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On odour classification

R. HARPER

Introduction

Odour classification remains one of the outstanding problems of the human senses. It is of both theoretical and practical interest in various ways. A short review can hardly do justice to the subject and what follows is deliberately selective, drawing upon a much more extensive critical analysis of odour classification by Harper, Bate-Smith & Land (1966) which contains 170 references. Since flavour is usually more a matter of odour than of taste, odour classification has a number of potential applications in food technology. The first task is to establish the total range of odours which have to be classified, although such a list is not in itself a classification. Valuable source material may be obtained from the terms used to describe the important qualities of different products or commodities. In practice, this information exists scattered amongst the literature. Not only is it desirable to be able to characterize the normal flavours and aromas of foods but also taints and off-flavours. Only odour terminology will be discussed here. It has long been evident that the language of odour is primarily an 'object language'; a language of substances and things (cf. Zwaardemaker, 1925, p. 178). Over 20 years ago Hunziker (1940) stressed that off-flavours in dairy products are defined in terms of their known or likely origin. Harper (1956a) prepared a list of over 350 terms used to describe the sensory qualities of foods. These were taken from the technical literature and from the *Concise Oxford Dictionary*. Previous lists assembled by Crocker (1945) and by Wagner (1950) were also taken into account. Amongst the interesting points emerging from this compilation were:

1. Not one single word could be described as abstract.
2. One-third of the terms referred to specific substances designated by such words as 'Acetic', 'Bready', 'Earthy', 'Fruity', 'Minty', 'Vinegary', 'Yeasty', etc.
3. Apart from a few common items such as 'Ammonia' or 'Phenolic', specific odorous chemicals were omitted. (Such terms would probably number in all about 17,000.)
4. About one-sixth of the terms listed referred to undesirable or off-flavours.
5. Only about one-thirtieth referred explicitly to what is pleasant.

None of the three contributions noted above was limited to odours. The various terms were classified under a number of very different headings which are summarized

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elsewhere (Harper, 1964). The list prepared in 1956 has been revised from time to time and in the current version ninety-six out of a total of 366 terms refer to odours. The international importance of a better understanding of the language concerned is well illustrated by the appearance of a *Vocabulaire Technique des Caractères Organoleptiques . . .* (edited by J. Le Magnen, 1962). This 86-page glossary contains fifty-seven terms (in French) which refer to the odour of food and drink. Other glossaries are available. International interest is also illustrated by the observation that in studying food habits in different parts of the world, the greatest difficulty is that of a lack of a satisfactory language of taste, odour and texture (Moore, 1964). To give more direct practical examples, Spencer (1962, 1964) summarized the terminology developed for use in connection with the odour and other qualities of white fish, and Stewart (1962) discussed the terms used to describe the flavour of beer. These examples are simply illustrative. Language problems are also important in laboratory investigations as well as consumer responses. This is becoming increasingly apparent in the need to relate the micro-analytical data about the constituents of food flavours to what is actually perceived. Such investigations deal with natural and synthetic blends and with selected model systems. See, for example, Kendall & Neilson (1964, 1966), Guadagni *et al.* (1966) and Amoore & Venstrom (1966) for recent published work.

The colour analogy

In order to indicate more clearly the ultimate aims of odour classification it is useful to consider what has been achieved in colour. In many respects the situation is simpler than in odour classification, both with regard to knowledge of the systematic arrangement of colours and measurements of their physical properties. In 1666 Newton (see Cohen, 1958) made the first controlled study of the Sun's spectrum. Ultimately, this is the foundation of modern methods of measuring the wavelength-intensity distribution of light and colour. The relation between the orderly arrangement of colours (as perceived) and these measurements, through the response features of an hypothetical standard observer, is sufficiently familiar not to require elaboration. However, the problems of colour classification and colour naming are less familiar. This subject has been discussed at length by Chapanis (1965). In particular, the task involves the reduction of several million distinguishable colours, through a few thousand possible words to the eight, or so, which are commonly used. Colour is also simpler in so far as the rules for matching and mixing have been extensively studied and documented and the conception of 'primary colours' has a well-defined, operational meaning.

What of the corresponding problem of odour classification? Knowledge is only just beginning to be accumulated about the relationship (in multidimensional space) between different odours. In spite of much sustained effort there is, as yet, no single

and established physico-chemical measurement which will indicate what a particular odour stimulus will smell like and how it stands in relation to other odour stimuli. There is much accumulated experience in the minds of perfume and flavour chemists and the effects of limited changes between certain chemical groups are known, but there is nothing comparable with what has already been attained with colour. There is no clear definition of what conditions a series of 'primary odours' should satisfy. The primary odours seem most likely to represent the smallest number of descriptive terms that can cover the whole range of odours, rather like the limited areas or sections of the total colour solid which can be conveniently labelled and used for the ordinary transactions of everyday living. Their size and boundaries are arbitrary and are determined partly by what has been referred to as 'the limited channel capacity' of the perceiving organism. Limited channel capacity refers to the outcome of certain experimental investigations, the detailed form of which is outside immediate considerations. Suffice it to state that such investigations have been carried out on most of the human senses and a very definite upper limit is found to the number of useful categories or classes which can be used without error. In colour the upper limit amongst the untrained is about fifteen categories and may be increased to about fifty by special training (Hanes & Rhoades, 1959). Similar experiments on the sense of smell place the upper limit at three to five steps of perceived strength and sixteen qualities (Engen & Pfaffmann, 1959, 1960). Although the actual number quoted may not be final the fact that there is likely to be such an upper limit must be reflected in any acceptable system of odour classification.

Approaches to odour classification

In view of the elementary stage of development, it is essential to approach the subject of odour classification from many different points of view and then to attempt to appraise the current position. Historically, there is no need to go further back than Linnaeus (1756), for he developed the first systematic classification of odour qualities from his detailed knowledge of botany and materia medica. Many subsequent systems bear the imprint of the Linnaean system, however most commentators and reviewers have either overlooked or misquoted Linnaeus concerning the manner in which he grouped the seven classes of odours into three 'affective' groups dealing with odour qualities in terms of their pleasantness and unpleasantness. The first two such groups are obvious, but the third group shows a degree of insight which has been very much overlooked. Thus 'Aromatic' and 'Fragrant' odours were described as '*Suaveolentes*' (pleasant); 'Foul' and 'Nauseating' odours as '*Foetidi*' (unpleasant); and 'Ambrosial' (musk-like) and 'Hircine' (goaty) odours as '*aliis grati aliis ingrati*' (pleasant to some, unpleasant to others). For the sake of completeness, the only 'class' not yet referred to was 'Alliaceous' (garlic-like). This was not included in the three affective groups,

possibly on account of its pungency. However this observation is speculative, but it allows the point to be made that in odour classification pungency must be given special consideration and even eliminated from certain classifications, depending on their function. Pungency is a 'tactile' or 'trigeminal' sensation and thus depends upon a different set of sensory mechanisms. The fact of individual differences in reactions to odours also raises the question whether the odours concerned are actually perceived differently. That this is probably the case for certain odours must now be regarded as definitely established. The possibility was first suggested by Blakeslee (1918), whose name is more usually associated with the subject of 'taste blindness', in his investigation of the odour of verbena.

In tracing significant developments, the sequence often divides into one of several special disciplines which combine with others at a later stage. This creates difficulties in the way of a purely chronological treatment of the subject. The impact of the development of organic chemistry is evident in the classification of botanical odours by Kerner von Marilaun (1902) who also pointed out that some of the flowers which smell unpleasant are fertilized by carrion flies. Perhaps this is another example of '*aliis grati aliis ingrati*'. Zwaardemaker (1925, p. 180*ff*) brought together many of his earlier observations about the sense of smell and included a lengthy and informative chapter on odour classification. The system which is associated with his name involved the addition of 'Ethereal' and 'Empyreumatic' (burnt) to that originally proposed by Linnaeus. Henning's *Odour Prism* (Henning, 1915) now seems to be primarily of historical interest, but is still used as a starting point for further developments. Crocker & Henderson (1927) were the first to prepare and market a set of odour stimuli. The selection was based upon their wide experience as perfume and flavour chemists, and represented the following four qualities in eight levels:

'Fragrant – 'Acid' – 'Burnt' – 'Caprylic'

For various reasons this system is also now primarily of historical interest, but in its time it stimulated much profitable discussion. One particular limitation, which may prove to be inherent in all reference substances, is that none of the standards represents solely the designated quality. Thus, for example, citral, which represents 6 in the 'Fragrant' series, is characterized fully as 6645. This will be referred to again later as the problem of 'mixed standards'. The most extensive system encountered so far is that of Cerbelaud (1951) in which he divided botanical and floral odours into forty-five main categories, mainly in terms of the families of plants involved. In fact, this is more of a list in terms of origin rather than a classification, although it raises again the question of whether there is a definite upper limit to the number of useful categories and whether the more experienced a person is the more classes he needs. Cerbelaud was writing from the perfumers' standpoint. Many other important contributions could be listed. Jellinek (1951, 1954) discussed the description of odours

both in direct and in associative terms, and Paukner (1961) examined the extent to which a series of essentially evocative and associative terms applied to several important perfumery ingredients. Billot (see Editorial Comment, 1963) recently proposed the adoption of a list of eight terms to characterize perfume odours. Stoller (1965) and Masson & Silkin (1965) made significant contributions to a symposium on language problems, organized by the American Society of Perfumers Inc. In particular, Stoller stressed the lack of development and understanding of descriptive terminology, in relation to its application in the context of modern micro-chemical methods of analysis. Stoller maintained that these language problems should now be investigated as a matter of priority.

Perhaps it is necessary to stress that an odour is a sensation which is actually experienced by a person and what is perceived is not to be characterized completely in physical or chemical terms. This observation is made without reference to current practical or theoretical limitations. Nevertheless, most chemists believe that there simply *must* be a link between chemical structure and odour quality (Ruzicka, 1957; Beets, 1957). One of the most influential developments in recent years, which was anticipated by Moncrieff, has been Amoore's 'Steric Theory'. Although originally put forward over 10 years ago (Amoore, 1952, 1962a, b, 1964) Amoore's system remained largely 'undiscovered' until the late 1950s, by which time it had been used to predict what certain synthesized compounds would smell like (see Rubin, Apotheker & Lutmer, 1962; Johnston & Sandoval, 1962). Originally, Amoore proposed seven 'primary odours'; these were nothing more than the seven most frequently used terms in the chemical literature, as applied to over 600 odorous substances. These were:

'Ethereal' – 'Floral' – 'Pepperminty' – 'Camphoraceous' – 'Musky' – 'Pungent' – 'Putrid'

There is no point in making a detailed critical examination, for the system is in process of modification (Amoore, 1965a). In his most recent publication Amoore (1965b) has dropped the word primary. One of the most serious criticisms is that the original number (seven) is probably far too small. The inclusion of 'Pungency' in the system is questionable, for reasons already given (p. 170). Amoore's approach to the explanation of differences in odour qualities is primarily through the shape and structure of the molecules. There are other possible approaches which include the use of molecular size and the energy of desorption at an oil–water interface as coordinates which also spread out the molecules concerned in terms of their perceived qualities (Davies, 1965).

The question of how many distinctive (primary) odour types there are is also related to speculations about the number of specific receptor sites on the olfactory receptors. Recent information on this subject will be found in Gesteland, Lettvin & Pitts (1965), Gesteland (1966), Moulton & Tucker (1964) and Moulton (1965). Moulton's review is particularly relevant since it has been written with the problems of food odours especially in mind. The general physiological and psychophysical

background to the sense of smell, including many features outside the present terms of reference, have been summarized elsewhere (Harper, in press).

Some multidimensional studies

Multidimensional studies of odour classification have been reported in the psychological literature since the 1940s, but only recent developments will be considered. These methods indicate how certain features group together either in significant directions or in clusters in space. Since more than three dimensions may be involved, the approach is correctly described as 'multidimensional'. Several different statistical methods may be used, but only 'factor analysis' will be considered in any detail. Factor analysis was first used with food qualities by Harper & Baron (1948) in studies of Cheshire cheese and the method was later outlined in some detail and examined critically (Harper, 1956b). Perhaps the most important factorial study of odour classification reported to date is that of Schutz (1964) which represented the culmination of a series of studies sponsored by the U.S. Quartermaster Food and Container Institute for the Armed Forces (Chicago), and carried out over a period of 7 years. This report should be made prescribed reading for all who wish to have up-to-date knowledge of the sense of smell in general and of odour classification in particular. Twenty persons indicated the extent to which each of some twenty-nine adjectives applied to thirty odours. Analysis then proceeded by a series of reduction processes. Nine hypothetical 'factors' were 'isolated' and subsequently named and then defined by particular substances. From this information Schutz proposed a series of Reference Standards. Detailed examination makes it clear that the difficulties of 'mixed standards' referred to in connection with the Crocker–Henderson series have not been overcome. In addition, the sample of words and substances employed contain several significant omissions which inevitably affect the outcome.

Other investigations, some using other multidimensional methods, include those of Woskow (1964), Wright & Michels (1964) and several Japanese studies by Yoshida (1964a, b, c) have recently come to hand. Most studies usually reveal only a few dominant factors and the task of naming and identifying them invariably poses some difficulty. Perhaps the most general conclusion with inexpert people as judges is that the greatest identifiable variation between a selection of different odours is to be found in differences in pleasantness and unpleasantness.

Concluding observations

Before drawing together the consensus of evidence into a few conclusions it is first essential to state that the views of most authorities are undergoing progressive modification. The situation is fluid, a fact which is not surprising in view of the comparative

recency of sustained scientific investigations and the many complex problems involved. Quite clearly, the subject warrants further study for many different reasons. To some it may be the intellectual challenge of an unsolved problem. To others it is the light which might be shed on more practical problems. Different methods of approach still lead to differences in detail and emphasis, and something in the nature of a composite picture will be nearer to the truth than the outcome of any single study. Obviously one method of approach is to list all possible words and then to reduce these by intuitive or statistical methods to the irreducible minimum. Lists which have been prepared for investigations in progress at the Food Research Institute were assembled with this in mind. The latest list contains forty-four words, although it is too early to be certain how many, or which of these, will finally be retained. 'Guidance lists' developed entirely to prompt the unfamiliar with information indicating the sort of descriptions in mind contained forty items. Most individual systems of odour classification have included between seven and twelve essential terms, but the overlap between different systems is far from complete and the composite picture always includes far more terms than any individual system.

As stated earlier, a *list* is something less than a *classification*. Much depends ultimately on intentions, and classification can be carried out for a variety of purposes. This is something which has been far from adequately discussed in the past, and some of the observed differences may reflect differences of intention and function. In the widest possible context the aim is to develop a universal system, within which all existing and all future odours could be placed. New odours are often the by-product of new technical developments, well illustrated by attempts to describe and communicate the odour of irradiated meat. Those whose interest is restricted to particular commodities may be satisfied with just a small number of relevant terms. Such lists are of practical value, but the meaning of the words still needs to be clarified. Definition by pointing, or more technically, ostensive definition, in which qualities are defined by substances and samples provides one essential method of clarifying the situation. This has already been illustrated in discussing odour in fish and other products. Questionnaire, interview and group discussion methods can also be used to clarify the meaning of the various terms. This information is useful for training purposes. Gisella Jellinek (1964, p. 233) discussed at length odour recognition tests in terms of the interpretation of superficially divergent descriptions and narrowing these down to an agreed version. However, even from the practical point of view, the task of training is always made easier if some logical system can be demonstrated and used. In this way attention can be focused on general principles which will 'transfer' to different situations. Another potential application is associated with the development of instrumental devices. No satisfactory instrument, analogous to those now available in colour measurement, is likely to be developed without the incorporation of a rational system of odour classification.

Data still in process of detailed analysis suggest that any comprehensive system will require at least twenty distinctive terms. This provisional conclusion is based upon description and characterization of over fifty carefully selected substances by well over forty people. Another point of some significance is that the responses of about ten people, particularly in the case of non-experts, are essential to cover the complete range of dominant characteristics. Odours also seem to become more complex as they are characterized more thoroughly, and only in the case of a few familiar and clear-cut odours, such as that of naphthalene, is a single character well defined by the substance. These and other relevant details will be reported elsewhere, but they give a few additional pointers which should be noted in this review (Harper, Bate-Smith & Land, in preparation). It may be somewhat unsatisfactory not to end with a cut and dried system, but to present such a system would still be premature. However, even if contemporary views are still very close in principle to those of Linnaeus, there is every reason to believe that before long the simultaneous co-ordinated application of the methods of a number of disciplines, including investigations still in progress, will throw new light on this old problem.

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Early British patents for food preservation methods

C. G. TUCKER

Definition

patent, *n.*—an official document, open, and having the Great Seal of the government attached to it, conferring an exclusive right or privilege, as a title of nobility, or the sole right for a term of years to the proceeds of an invention. (*Chambers's Twentieth Century Dictionary.*)

Introduction

The present British patent system has its foundation in the Statute of Monopolies (21 Jac. 1, c. 3) of 1623, which limited the power of the Crown to grant monopolies (a power that had been much abused before this date), but specially excepted grants to inventors, for the term of 14 years or less, of the exclusive right to work or make the invention; this term could be extended only by a private Act of Parliament. Later, by the Patents Act of 1835, extension of term was permitted in certain recognized circumstances, and today the grant is normally for a term of 16 years. Further acts from 1852 onwards amended the procedure, and at present the law and practice are regulated by the Patents Acts of 1949 and 1957, together with various Rules made under the authority of these Acts (Aldous *et al.*, 1965).

The present review is limited to a study of patents for methods of food preservation granted before the Act of 1853 came into force.

The earliest food preservation patent

The earliest recorded British patent for a method of food preservation was granted to Thomas Porter and John White (Br. Pat. No. 278, 1691). The grant was very wide in scope, as is shown by this extract from the patent as reprinted by the Patent Office in 1855:

'. . . a grant unto them of the sole use, exercise, and benefit of their new invencõn of keeping and preserving by liquors and otherwise all sorts of flesh, fowle, and fish, and many other things, either in pieces or in whole bodyes, at a cheaper rate, for many years in all clymates, without changing the nature, quality, taste, smell, or colour thereof, as

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good, palatable, and wholesome, to be eaten and made use of for any intent and purpose whatsoever, as when first killed and put into such liquor; to hold and enjoy the same for 14 yrs according to the statute . . .'

It is most unfortunate that the precise details of the process are not given; Porter and White seem to have discovered the ideal method of food preservation, if their claims are to be believed!

Chemical methods of food preservation

Of these early British food preservation patents, about one in three was granted for some form of chemical preservative treatment. The second patent in the field was granted to Alexander Cockburn for a method of curing salmon with spices (Br. Pat. No. 793, 1763); then came William Jayne with a method of preserving eggs (Br. Pat. No. 1791, 1791). Next was John Donaldson (Br. Pat. No. 1933, 1793), whose literary style merits quotation:

'. . . I declare the operation to be performed by an exact combination of certain principles, most wholesome and nutritive, and which indeed are contained in vegetable bodies themselves; that is to say, not by means of any one principle, but by proportioning the farinaceous vegetable principle with the coagulative or mucilaginous one, and supplying such combination by admixture according as the quality of the substance or substances to be preserved may require. To be yet more particular, in order to preserve any vegetable which is in itself of a watery or deliquescent nature, a greater proportion of farina and mucilage is required than for others that are more solid and readily disposed to dry. Let the substance to be preserved, for example, be carrot or turnip, the preserving matter may be compounded of wheat or barley meal, with solution of any common gum or vegetable mucilage. The substance may be either preserved in a raw state or previously boiled or otherwise dressed, as their nature or occasion requires. But as the matters that may be preserved in this way, including the preserving ones, are inuberable and various, it is impossible that any uniform rule can be given. Thus any simple farinaceous vegetable matter, combined with a mucilaneous vegetable one, composes a preservative for other fresh vegetable or animal bodies or parts contained in them, which are of a less fixed or desecative nature. The substances, being thus accurately prepared, are dryed in a way simular to that by which maltsters dry their grain, that is, by stoves properly heated or otherwise, as occasion may suggest. And, lastly, they are carefully put up into wooden boxes or other close packages for keeping and use . . .'

A few years later, Benjamin Batley was curing and preserving herrings and 'spratts' by salting them and storing them in a pickle of bay salt, saltpetre, and molasses (Br. Pat. No. 2441, 1800); he later extended his process to include other fish (Br. Pat. No. 2465, 1801). Francis Plowden preserved meat by immersing it in a concentrated essence

of meat to exclude air (Br. Pat. No. 3051, 1807); Ludvig Granholm used melted fat (Br. Pat. No. 4150, 1817).

Following on this came the use of a controlled storage atmosphere (often believed to be a relatively modern idea). Augustus de Heine pumped the air out of his food containers (Br. Pat. No. 3310, 1810), and Louis Elizee Seignette also emphasized the importance of removing oxygen (Br. Pat. No. 7036, 1836). Donald Currie introduced carbon dioxide into the storage atmosphere (Br. Pat. No. 5614, 1828), and John Ryan also devised a method of 'gas storage' (Br. Pat. No. 11420, 1846); but John Bevan preferred to pump out air and replace it with gelatine (Br. Pat. No. 9312, 1842).

The injection of brine and other substances into the blood-vessels of meat carcases was patented by Daniel Rutter Long (Br. Pat. No. 6711, 1834), and Samuel Carson injected other preservative solutions (Br. Pat. No. 9435, 1842). Michael Fitch used wood distillate, with salt, sugar, etc., added, as a preservative liquor (Br. Pat. No. 10322, 1844); he may be considered to be the originator of the idea of using 'chemical smoke dips' for fish, which has been introduced in recent years as an alternative to the classical kippering process.

The drying of foods

Some aspects of modern food dehydration practice were anticipated by John Graefer, a 'botannic gardener', whose method for drying 'a vegetable of the Brassica kind' deserves to be better known (Br. Pat. No. 1275, 1780). He describes it thus:

'Put about one pound of salt into twenty gallons of water, and so in proportion for any greater or less quantity required; boil the same, and then put in the vegetables, where they must remain for the space of a minute or thereabouts, and then taken out and hung by seperate plants on lines or small hooks fixed to laths in a room previously impregnated with heat or fumigation, by means of a buzaglo or any other stove, or a steam issuing through funnels, or by the natural heat of the sun or atmosphere, where they must continue until they are perfectly dry. In order to compleat them for exportation they must, after they are dried as above, be removed into a damp room, in order to imbibe a sufficient degree of humidity to prevent their crumbling or falling to pieces in the packing.'

