig. 2). At higher storage temperatures (e.g. 20°C plot in Fig. 2) the linear model underestimated toxin production at all salt concentrations, whereas at 15°C the linear model overestimated toxin production.

Acknowledgment

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Circulation cleaning of a plate heat exchanger fouled by tomato juice

III. The effect of fluid flow rate on cleaning efficiency

A. T. JACKSON* AND WAI MING LOW

Summary

The effect of a change in flow rate of a 2% w/w caustic soda solution on the circulation cleaning of a plate heat exchanger fouled with diluted tomato paste has been investigated at a temperature of 90°C and fixed circulation cleaning times of 5 and 10 min.

For both circulation cleaning times a transition point was noted in the range 2.75–2.86 l/min (Reynolds number range 6600–6300, shear stress range 0.77–0.82 N/m^2). Below the transition point the effect of flow rate on cleaning efficiency was minimal, but at flow rates above the transition point there was a marked increase in cleaning efficiency as the flow rate (and hence shear stress at the surface) increased.

Introduction

In circulation cleaning, the friction between deposited soil and the fluid flowing over it provides the energy source essential for the final displacement of the soil deposit (Jennings, 1963). Hankinson & Carver (1968) stated that cleaning effectiveness is contributed to by both turbulent shear in the liquid bulk and by the shear stress at the wall surface. Jennings, McKillop & Luick (1957), working with P^{32}-labelled films of milk solids deposited on test discs and mounted in a pipeline, concluded that the effect of turbulence on cleaning was negligible until the rate of flow was high enough to achieve a pipe Reynolds number of 25 000. Hankinson *et al.* (1965) stated that the Reynolds number is a better basis for fluid flow characteristics than flow velocity, and gave charts to relate Reynolds number, flow rate and capacity in pipelines.

The U.S.A. 3–A sanitary standards (International Association of Milk, Food & Environmental Sanitarians, 1966) specify that a minimum average solution

Authors' address: *Department of Chemical Engineering and Procter Department of Food Science, University of Leeds, Leeds, LS2 9JT.

*To whom correspondence should be addressed.

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velocity of 5 ft/sec (1.52 m/sec) through each pipe or fitting should be provided for circulation cleaning, and Timperley & Lawson (1980) showed that the same degree of cleaning of pipes of different sizes is not achieved at equivalent Reynolds numbers, but is achieved only if the same mean flow velocity is used. Based on their experimental conditions, the level of residual micro-organisms on a surface is reduced to a minimum if the velocity of flow is about 1.5 m/sec.

Materials and methods

The experimental cleaning circuit consisted of an APV Co. Junior Paraflow plate heat exchanger with seven plates arranged to give three in-series passes or flow channels for the cleaning fluid. The surfaces of the heat exchanger plates were soiled using diluted 28–30% double concentrate tomato paste painted on the plates, the plates being dried in a laboratory oven at 112°C for 45 min. The cleaning fluid used was a 2% w/w caustic soda solution, and the soiled plates were pre-rinsed for 3 min with water at 70°C using a flow rate of 2 l/min. The cleaning solution was then circulated for a fixed time (5 or 10 min) at flow rates varying from 2–4 l/min at 90°C. After circulation cleaning, the caustic soda was flushed from the system using a 70°C water post-rinse for 3 min at a flow rate of 2 l/min. The plates were then dried in the laboratory oven. Details of the cleaning circuit, the soiling technique and determination of soil remaining on the plates after cleaning has been described by Cheow & Jackson (1982a). For all the experimental runs, the pressure at the outlet of the plate heat exchanger was atmospheric.

Results

The experimental results for circulation cleaning using a 2% w/w caustic soda solution at a temperature of 90°C are plotted in Figs 1 and 2 as best-fit, smooth curves passing through the average values of percentage soil remaining on the plates for each flow rate, individual points being omitted for clarity. Figure 1 represents the overall results for circulation times of 5 and 10 min. The repeat of the 10 min circulation time was carried out some weeks after the initial set of results using the same batch of tomato paste. Figure 2 represents the cleaning curves for each individual flow channel for the initial 10 min circulation time experiments. Channel 3 was the channel nearest the fluid inlet, Channel 1 nearest the fluid outlet. The 5 min circulation cleaning results and the 10 min repeated results showed the same tendencies in that the channel nearest the fluid outlet gave the lowest level of residual soil.

Statistical analysis of results

The results obtained for the overall percentage of soil remaining on the plate heat exchanger after cleaning were analysed using linear regression theory

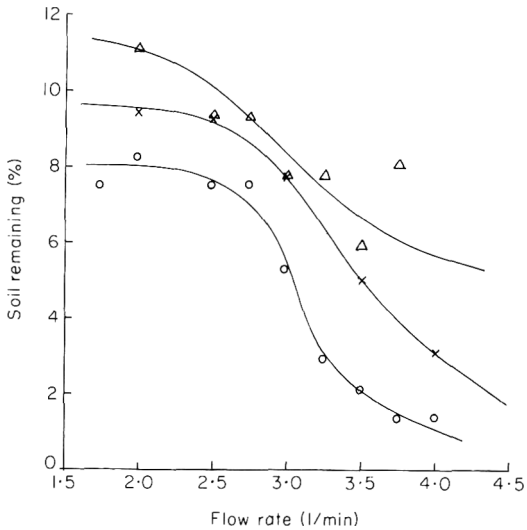

Figure 1. Effect of flow rate on circulation cleaning. ×, 10 min circulation time; ○, 10 min circulation time (repeat); △, 5 min circulation time.

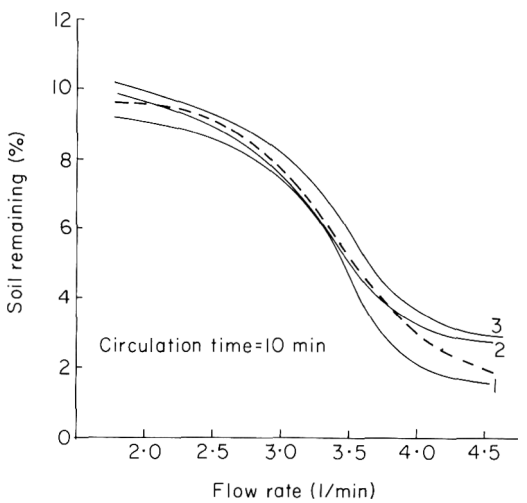

Figure 2. Effect of flow rate on cleaning of individual channels. – – –, overall cleaning curve; Channel 3 nearest fluid inlet; Channel 1 nearest fluid exit.

(Murdoch & Barnes, 1973). The results were found to be best represented by a power law in log–log form, and in each case showed a discontinuity at some critical value of the flow rate. The slope of the equation of best-fit regression line, coefficient of correlation and range of circulation flow rates are given in Table 1, and the results are plotted on log–log scales in Fig. 3.

Table 1. Statistical analysis of results (log–log data). Equation $y = AQ^B$ (y = % soil remaining; Q = flow rate, l/min)

Cleaning time (min)	Critical flow rate (l/min)	Correlation coefficient	Slope value of (B)	Slope value of (A)	Flow rate range (l/min)
10	2.86	− 0.84	0.0	9.58	2.00–2.88
			− 3.58	413.0	2.88–4.0
10 (repeat)	2.79	− 0.96	0.0	7.35	1.75–2.78
			− 5.75	2676.0	2.78–4.0
5	2.75	− 0.90	0.0	10.1	2.00–2.76
			− 1.81	62.9	2.76–3.75

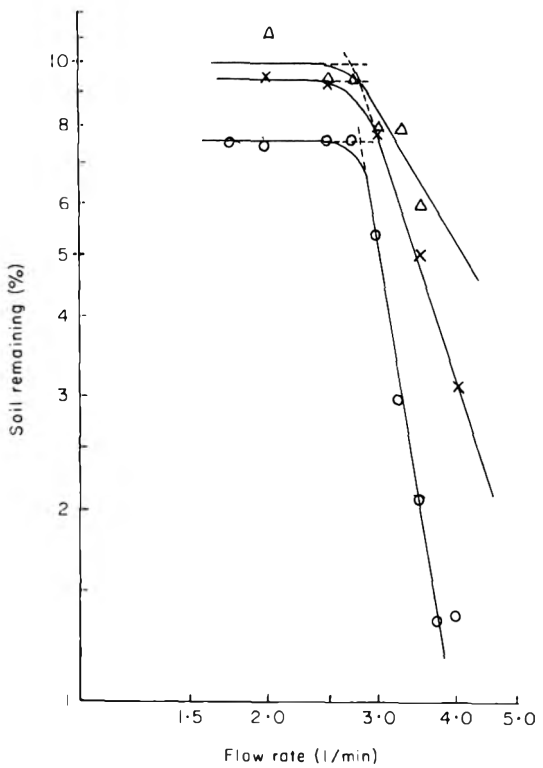

Figure 3. Soil remaining versus flow rate (log–log). Key as for Fig. 1.

Discussion

The results for all the experiments show a clear discontinuity at some critical value of the flow rate of the 2% caustic soda solution when plotted on log–log scales (Fig. 3).

For a Newtonian fluid flowing over a solid surface, the shear stress exerted by the fluid at the surface (R_W) is related to the shear rate in the bulk of the fluid

expressed as a velocity gradient (du/dy) by the relationship

$R_W = -\mu(du/dy)$, where μ = fluid viscosity; y = perpendicular distance from surface.

In circulation cleaning, the shear rate will give a measure of the turbulence in the bulk of the fluid (the capacity to sweep away removed soil), and the shear stress will give a measure of the forces available for removing soil adhering to the surface.

For the turbulent flow of fluids in smooth pipes and channels, the shear stress at the wall (R_W), expressed as the Stanton & Pannel (1914) friction factor ($R_W/\rho u^2$), is related to the Reynolds number by the Blasius (1913) expression

$$R_W/\rho u^2 = 0.0396\,(\mathrm{Re})^{-0.25}$$

the Reynolds number (Re) being defined by

$$\mathrm{Re} = d_e u\rho/\mu$$

where d_e = equivalent diameter of the flow channel being two times the mean plate gap; u = fluid velocity; ρ = fluid density; μ = fluid viscosity.

The physical properties of water and 2% caustic soda solution at 50 and 90°C are given in Table 2, the density and viscosity of water and density of caustic soda solution being taken from Perry (1950), the viscosity of 2% caustic soda solution from L. Barker and A. T. Jackson (unpubl. data).