Graefer considered that his product would 'keep a twelvemonth or longer without loosing any of its natural flavour, and make it an excellent food, and its virtue a great preventive of scorbutic disorders, which will be of great public utility, particularly to His Majestie's Navy' (i.e. George III).

No further patents for methods of drying food were granted for 60 years; then Downes Edwards (Br. Pat. No. 8597, 1840) and Charles Grellet (Br. Pat. No. 8717, 1840) obtained patents for methods of preserving potatoes; the former's was interesting in that he cooked and extruded the flesh of the potatoes and dried the result on a

specially-designed water-bath. Processes for drying other foods by hot air were invented a little later by Robert Davidson and William Symington (Br. Pat. Nos. 10126 of 1844 and 11947 of 1847), and William Trueman Yule was well ahead of his times when he patented the use for the drying of food of air which had been dried by passage over calcium chloride (Br. Pat. No. 10496, 1845). These inventors seem however to have overlooked the importance of Graefer's 'scalding' treatment (essential, in some form, for the inactivation of enzymes in the drying of vegetables), but Etienne Masson re-introduced it in his process for drying peas, beans, etc. (Br. Pat. No. 13338, 1850). James Murdoch (Br. Pat. No. 13477, 1851) and Charles Payne (Br. Pat. No. 13680, 1851) both used heated air in the drying of foodstuffs.

Canning and bottling

The first British patent for a canning process was granted to Peter Durand in 1810 (Br. Pat. No. 3372, 1810); the 150th anniversary of this grant in 1960 was the occasion of a series of commemorative meetings, articles in technical journals, etc. (e.g. *Food Manufacture*, August 1960). Aeneas Morrison developed a bottling method (Br. Pat. No. 4350, 1819). James Walker made food containers in the form of lead or copper tubes (Br. Pat. No. 3585, 1812) —horrid thought —and Pierre Antoine Angilbert introduced food cans with soldered lids (Br. Pat. No. 6432, 1833).

In 1840–41 there were four patents dealing with canning and related processes; John Wertheimer packed food in closed 'cases' from which the air had been removed (Br. Pat. No. 8378, 1840), and in collaboration with Stephan Goldner he used chemical solutions of high boiling point in which to cook his sealed cans (Br. Pat. Nos. 8873 and 8874 of 1841). A canning process was also patented by Henry Gunter (Br. Pat. No. 8776, 1841).

Freezing and cold storage

The value of low temperatures in food preservation was well known, and did not produce many patents. The earliest (in 1842) was granted to Henry Benjamin and Henry Grafton for the freezing of fish in an ice/salt mixture (Br. Pat. No. 9240, 1842); further work was done by John Lings, who described an insulated ice-box (Br. Pat. No. 10781, 1845), and by William Edward Newton, who designed an ice-house (Br. Pat. No. 11372, 1846).

Preservation of milk

A form of sweetened condensed milk was patented by William Newton in 1835 (Br. Pat. No. 6787, 1835). Four later grants were made to men who from their names may have been refugees from continental Europe: Francis Bernard Bekaert described a heat-sterilized milk (Br. Pat. No. 11726, 1847); Thomas Shipp Grimwade evaporated

milk with added saltpetre (Br. Pat. No. 11703, 1847); Jules Jean Baptiste Martin de Lignac also had a process for evaporating milk (Br. Pat. No. 11892, 1847); and Felix Hyacinthe Folliet Louis patented a sweetened condensed milk (Br. Pat. No. 12166, 1848).

A message for today

This brings our review of early food preservation patents up to the operative date of the Act of 1853. Many of the specifications are much more general in character than would be permitted today, and their scope is often very wide; the legal wording, which comprises a much greater part of each grant than the technical portion, is very involved to the eye of the ordinary reader, and tends to hinder the scientific student. Nevertheless it is well worth while for the food technologist to study the early patents in his field, and to honour those whose pioneering work is too often forgotten. It is sometimes chastening to realize, in this age of rapid progress, how long ago some of the 'new' processes were discovered, even though through force of circumstances (perhaps bad communications, lack of capital, or inadequate technical facilities) the inventions may not have been developed until they were re-discovered many years later.

In the present state of technical development in Britain, new inventions and processes are being patented at the rate of about 700 each week, and the pace is increasing. One wonders now if many of these, however ingenious or worth while, may not have to be overlooked through sheer weight of numbers, or may remain undeveloped or unexploited for some commercial reason rather than from lack of merit. In view of the present world food shortage, we cannot afford to neglect any means of extending our scanty supplies in space and time, and we should continue to encourage our younger members particularly to study and build on the clever ideas of their predecessors for the good of all.

Acknowledgments

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Dielectric thawing of meat and meat products

H. R. SANDERS

Summary. Conditions are given for the thawing by dielectric heating of regularly shaped blocks of meat, and of several different meat products. Blocks up to 15 cm thick have been treated by this method; short thawing times and low surface temperatures keep drip losses low. Where fat is present as a separate layer, difficulties arise owing to differential heating; this risk is diminished when the fat is mixed more intimately with lean. A description of an existing industrial plant is given.

Introduction

Dielectric heating has been applied to the thawing of many types of food. Cathcart & Parker (1946) successfully thawed small samples of egg, fruit, vegetables and fish; Sherman (1946) reports the thawing of chickens by this method. Satchell & Doty (1951) thawed frozen pork bellies, singly or in layers of two or three, by means of a special electrode. Podsevalov (1958) thawed blocks of sprats, Vasilyev & Vologdin (1959) pieces of meat.

Early results of the thawing experiments at this laboratory using a continuous thawer were reported by Jason & Sanders (1959). The more recent work on the thawing of herring and white fish, including the immersion of blocks in ice or water, has since been published (Jason & Sanders, 1962). It is the purpose of the present paper to detail the work on meat and meat products which is necessarily of a less systematic nature having been carried out solely in response to specific enquiries from industry.

Bengtsson (1963) carried out laboratory tests on meat at 35 MHz using a 1 kW generator equipped with a conveyor belt. Blocks of lean beef, 4 cm thick, were thawed in two passes through the unit. The heat treatment lasted 34 min during which time 0·26 MJ/kg were absorbed at an estimated power density of 0·125 kW/kg. Von Heeren (1964a, b) thawed blocks weighing 30–60 kg in a 25 kW batch thawer in $1\frac{1}{2}$ hr at a power density of 0·050 kW/kg and an energy density of 0·27 MJ/kg. Meat on the bone had to be thawed under water. In both these studies it was found possible to thaw meat unwrapped or in plastic packages. Drip losses were less than 1%.

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Apparatus and method

The experiments were carried out with a commercial r.f. generator of nominal power rating of 6 kW working in the frequency range of 36–40 MHz. Bolted to one side of the generator is a metal case containing the electrodes. The lower electrode is bolted to the framework, the upper electrode (76 cm long and 79 cm wide) is adjustable in height. An 82 cm wide rubber conveyor belt passes over the lower electrode; its speed is adjustable up to a maximum of 4·5 cm/sec. The power is estimated from an ammeter in the h.t. supply line to the oscillator valve.

The material to be thawed was loaded evenly on to the belt, utilizing its full width, and then passed between the electrodes. Whenever possible, the power was controlled at the maximum available 6 kW. In some cases, when the mass of the material between the electrodes was small, a lower value of power had to be chosen. The resulting power densities are a function of the apparatus and do not necessarily represent the upper limit for the given material. The calculated values for the energy absorbed by the material are only approximate, as the calibration of the meter indicating the power varies with the loading.

Temperatures were measured with a spear-type resistance thermometer immediately after the material had emerged from the field.

When thawing under water was required, the material to be thawed was put into boxes of dimensions 91 × 38 × 13 cm with wooden sides and a hardboard base. For convenience these boxes were sometimes used even when water was not required. When it was necessary to pass the material through the r.f. field more than once it was returned after each pass to the inlet.

Results

Beef

Frozen beef intended for cooked meat products, pies and sausages must be thawed sufficiently to allow cutting and trimming. For the experiments frozen blocks of meat were sliced to obtain regular faces and cut to fit into the boxes. Each run was carried out with four boxes. The machine was started fully loaded and after the requisite number of passes the first pair of boxes was passed into the field again to finish in the starting position. The full power of 6 kW was used at all times.

Details of the conditions are given in Table 1. In run 1 the blocks were covered in water but runs 2 and 3 show that water immersion is not essential. The meat used in run 2 had been stored at a higher temperature than the remainder, therefore requiring only a lower energy for thawing. In run 4 the conditions of run 3 were repeated for a single pass, resulting in a very uneven temperature distribution.

For best results the thickness of the blocks should be constant. This was, however, not the case in these tests; the average thickness varied also considerably between

TABLE 1. Beef, 6 kW

Average weight per box (kg)	Thickness (cm)	Storage temperature (°C)	Water immersion	No. of passes	Power density (kW/kg)	Energy density (MJ/kg)	Time between electrodes (min)	Results
24·3	8–10	−29	Yes	4	0·150	0·39	43	Satisfactory
32·6	8–13	−8	No	3	0·110	0·17	25	Satisfactory
38·9	13	−29	No	5	0·093	0·29	52	Satisfactory
34·5	13	−29	No	1	0·104	0·29	46	Partial overheating

different runs. The temperature of the thawed material in the satisfactory runs ranged from −2°C to +19°C; occasional higher temperatures were recorded near discontinuities in the thickness of the blocks and in continuous layers of fat.

Offal

Frozen offal in block form destined for dog and cat food was thawed in this series of tests with the aim of enabling the material to be passed through a mincing machine. Three types of blocks were used as shown in Table 2. The thickness of the blocks was

TABLE 2. Offal, 6 kW single pass

Material	Average thickness (cm)	Power density (kW/kg)	Energy density (MJ/kg)	Final temperature (°C)	Weight loss (%)	Time between electrodes (min)
Lungs	14	0·122	0·22	−2–+7	0·7	30
Livers	14	0·084	0·22	−2–+4	1·6	44
Maws	15	0·089	0·23	−3–+1	2·8	44

very irregular and in some cases reached 18 cm. Prior to thawing, the blocks had been stored at about −17°C. The offal was placed directly on the belt and was passed through the field once only; the power was controlled at 6 kW.

After treatment the material separated well, was nearly completely thawed and ready for mincing. Drip losses were low.

Pork pieces

Blocks consisting of pork pieces with lean and fat portions mixed at random were thawed. The blocks, 6 cm thick, which had been stored at −14°C, were passed through the field once only; the power was controlled at 6 kW. Temperatures were taken at various points in the mid-plane of each block and ranged from −2°C to +12°C.

The conditions of the test are shown in Table 3. There was no overheating in any part of the block and the pieces could be separated easily from one another.

TABLE 3. Miscellaneous meat products

Material	Power (kW)	No. of passes	Power density (kW/kg)	Energy density (MJ/kg)	Time between electrodes (min)
Pork pieces	6	1	0·24	0·20	14
Ham	6	1	0·26	0·21	13
Bacon joints	6	1	0·29	0·14	$8\frac{1}{2}$
Bacon rashers	1·5	1	0·43	0·30	$11\frac{1}{2}$
Sausages	6	1	0·40	0·21	$8\frac{1}{2}$
Pork pies	4·5	2	0·40	0·20 +0·07	$8\frac{1}{2}$ +3

Ham

Ham legs, boned and split, had been frozen into pieces about 6 cm thick, weighing about 4·5 kg each, and then stored at −14°C. The thickness was fairly uniform but the shape irregular. The fatty layer covered one side of the piece. The conditions of the run are shown in Table 3. The fat overheated considerably while the lean portions were still too hard. This effect was particularly pronounced when the fat layer was underneath during heating.

Bacon

Boiling joints, average weight 0·6 kg, of approximately cylindrical shape, 8 cm thick and 10–12 cm in diameter, were placed on the belt with their axes vertical. The fatty tissue which constituted up to 20% of the total weight was oriented parallel to the axis of the cylinder. The joints were thawed in a single pass at 6 kW (Table 3). The final temperatures at the centres of the joints were 2–13°C and at the surface 12–14°C. Although the joints were thawed, the desired colour did not appear immediately and a further period of storage after thawing was required.

Rashers, packed in sealed plastic pouches, were treated in a single pass at 1·5 kW (Table 3). Each package contained five rashers, 0·23 cm thick. The final temperatures of the lean portions were about −5°C and of the fat +5°C. Although not completely thawed, the product was sufficiently flexible and the packaging was undamaged.

Sausages

Sausages wrapped in plastic packaging were thawed in a single pass at 6 kW (Table 3). The weight of each pack was 0·45 kg and the dimensions about 11 × 10 × 2·5 cm.

The packs were laid on the belt with about 2·5 cm between adjacent packs. In one run both plate and blast frozen material was used which had been stored at −13°C. The final temperatures ranged generally between −4°C and +10°C and the consistency of the sausages was satisfactory. In another run under the same conditions the initial temperature varied from −13°C to −8°C and the final range was from −4°C to +19°C.

Pork pies

Pork pies weighing 0·11 kg each and measuring about 7 cm in diameter and 4 cm in height were initially treated in one pass at 4·5 kW to give the same conditions of power density and energy density which were used for the sausage packs. The meat, however, was still too hard at −3 to −2°C. After a second pass at treble the speed of the first, the temperature of the meat was 16°C and that of the pastry, which had retained its consistency, 21°C. Details are given in Table 3.

Discussion

In the idealized picture of dielectric heating, a regular slab of homogeneous material at a uniform temperature is placed between parallel electrodes; no heat exchange with the surroundings takes place. When an alternating e.m.f. is applied to the electrodes the resulting field in the slab is uniform, and the energy absorbed and therefore the temperature rise are the same at all points in the material.

In practice, however, three main factors disturb this situation: (1) the block may not be a perfect parallelepiped; (2) the material to be thawed may consist of two or more major components, e.g. fat and lean, pastry and filling; and (3) temperature differences may be present initally owing to warming of the material on its way to the thawer or may develop later owing to heat exchange with the surroundings, temperature differences will furthermore be caused by uneven power absorption resulting from one or both of the first two factors.

The dielectric properties of a material may be specified by the loss angle δ, the real and imaginary permittivities ε' and ε'' (where $\tan\delta = \varepsilon''/\varepsilon'$) and the conductivity σ. Dielectric theory (e.g. von Hippel, 1954) shows that when such a material forms the dielectric of a parallel plate condenser which is connected to a source of sinusoidal e.m.f. of angular frequency ω, the power per unit volume P absorbed by the dielectric material is given by:

$P = \sigma E^2$, where E is the r.m.s. field strength in the material. The r.m.s. current density J in the material is given by:

$$J = (j\omega\varepsilon' + \omega\varepsilon'')E,$$

and the conductivity by:

$$\sigma = \omega\varepsilon''.$$

It is now possible to express the power absorption by the properties of the material, the frequency, and either the field strength or the current density:

$$P = 0{\cdot}556 \times 10^{-10} E^2 f \varepsilon_r \tan \delta \quad (1)$$

or

$$P = \frac{J^2 \sin 2\delta}{0{\cdot}556 \times 10^{-10} \times 2f \varepsilon_r}, \quad (2)$$

where $f = \omega/2\pi$ and ε_r is the relative permittivity ($\varepsilon_r = \varepsilon'/\varepsilon_0$, $\varepsilon_0 = 8{\cdot}85 \times 10^{-12}$ F/m). SI units are used throughout.

Which of these expressions best describes a particular situation depends on the configuration of the material being heated. In the extreme cases (Fig. 1) two dissimilar

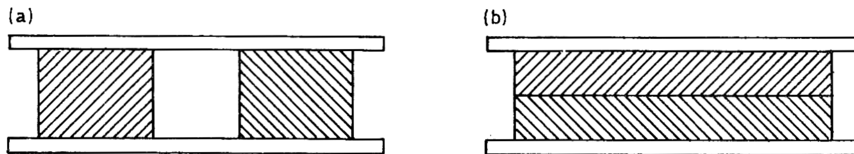

Fig. 1. Two dissimilar dielectric materials between the plates of a parallel plate condenser. (a) Parallel arrangement; (b) series arrangement.

materials form the dielectric and are arranged in parallel (a) or in series (b). In the parallel arrangement the field strength is the same in the two constituents and equation (1) applies, while in the series arrangement the current density in the two constituents is the same and equation (2) applies. In the former case the power absorbed by unit volume of each material is proportional to its $\varepsilon_r \tan \delta$ value and in the other case to $(\sin 2\delta)/\varepsilon_r$. In this manner Hartshorn & Rushton (1945) have shown how the drying of vegetables can be facilitated by a suitable choice of field orientation and have explained the observed difficulties in the sterilizing of ham.

The dielectric properties of lean beef and beef fat have been determined by Bengtsson *et al.* (1963) and Table 4 shows the values of $\varepsilon_r \tan \delta$ and $(\sin 2\delta)/\varepsilon_r$ for frozen and thawed meat calculated from their experimental results at 35 MHz, very near the

Table 4. Dielectric properties of beef at 35 MHz

		$\varepsilon_r \tan \delta$ (parallel)	$(\sin 2\delta)/\varepsilon_r$ (series)
Lean	Frozen	6·0	0·09
	Thawed	202	0·01
Fat	Frozen	0·6	0·13
	Thawed	5·4	0·14

frequency used in the present experiments. It is apparent from the table that if the two components in Fig. 1 represent frozen and thawed lean meat, more power will be absorbed by the frozen portion in the series arrangement, and by the thawed portion in the parallel arrangement. It is the latter case which leads to run-away heating when the warmest parts take more and more of the available power at the expense of the coldest. If the two components represent lean meat and fat, it is the series arrangement which leads to selective heating of the fat.

In most applications of dielectric heating to food, run-away heating is unavoidable if contact with both electrodes is maintained. This is caused either by the process outlined above or by high local intensities of field strength brought about by irregularities of the surface in contact with the electrodes. In practice, therefore, an airgap is introduced between the top electrode and the upper surface of the material being heated. A part of the voltage between the electrodes appears in this gap, the amount depending on the relative heights of the gap and of the material and on the dielectric properties of the material. In the series arrangement there is no effect on the relative power absorption by the two constituents, the current through both being identical. In the parallel case, however, the voltages across the two constituents are no longer identical. It can be shown that the effective voltage is reduced by a factor

$$\left[\left(\varepsilon_r \tan \delta \frac{h_a}{h_s}\right)^2 + \left(\varepsilon_r \frac{h_a}{h_s} + 1\right)^2\right]^{-\frac{1}{2}}$$

where h_a and h_s are the heights of the air-gap and the material respectively. Thus the voltage and therefore the power absorption is decreased to the greatest extent in the material of highest conductivity. An air-gap of one-tenth the height of the material reduces the voltage across frozen meat to 48% and across thawed meat to 5% of that across the plates. It is this difference which makes possible a continuous process where material at different stages of thawing is present between the electrodes at the same time. In practice, where the frozen and thawed material, or the fat and the lean, form part of the same slab of material, the electrical continuity puts a constraint on the voltage differences and some intermediate values will be taken up.

The temperature rise in any material for a given amount of energy absorbed is inversely proportional to its thermal capacity. Thus in the region of maximum phase change there is relatively little temperature increase and it is only when thawing is complete in part of the product that the danger of run-away heating arises. The total energy which must be supplied to raise the temperature of the material through any given temperature interval can be found from the difference in the enthalpy of the material at the initial and final temperatures. Riedel (1957) has determined the specific heat and enthalpy in the temperature range of -60 to $+20$°C for lean beef of different water contents. Values for beef, ham and many other foodstuffs are given by Short & Bartlett (1944).

It has been found in previous work on continuous dielectric thawing that improved results can be achieved in three stages. The power absorbed per unit volume (more conveniently expressed as a power density per unit mass in kW/kg) must be limited, the process is thus slowed down and time is provided for thermal equilibration within the material. The material may also be passed through several separate fields in succession, so that the temperature range of the material between any given set of electrodes is less than the range in the single pass procedure. In addition, it may be necessary to immerse the material in water or to surround it with ice; by this means field distortions due to any irregularities are minimized.

In the present experiments water immersion was found to be unnecessary and only the blocks of beef required multiple passes. A single pass was sufficient for the much thinner blocks of pork pieces and for the blocks of offal where thawing was not carried to completion.

When fat is present as a separate layer its orientation is all-important. In ham, where the fat formed a continuous horizontal layer perpendicular to the field, it was heated selectively as would be expected from the above considerations of dielectric properties. In the bacon joints, on the other hand, where the fat was placed vertically no overheating occurred. In the packages of bacon rashers which may be considered as a combination of the two cases, the fatty portions warmed slightly more than the lean. When fat and lean pieces were mixed randomly as in the pork pieces no selective heating was observed.

Industrial application

For the design of an industrial plant, the required energy density, the maximum power density and the minimum numbers of passes must first be determined for the material to be treated. As, however, the generators at present available are limited to 20 kW, the required throughput may necessitate the use of more generators than the minimum determined from thawing considerations. If, for example, 1½ tons of beef are to be thawed per hour requiring 0·29 MJ/kg, six generators are needed to provide the necessary 120 kW, although three or four passes may give satisfactory results. The dimensions of the electrodes must be such that the maximum permissible power density is not exceeded. On the other hand, it is desirable to keep the electrodes small, particularly in the direction perpendicular to the movement of the belt to avoid uneven heating due to standing waves.

A value of 0·2 kW/kg has been shown to be a suitable (though not necessarily the maximum) power density for those blocks of meat where this value could be applied in the experimental apparatus. With the blocks of beef the loading was about 100 kg/m^2 leading to a design value of 20 kW/m^2. A 20 kW generator would therefore need electrodes of 1 m^2.

A plant for thawing meat offal has now been in commercial operation for 4 years. One unit consists of four 20 kW generators and a conveyor system which passes the material to be thawed through each generator in succession. The conveyor belt is 1·2 m wide and has a working length of 12 m. The height of the top electrodes above the belt can be adjusted to allow material of thicknesses up to 23 cm to be thawed. The size of the electrodes is 107 × 107 cm. Two separate units are installed side by side and several tons of offal can be treated in 1 hr, the exact amount depending on the initial temperature and the required degree of thawing. Fig. 2 shows a general view of the plant.