For the plate heat exchanger used in the experiments, the mean plate gap is 2.5 mm, giving an equivalent diameter (d_e) of 0.005 m, and based on the cross-sectional area of flow of the heat exchanger channels, for a critical fluid flow rate of 2.86 l/min at 90°C (Table 1) the fluid velocity will be 0.435 m/sec.

Critical Reynolds number, $\mathrm{Re} = 0.005 \times 0.435 \times 998.7/(0.3173 \times 10^{-3})$

$$= 6840$$

and,

$$R_W/\rho u^2 = 0.0396(6840)^{-0.25}$$

$$= 0.00435$$

Critical shear stress at wall, $R_W = 0.00435 \times 998.7(0.435)^2 = 0.823\ \mathrm{N/m^2}$.

Since, by definition, (Shear stress) $= \mu$ (Shear rate)

Critical shear rate $= 0.823/(0.3173 \times 10^{-3}) = 2591\ \mathrm{sec^{-1}}$.

Table 2. Physical properties of fluids

	Density (kg/m³)		Viscosity (cP)	
Fluid	50°C	90°C	50°C	90°C
Water	988.1	965.3	0.5494	0.3165
2% Caustic soda	1009.2	998.7	0.5523	0.3173

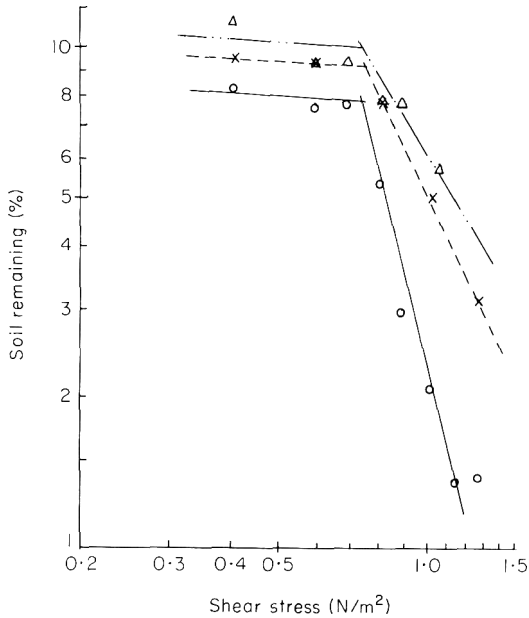

Figure 4. Soil remaining versus shear stress (log–log). Key as for Fig. 1.

The flow rates used in the experiments were converted to shear stress at the surface of the heat exchanger as above, and the results were correlated using a combination Newton–Raphson/least squares iterative curve fitting procedure in terms of soil remaining *versus* shear stress. The results of this analysis are plotted on log–log scales in Fig. 4, and as expected, the discontinuity observed in Fig. 3 is apparent in Fig. 4. For the APV Junior Paraflow plate heat exchanger used in the experiments, the values of flow rate, fluid velocity, Reynolds number, shear stress and shear rate using 2% caustic soda solution at 90°C are reproduced for the critical points in Table 3.

Table 3. Flow characteristics at the critical points

Cleaning time (min)	Fluid flow time (l/min)	Fluid velocity (m/sec)	Reynolds number	Shear rate (sec^{-1})	Shear stress (N/m^2)
10	2.86	0.435	6600	2523	0.82
10 (repeat)	2.79	0.424	6434	2400	0.78
5	2.75	0.418	6343	2369	0.77

The mechanisms involved in circulation cleaning are extremely complex (Bourne & Jennings, 1963) and involve the physical characteristics of the soil and detergent as well as the flow characteristics of the system. The flow characteristics of the system depend on temperature, and an increase in Reynolds number solely due to a change in physical properties due to temperature (particularly viscosity) can lead to a decrease in the shear stress at the wall, although the value of the shear rate will increase. Table 4 shows this effect for

Table 4. Effect of temperature on flow characteristics (water)

Velocity (m/sec)	Pipe diameter (m)	Reynolds number		Shear stress (N/m^2)		Shear rate (sec^{-1})	
		50°C	90°C	50°C	90°C	50°C	90°C
0.365	0.038	25 000	42 300	0.415	0.355	755	1 122
0.426	0.005*	4 839	6 496	0.85	0.80	1546	2 527
1.5	0.038	102 740	174 000	4.92	4.21	8955	13 300
1.5	0.076	205 480	348 000	4.14	3.54	7530	11 183

* Equivalent diameter for the plate heat exchanger.

water flowing in a smooth pipe at various velocities for temperatures of 50 and 90°C, using the physical properties from Table 2.

The work of Jennings, McKillop & Luick (1957) was carried out with test discs in a 1½ in diameter pipe using P^{32}-labelled milk solids. The critical flow velocity at a Reynolds number of 25 000 was 0.365 m/sec, and from Table 4 it can be seen that the critical shear stress would have been approximately 0.415 N/m^2 at 50°C. Timperly & Lawson (1980) and the U.S.A. 3–A Standards, using a velocity of 1.5 m/sec would generate a shear stress at 50°C with water of 4.92 N/m^2 at the surface of a 1½ in pipe, almost a twelve-fold increase on the Jennings, McKillop & Luick figure.

The present work using a plate heat exchanger would be expected to yield different criteria for the transition point, since the flow channels are designed with corrugated surfaces to enhance turbulence, and this would be expected to enhance the cleaning of these surfaces at lower velocities and shear stresses than those for smooth pipes.

It is interesting to note that Timperly (1981) reports that with water velocities of 1.5 m/sec at 45°C in pipelines of 0.038 and 0.076 m, diameter, the fluid velocity at the edge of the laminar sub-layer is calculated to be 0.45 m/sec. The thickness of the laminar sub-layer was calculated to be 0.05 mm thick; for the plate heat exchanger used in this present work, the mean plate gap was 2.5 mm, and the critical velocity found to be 0.426 m/sec.

Conclusions

At flow rates above the mean transition point of 2.83 l/min (wall shear stress 0.8 N/m^2) for the 10 min circulation cleaning time, the cleaning efficiency increases with flow rate. Below the transition point, the cleaning efficiency appears to remain constant, irrespective of flow rate.

Based on the statistical analysis, the log–log relationship between the soil remaining on the plates and flow rate was found to be statistically significant, and the experimental results were found to lie well within prediction limits.

More residual soil was found in the entry flow channel after cleaning than in

the exit channel of the plate heat exchanger, a phenomenon noted by Cheow & Jackson (1982b).

Although plate heat exchangers exhibit turbulent heat transfer characteristics above a Reynolds number as low as 100 (APV Co. Ltd, 1973; Alfa-Laval Co. Ltd, 1978), and manufacturers recommend operation (for heat transfer) at Reynolds numbers above 1500, in terms of circulation cleaning efficiency it would appear that Reynolds numbers greater than 6800 or a shear stress value at the surface greater than 0.8 N/m^2 should be recommended.

The soil system used in these experiments represents a very severe fouling situation, most plant cleaning problems should be less severe.

Acknowledgments

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Effect of diacetyl on the heat stability of concentrated milks

S. I. SHALABI AND P. F. FOX*

Summary

Very low levels of diacetyl (1–5 mM) markedly increased the heat stability of concentrated milks (20% total solids) reconstituted from skim milk powders. Diacetyl caused only slight stabilization of the concentrates (following dilution to 20% total solids) used in the manufacture of these powders but its efficacy was increased by heating the concentrates (70°C for 10 min) prior to diacetyl addition and especially by freeze drying. Laboratory concentrated milks were destabilized by diacetyl and these samples were also destabilized by freeze drying. However, addition of diacetyl prior to preheating and concentration increased stability.

Introduction

While urea has a stabilizing effect on unconcentrated milk (Pyne, 1958; Robertson & Dixon, 1969; Muir & Sweetsur, 1976, 1977; Holt, Muir & Sweetsur, 1978b) it does not stablize concentrated milk (Muir & Sweetsur, 1977). The stabilizing action of urea appears to depend on the presence of a carbonyl compound, including reducing sugars (Kudo, 1980; Shalabi & Fox, 1982a). In contrast, aldehydes, including low molecular weight sugars, stabilize both unconcentrated and concentrated milks (Kosikowski, 1944; Nelson, 1954; Holt, Muir & Sweetsur, 1978a), with or without urea, although urea considerably increases the efficacy of carbonyls (Shalabi & Fox, 1982a). Holt *et al.* (1978a) showed that the dicarbonyl, glyoxal, was the most effective stabilizer, on a molar basis, of concentrated milks of the carbonyls studied by them. This has been confirmed by Shalabi & Fox (1982b) who showed that several dicarbonyl compounds, including diacetyl, at very low concentrations are very effective stabilizers of unconcentrated milks.

Authors' address: Food Chemistry Department, University College, Cork, Irish Republic.
* To whom correspondence should be addressed.

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Since diacetyl is a natural constituent of fermented dairy products (yoghurt and cheese), and is a permitted food additive (e.g. for margarine) it may be acceptable for use as a stabilizer for concentrated milks. This communication reports the results of an investigation on the effect of diacetyl on the heat stability of concentrated milks.

Materials and methods

Material

Milk supply. Raw bulk milk samples were obtained from the University herd and defatted by centrifugation at 2000 *g* for 20 min. Skim milk powders were obtained from the Irish Dairy Board, Golden Vale Co-Op Creameries, Ltd, Mitchelstown Creameries Ltd and Ballyclough Co-op Ltd, Ireland.

Concentrated milk. Concentrated milk was prepared from skim milk using a laboratory rotary evaporator at 40°C. Commercial concentrated milk samples were obtained from the Golden Vale, Mitchelstown, Ballyclough Creameries. In some cases concentrated milks were obtained by reconstituting skim milk powders to 20% w/v total solids, or by reconstituting freeze dried samples to 20% w/v.

Chemicals. Diacetyl was obtained from B.D.H. Chemicals, England.

Methods

The total solids (TS) content of the concentrated milks was determined by the International Dairy Federation (1961) method.

pH adjustment. The pH of the concentrated milk samples was adjusted in the pH range 6.2–7.2 with 2 N HCl or 2 N NaOH and held for 1 hr to equilibrate before heat stability assay.

Heat stability. The heat coagulation time (HCT) was determined in a thermostatically controlled oil bath at 120°C according to the method of Davies & White (1966).

Results

The results in Fig. 1 show that addition of diacetyl (1 mM) to a laboratory concentrated sample (22.5% TS) had a destabilizing effect on both a pre-heated and especially on a non-pre-heated sample. However, if diacetyl was present during pre-heating the stability of a concentrate produced subsequently was considerably increased.