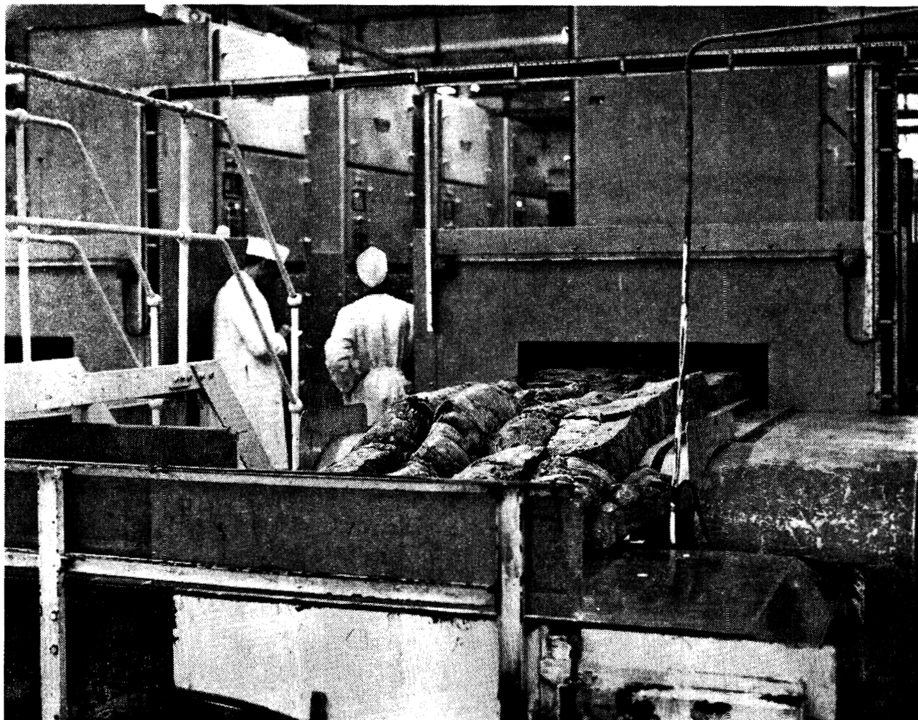

FIG. 2. A 160 kW plant for thawing blocks of offal. (By permission of Scottish Animal Products Ltd and Radyne Ltd.)

Conclusions

Blocks of meat and many other meat products can be thawed on an industrial scale by dielectric heating. Blocks less than about 8 cm thick, sausages, pies, bacon joints, can be successfully treated in a single pass. Thicker blocks may need several passes depending on the regularity of the blocks and the degree of thawing required. Thawing

times are much shorter than when conventional methods are used and drip losses are low. When products composed of different constituents are to be treated, it is possible from a knowledge of their dielectric properties to determine the conditions under which this can be done successfully. Fat when mixed with lean has no adverse effect. When it is present as a separate layer, however, this must not be placed in a direction perpendicular to the field, otherwise selective heating of the fat occurs.

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The incidence of watery muscle in commercial British pigs

A. McM. TAYLOR

Measurements of the pH of the leg muscle approximately 45 min after slaughter (pH_1) have been made in 4737 commercial pigs slaughtered at eight factories in Great Britain. The values found lie on a single-peaked distribution curve with a maximum at pH 6·4–6·5. No evidence was obtained of any marked influence on pH_1 distribution due to sex, weight or period of lairage. Indications of watery muscle were observed in about two per 1000 of the pigs examined. The distribution of watery muscle between factories was very irregular, most of the watery carcases being observed in a single factory.

Introduction

There has in recent years been increasing interest in the incidence in pigs of a condition commonly referred to as 'watery muscle'. This condition, which affects particularly the longissimus dorsi or 'eye' muscle in the loin and the semi-membranosus muscle in the leg (Lawrie, Gatherum & Hale, 1958; Wismer-Pedersen, 1959) is characterized by an unusually pale colour and by the separation of free fluid from the tissue. The basic cause of the condition is not known, but it is associated with an unusually rapid fall in the pH of the muscle after death. The pH value 45 min after slaughter, referred to by Wismer-Pedersen (1959) as the pH_1 value, has been used in Denmark as a criterion of potential watery muscle development. Using this criterion, a collaborative study of British pigs has been carried out by the Meat Research Institute of the Agricultural Research Council and the British Food Manufacturing Industries Research Association. In this study the Meat Research Institute has been concerned largely with progeny-tested pigs and the Research Association has made a background survey of run-of-the-mill commercial pigs slaughtered in the factories of Member firms. This Report presents the results of the B.F.M.I.R.A. work.

General plan of work

Measurements of pH_1 were taken in eight factories, located in the Home Counties, the West Country, the Midlands and Scotland, and covering a range of size from a kill

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of about fifty pigs per day to one of the order of 1000 per day. In most factories measurements were taken over a period of three successive days. All measurements were taken during the period June to September 1964. Measurements of the ultimate pH (i.e. the final equilibrium pH value after overnight cooling) were made on some, but not all, of the experimental carcases. General observations on conditions of lairage and handling were made, and the ambient temperature during the working period was also noted.

Experimental

pH measurements were made using a Radiometer portable pH meter Model 24 (made by Radiometer, 72 Endrupvej, Copenhagen). This instrument was selected since it had already been used for similar work in Denmark. The instrument has separate glass and reference (calomel) electrodes, both designed as spear electrodes suitable for direct insertion into the muscle. Measurements were made in the ham muscles, the electrodes being inserted into the muscle face of the hind leg exposed by the splitting of the carcase. In making measurements the electrodes were inserted and the reading noted; the glass electrode was then twice transferred to a new position, the reference electrode being left undisturbed, and the reading repeated. The mean of the three readings was regarded as the pH of the muscle being tested. This triplicate reading procedure was occasionally relaxed to avoid hold up on the line, but was maintained for the great majority of the readings obtained. At the commencement of each day the meter was calibrated against a standard buffer of pH 6·5 (supplied in concentrated form by the manufacturers of the meter); the calibration was repeated routinely at intervals of approximately 15 min (or about every fifty pigs on the larger slaughter lines) and was also checked after any particularly unusual observation.

The conditions of observation precluded any adequate control of temperature during the pH_1 measurements, since the carcase was still well above ambient temperature at the time of measurement and the repeated insertion and withdrawal of the electrodes must have resulted in continual temperature fluctuations, the electrodes tending to warm up during periods of residence in the meat and to cool again during the intervening periods. No attempt was made to compensate for these temperature fluctuations, the temperature compensator on the Radiometer instrument being maintained at an arbitrary setting of 20°C throughout the whole of the pH_1 measurements, including the buffer standardization. The recorded pH_1 values must therefore be regarded as indicative figures rather than as absolute measurements of pH, but they should be comparable both within themselves and with other observations taken under similar conditions.

In approximately 25% of the carcases measurements of the ultimate pH value (pH_2) were made after overnight cooling. In these measurements the temperature

TABLE 1. Observations on individual factories visited

Factory	Ambient temperature (°C)		Method of stunning	Killing rate (approximate)	Carcase weights (cold)	Interval between sticking and pH_1 measurement (min)	Total No. of carcases examined	Remarks
	On slaughter-line	In lairage						
A	Approx. 20	17–26	Electric	110/hr	Mostly 180–240 lb Limits 150–300 lb	35–40	336	Lairage conditions good: most pigs held overnight before slaughter. Mainly large white and saddleback, or cross of these breeds.
B	20·5–22·5	—	Electric	180/hr	Mostly 180–230 lb Limits 140–260 lb	35	727	Pigs in lairage very quiet: lairage relatively cool.
C	20–21	14·5–24	Electric	50/day	Mostly 140–160 lb Limits 130–180 lb	45	294	Pigs in lairage generally very quiet: most pigs held overnight before slaughter.
D	19–20	19–20	Electric	—	Mostly 140–180 lb Limits 120–200 lb	45	305	Pigs in lairage restless and noisy: most pigs held overnight before slaughter. Slaughter line rate rather variable.
E	18–19	15–16	CO_2	160/hr	(i) Mostly 140–160 lb a few up to 170 lb (ii) 'Heavies' mostly 180–220 lb	45	372	Lairage conditions good, with fan ventilation. Most pigs held overnight before slaughter. Pigs rather noisy in transit to slaughterhouse, particularly in conveyor to CO_2 chamber.
F	17–18	Below 18	Electric	130/hr	Mostly 140–170 lb	40	642	Most pigs held less than 24 hr in lairage: many slaughtered within 1 hr of arrival. Mostly cross-bred pigs with little or no Landrace.
G	18–24	—	CO_2	200/hr	Mostly 130–170 lb	45	1258	Pigs often restless in lairage and noisy on way to CO_2 chamber; electric goad used. Some pigs held overnight before slaughter; others killed after only a short time in lairage.
H	24·5–27	1 or 2° above outside temperature when lairage full	Electric	180/hr	Mostly 140–170 lb	45	803	Lairage conditions good: pigs in lairage quiet. Pigs roughly handled and allowed to run about during unloading. Some pigs in lairage overnight, others slaughtered almost immediately on arrival.

compensation device was adjusted to correspond with the ambient temperature at the time of measurement.

Results

In a preliminary experiment a direct comparison was made on forty-four carcases of pH_1 measurements on the ham muscles and on the longissimus dorsi muscle, which has been used by other observers (Wismer-Pedersen, 1959; Elliott, 1965). The difference observed in individual carcases ranged from 0 to 0·52 pH unit; the differences were, however, randomly distributed and the mean difference over all carcases was zero, the mean pH_1 value being 6·47 in both muscles. It seems reasonable to conclude that, in an extended survey, the results are unlikely to be systematically different for the two sites of observation. A similar conclusion was reached by Wismer-Pedersen (1959).

The general observations on the individual factories visited are shown in Table 1. In some factories the carcases entered the chill room within 45 min of slaughter and in these cases the interval between sticking and observation of the pH_1 value was necessarily less than the 45-min period prescribed by Wismer-Pedersen. All such readings were taken between 35 and 40 min after slaughter and the effect of this deviation in procedure was examined in a separate experiment in which comparative observations at 35 and 45 min after sticking were made on fifty-five carcases. The mean values obtained were 6·57 at 35 min and 6·48 at 45 min; on average, therefore, the short-period readings are likely to be displaced to the extent of 0·05–0·09 pH unit in the direction of higher pH. Fig. 1 shows the overall distribution of the pH_1 values in histogram form for all the carcases examined and for those carcases only in which the pH_1

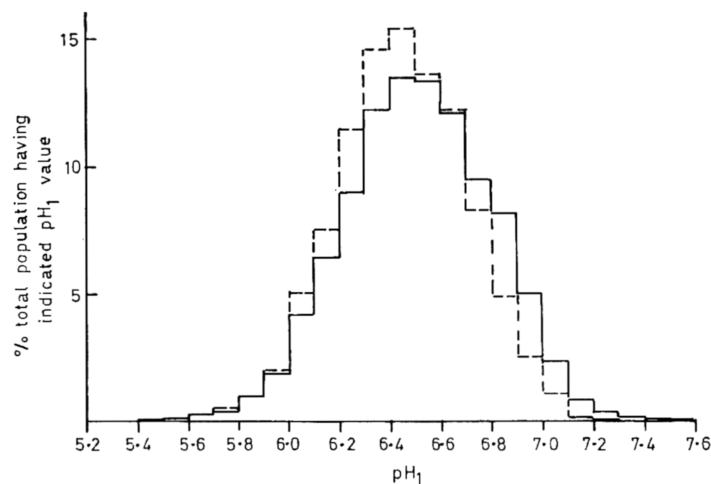

Fig. 1. Overall distribution of pH_1 values. ——, All carcases (4737); – – – –, carcases examined at 45 min after slaughter (2973).

measurement was made after the prescribed period of 45 min. The results show the anticipated displacement of the distribution by the inclusion of the short-period observations, but this does not affect the general shape of the distribution. In particular, both histograms show only a single maximum at pH 6·4–6·5.

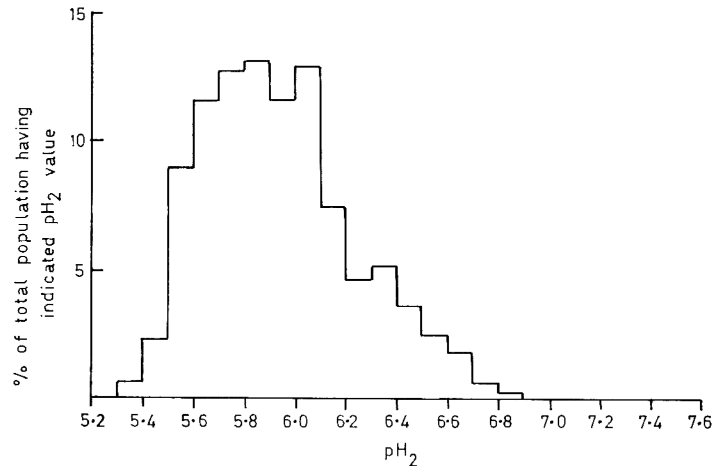

Fig. 2. Distribution of pH_2 values. 1297 carcases: pH determined after overnight cooling.

Fig. 2 shows the overall distribution of the pH_2 values. This distribution shows a flatter maximum, but over 75% of the recorded values were between 5·5 and 6·2.

During the course of the factory surveys the carcases were scrutinized for visual indications of watery muscle. The observations are summarized in Table 2; they were necessarily made on relatively intact carcases and hence under conditions not particularly favourable for the detection of wateriness.

Table 2. Observations on carcases judged as showing wateriness

Factory	Carcase No.	Observations	pH_1	pH_2
B	274	Slightly pale: watery	5·43	—
C	153	Good colour, but dripping fluid from leg muscle: slightly spongy	6·11	5·68
	231	Spongy and dripping fluid: slightly pale	6·30	5·58
D	311	Slightly pale: watery	5·42	—
G	9178	Slightly pale: watery and spongy	5·85	5·52
	9204	Slightly pale: watery	5·70	5·37
	9283	Pale and watery	5·67	5·50
	9527	Pale and watery	5·83	5·38
	666	Very pale and watery	5·67	—
	677	Very pale and watery	5·71	—

Discussion

The frequency distribution of the pH_1 measurements shows no indication of the separation into two groups which is referred to by Bendall & Lawrie (1964) as having been observed in Danish factories, and in this respect the present results agree with those obtained by Elliott (1965) in Northern Ireland. The overall incidence of carcases judged as showing visual evidence of wateriness (Table 2) amounts to about two per 1000 pigs. More than half of these carcases were, however, observed in one factory and in this factory the rate of incidence was of the order of five per 1000 pigs. The two suspect carcases from factory C are quite different from the remaining carcases of Table 2 in respect of their pH_1 values and this fact, coupled with the observation that one was recorded as being of good colour, suggests that these two carcases may not have been exhibiting true watery muscle.

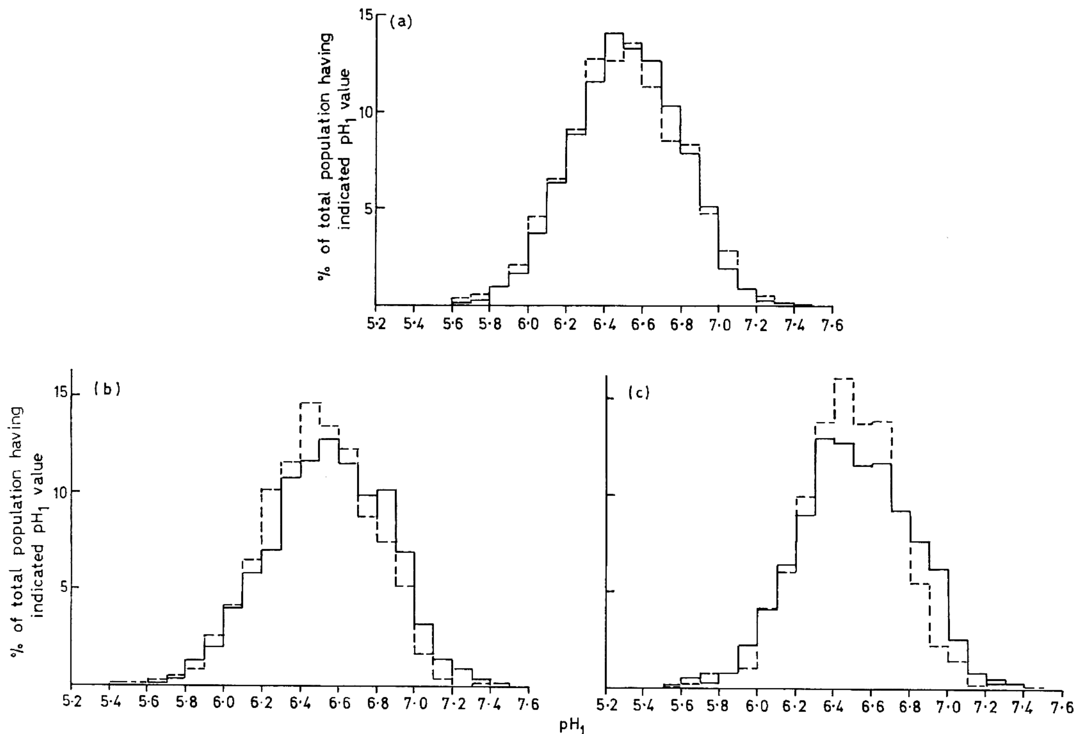

FIG. 3. (a) Effect of sex (———, male, 2447 carcases; – – – –, female, 2259 carcases) on distribution of pH_1 values.

(b) Effect of carcase weight (———, pigs weighing more than 160 lb, 1694 carcases; – – – –, pigs weighing less than 150 lb, 1444 carcases) on distribution of pH_1 values.

(c) Effect of period of lairage (———, pigs held in lairage overnight, 1397 carcases; – – – –, pigs slaughtered on day of arrival, 1007 carcases) on distribution of pH_1 values.

It is of interest to apply as far as possible to the present data for pH_1 values the criteria which have been suggested elsewhere as indicative of potential wateriness. Bendall & Lawrie (1964) report that for Danish pigs a pH_1 value of 6·1 or below has been found to be associated with watery meat; they emphasize, however, that the ultimate pH is also important and that this finding relates only to carcases having an ultimate pH value between 5·7 and 5·2. Application of this criterion is restricted by the fact that, out of a total of 386 carcases recorded as having pH_1 values of 6·1 or below, pH_2 measurements are available on ninety-one carcases only. Nevertheless, thirty-six carcases in this group had pH_2 values within the stipulated range and of these only four were noted as being watery (Table 2). It appears, therefore, that the Danish criterion is not applicable to British pigs, at least as covered by the present survey. In this respect also the characteristics of the British pigs appear to correspond more closely with those of the Northern Ireland pigs for which Elliott (1965) specifies a pH_1 of less than 5·8 to produce pale muscle and of 5·4 or less to produce wet muscle which will not maintain its shape at 20 hr post mortem.

By appropriate grouping of the results it has been possible to examine the effect of specific factors on the distribution of the pH_1 values. In Fig. 3 the data have been selected in terms of sex, carcase weight and lairage period. None of the distribution curves shows any substantial difference between the two groups, although there is an indication of a small systematic difference between the two weight groups, the distribution for the lighter pigs being displaced in the direction of lower pH. There may, however, be a factory-to-factory effect involved in this difference, since the heavier pigs were derived largely from factories A and B while the lighter pigs were mainly from factories F, G and H. The data for the effect of sex, on the other hand, cover all the factories visited and that for the effect of lairage period includes comparative groups within each of three factories. The possibility of between-factory variation also precludes the grouping of the data in terms of the method of stunning employed, although information on this point would be of considerable interest.

Acknowledgments

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A survey of pH_1 and ultimate pH values of British progeny-test pigs

J. R. BENDALL[1], A. CUTHBERTSON[2] AND D. P. GATHERUM[1]

Summary. 1. A total of 2878 progeny-test pigs from five stations, and of 1532 commercial pigs, were surveyed for the pH_1 values, at 45 min after death, and the ultimate pH values, at 24 hr after death, of their LD muscles at the last rib. Values are also available for the heads of the adductor and semimembranosus muscles, where they are exposed in the gammons on splitting the carcase.

2. Factors which affect the pH_1 values are the method of stunning, the breed of pig and the waiting time between station and factory, before slaughter.

(a) CO_2 stunning lowers the mean pH_1 values and increases the % of these values lying below pH 6·0 about three-fold, as compared with electrical stunning. The effect is easily detectable. In extreme cases, a distinctly bimodal distribution of the pH_1 values appears with CO_2-stunned pigs.

(b) Of the progeny-tested breeds, Large White shows the lowest % of low pH_1 values and Welsh and Landrace the highest, but the differences (about two-fold) are not as marked as those brought about by changing from electrical to CO_2-stunning of any particular breed. Commercial pigs of mixed breed, for instance, show a lower % of low pH_1 values even than Large White, but this % can be raised beyond that for electrically stunned Large White, if the commercial pigs are stunned with CO_2.

(c) Waiting time between leaving the station and slaughter has a marked effect on the shape and position of the frequency polygons for pH_1. As the time is increased, so the frequency polygons become broader, the mean pH_1 shifts to lower pH values and the % of values below pH 6·0 increases. At the shortest waiting times, the frequency polygons and the other two parameters for progeny-tested pigs are almost indentical with those for commercial pigs, and may even be an improvement on them, in the sense that the tendency to watery pork is further decreased. This effect of waiting time is independent of ambient temperature, which itself affects the distribution of pH_1 values but only to a minor degree. There is, similarly, a tendency for

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the % of low pH_1 values to be affected by season, being lower in spring and early summer than in autumn and winter, contrary to expectation.

3. Factors which do not significantly affect the distribution of the pH_1 values, or their mean, are the sex of the pig, and the deep muscle temperature at 45 min after slaughter. In fact, the pH_1 values are completely randomly distributed with respect to deep muscle temperature which in its turn appears to be quite unrelated to the ambient temperature in the holding pens or the factory.

4. There are some differences between the pH_1 values of gammon and LD muscles, the former tending to be slightly higher on average, but randomly distributed, so that a pH_1 value of below 6·0 in the LD muscle may be accompanied, on the same carcase, by one of 6·30 or higher in the gammon or vice-versa. For the purposes of an overall survey of the likely occurrence of watery pork, the differences between the two muscles are negligible.