In contrast to its effect on the stability of laboratory concentrated milk, diacetyl markedly increased the stability of concentrates prepared by reconstituting commercial skim milk powder (Fig. 2). Concentrates prepared from seven powders produced by separate manufacturers using different types of

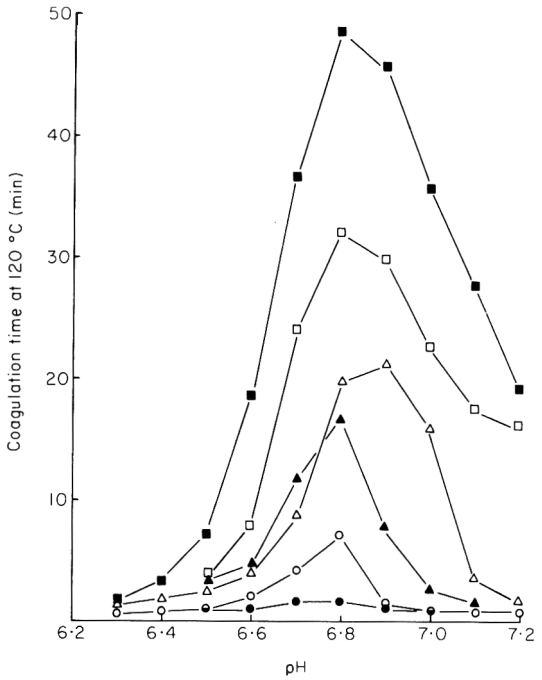

Figure 1. Effect of diacetyl on the heat stability of laboratory concentrated milk (22.5% TS). ○, Concentrated milk; ●, concentrated milk + 1 mM diacetyl; △, milk pre-heated at 90°C for 10 min, then concentrated; ▲, milk pre-heated at 90°C for 10 min, concentrated, then 1 mM diacetyl added; □, milk + 1 mM diacetyl, pre-heated at 90°C for 10 min, then concentrated; ■, milk + 2 mM diacetyl, pre-heated at 90°C for 10 min, then concentrated.

drying plant and at different seasons of the year all showed a stabilizing effect although the magnitude of the effect varied (Table 1).

Diacetyl had only a slight stabilizing effect on the concentrates (following dilution to 20% TS) from which powders 5, 6 and 7 were produced (Fig. 3a) suggesting that some change occurred during spray drying which pre-disposed the protein to stabilization by diacetyl, possibly due to further heating during dehydration or to the effect of dehydration itself (concentrates used for powders 1–4 were not investigated).

To assess the possible effects of heating, a sample of the concentrate (~ 45% TS) was heated at 75°C for 10 min prior to dilution to 20% TS. The effect of diacetyl on the heat stability of this sample was greater (Fig. 3b) than on the unheated concentrate (Fig. 3a) but much less than on a concentrate (20% TS) prepared from powder (Fig. 3c) suggesting that dehydration *per se* had a direct effect. To investigate this a sample of concentrate was freeze dried and then reconstituted to 20% TS. Diacetyl very markedly increased the stability of all three samples so treated (Fig. 3d); in two cases the effect of diacetyl on the stability of the freeze dried concentrate was greater than on the spray dried concentrate while in the third it was somewhat less.

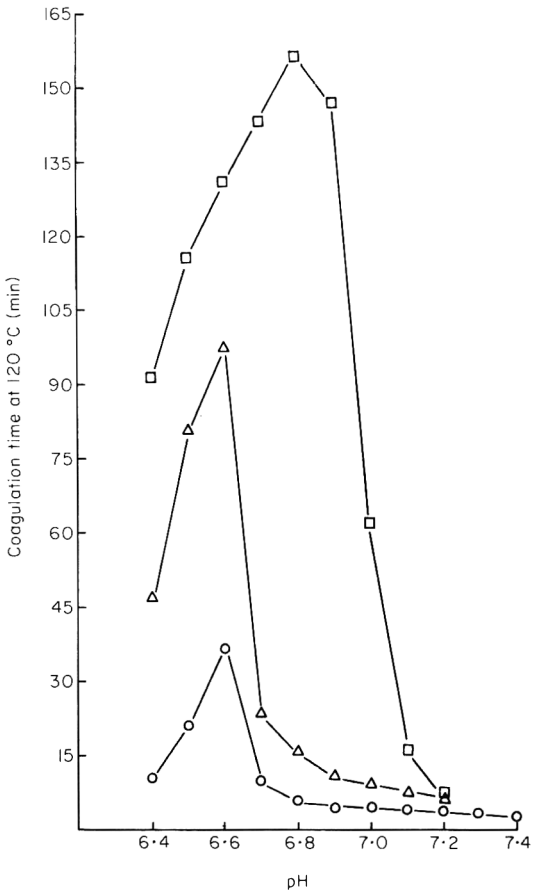

Figure 2. Effect of diacetyl on the heat stability of reconstituted concentrated skim milk powder (20% w/v). ○, Concentrated milk; △, concentrated milk + 1 mM diacetyl; □, concentrated milk + 5 mM diacetyl.

Table 1. The percentage increase in heat coagulation as a result of the effects of diacetyl on the heat stability of concentrated milks (20% w/v) prepared from skim powders

	Concentration of diacetyl added (mM)		
Sample	1	2	5
1	269	—	430
2	128	160	252
3	111	138	389
4	147	275	420
5	—	—	214
6	—	—	357
7	—	—	320

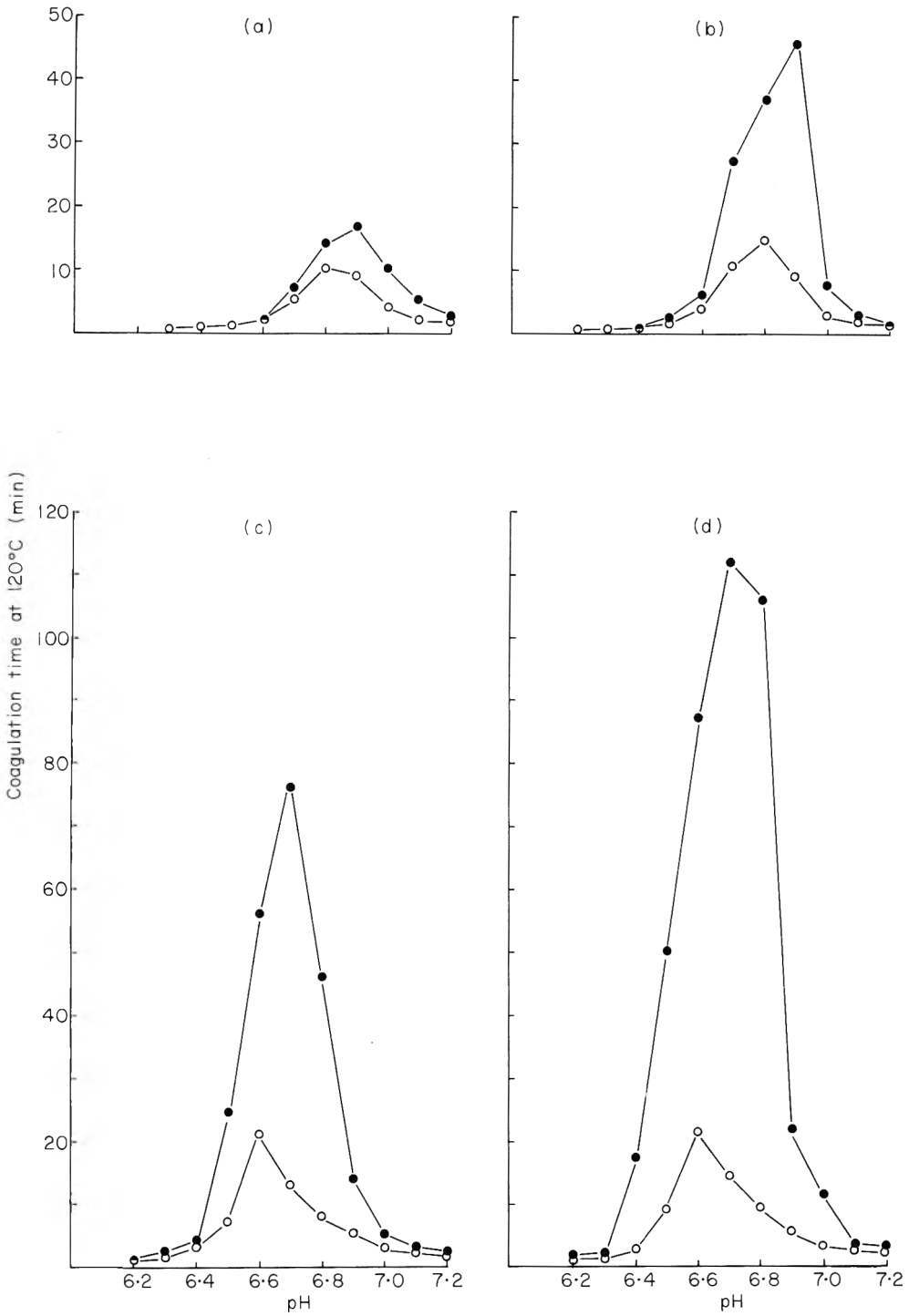

Figure 3. Effect of diacetyl on the heat stability of commercial concentrated milk (45% TS). (a) Diluted to 20% TS; (b) pre-heated at 70°C for 10 min, then diluted to 20% TS; (c) spray dried, then reconstituted at 20% TS; (d) freeze dried, then reconstituted at 20% TS; ○, no added diacetyl; ●, 5 mM diacetyl added.

An attempt was made to investigate the effect of freeze drying on laboratory concentrated milk but the dried sample was found to be insoluble. This is not unexpected since it is well known that freezing destabilizes concentrated milks (Samuelsson *et al.*, 1957; Rose & Tessier, 1959). The ability of commercially concentrated milk to withstand freeze drying may be due to precipitation of soluble calcium phosphate, which is known to have a destabilizing effect on freezing, during heating and concentration.

In confirmation of the work of Muir & Sweetsur (1978), small differences in the solids content of commercial concentrates had a very large effect on heat stability without added diacetyl but it had an even larger effect on the stabilizing capacity of diacetyl on commercial concentrates or concentrates prepared from skim milk powder (Table 2).

In agreement with previous reports (Shalabi & Fox, 1982b), diacetyl and urea had a synergic effect on heat stability, especially if urea and diacetyl were heated together at 120°C for 5 min prior to addition to reconstituted milk (20% TS) (Table 3).

Table 2. Influence of concentration on the heat stability of concentrates, with and without diacetyl

	Maximum heat stability at 120°C (min)	
Sample	Control	+ 5 mM diacetyl
Commercial concentrate (% TS)		
20	6.0	9.0
17.5	10.5	31.5
15	24.5	86.5
Reconstituted powder (% TS)		
20	23.2	74.0
22.5	11.3	16.0

Table 3. Synergic effect of urea and diacetyl on the heat stability of concentrated milk (20% TS) reconstituted from powder

Sample	Maximum heat stability at 120°C (min)
Concentrate (control)	21
Concentrate + 1 mM diacetyl	32
Concentrate + 1 mM diacetyl + 1 mM urea	40
Concentrate + 1 mM diacetyl + 1 mM urea pre-heated together at 120°C for 5 min	54

Discussion and conclusions

The heat stability of milk decreases sharply on concentration and the stability of concentrates is frequently insufficient to withstand commercial sterilization. Recent developments in the use of so-called heat stable powders for the manufacture of sterilized concentrated milks has renewed interest in the heat stability of concentrates. The heat stability of such concentrates is frequently inadequate and the stabilizing influence of various techniques have recently been investigated (Newstead, Sanderson & Baucke, 1975; Newstead, Conaghan & Sanderson, 1976, 1977; Newstead *et al.*, 1977; Newstead, 1977).

Low levels of diacetyl appear to offer a solution to the inadequate heat stability of such concentrates. Since diacetyl is a natural constituent of many dairy products, its use as an additive might be acceptable. The stabilizing mechanism of diacetyl and other dicarbonyl compounds has not been established but is suggested (Shalabi & Fox, 1982b) that they modify arginine with which they react with a high degree of specificity. It is also suggested that urea, which increases the effiicacy of dicarbonyls, acts by converting lysine to homocitrulline with which dicarbonyls then react. The flavour of heated milk is not adversely affected by added diacetyl; in fact addition of diacetyl and urea pre-heated together (120°C for 5 min) imparts a pleasant odour to milk. The stabilizing action of diacetyl on concentrated milk appears to be sufficient to warrant a detailed study of the nutritional and toxicological consequences of such treatments.

The peculiarities of the stabilizing effect of diacetyl, e.g. its large effect on reconstituted concentrate, little effect on commercial concentrate and a destabilizing effect on laboratory concentrates, is perplexing. Additional heating of concentrates and particularly dehydration, appear to be important predisposing factors. The effects of drying on heat stability has received very little attention. Muir, Abbot & Sweetsur (1978) report that spray drying increases the heat stability of milk and off-sets the deleterious effects of concentration. It is also noteworthy that urea added to milk before drying increased the stability of concentrates (20% TS) prepared from such powders (Kelly, 1982) and urea also had a slight stabilizing effect on concentrates prepared from powders (Shalabi & Fox, 1982a) whereas addition of urea to laboratory concentrated samples was ineffective (Muir, Sweetsur & Holt, 1979). Investigation of the change induced in the caseinate system during spray drying appears warranted.

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Technical note: Effect of defatting on amylose contents, viscosity characteristics and organoleptic quality of cassava (Manihot-esculenta Crantz)

K. C. M. RAJA,* EMILIA ABRAHAM AND A. G. MATHEW

Introduction

The amylose content of cassava has been reported to be varying from 15.3 to 17.5% by Resenthal (1972), who, however, did not analyse the amount of soluble and insoluble fractions in any of the varieties. In the present work a few varieties of cassava have been studied for their total, water soluble, and insoluble amylose contents. The changes in amylose contents, viscosity characteristics and organoleptic quality in terms of stickiness occurring during defatting of cassava flour were also examined.

Materials and methods

Materials

Fresh cassava tubers were procured locally. The varieties used for the studies included Malayan-4 (M-4) which is the most popular variety grown in Kerala, and the hybrid varieties H-97, H-2304, H-165, H-226 and H-1687 which have recently been developed and commercially popularized in this region. The hybrid varieties were procured from the Central Tuber Crops Research Institute, Trivandrum.

Preparation of samples

Freshly harvested tubers were processed into flour having a moisture content of 10.0%. Fresh samples were defatted by (1) extracting with *n*-hexane in a Soxhlet for 16 hr and (2) by extracting with a solvent system consisting of chloroform-methanol (2 : 1) in a ratio of 1 : 5 (w/v) at room temperature in a

* To whom correspondence should be addressed.

Authors' address: Division of Food, Regional Research Laboratory, Trivandrum-695019 Kerala, India.

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blender. The extract was filtered under vacuum and the residual solvent was removed by air drying. The moisture content in the defatted samples varied from 9–10%. The amount of fat extracted from the samples using *n*-hexane ranged from 0.40 to 0.57% while the fat extracted using chloroform-methanol ranged from 0.9 to 1.2%.

Analyses

The total amylose content was determined by the method recommended by Sowbhagya & Bhattacharya (1971). The method suggested by Hall & Johnson (1966) was adopted for determining the hot water soluble amylose content. Viscosity characteristics and gelatinization temperatures of both plain and defatted flour prepared from M-4 variety were studied using a Brabender visco-amylograph. Samples of both plain (non-defatted) and defatted samples were steam cooked and organoleptically evaluated for their acceptability by a selected panel of judges.

Results and discussion

The results of the study are presented in Table 1 and Table 2. The inter varietal variation both in total and soluble amylose contents was noticed. Defatting the flour with *n*-hexane did not bring any significant change in the total amylose content while extraction with chloroform-methanol enhanced the amylose values. The true amylose content of the cassava varieties analysed varied from 20.3 to 21.9%. The hot water soluble amylose content of plain cassava samples analysed varied from 12.4% to 15.4%. Defatting with chloroform-methanol increased the hot water soluble amylose content except in H-1687. An increase in both the total and soluble amylose content noticed in the samples defatted with chloroform-methanol suggests the possible cleavage of lipid amylose complexes involving polar lipids and amylose. This is also confirmed from the identical amylose values of both plain samples and those defatted with hexane which remove only non-polar lipids from the sample. The effect of defatting in increasing both the apparent and hot water soluble amylose content has already been observed by Maningot & Juliano (1980) in the case of rice starch. Defatting of flour lowered the gelatinization temperature of cassava flour. Also the chloroform-methanol defatted sample attained peak viscosity much earlier than plain flour sample (Table 2). This is in agreement with the observations made by Eliasson *et al.* (1981) and Melvin (1979) in the case of wheat, corn and potato starches respectively. However, unlike these starches, cassava flour showed a lower peak viscosity and also hot paste viscosity after defatting especially with chloroform-methanol. This might be due to the 'C' type pattern of starch molecule in the case of cassava which is different from that of potato and cereals (Henry, 1964). Further, in contrast to rice (starch or flour) (Bhattacharya, Sowbhagya & Indudharaswamy, 1978) no significant, direct and consistent

Table 1. Amylose contents and cooking quality of cassava samples

Variety	Plain non-defatted flour				Defatted flour				
					Total true amylose content (%)*				
	Total apparent amylose (%)*	Hot water soluble amylose (%)*	Insoluble amylose (%)*	Stickiness score†	Extracted with *n*-hexane	Extracted with chloroform methanol	Hot water soluble amylose (%)*	Insoluble amylose (%)*	Stickiness score†
M-4	18.8	13.2	5.6	2.6	18.4	20.3	13.9	6.4	2.3
H-97	19.1	15.4	3.7	2.7	18.9	20.8	16.6	4.2	1.4
H-2304	20.3	15.0	5.3	3.5	19.9	21.6	17.8	3.8	1.9
H-165	18.9	13.8	5.1	1.5	18.4	21.9	15.4	6.5	1
H-226	19.7	14.5	5.2	1.5	19.5	21.4	15.5	5.9	1
H-1687	19.6	12.4	7.2	3.2	19.7	21.2	12.4	8.8	2.5

* Dry weight basis.

† Stickiness was assessed organoleptically on a scale of 0–10 of lowest to highest acceptability.

Table 2. Viscosity characteristics of plain and defatted cassava flour—M-4 variety

Sample	Gelatinization temperature (°C)	Peak viscosity[a] (Bu)*	Temp. at peak viscosity (°C)	Hot paste viscosity[b] (Bu)*	Cold paste viscosity[c] (Bu)*	Break down[a–b] (Bu)*	Set back[c–a] (Bu)*
Plain	73.5	600	90.0	350	460	250	(−) 140
Defattted (*n*-hexane)	69.0	600	70.5	300	360	300	(−) 240
Defatted (chloroform-methanol)	66.0	480	70.5	80	160	400	(−) 320

* Bu = Brabender units.
[a] Peak viscosity.
[b] Viscosity at 95°C after 20 min.
[c] Viscosity taken at 50°C.

correlation between insoluble amylose content and stickiness could be observed in the case of the cassava varieties studied. The variety H-2304 which had lower insoluble amylose content than H-1687 scored more in acceptability due to less stickiness. The same was true in the case of M-4 and H-97. Further H-165 and H-226 though had higher insoluble amylose content scored least for acceptability due to highest stickiness. Among the defatted samples also, the trend of the results was more or less the same. It was generally noted that steam cooked products prepared from defatted samples showed a trend to reduce acceptability of the product due to their increased stickiness. Such an increase could be due to easier and earlier gelatinization of starch occurring in the case of defatted flour samples.

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Technical note: The content of sarcoplasmic, myofibrillar and connective tissue proteins in mechanically separated tissue from filleting offal of cod *(Gadus morhua)*

B. W. THOMSON AND I. M. MACKIE*

Introduction

While the use of flesh separating machines can give a substantial increase in the yield of flesh from fish (Keay, 1976) the organoleptic qualities of the product are so different from those of the fillet that problems of acceptance arise. This is not only because of its comminuted or minced nature but also because of the varying degree of colour and textural change associated with the inclusion of tissues other than skeletal muscle as, for example, connective tissue, blood or visceral organs. Although it is generally accepted that the mechanical disruption of cells leads to greater interaction of enzymes and substrates and to an acceleration of protein denaturation and lipid oxidation (Laird, Mackie & Hattula, 1980), all of which contribute to textural properties, the relative proportion of the main muscle proteins is also of importance.

This paper presents comparative data on the composition of separated flesh from whole skeletons, backbone and belly flaps of cod in terms of the main protein fractions and compares them with the corresponding values for fillets.

Materials and methods

Materials

Cod (*Gadus morhua*) caught off Aberdeen were gutted and stored in ice for 2–3 days before being filleted. The separated flesh was obtained from whole skeletons, backbones and belly flaps using a Baader 694 flesh separating machine fitted with a 5 mm hole drum. Fillets were also minced in the machine to give representative samples for direct comparison. All the samples were held at 0°C prior to the extraction of the proteins.

Author's address: Torry Research Station, P.O. Box 31, 135 Abbey Road, Aberdeen AB9 8DG, Scotland.