5. The ultimate pH values of the progeny-tested pigs are raised as the waiting time before slaughter increases, due no doubt to increased utilization of glycogen reserves during the tension and excitement of waiting. Ambient temperature, on the other hand, has no significant effect on the ultimate pH, even at the longest waiting time of $1\frac{1}{2}$ hr, although the pigs may have been exposed during this time to temperatures below 4·5°C. Hence, the wastage of glycogen by shivering, observed by earlier workers, does not seem to occur here.

The grand mean of all the ultimate pH values was 5·68, which is higher than that of 5·50 usually observed in large samples of Danish Landrace.

Introduction

Of the methods for diagnosing the likely occurrence of watery and pallid pork on the carcase next day, the measurement of the pH_1 value, taken by probe electrode in the musculature at 45 min after slaughter, is the simplest and most reliable (Bendall & Lawrie, 1964), and can keep pace, in most factories, with the carcases as they come off the slaughtering line. This method has been used for a number of years in Denmark, where the problem of watery pork, amongst Danish Landrace pigs, is more acute than in this country (Wismer-Pedersen, 1959). It was first applied here in a limited survey by the Meat Research Institute in 1962, which showed that the occurrence of watery pork in British commercial pigs was, at that time, almost negligible. However, a feature of the earlier Danish observations was that the carefully selected pigs, tested by the Progeny Testing Stations, showed a higher incidence of the condition than did the ordinary run of commercial pigs. For this reason, the present extensive survey of 'progeny' pigs was undertaken to run in conjunction with the survey of commercial

pigs made by the B.F.M.I.R.A., and reported by Dr Taylor in a separate contribution to this journal.

The survey was designed to test not only the effect of breed, which is considerable, but also that of the arbitrarily imposed conditions of slaughter at the various factories and also of season and ambient temperature. As will be shown, all but the latter two conditions can have marked effects on the incidence of the condition.

Methods

pH measurements

These were carried out by the use of the portable Radiometer pH meter, No. 24, described by Dr Taylor, using probe electrodes G 213 C and K 4111. Because our progeny pigs were slaughtered for bacon manufacture, and therefore had their backbones removed, it was possible to take measurements directly in the longissimus dorsi (LD) muscle at the level of the last rib. These values are the main basis of the present report, although some values are also available for the semimembranosus and adductor muscles in the gammons, which Dr Taylor had perforce to use for the majority of his measurements.

Temperature

Ambient temperatures in the holding pens and factory were measured in all cases, and also the temperature of the long. dorsi muscles at a depth of 2 in.

Results

Before discussing the results in detail, we must describe the method we have employed to test the significance of the differing distributions of pH_1 values, due to differing treatments or methods of slaughter. We are particularly interested, not in the general distribution, but in the % values of below pH 6·0 (*low pH_1 values*), because it is these which reveal the tendency to wateriness in any particular batch of pigs. Since the pigs were slaughtered, in weekly batches of about twenty, on the same day of the week at each factory, we can use these batches as the unit, and calculate the % of low pH_1 values in each batch, and then the mean % value for a number of batches, treated in the same way. This mean value can then be compared with the mean of a similar number of batches, treated in a different way, and the significance of the difference between the two means tested by the t-test or the F-test. As far as possible, the total number of pigs in each test group should be similar. This batch-wise method of testing has been used, for instance, in the calculation of the standard errors of the means and the significance of the differing conditions given in Tables 2 and 3; in the former case for the effect of differing ranges of ambient temperature, and in the latter for the effect of 'waiting' time at the various factories.

(a) *Overall results for progeny-tested and commercial pigs, and the effect of breed*

Fig. 1(a) shows the frequency polygons for the pH_1 values of all the progeny-test and commercial pigs investigated, except those stunned by CO_2. The results cover the period from June, 1964 to May, 1965.

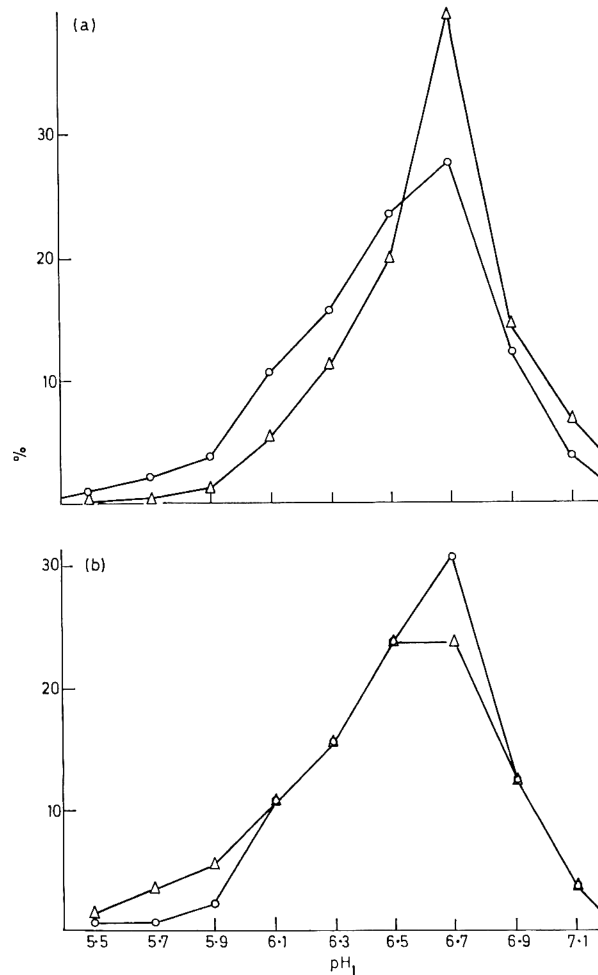

Fig. 1. (a) Frequency polygons for the pH_1 values of all progeny-tested pigs and commercial pigs, at four factories, using electrical stunning. ○, Progeny-tested (2312 pigs); △, commercial (1204 pigs).

(b) Frequency polygons for the pH values of all Welsh and Landrace pigs, compared with those of all Large White pigs, electrically stunned. ○, Large White (1360 pigs); △, Welsh + Landrace (952 pigs).

It is seen that both polygons are somewhat skewed, but the one for the progeny pigs is broader and shifted more towards lower pH_1 values than that for the commercial pigs. The mean pH_1 values for progeny-test and commercial pigs are respectively pH 6·50 and 6·62, and the percentages below pH 6·0 are 6·6 and 1·8% (see Table 1). When tested as outlined above, these percentages were found to differ significantly at the 0·1% level of probability.

TABLE 1. Summary of mean pH_1 values for all pigs

Type of pig	Method of stunning	Numbers	Mean pH_1 value	Difference of mode from mean	% of values below pH 6·0
Progeny	Electric	2312	6·50	+0·20	6·6
(all pigs)	CO_2	566	6·33	+0·33	18·1
Large White	Electric	1360	6·54	+0·16	3·9
Welsh + Landrace	Electric	952	6·42	+0·18	10·5
Special trial at factory	Electric	61	6·50	+0·30	14·4
2 on progeny pigs	CO_2	61	6·27*	+0·03 −0·37	25·6*
Commercial pigs	Electric	1204	6·62	+0·08	1·8
	CO_2	328	6·47	+0·04	5·5
LD muscles and	LD	190	6·43	—	6·7
gammons at factory 1 (Electric)	Gammon	190	6·52	—	7·9

* Indicates a bimodal distribution for which the differences of each mode from the mean are given.

There are considerable differences between the three progeny-test breeds as shown in Fig. 1(b) and Table 1, where the average pH_1 value for Welsh and Landrace pigs, combined, is 6·42, compared with 6·52 for Large White, and the percentages below pH 6·0 are respectively 10·5 and 3·9%. These differences are significant and show up on much smaller samples. It would be more difficult, however, to distinguish Large White progeny from commercial pigs, as we see by comparing Fig. 1(a) with (b).

(b) *The effect of the method of stunning*

CO_2-stunning was used at one of the factories (factory 2) where progeny-test pigs were slaughtered, whereas the other four factories used electric stunning. The overall effect on progeny-test pigs is shown in Fig. 2(a), where we see that the use of CO_2 has shifted the frequency polygon quite markedly to lower pH_1 values, so that the mean value for CO_2 is pH 6·33, compared with 6·50 for electric stunning, and the percentages below pH 6·0 are respectively 18·1 and 6·6%. These latter differences are

highly significant ($P < 0{\cdot}1\%$). Note that this effect is quite independent of breed, since the breeds were represented to more or less the same extent in the CO_2 and electrically-stunned groups.

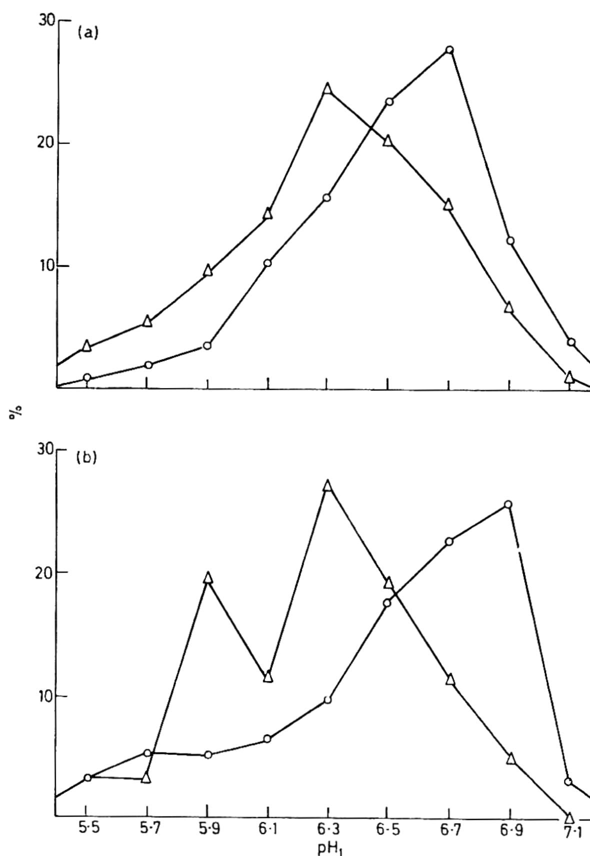

FIG. 2. (a) Frequency polygons for pH_1 values of all progeny-tested pigs, stunned electrically, compared with those of pigs stunned with CO_2. O, Electric-stunning (2312 pigs); △, CO_2-stunning (566 pigs).

(b) Frequency polygons for pH_1 values of pigs, stunned with CO_2 or electrically, at factory 2 (sixty-one pigs in each group).

The overall effect on commercial pigs is similar, as seen from Table 1, where the average pH_1 value is lowered by CO_2-stunning from 6·62 to 6·47, and the percentage below pH 6·0 is raised from 1·8 to 5·5%. Thus, CO_2 stunning can increase the tendency to watery pork in commercial pigs beyond that for the Large White progeny stunned electrically, where the % below pH 6·0 = 3·9%.

To show that this effect was not due to some condition at the factory other than

CO_2-stunning, two groups of sixty-one pigs were tested, at factory 2, one stunned with CO_2 and the other electrically. The result is shown in Fig. 2(b), from which it is obvious that CO_2 is the cause and gives a mean value of 6·27 for pH_1, and a % below pH 6·0 of 25·6%, compared with values of pH 6·50 and 14·4%, respectively, for the electrically-stunned group. It is also seen that the frequency polygon for the CO_2-stunned group has become bimodal, the first mode lying at pH 6·30 and the second at pH 5·90. This is also a feature of the frequency polygons for Danish Landrace pigs, where the % of values lying below pH 6·0 can often exceed 30%.

Incidentally, the difference between breeds are brought out rather more clearly by CO_2-stunning than electrical stunning. Thus, 12·2% of the pH_1 values for 280 Large White pigs, stunned with CO_2 were below 6·0, while for a group of 280 Welsh and Landrace pigs, 24% were below 6·0. This result has been confirmed recently in two groups of sixty-five pigs, where the Large White group gave 15% below pH 6·0, and the Landrace 28·4%.

(c) *LD muscles and gammons, compared*

The difference in pH_1 values between LD muscles and gammons has been tested on 190 progeny-test pigs. As Table 1 shows, the mean pH_1 value in LD muscles is lower than in gammons, whereas in this particular sample the frequency polygon for gammons was more skewed than that for LD muscles, so that the former showed a rather higher % of values below pH 6·0. The latter difference was not significant, whereas the difference between the values for pairs on the same carcase was significant at the 1% level of probability. By this test, the LD muscles had a pH_1 value 0·056 units lower than that for the gammon of the same animal ($t = 2{\cdot}6$, for $n = 190$). However, the standard error of the difference was high (±0·022), giving a standard deviation for this number of values of ±0·31. This means that pigs showing the watery condition in their LD muscles need not necessarily do so in their gammons, and vice-versa, although for the purpose of an overall survey, it makes little or no difference to the shape or position of the frequency polygons which muscle group is chosen.

(d) *The effect of sex*

The effect of sex on the pH_1 values has been tested on 535 pairs of progeny gilts and hogs, and also on fifty-two entire males. The mean pH_1 value for gilts was 6·43 and that for hogs 6·45, and the % of values lying below pH 6·0 were 10·1 and 9·9% respectively. The small sample of entire males gave almost identical average values. Thus, sex has no significant effect on pH_1.

It should be noted that the reason for the rather high % of values lying below 6·0 in this series is that about one-third of the pigs in each group were CO_2-stunned.

(e) *The effect of position on the line*

As we will show in section (g), the incidence of low pH values increases as the average time between leaving the progeny-testing stations and slaughter increases; we would therefore expect that the last pigs to be slaughtered in a batch would have a higher incidence than the first. To show whether or not this was so, we compared the incidence of low pH_1 values in the first half of the slaughter lines with that in the second half. We chose days on which between fifteen and forty pigs were slaughtered in a batch (average batch size = twenty-three pigs). All breeds were included, but they were quite randomly dispersed throughout the batches, so that this factor could not have affected the results.

At factory 1 (electrical stunning), the mean % of pH_1 values below pH 6·0, per batch, was 8·6% in the first half of the lines and 12·2% in the second half (total number of pigs = 568; number of batches = twenty-six). The difference between these percentages was tested batchwise by the *t*-test, but was not significant, because of the high variance. A similar result was obtained at factory 2, where CO_2-stunning was used and the % of low pH_1 values was therefore higher. In the first half of these lines, the mean % of low pH_1 values per batch was 15%, and in the second half 21% (total number of pigs = 466; number of batches = nineteen). Again because of the high variance, the difference between these mean % values was not significant.

As a further test, we applied the same criterion, batch by batch, to 600 Large White pigs; 300 in each half of the lines. The mean % of low values in the first half was 5·3% compared with 7·3% in the second half, but again the difference was not significant. Thus although statistically insignificant, there does appear to be a definite trend towards lower pH_1 values in the second half of any slaughter line compared with the first half, no matter what method of stunning or breed of pig is investigated, because of the increase in waiting time.

(f) *The effect of season and external temperatures*

The effect of season was examined at factory 1, where four quarterly periods were considered, during each of which approximately 220 pigs of all breeds were slaughtered. The % of pH_1 values below pH 6·0 were: 6·2% from June to August 1964 inclusive; 8·6% from September to October 1964; 11·7% from December 1964 to February 1965; and 8·3% from March to May 1965. The mean pH_1 values were respectively: 6·50, 6·45, 6·46 and 6·47. Thus the effect of season is the reverse of what would be expected, the early summer showing a lower % of low pH_1 values than the autumn, winter and spring, although none of these differences are significant statistically, when tested batchwise, as we have described.

To a certain degree, the above values should also reflect the effect, if any, of the ambient temperatures in the holding and sticking pens, which closely follow the

TABLE 2. Effect of ambient temperature on distribution of pH_1 values and ultimate pH values, at factory 1

	Temperature range (°C)	Mean temperature (°C)	No. of pigs	No. of batches	% of pH values below 6·0	Mean ultimate pH
(1)	18–26	22·2	193	9	6·2±1·4	5·75
(2)	13–17·9	14·4	127	6	11·0±3·2	5·74
(3)	8–12·9	10·5	275	14	11·2±1·6	5·76
(4)	Below 8	4·3	171	9	8·2±2·5	5·76

seasonal changes in external shade temperatures. More detailed analysis of the effect of ambient temperature at factory 1 is given in Table 2, where we observe the curious phenomenon that the smallest proportion of low pH_1 values occurs in the highest of the four arbitrarily chosen temperature ranges. The difference between the values for this range and those for the lowest range but one is, however, the only one which is statistically significant (at the 3·5% level of P).

TABLE 3. Summary of pH values and deep muscle temperatures, and of the effect of waiting time on them, for progeny-test pigs, over the same period (9 October 1964 to 6 May 1965)

Station	Total waiting* time (hr)	Numbers†	Mean pH_1	% below 6·0	Ultimate pH‡	Deep muscle temperature (°C)
1 (Electric)	1·50	574	6·46	9·8±0·9	5·75	38·8
3 (Electric)	0·50	525	6·61	3·2±0·7	5·57	39·5
4 (Electric)	1·25	278	6·43	9·0±1·2	5·68	39·0
5 (Electric)	0·75	630	6·53	5·2±0·9	5·68	39·9
2 (CO_2)	1·00	566	6·33	18·1±2·0	5·66	39·1

Differences in % of values below 6·0:
(1)–(3) Significant at 1·0% level of probability.
(1)–(5) Significant at 1·0% level of probability.
(1)–(2) Significant at 0·1% level of probability.
(3)–(4) Significant at 1·0% level of probability.

* Total waiting time equals time on route plus time in holding pen.
† Total 2878.
‡ Grand average 5·68.

(g) *Variability of the occurrence of low pH_1 values from factory to factory, and the effect of holding time in the pens upon it*

The variability between the four factories, using electrical stunning, in average pH_1

values and in the % of these values below pH 6·0, is shown in Table 3. None of this variability is due to seasonal or temperature effects, because the batches were compared over the same period, from October 1964 to May 1965. The effect of breed has also been eliminated by working out the % of low values separately for Large White and for Landrace plus Welsh at a given factory, and then averaging them. This was necessary particularly in the case of factories 3 and 4 where the % of Landrace plus Welsh was lower than the average of about 50% at the other three factories. It is quite clear, however, that there is a high degree of correlation between the time taken on the journey from progeny-testing station to factory plus the time in the holding pens, on the one hand, and the % of low pH_1 values, on the other, as seen by the highly significant differences between the mean values for batches, given in the table. The corollary is that the average pH_1 values fall as the total time between leaving the stations and slaughter increases. In other words, the pigs become excited and tensed up during their journey by truck and in the holding pens, and this leads to lower pH_1 values the longer it lasts. The possible physiological reasons for these effects have been discussed by Bendall (1966).

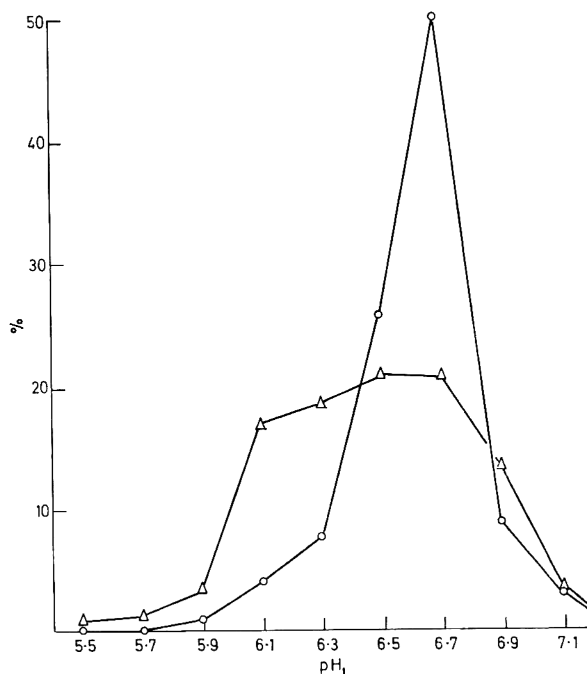

FIG. 3. Frequency polygons for pH_1 values at two of the factories using electric stunning, to show the variability which can occur from factory to factory (large White pigs only). △, Factory 1 (431 pigs): mean pH_1 = 6·46, % below 6·0 = 5·9; ○, factory 3 (408 pigs): mean pH_1 = 6·61, % below 6·0 = 1·2.

It will be noted from Table 3 that, at the factory where the 'waiting' time was shortest (factory 3), the mean pH_1 value and the % of low values were very close to the overall mean values for the commercial pigs tested in this study (cf. Table 1 and Fig. 1a). This is brought out more clearly by the frequency polygon, shown in Fig. 3, for the pH_1 values of the Large White pigs at this factory, which is even sharper than that for the commercial pigs in Fig. 1(a). In contrast the frequency polygon for factory 1, where the 'waiting' time was one of the two longest, is much broader and has a more extensive area in the lower ranges of pH.

(h) *The effect of deep muscle temperature after slaughter, and its relation to ambient temperature in the factory*

It has been claimed by one school of American workers (Kastenschmidt, Briskey & Hoekstra, 1964) that cooling down pigs in water before they are slaughtered leads to lower deep muscle temperatures after slaughter, and, therefore, to higher pH_1 values and less watery meat. It might be thought that low ambient temperatures would have the same effect, particularly when the time in the holding pens is extended. We therefore first tested these effects at factory 1, where the holding time averaged $1\frac{1}{4}$ hr. We found a deep muscle temperature in the LD muscles of 842 pigs, at 45 min after slaughter, of 38·8°C, from June 1964 to May 1965 (see Table 3). During one period of 4 weeks in January to February 1965, however, the mean ambient temperature in the factory dropped to 4·5°C. The mean deep muscle temperature of these pigs, instead of being lower as expected, was on the contrary 40·4°C, that is 1·6°C higher than average. In spite of this higher muscle temperature, however, the % of pH_1 values below pH 6·0 *dropped* from the overall mean value of 9·5% to 6·85% (i.e. five pigs out of seventy-three). Thus the reactions of muscle temperature to ambient temperature and of pH_1 to muscle temperature were exactly the opposite to expectation.

Considering the other factories using electrical stunning, we see from Table 3 that, although the mean muscle temperature varies slightly from factory to factory, it again bears no relation to the % of low pH_1 values. In fact, factory 3 which is the best from the point of view of pH_1 shows one of the highest mean muscle temperatures.