*To whom correspondence should be addressed.

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Methods

Nitrogen. Nitrogen was determined by the micro-Kjeldahl procedure on suitable aliquots of the protein fractions.

Extraction of protein fractions. (1) Sarcoplasmic protein and non-protein nitrogenous substances. Comminuted flesh (50.0 g) was added to 300 ml of 0.05 μ phosphate buffer pH 7.5 at 5°C, stirred well and allowed to stand overnight. The supernatant solution was separated by centrifugation at 6000 *g* for 15 min and the residue re-extracted with a further 300 and 100 ml respectively of buffer solution. The supernatant solutions were combined to give the extract for sarcoplasmic nitrogen (SPN) and non-protein nitrogen (NPN) determinations. Non-protein nitrogen was determined on the supernatant solution obtained on centrifugation after adding an equal volume of 10% trichloroacetic acid to an aliquot of the above extract.

(2) Myofibrillar proteins. Comminuted flesh (50 g) was blended with 250 ml of 0.95 M potassium chloride, 0.05 M sodium bicarbonate solution at 5°C for 30 sec in an 'Atomix' blender, fitted with a baffle to avoid excessive frothing. The mixture was then stirred in the cold at 5°C for 12 hr and the supernatant solution removed by centrifugation at 12 000 *g* for 10 min. This extraction procedure was repeated twice more each time for 6 hr with 300 ml extractant. The residue was finally washed with a further 50–100 ml of extractant and all supernatants were pooled. Myofibrillar protein nitrogen (MPN) was taken as the difference between total nitrogen in the extract and the total nitrogen in the 0.05 μ phosphate extract.

(3) Collagen. The residue from the myofibrillar protein extraction was heated in 50 ml 5% trichloroacetic acid at 90°C for 30 min (Harkness *et al.*, 1958). It was filtered and the residue re-extracted with a further 50 ml aliquot of hot trichloroacetic acid and finally with 50 ml cold trichloroacetic acid. The filtrates were pooled and collagen nitrogen (CN) determined on the extract after dialysis against water for 12 hr.

(4) Residual nitrogen. The residual nitrogen (RN) content of the residue from the collagen extraction was determined after dissolving it in 100 ml 60% concentrated sulphuric acid.

Results and discussion

The data for two batches of cod given in Table 1 show, not surprisingly, that collagen nitrogen is substantially higher in the separated flesh—particularly in that from the backbone where it can be as high as 33% of the total nitrogen or 37% of the total protein. The main source of collagen is the swim bladder but skin and connective tissue on the bones are also of importance. In the separated flesh from belly walls, on the other hand, the increased concentration of collagen nitrogen is due mainly to skin.

The content of collagen nitrogen obtained in the flesh is of the order of those previously reported values for flesh of fish (Hamoir, 1955; Connell, 1964; Webb

Table 1. Nitrogen content of protein fractions in separated flesh from various parts of filleting offal of cod *(Gadus morhua)*

Source of separated flesh	NPN	SPN	MPN	CN	RN
A (Batch 1)					
Whole skeleton	12.23	16.21	41.07	9.36	21.11
Backbone	10.34	17.27	15.59	33.40	23.43
Belly wall	11.58	17.75	40.17	11.08	19.40
Fillet	13.00	17.77	61.40	5.34	2.45
B (Batch 2)					
Whole skeleton	12.21	18.13	34.89	10.37	24.38
Backbone	10.14	15.51	31.17	19.55	23.13
Belly wall	10.80	12.85	36.31	13.16	26.90
Fillet	13.69	16.64	52.50	5.60	11.55

et al., 1976) but somewhat higher than the 3–4% reported by Dyer, French & Snow (1950) for cod. To a large extent this difference can be attributed to the extraction procedures for separating connective tissue from myofibrillar and sarcoplasmic proteins.

For the purpose of this exercise, myofibrillar proteins have been assumed to be those proteins which are extractable with high concentrations of salt and are determined as the difference between the value for total nitrogen of the extract and that for total nitrogen of the 0.05 μ phosphate extract. These proteins are extractable in strong salt solutions only for as long as they remain in their native undenatured state. Should they suffer denaturation as, for example, during frozen storage they are no longer fully extractable (Connell, 1964). Indeed extractability in strong salt solution is a sensitive indicator of frozen storage deterioration of fish flesh. The low values for MPN and the correspondingly high values for RN in the three forms of separated flesh are indicative of protein denaturation. They confirm previous observations (Laird *et al.*, 1980) that the presence of tissue from visceral organs has an accelerating effect on the rates of protein denaturation in separated flesh even during iced storage. It would appear too, that comminuted fillet tissue can itself show reduced extractability of the myofibrillar proteins (Batch 2). The most likely explanation would be heat-induced denaturation during extrusion through the small holes of the drum of the flesh separating machine but it is also possible that the conditions of extraction could be contributory factors. Because of the large sample required for determining the various protein fractions in this study, it was not possible to adhere to the conditions recommended by Cowie & Mackie (1968) for obtaining optimal yield of the salt extractable protein and it may be that the lengthy extraction periods or the degree of manipulation involved has induced some protein denaturation.

The differences in composition of the separated flesh and fillet may be expected to be reflected in the nutritional value but it may not be significant in

the diets in which these materials are used. However, the observed loss of water holding capacity of such products is likely to be due not so much to the reduced proportion of myofibrillar proteins but more to their state of denaturation.

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Technical note: The use of taro products in bread making

JOAN CRABTREE AND JANE BALDRY*

Introduction

Taro *(Colocasia esculenta)* is widely grown in the Pacific area, India, South-east Asia and West Africa where the corms are often eaten as a steamed, boiled or baked vegetable. Alternatively, they may be salted or dried and stored for future use. Previous work on the preparation of dried taro products has been carried out by Jain, Das & Girdhari (1953) and Hsu & Chiou (1971). Jain *et al.* (1953) showed that taro flours could be easily prepared and incorporated into wheat flour chapattis. The purpose of this study was to determine the feasibility of incorporating various fresh and dried taro products into leavened bread, thereby reducing wheat flour imports in those countries where taro is widely grown.

Materials and methods

The taro corms were obtained through the Government of Western Samoa and air freighted from Apia. Upon receipt, the corms were washed in a proprietary fungicide and stored until required in damp sawdust under refrigerated conditions. The proximate composition of the taro corms is given in Table 1.

Product preparation

The taro corms were peeled by hand: peeling losses were approximately 15%. The corms were sliced to approximately 1 cm thickness. Portions of the slices were processed as follows:

(1) Slices were dipped into a 0.02% solution of sodium metabisulphite (approximately equivalent to 1% SO_2 solution). Excess moisture and mucilage were wiped away and the slices were minced mechanically by passing successively through $^3/_8$ in and $^3/_{16}$ in plates. The minced material was refrigerated overnight prior to incorporation into bread (Sample I).

Authors' address: Tropical Products Institute, Industrial Development Department, Culham, Abingdon, Oxon OX14 3DA.

* Deceased.

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Table 1. Proximate composition of taro corms

	Fresh basis (%)	Dry basis (%)
Moisture	65.71	—
Protein	2.02	5.89
Fat	0.04	0.12
Ash	0.96	2.80
Crude fibre	0.81	2.36
Starch	25.40	74.07

(2) Slices were minced mechanically, without pre-treatment, by passing once through a $^3/_8$ in plate and twice through an $^1/_8$ in plate. The minced material was immediately incorporated into bread (Sample II).

(3) Slices were soaked in a 0.02% solution of sodium metabisulphite (approximately equivalent to 1% SO_2 solution) for 1 hr. Excess moisture and mucilage were wiped away and the slices dried in a laboratory forced draught oven at 45°C for 48 hr. The dried slices were milled on a hammer mill by passing successively through 0.063 in and 0.032 in screens (Sample III).

(4) Without pre-treatment, the slices were dried and milled as in (3) (Sample IV).

(5) Slices were treated according to the recommended method of Jain *et al.* (1953), by soaking overnight in water and thorough washing to remove mucilage. They were further soaked for 3 hr in a 0.005% solution of sodium metabisulphite (approximately equivalent to 0.25% SO_2 solution) and again washed thoroughly. The slices were blanched in boiling water for 4 min and dried in a laboratory forced draught oven at 60°C for 24 hr. The dried slices were milled as in (3) (Sample V).

Using a standard set of oscillating laboratory sieves, mesh sizes 470, 170, 124 and 106 μm respectively, the particle size distributions of the dried Samples III, IV and V were determined (Table 2).

Table 2. Particle size distribution of the dried samples

		Distribution (%)				
Sample	Treatment	>470 μm	470–170 μm	170–124 μm	124–106 μm	<106 μm
III	SO_2PT*, dried 45°C	22.1	38.6	8.3	2.0	29.0
IV	NO PT*, dried 45°C	15.2	32.6	8.8	2.2	41.2
V	Soaked water SO_2PT*, blanched dried 60°C	20.4	33.6	8.6	2.1	35.3

* Pre-treatment.

Breadmaking procedures

On a 14% moisture basis, the taro products were incorporated into bread at substitution levels of 5, 10 and 20% (calculated on flour weight) assuming moisture contents of 65% for Samples I and II and 14% for Samples III, IV and V. Subsequently, the moisture contents of the samples were determined accurately by the AACC method (1969) and actual substitution levels were calculated (Table 3).

Each sample, at the three substitution levels, was baked together with a wheat flour control. A bulk fermentation method of bread making was used, according to the recipe in Table 4.

The bakers' flour used was of about 72% extraction and 11.7% protein content. To give a dough of suitable consistency, the volume of the mixing water was varied according to the moisture content of the taro product used.

The ingredients were mixed in a laboratory scale mixer at slow speed for 4 min and the dough was fermented for 3 hr in a large polythene bag at 27°C in a temperature controlled cabinet. After fermentation, the dough was scaled at 450 g, mechanically shaped and allowed to recover for 15 min. The dough was mechanically moulded in a laboratory scale moulder and allowed to prove to a height of 11.5 cm at 40°C, 75% relative humidity (r.h.) The dough was baked for

Table 3. Moisture contents and actual substitution levels of the taro products

Sample	Treatment	Moisture content (%)	Actual substitution levels (%)
I	SO_2PT^*, coarse mince	65.7	5, 10, 20
II	NO PT*, fine mince	63.6	5.3, 10.6, 21.2
III	SO_2PT^*, dried 45°C	11.1	5.2, 10.3, 20.7
IV	NO PT*, dried 45°C	8.6	5.3, 10.6, 21.2
V	Soaked water SO_2PT^*, blanched dried 60°C	12.1	5.1, 10.2, 20.5

* Pre-treatment.

Table 4. Recipe for bread making

Dried yeast reconstitution		
Active dried yeast	10 g	Aerobic respiration 15 min at 38°C
Sugar	3 g	
Water at 38°C	110 ml	
Bakers' flour Taro product (at 14% moisture basis)	1300 g	
Salt	23.4 g	
Fat	9.1 g	
Sugar	10 g	

Table 5. Loaf evaluation

Sample	Treatment	Substitution level (%)	Loaf volume (% of control)
I	SO_2PT*, coarse mince	Control	100
		5	99.5
		10	96.9
		20	89.6
II	NO PT*, fine mince	Control	100
		5.3	101.3
		10.6	93.9
		21.2	88.6
III	SO_2PT*, dried at 45°C	Control	100
		5.2	99.1
		10.3	94.5
		20.7	80.6
IV	NO PT*, dried at 45°C	Control	100
		5.3	95.6
		10.6	87.8
		21.2	75.6
V	Soaked water SO_2PT*, blanched dried 60°C	Control	100
		5.1	99.3
		10.2	92.6
		20.5	76.7

*Pre-treatment

25 min at 218°C in a rotary oven. The specific volumes of the baked loaves were determined by seed displacement and expressed as a percentage of the related control loaf volume (Table 5).

Sensory evaluation

Sensory evaluation of the samples was carried out to determine the effect of the level of substitution on the acceptability of the bread. A panel of fifteen assessors, chosen on the basis of interest and some previous experience with taste panel procedures, was used to represent a reasonably wide range of consumer opinion. Bread from each of the five samples of taro at the four levels of substitution (including the all-wheat control) was tasted at a single session. The panel rated the levels of substitution for each treatment on a basis of personal preference. The acceptability of the samples, rated on a scale anchored at the ends as 'unacceptable' and 'highly acceptable', was determined and the ratings converted into scores on a 0–100 scale. The mean value of ratings given for each of the substitution levels for all treatments was subsequently determined (Table 6).

Table 6. Substitution level mean ratings

Level of substitution (%)	Mean rating
All-wheat control	65
5	61
10	59
20	51

Results and discussion

Mincing of the fresh taro corms (Samples I and II) gave products which could be prepared in a single operation. It is well known that mucilage exudes from cut surfaces of taro corms and this interfered slightly with the mincing operation, giving a fairly sticky product. However, this did not prevent the minced material from being blended with the dry ingredients used in bread making. The fresh mince underwent browning action. This was more obvious in Sample I (with overnight storage), but it also occurred in Sample II after its incorporation into the dough and during the long fermentation period. The minced material was detectable in the crumb structure of the bread at all levels of substitution as pink/brown gelatinous particles, which also adhered to the surface crust. It was, however, less obvious in Sample II, where mincing through smaller plates had produced a finer material. At the 20% substitution level, the colour of the loaf crumb was unacceptable and the crumb texture was coarse, causing a weakening of crumb structure.

Drying of the taro slices and subsequent milling (Samples III, IV and V) produced finer particled products which blended more homogeneously with the dry ingredients used in bread making. Of these, Sample IV which had no pre-treatment, was the easiest to prepare. However, the colour of the flour was darker than either Samples III or V which had both been given a pre-treatment with SO_2 (as sodium metabisulphite). Sample V, prepared according to the recommendations of Jain *et al.* (1953) was the most difficult to prepare. The blanching process caused surface starch gelatinization of the slices and on drying, this produced a hard external crust which was difficult to break down in the milling operation.

Despite the small differences in substitution levels, the volumes of the loaves containing Sample IV were generally smaller than those containing Samples III and V. It would appear that the SO_2 treatment given to Samples III and V and the prolonged soaking in water given to Sample V have effected slight improvements in loaf volume, possibly due to the release of mucilage from the fresh slices. In all cases, the coarser particles of flour were noticeable on the surface crust at the 5 and 10% levels of substitution, and at the 20% level also in the side crust. At this high level of substitution, the crumb colour was unacceptable in all cases and the crumb texture was coarse, causing a weakening of crumb structure. Pre-treatment with SO_2 improved the colour of Samples III and V and this

was reflected in an improvement of crumb colour of these samples and in comparison to Sample IV. Sample V was, however, darker than Sample III and this was probably caused by a darkening of the slices during blanching and the higher drying temperature.

In the sensory evaluation of the samples (Table 6), the 0 and 5% levels of substitution were preferred to the 20% level. The assessors indicated that, whilst some minor change in flavour and texture was noticeable at the 20% level of substitution, the major factor detracting from the acceptability of the bread was the grey colour of the crumb which was particularly marked at this level. The gelatinous particles of taro mince in loaves containing Samples I and II were noted to have a slight bitter and astringent mouth-feel. This may be associated with the presence of a known irritant in taro which is thought to be associated with needles of calcium oxalate or raphides (Moy, 1979) and which have been described by Black (1918) as causing irritation to the mucuous membranes of the mouth.

Conclusion

There was no significant advantage in the immediate incorporation of fresh minced taro into bread as browning occurred in the fresh material in both Samples I and II. Finer mincing of the taro in Sample II effected some improvement in loaf crumb appearance since the gelatinized particles of taro were less obvious.

With Samples I and II, a 5% substitution level was acceptable and the maximum recommended substitution level would be 10%. At the 20% level, the loaves were of poor structure and appearance and this level of substitution would not be recommended. This contrasts with the results of Crabtree, Kramer & Baldry (1978) on the use of fresh minced cassava in bread, where a 20% substitution level produced a wholesome, acceptable loaf.

In the preparation of the dried samples, simple pre-treatment of the slices with SO_2 gave the lightest coloured product (Sample III). Loaves containing this sample had a better volume and colour than those containing Samples IV and V. With all the dried products, the loaves were acceptable at the 5 and 10% substitution levels with regard to structure and appearance. Sensory evaluation indicated that the all-wheat control and the loaves containing 5% of the taro samples were preferred to those containing 20%. Up to 10% substitution with taro might be possible without significant loss of acceptability.

Whilst it is known that raw taro corms contain calcium oxalate crystals, feeding trials on rats (Moy, 1979) indicated an aversion, but no grossly observable toxic response, to consuming raw taro. Thee are no known legal limits for oxalate levels in foodstuffs but it is generally accepted that the irritant may be removed by prolonged boiling or baking. The baking temperature in the centre of the loaf may not be sufficient to remove the irritant from the fresh products, Samples I and II. Since in this study the quantities of calcium oxalate retained in

loaves after baking were not determined, it is suggestd that the minimum processing conditions required for the removal of calcium oxalate in taro products used in bread making would be worthy of further investigation.

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Book reviews

Food Industry Wastes: Disposal and Recovery Ed. by A. Herzka and R. G. Booth.
London: Applied Science Publishers Ltd, 1981. Pp. viii + 246. ISBN 0 85334 957 6. £20.00.

The subject matter of this attractively produced, conveniently sized hardback is necessarily and perhaps fortuitously of much wider and more general interest than the title implies. Much of the information is applicable to wastes from other industries. It consists of seventeen chapters, each the individual paper of a named author(s), which were presented to a symposium in November 1980. A preface by one of the authors and one editor gives a concise précis of the contents. For reasons of economy in both effort and cost, the discussion by delegates is not included, which is a pity since professional discussion tends to make more clear and to enhance the value of papers.

Reproduction is by now the commonly acceptable photo reduction of the original typescript, very legible and only the few photographic illustrations suffer some loss of definition.

The opening chapters are devoted to a detailed synopsis of legislation and the implications of such recent legislation to industry in general and food processing in particular. One chapter details the legislation of the EEC while the other by Robin Chalmers, the internationally recognized authority on water pollution, provides comprehensive coverage, not only of legislative differences world-wide, which may indicate still further future trends and changes, but a well-reasoned explanation of the immediate and potential implications to industry. Some of those changes will lead to the evolution of trade effluent control and new approaches to trade effluent treatment. There is a good chapter on economics and the National Water Council recommended charging system, with comparison of the differences between Regional Water Authorities. It reiterates the well-established practice of reduction in volume and strength to minimize charges but does not extend to the less well-understood environmental and cost benefit, in the long term, of capital intensive, modern, in-house treatment, conservation and utilization.

Other chapters deal with specific treatment processes or wastes from certain types of processes such as dairy, meat and animal by-products, fruit and vegetables. There is a good paper from Professor Peter Isaac and co-author on 'Nature and disposal of effluents from Malting, Brewing and Distillation'. Some of these mention the recovery of by-products and some other chapters are devoted to specific recovery systems, with case histories and costs. Anaerobic treatment is adequately dealt with but clearly there remains scope for development of recovery and utilization techniques. Perhaps unintentionally, the editors show a

sense of humour and psychology, in placing last, a short chapter by a mechanical engineer, regarding screening. Screening, a preliminary function of prime importance in the treatment of most waste waters, must be the starting point in the design of new, re-modelled or refurbished industrial treatment plants and many will agree that there are a large number of plants in need of a fresh look and modernization.

Two chapters are odd in this collection of papers on food processing waste: 'Xenobiotics in the River Lee' is of questionable inclusion. Written by a young organic chemist of the Thames Water Authority, it outlines the concept of river basin catchment control, initially suggested by H. Fish, to investigate problems which might arise from minute concentrations of persistent non-biodegradable residuals in water required for potable supply. A crude, time-consuming, effort-intensitive, speculative and none too accurate approach to problems which might arise from several industries but not from food processing. Indeed, research laboratories, teaching establishments, hospitals and even highway surface run off are more likely sources. It is thus comforting to note the concluding sentence, that 'there are little grounds for concern as the particular chemicals (so far) identified are unlikely to pose a hazard in the concentrations predicted (by the method)'.

The chapter on river pollution by odorous chemicals by Eastman of the Anglian Water Authority, although out of context, provides a fascinating insight into the complexities of river(s) management in that area, the extent of water re-use and a case history of lemon-smelling effluent from Haverhill Sewage Works and points downstream. In spite of 20 years' investigation, some intensive and sophisticated, the source remains unproven but one suspects not a food process waste. Odour and more especially colour problems can arise, for example from instant coffee manufacture. A minor criticism is the use of unpublished and to-be-published references which one suspects have by now been written up, but where?

The book should be compulsory reading for all students of Public Health and Pollution Control. Practicing scientists and engineers in Water Authorities, Environmental Consultancies and Manufacturers, particularly in Food Processing will find it a valuable source of information, very well brought together, and worthy of a place within easy reach on their bookshelves.