(i) *Factors affecting the ultimate pH values*

The ultimate pH values for the pigs killed at all five factories are given in Table 3. It is noticeable that there is a tendency for the ultimate pH to rise as the time between leaving the stations and slaughter increases. This effect is probably due to prolonged excitement and muscular tension, leading to utilization of more of the glycogen reserves in the muscles. Again, the pigs at factory 3, which have the highest mean pH_1 values, indicating the least excitement and muscular tension, show the lowest mean ultimate pH, that is the highest reserves of glycogen in the muscles at slaughter.

It is interesting to note that the overall mean ultimate pH of 5·68 for all the progeny pigs is considerably higher than that of about 5·50 usually found in large samples of Danish Landrace pigs. It is also higher than the mean value of 5·40 for the ten Large White pigs used by Bendall in a study of the effect of curarization (Bendall, 1966). The latter pigs were, however, kept under very carefully controlled conditions with the least possible excitement before slaughter.

Factors which do not seem to affect the ultimate pH significantly are sex, breed or method of stunning. Thus gilts and hogs cannot be distinguished from one another, nor can Large White, Welsh or Landrace of either sex, nor can CO_2-stunned pigs and electrically-stunned pigs, as we see from Table 3.

Another factor which has been shown by some workers to lower the glycogen reserves, and thus to raise the ultimate pH, is exposure to low ambient temperatures for extended periods, no doubt due to shivering. The longest exposure to extremes of ambient temperature in our experiments was 1½ hr, as at factory 1. This, however, was evidently not sufficient to have any effect whatsoever on the ultimate pH values, as we see from the values for the four arbitrarily chosen temperature ranges, given in Table 2. Even at the extremes of ambient temperature of 22·2 and 4·3°C, the mean ultimate pH did not vary from 5·75 by more than 0·01 unit.

Discussion

The factors which most seriously affect the pH_1 values of pig carcases, and therefore, by implication, the incidence of watery pork, are the breed, the method of rearing, the holding time before slaughter and the method of slaughter itself, whereas factors such as sex, season of the year, ambient temperature and deep muscle temperature after slaughter are evidently of little or no importance within the range of variation observed in the present study.

To deal with the latter group of factors first, it may seem somewhat surprising that season of the year and ambient temperature had little or nothing to do with the occurrence of the condition, since both these factors have been implicated by previous workers: for example, Ludvigsen (1954) thought season was important because of its effect on the hormonal balance, which in its turn indirectly affected the meat structure; whereas Wismer-Pedersen (1959) attributed the supposed aggravating effect of high-ambient temperatures to increased fighting amongst the pigs, and Kastenschmidt *et al.* (1964) to its effect on the muscle temperature itself. However, we have been quite unable to find either the seasonal effect, or the effect of high muscle temperature in the British pigs we have examined so far. We also note that a change of ambient temperature downwards from 26°C to less than 8°C had no noticeable effect on the ultimate pH values, although this might have been expected, because of shivering at the lower

temperatures and hence wastage of glycogen reserves in the muscles, and a consequently lower production of lactic acid post-mortem.

The factors which do increase the incidence of low pH_1 values all have the one feature in common that they tend to increase the excitability of the pig before slaughter, although it is difficult, if not impossible, to assess this quantitatively. Thus, Landrace pigs which are more prone to the condition than Large White, are frequently reported by slaughtermen to be more 'nervous', and it is also true that progeny pigs, which have usually been reared in small numbers in carefully controlled conditions, are more excitable, when brought to the factory, than the usual run of commercial pigs, which have often been reared in larger communities and under 'tougher' conditions. This excitability factor is most noticeable amongst Pietrain pigs, which are also notorious for their proneness to the condition (Wismer-Pedersen, 1961). In this connection, it is interesting to note that, of the small number of Pietrain pigs which have recently been made available to us for testing in this country, all showed very low pH_1 values in their long. dorsi muscles and all were watery, a result very similar to that obtained by Wismer-Pedersen. These particular pigs were so excitable and prone to fighting that they had to be kept apart in separate pens before slaughter.

The difference between CO_2 and electrical stunning can also probably be accounted for by the increased excitement and struggling produced by the moving belt of the CO_2-stunner, and particularly by the rather precipitous descent into the CO_2-chamber in the particular factory concerned. Similarly, increased waiting time on the journey and in the holding pens considerably exacerbates the condition as we have shown in Table 3 and Fig. 3, and this also probably has an exciting effect upon already nervous pigs, at least up to the time when they have become thoroughly accustomed to their new conditions.

The above observations are, as we have said, open to the objection that we have no objective method of assessing excitability, but we can use the corollary of them to prove our point indirectly. Thus, if pigs are immobilized before death with the paralysants, myanesin or tubocurarine, so that no nervous stimuli can reach their musculature, they all show exceptionally low rates of pH fall post-mortem, that is very high pH_1 values, whatever the breed (Bendall, Hallund & Wismer-Pedersen, 1963; Bendall, 1966). On the other hand, if the musculature is directly stimulated electrically just after death, which has a similar effect to that of natural nervous stimuli, the pH fall is accelerated for a long time after the stimulation has ceased (Hallund & Bendall, 1965; Bendall, 1966), and its rate is often as great as that in pigs showing the watery condition. Thus, we conclude that excitability is probably the most important single factor in producing the watery condition, due to its accelerating effect on the fall of pH post-mortem, and hence to the likelihood that the muscles will be exposed to acid conditions and high temperatures long enough for the proteins to become denatured and lose their natural, high water-binding ability.

Lastly, we should point out that interaction between the various factors we have mentioned above can lead to apparently contradictory results. Thus, if we were to compare a number of Landrace pigs, slaughtered at factory 3 under the best conditions, with a number of Large White slaughtered at factory 1, where the conditions are not so good, we should probably arrive at the conclusion that Large White pigs were more prone to wateriness than Landrace, a result in direct contradiction to what would be observed if both groups had been slaughtered under the same conditions. Even more contradictory results would be obtained by slaughtering the Large White group at the factory which uses CO_2 stunning. Hence, in comparing breeds, it is absolutely essential to ensure that the pre-slaughter and slaughter conditions are very nearly identical, because these clearly have an overriding effect.

In conclusion, we must stress that although progeny pigs, slaughtered under identical conditions, are more prone to wateriness than commercial pigs of mixed breeds, the condition is still not serious in this country, compared to Denmark, where some surveys show more than 30% of the pigs to have pH_1 values below 6·0. However, this is no reason for complacency because the desire to produce a leaner pig, and thus to introduce strains such as the Pietrain, may bring with it all the most undesirable features of the Danish Landrace. In that case, it would be necessary to consider drastic methods of combating the condition, such as the use of tranquillizers just before slaughter, because nobody wishes to sell or buy pig meat which would lose more than 10% of its weight in drip fluid, before arriving on the table.

Acknowledgments

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Relation between oxygen tension, biosynthesis of ethylene, respiration and ripening changes in banana fruit

L. W. MAPSON AND J. E. ROBINSON

Summary. The ability of unripe bananas to synthesize ethylene is dependent on the oxygen tension of the atmosphere surrounding the fruit. Unripe bananas do not synthesize significant amounts of ethylene at 18°C unless the oxygen tension is above 7·5–8·0%. At oxygen tensions of 10–13% synthesis does occur but it is delayed compared with fruit in the air. It has been demonstrated that delay in the onset of the ripening syndrome occasioned by holding fruit in 5–7·5% oxygen is caused by their inability to synthesize ethylene. The ripening syndrome may, however, be initiated even in atmospheres of low oxygen by the inclusion of exogenous ethylene in physiological concentrations. Once the synthesis is initiated, the fruit are capable of producing ethylene even in atmospheres of low oxygen.

Introduction

The necessity for oxygen in the biosynthesis of ethylene by many fruits is well established by the work of Gane (1934) with apples and by other workers with other fruits, including pears and tomatoes (Hansen, 1942; Biale, Young & Olmstead, 1954). Conversely, exposure to high tensions of oxygen has been shown to accelerate the production of ethylene in citrus fruits (Aspinall & Cairncross, 1960) and tomatoes (Graft, 1960). More recently the work of Lieberman & Mapson (1964) and of Lieberman *et al.* (1965) on the production of ethylene in model systems from linolenic acid and methionine has indicated a reason for this requirement.

The reduction of oxygen in the atmosphere in combination with an increase in CO_2 has been long recognized as a means of prolonging the storage life of certain fruits (apples and pears) and is now employed on a commercial scale. The present experiments are concerned with the effect of reducing the oxygen in the storage atmosphere on the synthesis of ethylene and on the related phenomena of respiration and onset of ripening in bananas. We have been able to show that with bananas: (1) the synthesis of ethylene is controlled by the tension of oxygen in the storage atmosphere, and (2)

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ethylene *per se* is the factor which induces both the accompanying respiration climacteric and associated ripening changes.

Experimental

Material

Banana fruit of two varieties were used, *Lacatan* from the West Indies and *Gros Michel* from West Africa. In each experiment the samples consisted of three or four connected fingers taken from a single hand of bananas.

Methods

The fruit were placed in containers ($\sim$ 6000 ml in volume) and a constant stream of the appropriate gas mixture passed through at an average rate of approximately 700 ml/hr. Samples of emerging gas were taken for estimation of ethylene and CO_2. All experiments were conducted at 18°C.

Carbon dioxide was determined by absorption in soda-lime and samples of gas for ethylene, taken before passage over soda-lime, were analysed by a gas-chromatography technique using a flame ionization detector as described by Lieberman *et al.* (1965).

At the termination of each experiment the fruit were sampled for appearance, taste and flavour. It was, of course, impossible to compare at the same time the eating quality of control fruit with the experimental fruit held in low oxygen since these ripened at a much later date. Fruit were therefore assessed on the basis of whether they were to be considered of good eating quality.

Results

When full 'three-quarter grade'* but unripe green bananas are held at a ripening temperature (18°C), in atmospheres in which the oxygen level is reduced to a value of 1–10%, the ripening process is prevented or retarded as long as the fruit is subjected to the lower tension of oxygen. The results of an experiment using bananas (Lacatan variety) held in atmospheres containing 1, 2·9 and 5·4% oxygen in nitrogen are illustrated in Fig. 1. In this experiment the fruit was placed in large desiccator jars and a continuous stream of the appropriate gas mixture was passed through the container. There was thus no build-up of CO_2 or reduction of oxygen tension due to respiration of the fruit. The control fruit held in air showed signs of ripening, as evidenced by climacteric rise in respiration and change of colour of the skin almost immediately after the experiment was started, but the fruit held at the low oxygen levels did not. No change in colour or in respiration occurred with these during the whole time of their sojourn in the low oxygen (11 days). On the eleventh day the low oxygen was replaced by air,

* The grade of maturity normally selected for export to U.K.

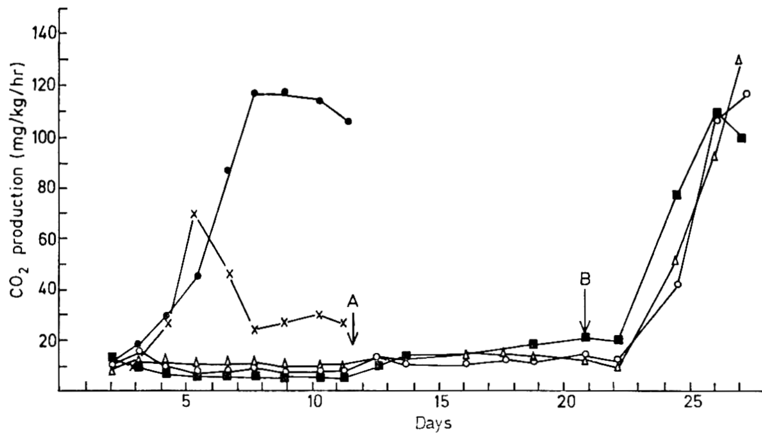

FIG. 1. Effect of low oxy-‑n atmospheres on the respiration of banana fruit. Control in air: ●, CO_2 product‑ , ethylene production. Fruit in low oxygen: CO_2 production: △, held in 5·4‑ ld in 2·92% O_2; ■, held in 1% O_2—returned to air on 11th day and e‑ ‑en on 21st day. At A, samples in low oxygen returned to air; at B to ventilating air.

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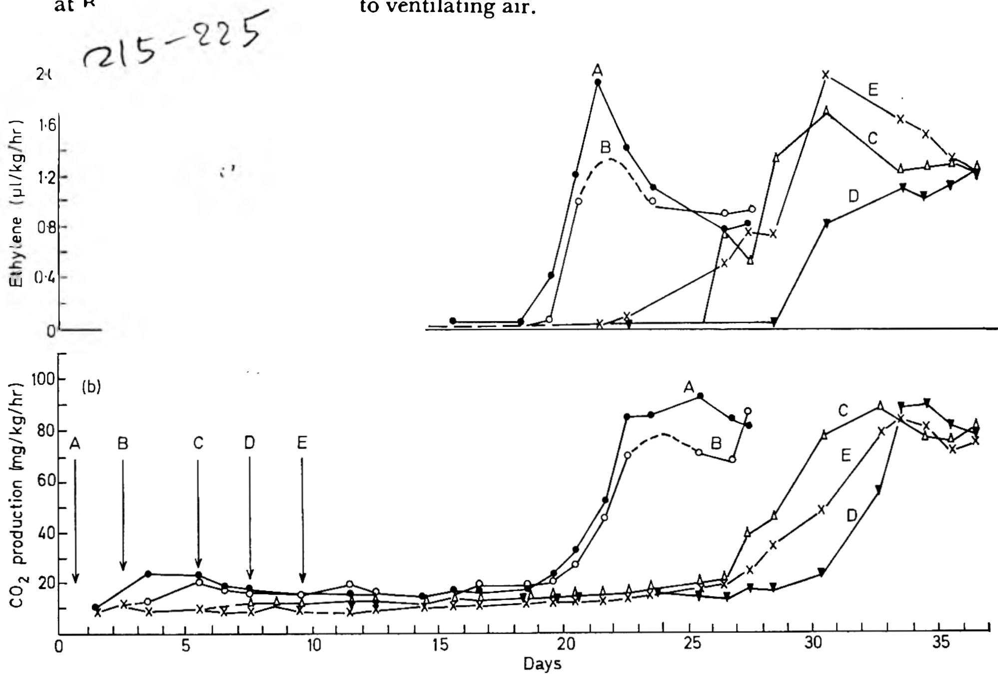

FIG. 2. Effect of low oxygen for short periods on the biosynthesis of ethylene and climacteric rise in respiration. A, In air throughout; B, 2 days in 5% oxygen in nitrogen; C, 5 days in 5% oxygen in nitrogen; D, 7 days in 5% oxygen in nitrogen; E, 9 days in 5% oxygen in nitrogen.

but after a further 9 days still no significant sign of ripening was observed. The fruit was eventually induced to ripen by the introduction of ethylene in a concentration of 2 ppm into the atmosphere. With the exception of the fruit held in 1% oxygen, all were satisfactory as far as flavour, texture and colour were concerned. The fruit held in 1% oxygen when finally ripe lacked flavour and sweetness, and was less attractive on this account. It seems possible that some degree of anaerobiosis was responsible for this deterioration.

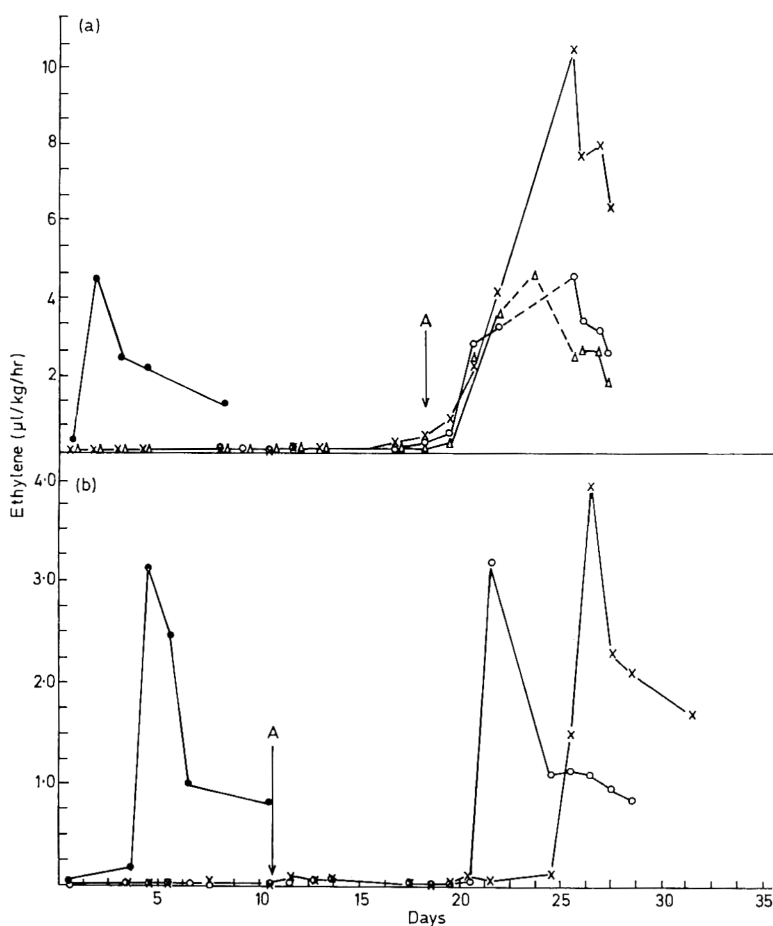

Fig. 3. The effect of reducing the tension of oxygen in the atmosphere on the synthesis of ethylene of two varieties of banana fruit. (a) Gros Michel variety: ●, In air throughout; ×, in 1% oxygen, 99% nitrogen; ○, in 3% oxygen, 97% nitrogen; △, in 5·5% oxygen, 94·5% nitrogen. (b) Lacatan variety: ●, In air throughout; ×, in 1% oxygen, 99% nitrogen; ○, in 3% oxygen, 97% nitrogen. At A, all transferred to air.

In a succeeeding experiment the fruit (Lacatan variety) was exposed for varying periods of time to low oxygen before being moved back to air. In this experiment ripening was followed by measuring (1) ethylene production, (2) CO_2 production, and (3) colour changes. Apart from the shortest period in low oxygen (2 days) ripening of the fruit was delayed by approximately the time the fruit had been held in low oxygen (Fig. 2). All samples eventually ripened satisfactorily and all were of good colour and excellent flavour; there was, in fact, no evidence that the retardation of ripening of the fruit exposed to low oxygen produced any adverse off flavours. It will be noted that in all cases the biosynthesis of ethylene preceded slightly the onset of the climacteric rise in respiration. A repeat of this experiment with a West African variety (Gros Michel) gave very similar results. In this experiment the fruit was held in atmospheres containing 1, 3 and 5·5% oxygen in nitrogen. The controls held in air ripened rapidly and this is shown by the rapid production of ethylene (Fig. 3). No ethylene was produced in the fruit held in the atmospheres containing low oxygen, but when such fruit was returned to air there was a production of ethylene within 24–36 hr. It is of interest that the fruit held in 1% oxygen produced far more ethylene on return to air compared with the fruit held at 3 or 5·5% oxygen levels. The fruit held in the lowest oxygen also produced marked amounts of CH_3CHO on return to air. All fruit with the exception of those at 1% oxygen ripened to an excellent colour and eating quality. The flavour of the fruit held in 1% oxygen on ripening in air was again inferior to that of the rest, there was an absence of banana flavour, and the flesh was somewhat astringent and sour.

A further experiment with Jamaican (Lacatan) fruit held in 1% and 3% oxygen in nitrogen produced almost identical results. No ripening occurred during 10 days sojourn in low oxygen, although controls in air started to ripen on the third day. The fruit in low oxygen on return to air started to produce ethylene on ripening after they had been returned to air for a further 10 days. This lag period was always noticeable with the Lacatan variety, as opposed to the Gros Michel variety which usually started to produce ethylene and ripen within 24–48 hr after return to air. In this particular experiment the samples held at the 3% oxygen level gave fruit of excellent eating quality, and even those held at 1% oxygen, though not as good, were in this case acceptable. In later experiments we have delayed the onset of ripening of bananas for as long as 39 days at 18°C by holding the fruit in 6·5% oxygen in nitrogen. On transfer to air onset of ripening occurred within 48 hr, the fruit becoming eating ripe after a further 16 days. Despite this extended storage period the fruit when ripe was of excellent colour, texture and flavour.

Use of higher levels of oxygen

We have shown in the preceding experiments that levels of oxygen of 1–5% are all capable of retarding, apparently indefinitely, the production of ethylene, the climacteric rise in respiration, and the changes accompanying the ripening process. It was of

interest to determine the lower limit of oxygen which will allow these reactions to proceed normally. Accordingly we have placed fruit in atmospheres containing from 4 to 21% oxygen. The results of an experiment in which the fruit was held in 6, 10 and 13% oxygen and in air are illustrated in Fig. 4.

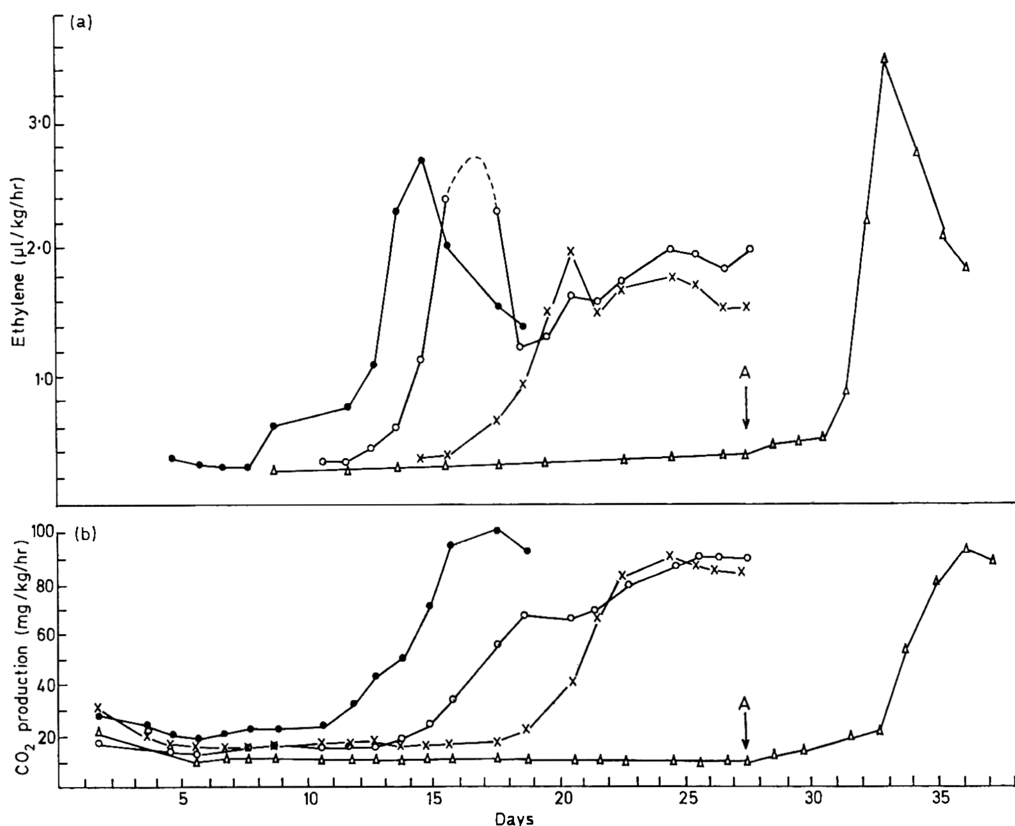

Fig. 4. Effect of oxygen atmospheres containing 6, 10 and 13% oxygen on ethylene and CO_2 production of unripe bananas. ●, In air throughout; ○, 10% oxygen in nitrogen; ×, 13% oxygen in nitrogen; △, held for 27 days in 6% oxygen, then replaced by air at A.