V. H. Lewin

Studies of Food Microstructure Ed. by D. N. Halcomb and M. Kalab. Illinois: Scanning Electron Microscopy Inc., 1981. Pp. x + 342. ISBN 0 931288 22 3. US$52.00.

Since 1979, programmes on food microstructure have been included in the Scanning Electron Microscopy Inc. meetings and the presented papers published in the respective transcripts of these meetings. This book contains thirty-

six of these papers collected together and is the forerunner of a new journal, *Food Microscopy*. The papers are divided into four classes: (1) General applications (five papers) (2) Meat foods (seven papers) (3) Milk products (thirteen papers) (4) Foods of plant origin (eleven papers). Within each section there are review papers covering the particular subject with emphasis on the author's own researches and there are also 'tutorial' papers which present the material in a teaching format and emphasize the techniques used.

The book is intended as an introduction to the study of food microstructure for food technologists and scientists entering the field. It should be noted, however, that the title, *Food Microstructure,* is misleading since all the included papers are reprinted from the Proceedings of the Scanning Electron Microscopy Inc. Meetings (1979, 1980 and 1981) and are therefore almost entirely restricted to this type of microscopy. Given this limitation, the papers are well chosen and are by leading scientists in their fields. The review and tutorial papers give a wide view of their subjects, a comprehensive, accurate and fairly recent list of references and good information on the methodology. One paper lists 146 references, but the average is around twenty-five. Following each paper is a useful discussion between its authors and reviewers similar to the questions and answers which normally follow a verbal presentation. A notable omission, however, is a section devoted to Oils and Fat—very important food materials—although not, it must be admitted, very amenable to study by EM scanning.

The book is well produced, clearly legible and error free. The micrographs, of which there are many, are clearly printed and well chosen to illustrate their points. There is also a subject and author index at the back, which makes the book simple to use.

Although the contents have been published previously, this book, reasonably priced by today's standards at $52, has the merit of collecting together important review papers and references in the area of food microstructure where the literature is sparse and scattered and it will be of particular value to those new to this expanding field. With regard to the journal which is to follow, I note that the call for papers includes all types of microscopy which should make it a useful addition to the food literature.

J. M. Stubbs

Smith's Introduction to Industrial Mycology, 7th edn. By A. H. S. Onions, D. Allsop and H. O. W. Eggins.
London: Edward Arnold, 1981. Pp. viii + 398. ISBN 0 7131 2811 9. £37.50.

The seventh edition of a well-known and well-established work has been undertaken by the Curator of the Culture Collection of the Commonwealth Mycological Institute, and the Information Manager and Director of the Biodeterioration Centre of the University of Aston in Birmingham. The overall layout is largely that of the sixth edition, and the revision has been accomplished within the same length of text.

Most of the excellent photomicrographs of the sixth edition have been retained in this new edition, but some good scanning electron micrographs have been added. Overall the illustrations are very successful, although I think it a pity that Fig. 49 in the sixth edition, of *Aureobasidium pullulans* has been replaced—the previous micrograph provided a much more readily distinguishable picture of this common mould than the two micrographs and line drawing now included. One useful feature throughout the book has been the addition of very clear and informative line drawings, to supplement the photomicrographs.

Sixth-edition chapters omitted from the new edition are those on 'Mycology of the Soil', 'Microscopy' and 'Mycological Literature'. These omissions are understandable, and indeed the rationale for the omission of the chapter on 'Microscopy', for example, is presented. However, in this statement of policy, the authors state that 'those wishing to delve further are referred to more specialist books . . .'. In fact, no specialist books are listed. I think that a little more bibliographic guidance would be a great help to those readers who do not have ready access to the extensive library of university or research institute.

The use of diagnostic tables and dichotomous keys has been extended and improved in many places—notably in the chapters on 'Yeasts', 'Hyphomycetes', and '*Aspergillus*'. The keys are frequently supplemented by the addition of thumbnail sketches of morphological types. An interesting addition in Chapter 9 on the hyphomycetes is of a synoptic key based on main morphological characters. This is a type of identification aid frequently found in field guides, for example of birds or of macrofungi. As in those cases a synoptic key can assist in a rapid screening identification which can then lead if necessary to an easier selection of the other characters which need to be observed. The authors of the next edition may care to extend this feature so that a synoptic key can serve as an entry into the entire book for workers unfamiliar with the distinguishing characteristics of the main groups of microfungi.

In the chapter on 'Control of Mould Growth' the material on a_w has been updated with a discussion of adsorption isotherms and methods for their determination; the section on chemical preservatives has also been re-organized.

Overall, the book remains as one of the most successful reference works and identification aids for fungi encountered by laboratory workers in the food industry, and is wholeheartedly recommended.

W. F. Harrigan

Dairy Microbiology: Volume I: The Microbiology of Milk; Volume II: The Microbiology of Milk Products Ed. by R. K. Robinson.
London: Applied Science Publishers Ltd, 1981. Vol. 1: Pp. x + 258. ISBN 0 85334 948 7. £19.00. Vol. 2: Pp. ix + 333. ISBN 0 85334 961 4. £23.00.

For many years there has been a great need for a textbook in dairy microbiology and *Dairy Microbiology* should fulfil this need. The book contains sections on

different aspects of dairy microbiology, each written by an authority on the subject, and covers the subject from when the milk is in the cow up to its reaching the consumer. Volume I is concerned with the microbiology of raw milk, bottled milk, dried milk and concentrated milk, whereas Volume II deals with milk products including fermented milks, cheese, butter, ice cream, cream and dairy desserts and also includes a chapter on quality control in the dairy industry.

The books are intended to be a standard reference text in which all the latest ideas on the subject are brought together and in this it has been successful. The references are up to date and accurate and the authors have successfully concentrated on a modern approach rather than restating the clichés of a past generation. The appearance and layout is attractive and tables and illustrations are of a high quality which makes for easy reading.

Although there is an obvious attraction in having two volumes of a similar size, dried milk and concentrated milk are as much milk products as cheese and fermented milk and therefore there is no logical reason for including them in a separate section. It would have perhaps been better if the whole text was treated as one, albeit in two volumes, rather than dividing it into two. The index could then have covered all the material.

In the dairy industry today there is great interest in whey utilization and the production of lactose and casein. These processes create many microbiological difficulties and deserve some attention in any comprehensive text on dairy microbiology. Apart from a passing reference to the cleaning of membranes used for ultrafiltration in the section on the 'Control and Destruction of Microorganisms' and a brief description of the ultrafiltration process in the chapter 'The Microbiology of Concentrated Milks' these have been largely ignored. A more comprehensive discussion of techniques such as the use of ultrafiltration and enzymes would have been desirable. Another small criticism which could be made is that although the public health aspects of each product is, on the whole, mentioned in the chapter on that product, this aspect of dairy microbiology is important enough to justify a section on its own.

In conclusion, these books fill a long standing need in microbiology and should prove to be an important tool for all people concerned with dairy microbiology above the elementary level.

G. Prentice

Foods, Nutrition and Dental Health Ed. by J. J. Hefferen, W. A. Ayer and H. M. Koehler. (Proceedings of the 4th Annual Conference of American Dental Association Health Foundation, Volume 3.)
Park Forest South, Illinois: Pathotox, 1981. Pp. vii + 265. ISBN 0 930376 32 3. US$25.00.

This volume is rather a heavy hardback book both in the literal and metaphorical sense. It comprises twenty-one chapters in 265 pages reporting the

proceedings of the 4th Annual Conference on Foods, Nutrition and Dental Health which was held in 1980 and sponsored by the Research Institute of the American Dental Association and Health Foundation. The conference provided an opportunity for 168 delegates representing academia, government and industry to review many of the issues of mutual concern, and the extensive coverage and discussions make this book a useful record of the event.

A major criticism is that the editors have not provided a summary of their objectives, or a final round-up of the major conclusions reached during the meeting. Furthermore, the chapters are not given a numerical designation and their arrangement could have been more clearly defined into three fairly distinct areas. The first eleven chapters—over half the book—is dedicated to a detailed appraisal of the various procedures and model systems used for food cariogenicity testing. Animal models, clinical trials with human subjects; the measurement of pH changes in the plaque by means of micro-electrodes; the formation and quantification of the individual organic acids and identification of the specific micro-organisms are some of the topics of interest. The following five chapters explore trends in food consumption, dietary change and public policy in the U.S.A., and the final five chapters develop the theme of strategies for prevention of dental caries. Behaviour modification, oral hygiene habits and the ways of conveying established scientific information to the public are some of the factors which could contribute to caries prevention. The impact of 'fluoridation', fluoride dentifrices and dietary fluoride supplements to decrease caries prevalence is described in a useful chapter by Robert Glass and Sylvia Fleisch.

The contents of the book range from being too technical to not technical enough. Nevertheless, this book could be very useful to professional people working in health education, in the regulatory agencies and in the food industry, who should understand the wide-ranging and complex factors which are responsible for the development of the clinical lesions leading to caries. Despite the enormous amount of scientific work that has been carried out over the last 10 years, the reader is left with the feeling that there is still a great need for improved understanding of the methods used to assess the cariogenic potential of foods and a clear lack of scientific and clinical proof of the cariogenicity of specific foods and ingredients. The individual variations in response to the same test foods is great, but the number of acceptable studies on human subjects is still very small. It is also difficult to attempt to associate a life-time's exposure to the risk of caries with short-term diet surveys. A flaw in many of the experiments to determine the cariogenic potential of foods, is clearly identified in the book, namely that no attempts have been made to standardize the food products which are tested. Furthermore, it is pointed out that the chemical and physical characteristics of the foods are frequently not described. Valid conclusions about the relative acidogenicity of foods, comparisons of results from different laboratories or in the same laboratories at different times are very difficult to make. Dr Gilbert Leveille from the Department of Food Science and Human Nutrition at Michigan State University, presents a brief chapter on a project to develop and

maintain reference foods which can be used in future cariogenicity studies. In conclusion, it seems that many questions remain unanswered. However, the goal is to minimize the role of foods as risk factors in dental caries and this book provides an up-to-date collection of papers on current knowledge in this particularly complicated area of research.

D. P. Richardson

Introduction to Fishery By-Products By M. Windsor and S. Barlow. Farnham, Surrey: Fishing News Books, 1981. Pp. xv + 187. ISBN 0 85238 115 8. £13.50 (+ £1.35 post and packing).

This well-produced book is, as its title states, an introduction; the methods of production and uses of a range of fishery by-products are described with by far the greatest attention, about half the total number of pages being devoted to fish meal. Fish oil, fish silage and other hydrolysates, fish protein concentrate and an array of relatively minor, albeit important, products are dealt with in the other half of the book.

For different reasons the book has been written for several classes of readers; fishermen, fish merchants, food processors, animal feedstuffs manufacturers, agriculturalists, farmers, pet food manufacturers, prospective investors in the fish industry, port and local health authorities, administrators, researchers and students. With such a wide potential readership the authors have had to write what is, in essence, a technical book for the general reader and in this they have been remarkably successful; scientific and technical terms are explained with admirable clarity and the book is written in a readable, journalistic style. Only occasionally has the necessary simplification led to what a chemist would regard as an error but this does not detract from the value of the book. The explanations and descriptions are aided by the use of several clear diagrams and a judicious selection of good photographs.

The book does have other imperfections. Whilst devoting a large proportion of the text to fish meal is justified, in view of the current importance of fish meal and oil compared with other fishery by-products, I feel that the authors have on occasions gone into rather too great detail in some areas (e.g. cleaning of evaporators), overemphasized others (e.g. providing what amounts to a detailed code of practice for reducing odours in fish meal production) and given, in comparison, rather scanty treatment to the variety of products described in the last chapter (e.g. the absence of a description of the methods used for converting fish skins into leather). Furthermore, the omission of isinglass from the last chapter is somewhat surprising.

The typeface is beautifully clear and legible and typographical errors are rare. A few solecisms have, however, not been edited out and the appearance of some of the diagrams is marred in places by poor positioning of the lettering. The index is fairly comprehensive but could with advantage be extended as there are

some annoying omissions (e.g. glue, phospholipid, winterization). Finally, the appendix contains a useful set of methods for analysing fish meal and oil for their commercially important properties; this compendium should prove valuable to some of the readers at which the book is aimed but the reproduction of some notes on an investigation into the Kjeldahl procedure seems inappropriate in a book such as this.

In conclusion this is a book which I would commend not only to those listed above but to anyone who is interested in how marine resources can be utilized; the faults mentioned above are minor ones and could be rectified in the subsequent editions to which I hope this book will run.

J. R. Burt

Problems in Nutrition Research Today. Ed. by H. E. Aebi, G. B. Brubacher and M. R. Turner. (Proceedings of a Symposium of the Swiss Nutrition Foundation, University of Berne, 18–19 October, 1979.)
London: Academic Press, 1981. Pp. x + 151. ISBN 0 12 044420 8. £12, US$29.00.

This book is made up of a collection of the papers from sixteen well-known contributors which were presented at a symposium held in Switzerland in 1979 to mark the tenth anniversary of the Swiss Nutrition Foundation.

The introductory chapter by Dr Aebi of the Swiss Nutrition Foundation, is entitled 'Nutrition Research Today, Society's Expectations and the Need for International Co-operation'. The author draws attention to the growing need for nutritional scientists to analyse and evaluate the vast number of scientific observations and to put the facts across to an increasingly interested general public in a simple and understandable manner. He points out that over the next few years much greater emphasis will need to be placed on information retrieval and computerized data bases especially in multidisciplinary sciences like nutrition.

Chapter 2, 'Nutrition Guidelines: Food for Reflection' by Joseph Hautvast of the Netherlands Nutrition Foundation, summarizes food consumption patterns in the Netherlands since 1936, and a study carried out on schoolchildren to identify risk factors associated with coronary heart disease in later life.

In Chapter 3, J. Solms discusses the role of food components in 'Nutrition and Food Acceptance'. This interesting paper consists of several brief sections on: nutritional value and acceptability; an introductory demonstration with food appearance; decisions and eating behaviour; colour and taste sensations; the role of odour, how odour is judged; the importance of taste; food texture, acceptance and nutritional value. In Chapter 4 Dr M. Turner of the British Nutrition Foundation urges an increase in research into the sociological and psychological aspects of nutrition and the allocation of resources for the more effective application of existing knowledge. Felix Gutzwiller in Chapter 5, summarizes dietary changes and a National Research Programme for the

primary prevention of cardiovascular disease in Switzerland. The impact of marginal malnutrition on health and behaviour is discussed by R. Buzina in Chapter 6. Data are presented which indicate that chronic mild-to-moderate vitamin and mineral deficiencies may, even in the absence of clinical malnutrition, have a negative influence on physical working capacity, immunobiological competence and mental behaviour. Chapters 7 and 8 summarize the role of dietary fibre in food and the relation between lipids and cardiovascular diseases respectively. Several authors from Italy present a very useful Chapter 9, in which they set out the results of their investigations into the influence of dietary essential fatty acids on the prostaglandin system and its role in platelet function. In Chapter 10, R. G. Whitehead discusses the nutritional needs of babies, and in the following chapter, Sir Kenneth Blaxter presents a very thorough and critical review of the question 'Is there a worldwide protein gap?' —which many nutritionists will find salutary reading matter.

Emil Mrak in Chapter 12, sets out an excellent paper on 'Nutrition science and the triangle of food policy, industrial achievements and public opinion'. Finally, in Chapter 13, Dorothy Hollingsworth talks on the 'Knowledge of Nutrition and its applications'.

As in any symposium, several relevant topics, such as nutrition and cancer, cannot be included in the programme, and from this point of view the volume is incomplete. Furthermore, several chapters merely review and summarize areas which are extensively covered elsewhere. The book is, however, very readable and should appeal to many people in the medical profession and health services who are interested in knowing more about the impact of nutrition on disease.

In conclusion, the book is a record of the 1979 symposium and gives account of some selected topics of particular relevance for populations living in a highly-industrialized country. In bringing together so many distinguished authors, these proceedings will, as the preface states, undoubtedly receive the attention they deserve.

D. P. Richardson

Cheesemaking Practice. By R. Scott.
Barking, Essex: Applied Science Publishers Ltd, 1981. Pp. xix + 475. ISBN 0 85334 927 4. £24.50.

The author states that the textbook is intended to introduce science to the practicing cheese maker or the younger trainee but that it should also be of interest to those who wish to know more about cheese and the mysteries surrounding its production. With this in mind, the intention was that scientific discussion would be limited to what is required to provide adequate explanation of scientific aspects of the subject. In general the book meets these objectives.

A brief but interesting history of cheese production and its many varieties is given. A section on world markets and trade in cheese provides sufficient

information to indicate trends in supply and demand. Adequate information is provided on nutritional aspects of cheese. There are various ways of classifying and categorizing cheese types and the author presents several interesting classifications of varieties by different criteria. He draws attention to the growing trend for the addition of various flavouring materials to be added to cheese to create even further variety for the consumer.

The work provides the reader and practicing cheese maker with up-to-date information on many aspects of cheese making principles; milk composition and quality; additive materials and main ingredients, such as starters and rennets. Clear instruction and information is given on cheese making operations and the section on cheese quality and grading is given detailed treatment.

The author draws on a lifetime of involvement with all aspects of cheese production and this knowledge is reflected in a very interesting series of interpretations of analytical and cheese making data which might be met by the practising cheese maker.

Sections dealing with developments in methodology and equipment give sufficient details to keep the reader abreast of technological change. The appendix contains outline production information for ninety-nine cheese varieties and types. While it is recognized that more detail may be necessary in some cases for the successful production of a particular cheese variety, the descriptions provide much basic information in a concise form.

The references are composed of a selection of textbooks and reports and reviews. The reader might have expected a greater list of references but the objectives of the book probably do not require this. The references provided offer the reader scope for further study.

The general appearance and layout is simple but attractive. A wider range of photographs and illustrations would have improved the general appearance. The textbook meets the objectives defined by the author and should prove attractive to a wide range of readership.

R. J. M. Crawford

Journal of Applied Bacteriology

The Society for Applied Bacteriology, which has just celebrated its 50th anniversary, launched the *Journal of Applied Bacteriology* in 1954. Since that time the *Journal* has grown in size, two volumes per year being published from 1975 onwards, in prestige and in the subject matter covered. It has established an international reputation with readers and authors; indeed each number of the *Journal* contains papers from worldwide sources. The Society's interest in the systematics and ecology of groups of microorganisms is reflected in the *Journal* and a major change in the organization of papers on systematic microbiology is detailed in a revised Instructions to Authors published early in 1982 as a supplement to Volume 52. The Instructions also give details of a novel form of publication, observation papers. These are intended to provide the *Journal's* readers with a succinct up-date of rapidly developing areas of microbiology. Such articles will be of particular interest to young scientists who seek conceptual enlightenment and senior persons in industry, Universities, etc., who need to keep abreast of developments in many areas of microbiology. Comprehensive reviews have become another important feature of the *Journal* and the publication of critical book reviews has attracted enthusiastic comment.

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Abbreviations. Abbreviations for some commoner units are given below. The abbreviation for the plural of a unit is the same as that for the singular. Wherever possible the metric SI units should be used unless they conflict with generally accepted current practice. Conversion factors to SI units are shown where appropriate.

SI UNITS

gram	g	Joule	J
kilogram	kg = 10^3 g	Newton	N
milligram	mg = 10^{-3} g	Watt	W
metre	m	Centigrade	°C
millimetre	mm = 10^{-3} m	hour	hr
micrometre	μ = 10^{-6} m	minute	min
nanometre	nm = 10^{-9} m	second	sec
litre	l = 10^{-3} m^3		

NON SI UNITS

inch	in	= 25·4 mm
foot	ft	= 0·3048 m
square inch	in^2	= 645·16 mm^2
square foot	ft^2	= 0·092903 m^2
cubic inch	in^3	= 1·63871 × 10^4 mm^3
cubic foot	ft^3	= 0·028317 m^3
gallon	gal	= 4·54611
pound	lb	= 0·453592 kg
pound/cubic inch	lb in^{-3}	= 2·76799 × 10^4 kg m^{-3}
dyne		= 10^{-5} N
calorie (15°C)	cal	= 4·1855 J
British Thermal Unit	BTU	= 1055·06 J
Horsepower	HP	= 745·700 W
Fahrenheit	°F	= 9/5 T°C + 32

Figures. In the text these should be given Arabic numbers, e.g. Fig 3. They should be marked on the backs with the name(s) of the author(s) and the title of the paper. Where there is any possible doubt as to the orientation of a figure the top should be marked with an arrow. Each figure must bear a reference number corresponding to a similar number in the text. Photographs and photomicrographs should be unmounted glossy prints and should not be retouched. Line diagrams should be on separate sheets; they should be drawn with black Indian ink on white paper and should be about four times the area of the final reproduction. Lines and lettering should be of sufficient thickness and size to stand reduction to one-half or one-third. Whenever possible, the originals of line diagrams, prepared as described above, should be submitted and not photographs. The legends of all the figures should be typed together on a single sheet of paper headed 'Legends to figures'.

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