The fruit held in the lowest oxygen showed no signs of ripening, as measured by either production of ethylene or rise in respiration, for 27 days. On return to air, within 4 days stimulation of the production of ethylene was observed, which reached a peak 2 days later. The respiration climacteric rise began 24 hr after that of ethylene. Although atmospheres of 10–13% oxygen delayed the onset of the synthesis of ethylene and the associated respiratory changes they did not prevent these occurring. There is therefore a threshold concentration of oxygen below which the synthesis of ethylene cannot

occur. This threshold appears to be in the region of 7·5% oxygen at a temperature of 18°C. In this experiment it will be noted that these changes occurred slightly earlier in the fruit held in 10% oxygen compared with those in 13% oxygen. We do not attach any significance to this difference but believe it to be due to variation as between individual fruit.

Ethylene as inducer of the ripening process

The concept that ethylene functions as a ripening hormone was first put forward by Kidd & West (1928). This concept was challenged by Biale *et al.* (1954) who suggested that the gas was merely a by-product of the ripening process and not its initiator, on the basis that certain fruits showed climacteric rises in respiration without any detectable production of ethylene. However, later work has indicated that small amounts of ethylene may be detected in such fruits.

In our experiments with atmospheres of low oxygen we have been able to arrest completely the ripening process, but have shown that, provided ethylene at physiological concentration is included in atmospheres of low oxygen, the respiration climacteric and the ripening changes of colour, texture and flavour may be induced. Jamaican bananas (Lacatan) in the green condition were exposed to atmospheres containing 5% oxygen in nitrogen and held at 18°C; fruit held in air were set up as controls. The fruit, as in the experiments above, were placed in a container through which a slow stream of the appropriate gas mixture (~500 ml/hr) was passed; no perceptible sign of ripening was observed. After 6 days, during which time the level of respiration (CO_2 production) was measured, ethylene 2·5 ppm was incorporated in the gas stream passing over each of one of the fruit samples held in air or 5% oxygen in nitrogen. As the results (Fig. 5) indicate, both samples responded by showing a respiration climacteric, although the rate of increase in the respiration in the 5% oxygen sample was slower compared with that in air and only reached a maximum value of about 75% of the rate in air. The sample left in air alone showed a climacteric rise in respiration after 12 days, but owing to somewhat uneven ripening (one finger started to ripen on twelfth day, others delayed until 17–18 days) the CO_2 production showed no distinct peak. The sample left in 5% oxygen alone showed no sign of ripening (no increase in respiration) even after 30 days, and at the end of this period was transferred back to air. Even then it did not show any signs until after the elapse of a further 19 days, when it ripened and gave a good eating quality fruit. The long period of delay, occasioned by the low oxygen atmosphere, had not had, therefore, any detectable deleterious effect on quality, as measured by colour, flavour and texture.

The results of this experiment clearly indicated that the sojourn in the low oxygen retarded or prevented ripening, by its effect on the suppression of the biosynthesis of ethylene, and not by the inhibition of the associated respiratory changes. Although these latter were depressed in rate by low oxygen and were accompanied by slower

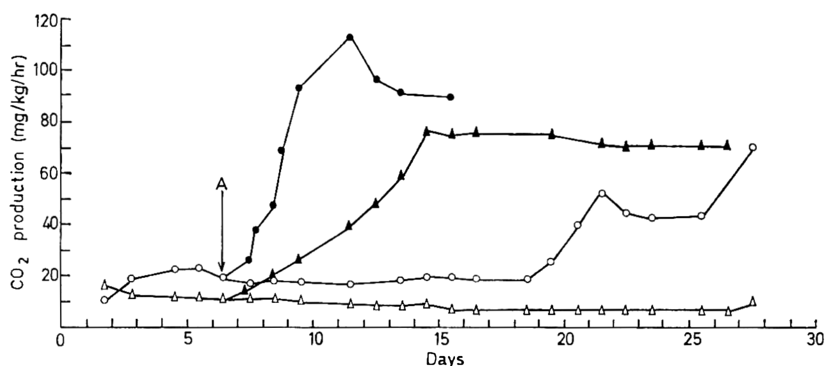

FIG. 5. Climacteric rise in CO_2 production induced by ethylene in air and in low oxygen. Two samples of fruit were placed in air and two samples in 5% oxygen, 95% nitrogen. After 6 days ethylene (2·5 ppm) was introduced (at A) in the atmosphere over one of each of the samples in air and 5% oxygen. At A: ●, Air + ethylene (2·5 ppm); ▲, 5% oxygen, 95% nitrogen + ethylene (2·5 ppm); O, in air throughout; △, in 5% oxygen in nitrogen throughout.

changes in the colour, texture and flavour usually associated with ripening, the fruit did eventually become eating ripe, although somewhat lacking in flavour, with texture somewhat firmer than that present in a fully ripe fruit. As was observed in earlier experiments the fruit which had been held in the low oxygen throughout, and then returned to air, ripened satisfactorily and were accounted of good eating quality.

This experiment was subsequently repeated using 6·5% oxygen to prevent the synthesis of ethylene. Ethylene at a concentration of 2·77 ppm was introduced into the gas stream passing over some of the fruit, and its concentration also recorded in the gas stream after emerging from the container. As in the previous experiment, the production of ethylene, the climacteric rise in respiration, and ripening changes were completely inhibited in 6·5% oxygen in nitrogen, but were initiated when ethylene at 2·7 ppm was introduced into the gas stream. This initiation of ripening even in low oxygen occurred when the fruit was exposed to ethylene (2·7 ppm) for only 24 hr, and was not significantly accelerated if the fruit was continuously exposed to externally added ethylene for much longer periods. Analysis of the gas emerging from the container during ripening of the fruit showed that the fruit themselves were producing ethylene in amounts comparable to those observed with the fruit in air (Fig. 6). The quality of this fruit when fully ripe was excellent, as judged by appearance, taste and flavour.

This experiment would seem to indicate that provided the ripening process is initiated with ethylene, endogenous production of sizeable amounts of the gas can proceed under conditions of oxygen tension in which it is not produced in the unripe fruit. It is, of course, true that minute amounts of ethylene (~0·01 to 0·04 ppm) may

be detected as emanating from unripe fruit, but at levels so low that the ripening process is not initiated.

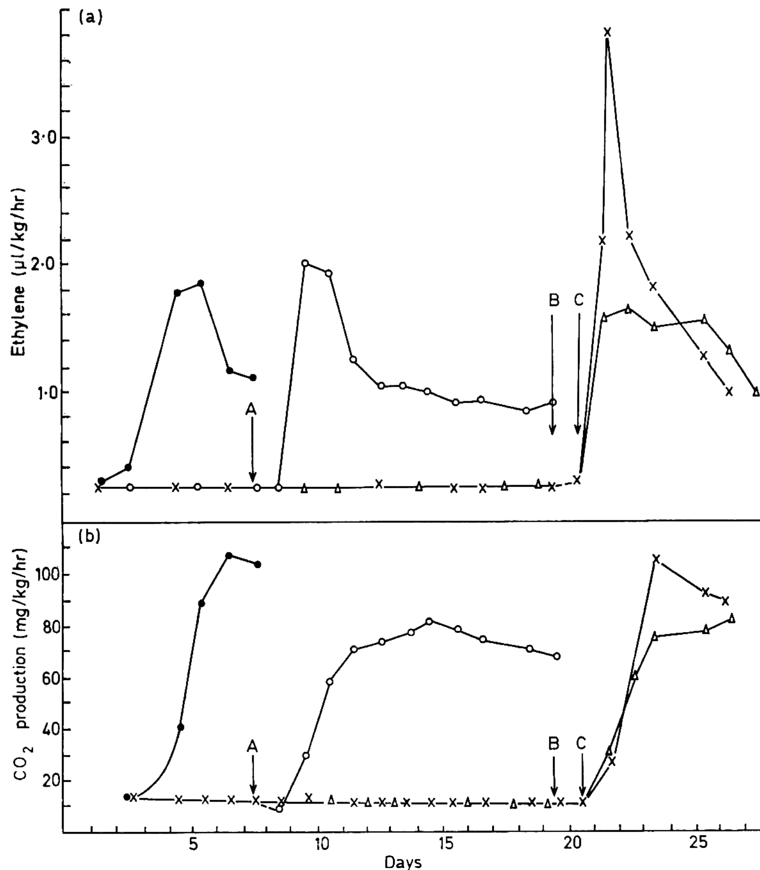

FIG. 6. Changes in ethylene and CO_2 production, induced by ethylene in low oxygen atmospheres. ●, In air throughout; ○, at A ethylene (2·7 ppm) added after 7 days in 6·5% oxygen; △, after 20 days at B ethylene (2·7 ppm) added for 24 hr, then returned at C to 6·5% oxygen; ×, after 20 days at B ethylene (2·7 ppm) added to 6·5% oxygen.

Discussion

The results described in this paper have emphasized the importance of the oxygen tension in the storage atmosphere for controlling the ripening of banana fruit. It has been shown that it is possible to prevent any synthesis of ethylene, above the minute amounts found emanating from unripe fruit, by storing the fruit in atmospheres of oxygen containing not more than 7·5% oxygen at the normal ripening temperature

(18°C). Under such conditions the oxygen tension (5–7·5%) is sufficient to maintain the basal metabolic rate of respiration, of the mature but unripe fruit, at a level which although lower than that in air (~50–60% of the rate in air), is adequate to prevent either injury or the accumulation of metabolites which would impart an objectionable taste or flavour to the fruit, as occurs if the fruit is held under anaerobic or semi-anaerobic conditions (~1·0% O_2). At the same time this treatment allows the fruit to ripen normally when returned to air, and to produce fruit of good eating quality. We have held fruit under such conditions for as long as 30 days without any apparent deleterious effect on the fruit when allowed to ripen.

The results of the experiments in which ethylene is incorporated into the storage atmosphere has also indicated that prevention of the synthesis of ethylene is the prime cause of the inability of the fruit to ripen. There is, however, an indication that the synthesis of ethylene, once this has been initiated by the application of exogenous ethylene, can proceed at lower oxygen levels than that required in the unripe fruit. Precisely why this is so is not at the moment clear, especially when the climacteric rise in respiration induced by exogenous ethylene might be expected to make greater demands on the available oxygen. It is, of course, possible that ethylene itself may arise from some product of the increased respiratory activity, or alternatively that initially ethylene might be synthesized from an entirely different source than that from which it is produced during the ripening syndrome. There is no concrete evidence that ethylene is produced from two different sources in plants, although this suggestion has been advanced in the work of Lieberman & Mapson (1964) on the basis of their finding that ethylene is produced under physiological conditions from both methionine and epoxidized linolenic acid, and their work with methionine stimulation of ethylene production from applied tissue (Lieberman *et al.*, 1966). A further possibility is that ethylene itself may trigger off oxidative reactions, the products of which may be converted to ethylene under conditions of low oxygen tension, in which case the system would behave in an autocatalytic manner.

Although the interpretation of these results may be a matter of conjecture, the conclusion seems inevitable that in order to prolong the storage life of bananas significantly with low oxygen this must be applied to the fruit before it begins to synthesize ethylene in any quantity. Once the synthesis has been initiated, atmospheres of low oxygen can only retard the ripening process by reducing the rate and extent of the subsequent climacteric rise in respiration. In such cases we have found that the ripening process is only retarded for a few days at 18°C.

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The heat resistance of anaerobic spores in aqueous suspension

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Summary. Aqueous spore suspensions of *Clostridium aerofoetidum*, *Cl. caloritolerans*, *Cl. histolyticum*, *Cl. sordellii*, *Cl. sporogenes* and *Cl. subterminale* were heated at temperatures within the range 70–95°C. 80°C for 1 hr was without effect on *Cl. aerofoetidum*, but reduced *Cl. caloritolerans*, *Cl. histolyticum* and *Cl. sporogenes* to about 25% of the initial count, and *Cl. sordellii* and *Cl. subterminale* to about 0·01%. No significant heat-activation was detected. Not all survivor curves were exponential.

Introduction

Most heat resistance studies on the mesophilic anaerobic spore former have been made on *Cl. botulinum* (e.g. Sugiyama, 1951) or a strain of *Cl. sporogenes* known as PA 3679 (e.g. Stumbo, Murphy & Cochran, 1950; Esselen & Pflug, 1956) with occasional studies on *Cl. welchii* (e.g. Barnes, Despaul & Ingram, 1963; Hobbs *et al.*, 1953). There is a marked lack of information on the thermal resistance of other clostridia.

The purpose of this study was to determine, under standard conditions, the heat resistance of spores of several clostridia where data are not already available.

Materials and methods

Organisms and preparation of spore suspensions

The organisms used were: *Cl. aerofoetidum* (NCTC 505), *Cl. caloritolerans* (NCIB 9360), *Cl. histolyticum* (NCIB 503), *Cl. sordellii* (NCIB 2914), *Cl. sporogenes* (NCTC 532) and *Cl. subterminale* (NCIB 9384).

Spores were harvested after incubation at 37°C from the media indicated, incubation times being given in parentheses; *Cl. aerofoetidum*, cooked meat medium (CMM)

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(10 days); *Cl. caloritolerans*, blood agar (2 days); *Cl. histolyticum*, CMM (10 days); *Cl. sordellii*, TPG (Roberts, 1965) with added ammonium sulphate (1% w/v) and yeast extract (0·2% w/v) (2 days); *Cl. sporogenes*, CMM (3 days); *Cl. subterminale*, blood agar (2 days).

Spores were recovered from the liquid media by centrifuging at 3500 rev/min for 15 min, washed once with distilled water and suspended in distilled water. Those spores on solid media were washed off with distilled water, spun down, and resuspended in distilled water. All spore suspensions were stored at 1°C. No heat shock was used during the preparation of the suspensions. Sporulation was, in every case, so heavy that vegetative cells were present only in small numbers, and were not therefore considered to be a problem. The aeration during vigorous shaking of the centrifuged pellet to resuspend spores was assumed to be sufficient to kill the few vegetative cells present.

Determination of heat resistance

One-tenth millilitre samples of aqueous spore suspension from a 1 ml tuberculin syringe (Everett Surgical Instruments, Thornton Heath, Surrey) were distributed in 0·5 ml freeze-drying ampoules (BSS 795, 1961, type L) and were sealed under air. Ampoules were heated within the range 70–95°C by total immersion in a thermostatically controlled water bath (Grant Instruments, Cambridge). After heating, ampoules were cooled by immersion in ice-water.

Viable counts of surviving spores were made in Reinforced Clostridial Agar (RCA) (Oxo Ltd, London, S.E.1), as described by Roberts, Ditchett & Ingram (1965). At low levels of survival the heated spore suspension was washed directly into RCA without prior dilution. Results were calculated using counts at two or more dilutions with weighting for dilution as described by Farmiloe *et al.* (1954). Survival curves of log percentage survivors against time were constructed, using the mean count from two to three unheated ampoules as 100%.

Results

An estimate of the viability of each of the stock spore suspensions was made by comparing the mean viable count with a total spore count using a Thoma slide (depth 0·02 mm), two workers counting at least 400 spores each. Mean viable counts of the stock spore suspensions are listed below with the percentage viability: *Cl. aerofoetidum*, $1{\cdot}36 \times 10^8$ spores/ml (s/ml), 50·4%, *Cl. caloritolerans*, $2{\cdot}29 \times 10^8$ s/ml, 100%; *Cl. histolyticum*, $3{\cdot}14 \times 10^8$ s/ml, 62·3%; *Cl. sordellii*, $8{\cdot}70 \times 10^7$ s/ml, 41·3%; *Cl. sporogenes*, $7{\cdot}70 \times 10^7$ s/ml, 33·0%; *Cl. subterminale*, $2{\cdot}23 \times 10^8$ s/ml, 31·5%.

Survival curves for *Cl. aerofoetidum*, *Cl. histolyticum* and *Cl. sporogenes* were linear on a plot of log percentage survivors against time of heating.

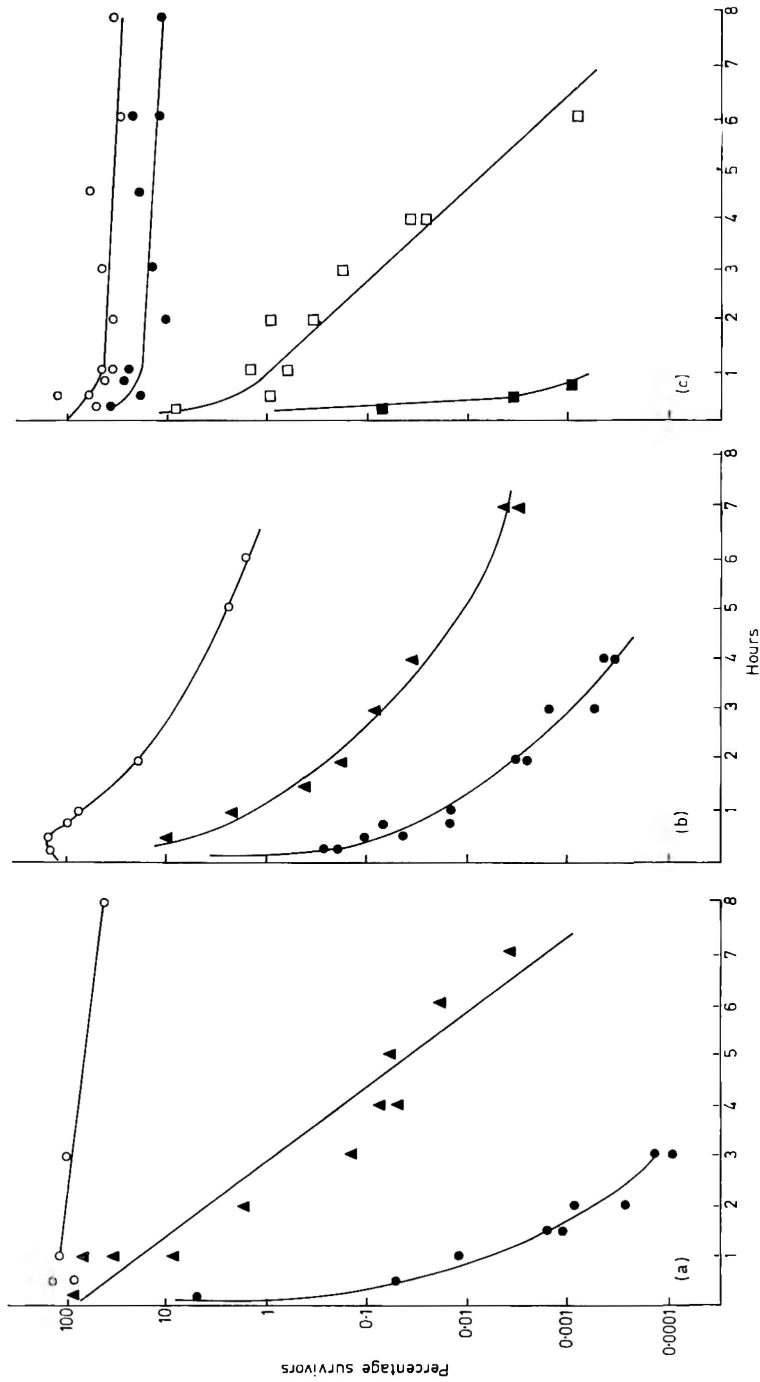

FIG. 1. The heat resistance of spores of *Cl. subterminale* (a), *Cl. sordellii* (b) and *Cl. caloritolerans* (c) in aqueous suspension. ○, Heated at 70°C; △, heated at 75°C; ●, heated at 80°C; □, heated at 90°C; ■, heated at 95°C.

At 70°C, *Cl. subterminale* (Fig. 1a) was inactivated slowly and with increasing temperature gave survival curves becoming more markedly concave upwards. All three curves for *Cl. sordellii* (Fig. 1b) were concave upwards. At 70 and 80°C *Cl. caloritolerans* (Fig. 1c) fell sharply to 40% and 15% survival respectively before appearing to resist those temperatures. No further inactivation occurred after heating at 70 and 80°C for 8 hr. At 90°C the sharp initial fall in count continued to 1% after about 1 hr, after which the slope decreased and continued linearly to 0·001% survival after 6 hr. 95°C caused a rapid fall in count, no survivors being detected after 45 min.

There was little evidence of increased counts due to heat activation. *Cl. sordellii* and *Cl. aerofoetidum* gave slightly higher counts after 30 min and 1 hr at 70°C than in unheated samples, as did *Cl. subterminale* after 1 hr at 70°C and 30 min at 75°C.

Storage of spore suspensions at 1°C for 3 months did not produce a detectable change in heat resistance.

The data for *Cl. aerofoetidum*, *Cl. histolyticum* and *Cl. sporogenes* yielded curves of log percentage survivors against time of heating which gave correlation coefficients, obtained by the method of least squares, greater than tabulated values at $P = 0{\cdot}05$ for the appropriate degrees of freedom. These curves are therefore exponential, and decimal reduction (D) values calculated from the data are summarized in Table 1. Calculated D values for 250°F (121·1°C) and calculated z values are also included in Table 1.

TABLE 1. Heat resistance of anaerobic spores in aqueous suspension

	D (min)						
	70°C	80°C	85°C	90°C	95°C	121°C*	z (°C)*
Cl. aerofoetidum	—	4205	—	139·1	27·2	0·0041	6·84
Cl. histolyticum	1097	243·1	40·5	11·5	—	0·011	10·00
Cl. sporogenes	1170	245·8	—	34·2	—	0·15	13·04

* Calculated from data in columns 1–5.

Survival curves for *Cl. caloritolerans*, *Cl. sordellii* and *Cl. subterminale* to the eye deviated from linearity, and were therefore drawn as curves. At 70, 80 and 90°C curves for *Cl. caloritolerans* all showed an initial rapid fall in count, but not to a constant level. Subsequent to this, the fall in count was linear with increasing time. The results were therefore subjected to analysis by sums of squares: (a) using all results, i.e. including the initial non-linear portions of the curves, and (b) using results only after the initial rapid fall was over and the linear portion of the curve had been reached.

Even if all points for *Cl. caloritolerans* were used in the calculation of correlation coefficients at 70, 80 and 90°C in each case the calculated values were greater than those tabulated at $P = 0{\cdot}05$. At 95°C the calculated value was less than the tabulated, but there was only 1 degree of freedom which results in a tabulated value of 0·9969. Omitting results up to 1 hr heating did not greatly increase correlation coefficients. Whether results for heating times up to 1 hr were included or omitted, the calculated D value for 80°C was greater than 70°C. This anomaly is doubtless due in part to neither temperature being strictly lethal since exposure for 6 hr at either 70 or 80°C resulted in more than 10% survival. As sporulation had been observed to be virtually 100%, an explanation implicating vegetative cells cannot be entertained. Such an explanation would in any case have resulted in a rapid fall in viability, due to death of vegetative cells, to a constant level of survival, and this was not observed. An initial rapid fall in count to a level which decreases with increasing temperature is best interpreted by the spore population possessing two different resistances. Similar observations have been reported by El-Bisi & Ordal (1956) using *Bacillus coagulans*.

Correlation coefficients for *Cl. subterminale* also indicated exponential relationships, although at 80°C the curve was apparently concave upwards.

Survival curves for *Cl. sordellii* were, to the eye, concave upwards, a small initial rise in count being evident at 70°C. All correlation coefficients were greater than tabulated values at $P = 0{\cdot}05$, and the data could therefore be represented by a straight line, although a curve appears more acceptable. The heat resistance of the spores of the six species examined is rather lower than anticipated, and it seemed possible that spores produced in the media used in this study were especially sensitive to heating. Further spore suspensions of three of the six, *Cl. aerofoetidum*, *Cl. sporogenes*, and *Cl. histolyticum*, were therefore obtained from the following media:

(i) Trypticase (BBL) 5%; Bacto-peptone, 0·5%; ammonium sulphate, 1%; and yeast extract ('Oxoid'), 0·2% (TPAY base).

(ii) TPAY base with added mineral salts (TPAY Min).

(iii) TPAY base with 0·4% glucose, and 0·2% sodium thioglycollate (i.e. the same medium as used originally for *Cl. sordellii*) (TPAY–G/T).

(iv) TPAY base with mineral salts, glucose and sodium thioglycollate (TPAY Min–G/T).

The heat resistance of spores of each organism from each medium was determined, in the manner previously described, at 85, 90 and 95°C. Results are summarized as D values, and z values in Table 2, where a comparison is also made with the resistance of spores from CMM, spores of each of these three organisms having been obtained previously from CMM. Our fears that spores obtained from the media initially used were unusually sensitive to heat were clearly unjustified. Spores of *Cl. aerofoetidum* from CMM were more resistant than those from any of the four TPAY media. Those spores from TPAY–G/T were most sensitive. Spores of *Cl. sporogenes* from CMM

TABLE 2. Heat resistance of anaerobic spores from different sporulation media

		D (min)				
		TPAY base*	TPAY Min*	TPAY–G/T*	TPAY Min–G/T*	CMM*
Cl. aerofoetidum	80°C	—	—	—	—	4205
	85°C	285	123	92	248	—
	90°C	75	36	13	60	139
	95°C	6	6	1·5	6	27·2
	z (°C)	6·0	7·8	5·6	6·2	6·9
Cl. sporogenes	70°C	—	—	—	—	1170
	80°C	—	—	—	—	246
	85°C	205	291	39	48	—
	90°C	90	69	9	14	34·2
	95°C	12	13·5	3	7	—
	z (°C)	8·4	7·6	9·1	12·1	13·0
Cl. histolyticum	70°C	—	—	—	—	1097
	80°C	—	—	—	—	243
	85°C	132	*ca* 375	27	222	40·5
	90°C	33	48	—	63	11·5
	95°C	3	6	2	6	—
	z (°C)	5·9	5·6	9·0	5·7	10·0

* For media, see text.

were more resistant to heating at 90°C than spores from TPAY–G/T or TPAY Min–G/T but not as resistant as those from TPAY base or TPAY Min. The presence of glucose and sodium thioglycollate in the sporulation medium appeared to render spores appreciably more sensitive to heat. Spores of *Cl. histolyticum* from CMM were about the same resistance as those from TPAY base, but less resistant than those from TPAY Min and TPAY Min–G/T. Spores from TPAY–G/T were again most sensitive. It was therefore established that our initial spore crops were of representative resistance. However, it was also apparent that the effects of certain constituents of sporulation media play an important role in determining the resistance of spores, since spores produced in TPAY–G/T were in each case more sensitive to heat than spores produced in any of the other media. z values also tended to be appreciably lower than the generally accepted 18°F (10°C) quoted for *Cl. sporogenes*, and also varied with spore crops from different media. The data for two suspensions of *Cl. sporogenes* gave z values greater than 10°C; CMM (13°C) and TPAY Min–G/T (12·1°C). There was no obvious correlation of z value and sporulation medium.

Attempts were also made to obtain spores by inoculating 1 ml of 24 hr CMM culture into an aqueous extract of fresh beef. Only *Cl. aerofoetidum* grew to any extent, and produced spores. The D value at 85°C was 200 min and at 90°C was 30 min, both of which fall within the range of values obtained from the different sporulation media. The z value (from only two D values) of 6°C is also of the same order as that of other spore suspensions. Our observations appear, therefore, to stand comparison with spores produced in more natural surroundings, although the reasons for failing to obtain growth and sporulation of the other clostridia in the meat extract would bear further scrutiny.

Discussion

Several points emerge from this preliminary study of heat resistance. It was anticipated that information might be produced regarding heat-shock, relative heat resistances and the shape of survival curves.

As viable counts were always in excess of 30% of the total spore count, the greatest expectable increase in count after heat activation was of the order of $\times 3$. This factor is considerably less than might have been anticipated from studies in this laboratory on *Cl. botulinum* type E (Roberts, unpublished data), when viability in slide culture varied in seven different strains from 0·8 to 18·6%, or from the studies of Barnes *et al.* (1963) on a food poisoning strain of *Cl. welchii* when viability was less than 10%. Similarly Gibbs (1964), studying germination of *Cl. bifermentans* spores, reported a six- to seven-fold increase after optimal heat-shock. The slight increases in count detected with *Cl. sordellii*, *Cl. aerofoetidum* and *Cl. subterminale* did not exceed $\times 1{\cdot}5$ and can hardly be regarded as significant. The observation of heat activation using macro-colony formation as a criterion may be, in many instances, largely a function of the counting medium, and the medium used in this study seems, from general experiences, particularly suited to the growth of clostridia. That water is an unsuitable suspending medium for the demonstration of heat activation is possible, but hardly likely, Busta & Ordal (1964a, b) having demonstrated that heat activation of *Bacillus subtilis* spores occurs in aqueous suspension, is largely independent of pH in the range 5–8, and is unaffected by the presence of certain sugars, sodium chloride and sodium phosphate.

Our inability to detect heat activation of the spores studied has led to further studies on this aspect of resistance, which will be the subject of a separate communication.

From these results, it is evident that the almost universally accepted heat-shock of the order 10–15 min at 80°C would have made isolation of *Cl. subterminale* and *Cl. sordellii* from contaminated material most unlikely, since the viability would have been reduced by such treatment by a factor of $\times 10^2$ to 10^3. The count of *Cl. histolyticum* was also reduced by 80°C for 15 min, to about 50% of the initial level, but *Cl. sporogenes* and *Cl. aerofoetidum* were virtually unaffected.

Coupled with the low heat resistance of spores of *Cl. botulinum* type E (Roberts

& Ingram, 1965) these results suggest that relatively heat sensitive spores might be less rare than hitherto supposed, and that heat resistance is not necessarily a criterion which should be applied to all bacterial spores. These results show clearly the desirability of a lower heat treatment than 80°C for 15 min in attempts to isolate clostridia, and indicate that heating at 60 or 65°C would be more suitable from this point of view. While it could be argued that reducing the heat treatment to 60–65°C for 1 hr would cause problems with the inactivation of the more heat tolerant vegetative cells, such as micrococci and streptococci, 60°C for 50 min has already been used successfully (Greenberg, Bladel & Zinglemann, 1966) in a survey for clostridia.

Spores of clostridia are generally regarded as 'heat resistant', a point of view based, in the main, on studies on *Cl. botulinum* types A and B, and *Cl. sporogenes* PA3679. The relative importance of these species in the canning industry stimulated studies on factors affecting their heat resistance, but depressed studies on other, perhaps less important, clostridial spores. It is now clear that extrapolation of such data on heat resistance to include by implication all clostridial spores would be most unwise. Detailed studies on the heat resistance of many other clostridial spores, notably food-poisoning strains of *Cl. welchii*, are obviously desirable.

While there are abundant data suggesting that the death of both vegetative cells and spores follows an exponential course, i.e. is linear on a plot of log percentage survivors against time of treatment, evidence is plentiful that this may not always be the case, although few authors have offered any statistical support for the lack of linear relationship.

Curves which are concave downwards, i.e. indicative of an accelerating rate of inactivation, have been reported for *Cl. sporogenes*, *B. brevis* (Anand, 1961), *B. stearothermophilus* (Anand, 1961; Humphrey & Nickerson, 1961) and *B. globigii* (Davis & Williams, 1948). Thermal death rate curves, concave upwards have been reported for *Cl. botulinum* type A and B and *Cl. sporogenes* (PA3679) (Reed, Bohrer & Cameron, 1951), *B. coagulans* (Frank & Campbell, 1957) and *Streptococcus faecalis* (White, 1953). In interpreting such curves certain care must be exercised, since Roberts & Ingram (1965) showed clearly that thermal death rate curves for spores of *Cl. botulinum* type E are grossly affected by the method of heating. When open tubes were used, curves with a resistant 'tail' were obtained, but if the spores were heated by total immersion of sealed ampoules, 'tails' were no longer evident. In that instance the 'tail' was clearly an artifact. The present study employed only sealed ampoules, and such an artifact may be fairly confidently eliminated.

Alderton, Thompson & Snell (1964) were able to increase the heat resistance of spores of *B. megaterium* by holding spores at sub-lethal temperatures. Survivor curves which are concave upwards may be interpreted in terms of a population resistance which increases during the heat treatment, and although no direct evidence is presented regarding this point in the present study, the possibility of it occurring should not be overlooked.

Acknowledgments

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Some applications of differential thermal analysis to oils and fats

K. G. BERGER AND E. E. AKEHURST

Summary. The DTA (differential thermal analysis) cooling curves of fats are simpler than the melting curves because complicated effects due to polymorphism are not obtained. The cooling curves of some synthetic glycerides are presented. Fractions of defined glyceride composition are obtained from palm oil, cotton-seed oil and soya bean oil and examined by DTA. A number of other oils and hydrogenated oils are examined and the DTA curves interpreted in terms of their glyceride composition.

Introduction

Most of the published work on differential thermal analysis (DTA) has been on the heating cycle, but the interpretation of DTA heating curves of fats is difficult because every fat is a complex mixture of glycerides, each of which may exhibit polymorphism. We have found that the cooling curves are reproducible and simpler in form than heating curves.

The present paper gives DTA cooling curves of some synthetic glycerides followed by curves for vegetable oils and for fractions obtained from the oils by thin layer chromatography on silica gel–silver nitrate. It has been possible to interpret many of the curves in terms of the known glyceride compositions of the oils.

Experimental

Apparatus and method

The apparatus is shown in Fig. 1. The sample (about 40 mg) is placed in a glass tube inside the cylindrical cell S and the reference substance, usually ballotini 0·1 mm diameter, is placed in a glass tube in cell R. When a larger amount (about 300 mg) of sample is available it may be placed directly in the cell.

Cells S and R fit into cylindrical cavities in an aluminium block, which can be heated electrically at various rates or cooled by being placed in a vacuum flask containing liquid nitrogen. The vacuum flask is lined with thin aluminium sheet. The nickel–chromium/nickel–aluminium thermocouples are connected in opposition to

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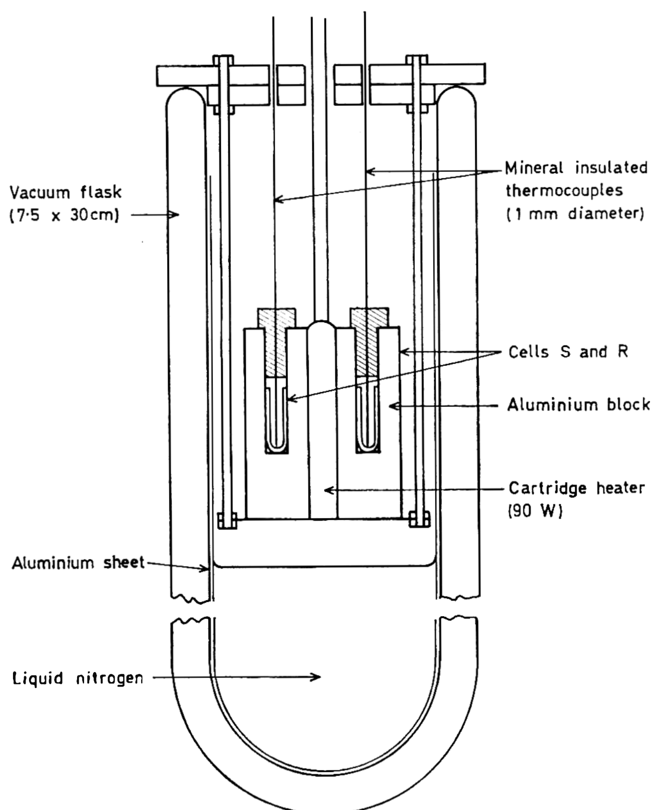

FIG. 1. Diagram of DTA cell and cooling arrangement.

measure the differential temperature. The sample thermocouple is also used to record the actual temperature.

The e.m.f.s corresponding to the temperature and the differential temperature are recorded alternately every 3 sec, using a Kipp Micrograph BD1 recorder.

Calibration of the thermocouples is carried out at liquid nitrogen temperature and at the melting points of mercury and water.

The system used gives reproducible but non-linear cooling and heating rates. The average cooling rate used in this work was about 6 degC/min.

Thin layer chromatography

Glass plates were coated with Silica Gel G (thickness 600 μ) containing 5% silver nitrate. The plates were dried in air and activated for $\frac{1}{2}$ hr at 110°C immediately before use. Forty milligrams of sample was applied in chloroform solution and developed twice with chloroform. The bands were visualized by spraying with 2,4-dichloro-fluorescein, scraped off, and the material in the band recovered. Where necessary,

more than one plate was used to obtain sufficient material for DTA. In some cases it was necessary to combine material from adjacent bands. The amount of material in each fraction was determined from the concentration in the chloroform solution measured by infrared spectrophotometry at 1742 cm^{-1}. The fractions were identified by reference to the literature, especially Gunstone & Padley (1965), and by calculation from the composition obtained by gas chromatography. In describing the glyceride types the convention used by Gunstone is adopted, i.e. 210 is a glyceride containing acyl radicals with 2, 1 and 0 double bonds. The only difference in our separations compared with Gunstone's was in the position of 111 glycerides which in our case appear between 200 and 210 glycerides. The solvents used by Gunstone were ether and benzene whereas chloroform was used in our work.

The position of the glycerides obtained was:

000, 100, 110, 200, 111, 210, 211, 221, 222.

Gas chromatography

Methyl esters were prepared by methanolysis using potassium methoxide. Gas chromatographic analysis was carried out at 200°C on a column 150 cm long, packed with acid-washed Celite coated with 15% polyethylene glycol adipate. A flame ionization detector was used.

Results

The DTA cooling curves of four synthetic glycerides of various degrees of unsaturation are shown in Fig. 2.

A fully saturated glyceride, myristodipalmitin, gives a single peak at about 33°C,

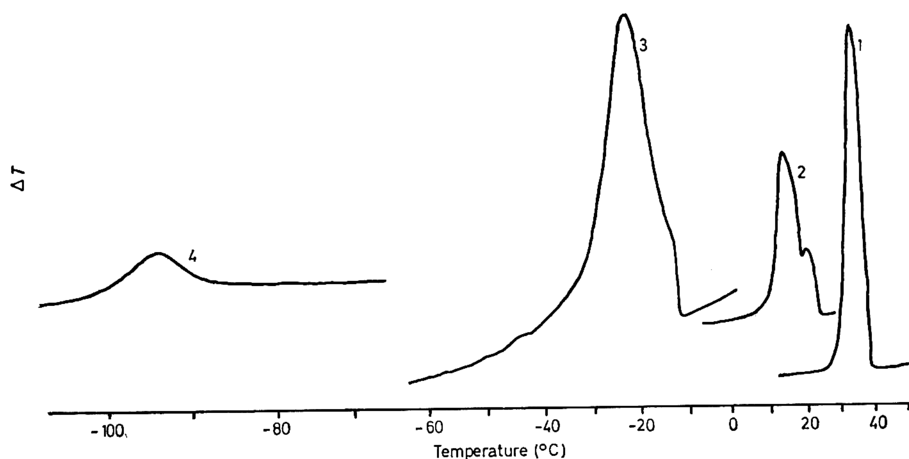

FIG. 2. Cooling curves of synthetic glycerides. 1, Myristodipalmitin; 2, oleodipalmitin; 3, palmitodiolein; 4, trilinolein.

whereas trilinolein gives a peak between −90 and −100°C. The partially unsaturated glycerides, oleodipalmitin and palmitodiolein, give peaks at intermediate temperatures. The small peak on the shoulder in Curve 2 is probably due to some saturated glyceride present. Gas chromatographic analysis indicated the presence of about 15% tripalmitin in the preparation.

Table 1. Results from thin layer chromatography fractionation

Fraction	Palm oil			Cottonseed oil			Groundnut oil		
		Composition			Composition			Composition	
	Glycerides	Present	Published	Glycerides	Present	Published	Glycerides	Present	Published
1	000	4·2	8·5	000? } 100	6·2	6	100	6·2	5
2	100	41·3	37·9	110 } 200	21·7	20	110	20·0	23
3	110	25·6	22·7	111 } 210	19·7	22	111	25·8	26
							200	3·3	4
4	111	5·8	3·2	211 } 220	28·9	32	210	14·0	14
	200 } 210	17·4	18·9						
5	220 } — } 211	5·7	6·7	221 } 222	23·5	20	211 } 220 } 221	30·7	23 / — / 5

Table 1 gives the results of thin layer chromatography (TLC) fractionations of palm oil, cottonseed oil and groundnut oil. The proportion of each fraction as determined by infrared measurement is compared with published data (Jurriens & Kroesen, 1965; Gunstone & Qureshi, 1965). The agreement is good with the exception of the saturated glyceride content of palm oil. Determinations of fully saturated glycerides of palm oil by chemical methods have given results of 5–6%.

Fig. 3 gives the DTA curves of palm oil and its fractions. The saturated glyceride fraction starts to crystallize at 43°C, whereas in the whole oil crystallization is delayed until 25°C. Interaction of this sort is observed in most of the oils examined.

The material for Curve 4 was obtained by combining bands 4, 5 and 6 from the thin layer chromatograms and would therefore be expected to contain 200, 111 and 210 glycerides. The symmetrical peak at −40 to −50°C is due mainly to triolein, whereas the glycerides containing one or two saturated acids crystallize together between 5 and −20°C. If the areas under these two peaks are compared the results indicate some 25% of 111 in this fraction. This is in good agreement with the measured proportion

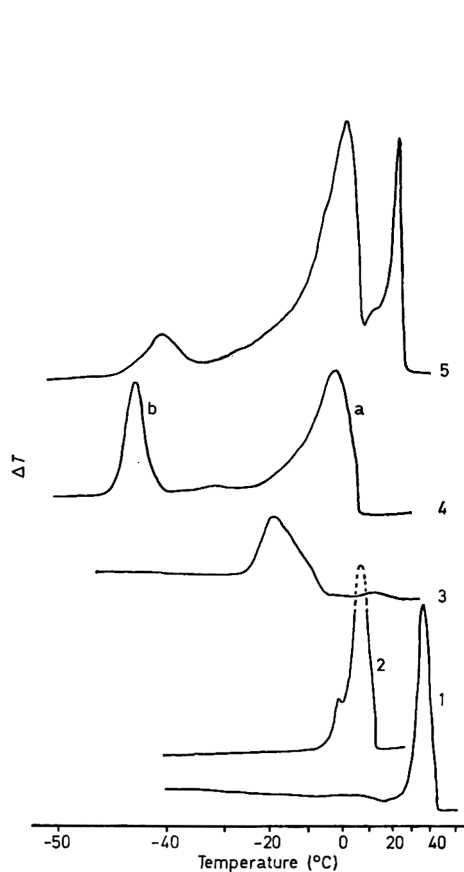

FIG. 3

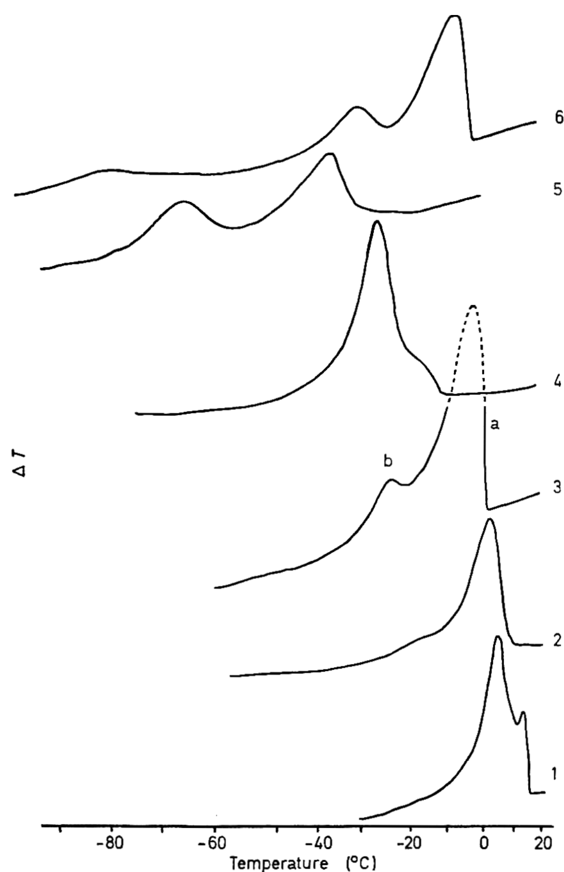

FIG. 4

FIG. 3. Cooling curves of palm oil and its fractions from TLC separation. 1, 000 glycerides; 2, 100 glycerides; 3, 110 glycerides; 4, Peak (a) 210 and 200 glycerides, Peak (b) 111 glycerides; 5, whole oil.

FIG. 4. Cooling curves of cotton-seed oil and its fractions from TLC separation. 1, 100 glycerides; 2, 110 and 200 glycerides; 3, Peak (a) 210 glycerides, Peak (b) 111 glycerides; 4, 211 and 220 glycerides; 5, highly unsaturated glycerides; 6, whole oil.

(see Table 1). A more unsaturated fraction was also obtained, but was insufficient for DTA examination.

Curves for cotton-seed oil and its fractions are shown in Fig. 4. In Curve 1 the main peak for the 100 glycerides is at 10 to −10°C. The smaller peak at 15°C is probably due to a small amount of saturated glyceride. The 110 and 200 glycerides crystallize in a single peak at 0°C (Curve 2). The fatty acid analysis indicated that this fraction contained about 60% 200 glycerides and 40% 110 glycerides.

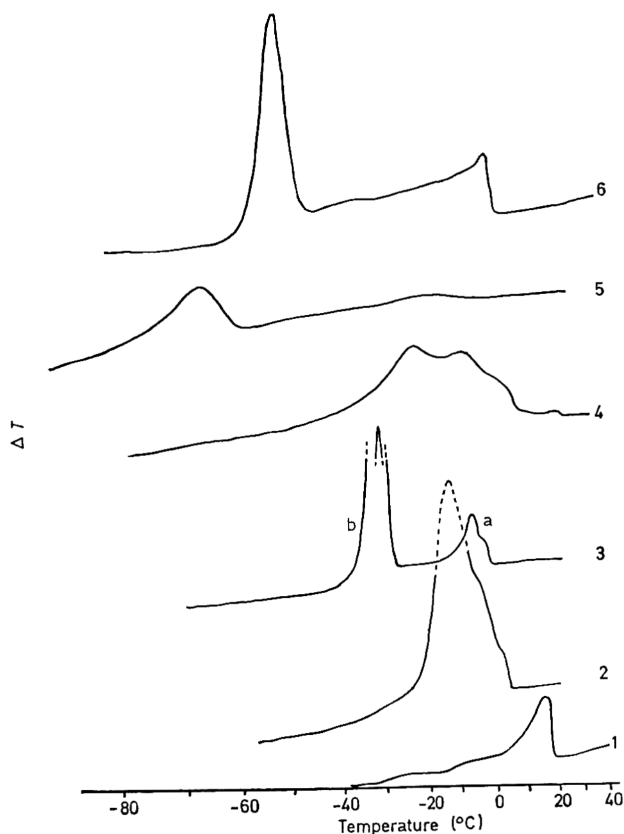

Fig. 5. Cooling curves of groundnut oil and its fraction from TLC separation. 1, 100 glycerides; 2, 110 glycerides; 3, Peak (a) 200 glycerides, Peak (b) 111 glycerides; 4, 210 glycerides; 5, highly unsaturated glycerides; 6, whole oil.

The main peak at −4°C of Curve 3 forms about 95% of the area and is attributed to 210 glycerides. Analysis indicated the presence of more than 90% 210 glycerides in this fraction.

Curves for groundnut oil and its fractions are shown in Fig. 5. Curves 1 and 2 gave single peaks at 17 and −13°C respectively, and the fatty acid analyses are consistent with their identification as 100 and 110 glycerides respectively.

Curve 3 shows peaks at −8 and −30°C, attributable to 200 and 111 glycerides respectively. The relative areas under these peaks indicate the presence of 86% 111 glycerides; this is in good agreement with the finding of 84% by gas chromatographic analysis.

Fig. 6 summarizes in diagrammatic form the crystallizing ranges for the various

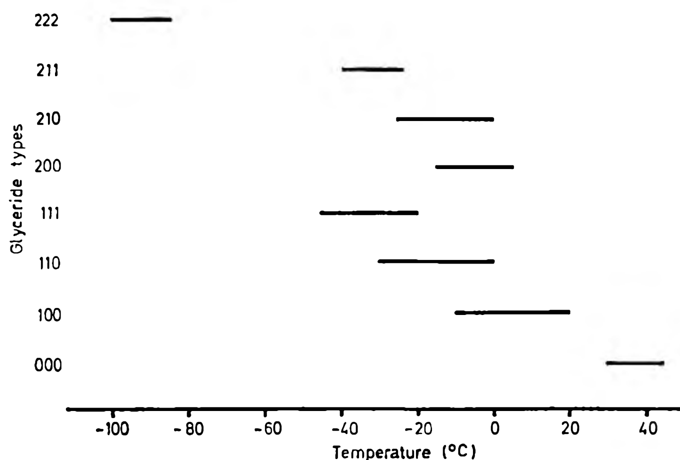

FIG. 6. Crystallizing ranges of glyceride types.

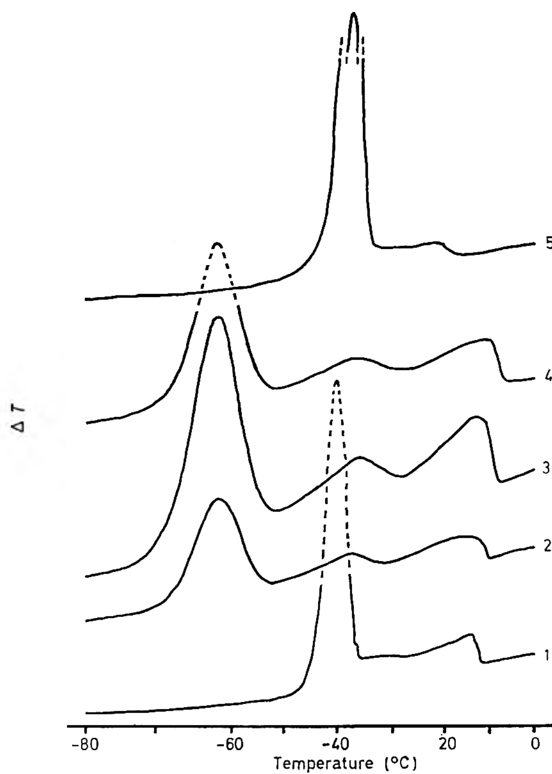

FIG. 7. Cooling curves of vegetable oils. 1, Olive oil; 2, maize oil; 3, sunflower seed oil; 4, soya bean oil; 5, rapeseed oil.

glyceride types observed in the foregoing experiments. Of particular interest is the marked effect of introducing one saturated acid into a tri-unsaturated glyceride. The temperature of crystallization is raised by about 20°C. It should be emphasized that the precise position of the peaks is somewhat dependent on the cooling rate. A faster rate results in the formation of the peaks at a somewhat lower temperature, but their relative positions are unchanged.

DTA cooling curves of several vegetable oils are shown in Fig. 7.

These oils contain 50–80% of U_3 glycerides, the remainder being S_2U and SU_2 glycerides. The low temperature peak in each curve is mainly due to the U_3 glycerides but the other two peaks cannot be quantitatively related to the S_2U and SU_2 contents. There is interaction between the many individual glycerides present. The temperature at which the main U_3 peak crystallizes is sharply dependent on the type of unsaturated acids present. In the case of rapeseed oil containing mainly erucic acid, and olive oil,

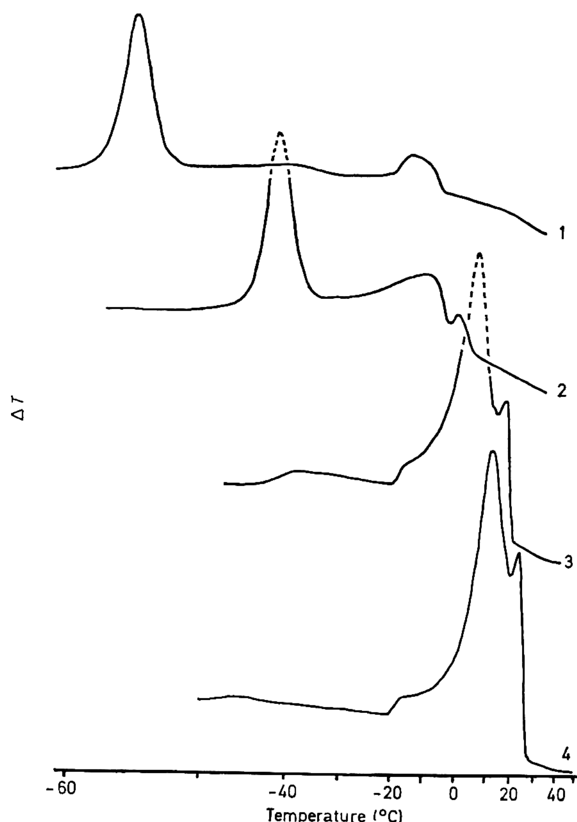

Fig. 8. Cooling curves of hydrogenated soya bean oils. 1, Soya bean oil; 2, hydrogenated soya bean oil iodine value 110; 3, hydrogenated soya bean oil melting point 32–34°C; 4, hydrogenated soya bean oil melting point 40–42°C.

containing mainly oleic acid, it is between −30 and −40°C. In the other oils all rich in linoleic acid, the U_3 peak is at about −60°C.

Fig. 8 shows curves for soya bean oil and three commercially hydrogenated soya bean oils:

(1) Soya bean oil.
(2) Soya bean oil hydrogenated to an iodine number of 110.
(3) Soya bean oil hydrogenated to melting point 32–34°C.
(4) Soya bean oil hydrogenated to melting point 40–42°C.

Product 2 had been prepared so as to preserve its liquid character, but with the particular object of reducing the linolenic acid content and thus enhancing its flavour stability. The main peak was at −35 to −50°C, but it may be noted that a small amount of material was solid at 0°C. Curves 3 and 4 show the progressive formation of more solid glycerides.

Fig. 9 shows curves for a commercial hardened palm oil, melting point 49–51°C,

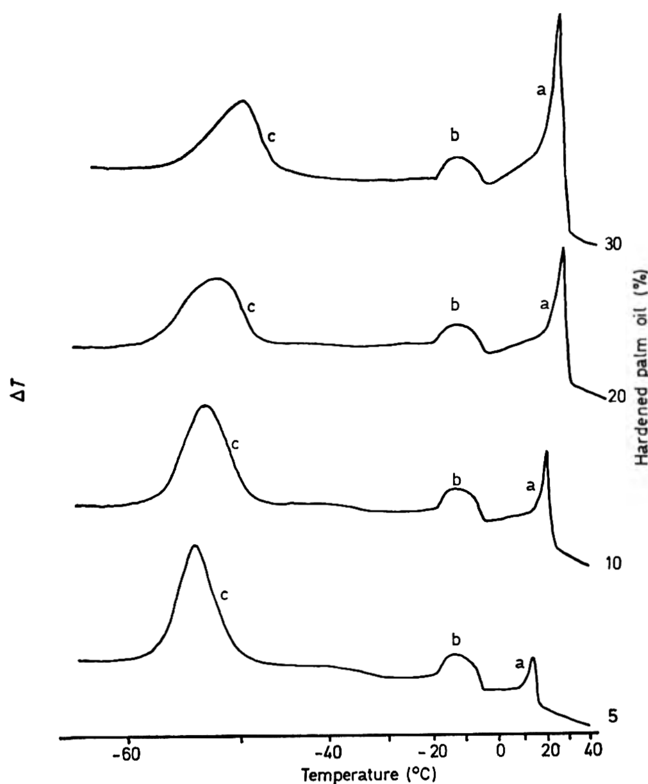

FIG. 9. Cooling curves of mixtures of soya bean oil and hardened palm oil melting point 49–51°C.

in mixtures with soya bean oil in various proportions. In the mixture the first peak (a) is contributed entirely by the hardened palm oil whereas the third peak (c) is contributed by the soya bean oil. The middle peak (b) is due to material from both oils. The area under Peak (a) is directly related to the proportion of hardened oil,

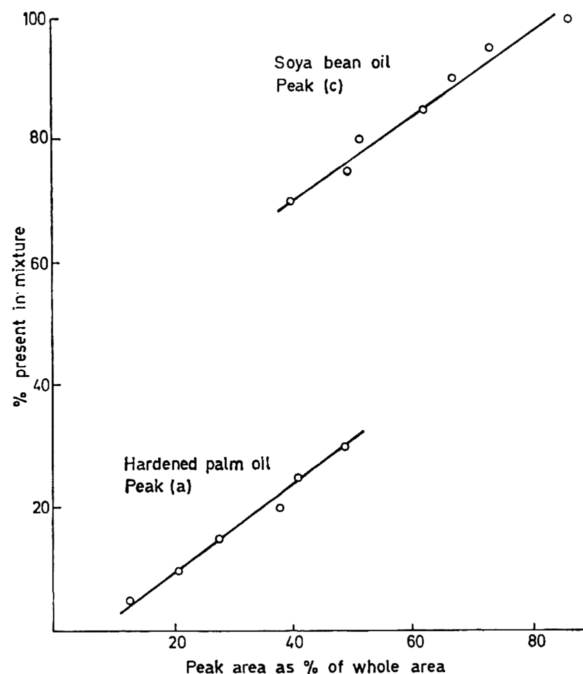

FIG. 10. Soya bean oil–hardened palm oil melting point 49–51°C mixtures. Relationship of area of peaks to amount present in mixture.

whereas the area under Peak (c) is proportional to the amount of soya bean oil. These relationships are shown in Fig. 10. A similar relationship was obtained using hardened palm oil, melting point 40–42°C, in mixtures with soya bean oil.

It is intended to investigate the quantitative aspects of DTA cooling curves further.

Discussion and conclusions

The results presented indicate that DTA cooling curves are a useful analytical tool. General information is obtained about the glyceride types present in a fat or fat mixture, and the technique promises to offer a rapid 'finger print' method useful for routine control purposes. Quite small proportions of highly unsaturated or saturated constituents can be identified. Examples have been given in which areas under the DTA curve can be quantitatively interpreted. The extent to which this is of general application is under investigation.

Acknowledgments

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An objective method for the measurement of starch gelatinization temperatures

G. K. BERRY AND G. W. WHITE

Summary. An objective method has been devised for measuring the gelatinization temperature of granular starch under the microscope. A hot stage is used to heat the specimen, and the progress of gelatinization is followed by microphotometry of the birefringence between crossed polars. The method has been used to study the gelatinization of wheat starch in the presence of sugars, proteins and lipids, in solution or suspension.

Introduction

The gelatinization temperature of starches in water or various solutions may be measured under the microscope if a hot stage is employed. Some workers define the gelatinization temperature as that at which 50% of the granules have lost their birefringence, others as that at which all the granules have lost their birefringence. Observations in these Laboratories, however, have shown that the visual judgement of gelatinization temperature by either criterion varies greatly from one observer to another. In order to overcome these subjective uncertainties, a new photoelectric method has been developed.

Experimental

Apparatus

The basic elements of the apparatus were a Spencer microscope, a Kofler hot stage, a Mullard ORP 12 cadmium sulphide photocell and a Kipp Micrograph BD1 pen recorder (see Fig. 1). Illumination was provided by a high-power lamp, run from a 12 V accumulator for steadiness of output, and the concave mirror was used in place of a substage condenser. The hot stage was located in the stage clip holes on the microscope stage and the specimen, on a 1 × 1½ in. slide, was observed with a long-working distance 16 mm objective. In place of the usual microscope eyepiece, a Zeiss beam-splitter, with horizontal-viewing eyepiece, was used as shown in Fig. 1.

Polaroid filters were mounted above the field lens of the vertical eyepiece and in the substage filter-holder (not shown) to act as analyser and polarizer respectively. The

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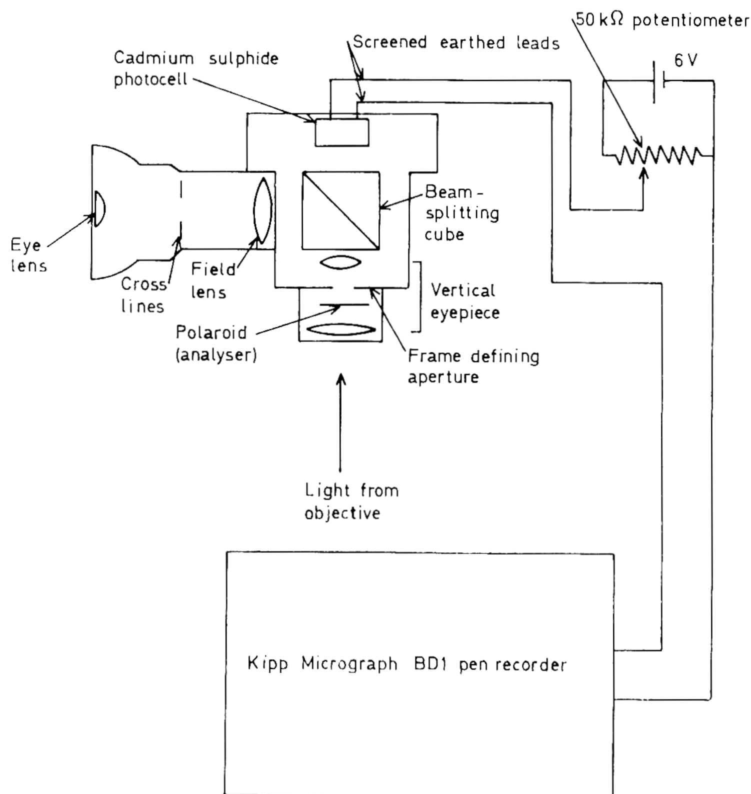

FIG. 1. Photometric eyepiece and external circuit for studying starch gelatinization.

cadmium sulphide photocell, mounted just above the beam splitter, was fed from a 6 V dry battery through a potentiometer, the current flowing into the recorder being controlled by the resistance of the photocell, which decreases as the illumination falling on it increases. The arrangement was used with crossed polars so that the disappearance of the birefringence of the specimens could be followed photometrically. The chart speed was 1·2 cm/min, and the recorder was operated so that full-scale deflection was obtained with 5 μA. The response with decreasing illumination was such that the recorder reached 90% of its final reading in 3 sec. Several checks on standard test-substances showed that melting points could be determined to within ±0·2°C.

Operation of the hot stage was facilitated by using an a.c. voltmeter (0–40 V, moving coil, rectifier instrument) across the input to the hot stage and calibrating the stage. Earthed screening of electrical leads, from the photocell to the recorder, was necessary to reduce electrical interference.

Materials

The starch used in this investigation was a Procea wheat starch. Other substances employed were sucrose and α-lactose monohydrate (both 'AnalaR'), light white soluble casein (B.D.H.), spray-dried skim milk and egg powders, freeze-dried egg white, egg yolk and gluten, and soya bean oil. The stock solution of lactose was allowed to stand for 24 hr to permit the equilibrium mixture of α-lactose and β-lactose to be reached.

Method

Specimens were heated so that they passed through the gelatinization temperature at a rate of about 2°C/min.

The progress of gelatinization was studied by recording the curve of photocell output versus hot stage temperature, with starch suspended in a 42% (w/w) sucrose solution; the starch–solution ratio used throughout the investigation was 1 : 2 (w/w). One drop of the suspension was mounted between a 1 × 1½ in. microscope slide and a No. 1½, 18 × 18 mm cover slip. The plot of photocell output versus specimen temperature so obtained (Fig. 2) exhibits several interesting features. The photocell output began to fall even in the range 20–30°C. Gelatinization proper occurred over a range of about 20°C, after which the rate of loss of birefringence slowed considerably. The shape of the end of the curve shows that it is unwise to define the gelatinization temperature as that at which all birefringence is lost. The high residual reading is due mainly to the light passed by the crossed polars alone.

Two methods of defining gelatinization temperature were investigated. In the first method parallel tangents were drawn along the top and bottom parts of the curve;

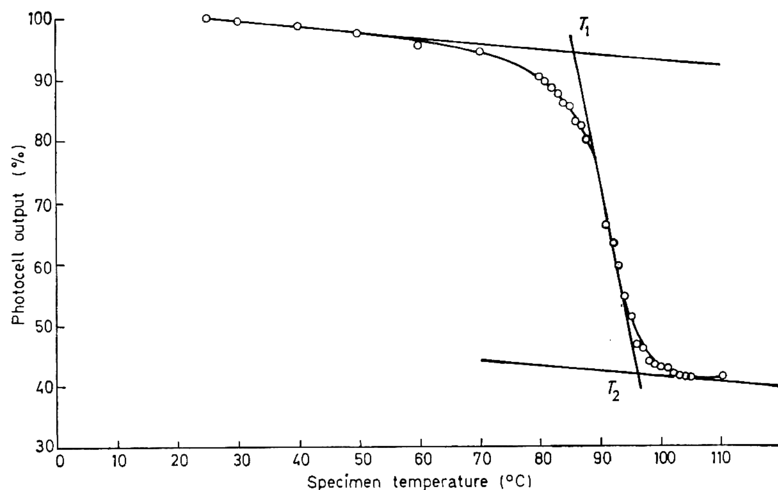

FIG. 2. Gelatinization of wheat starch in 42% sugar syrup.

the line of steepest descent was then drawn and where this cut the tangents defined two temperatures, T_1 and T_2 (Fig. 2). The average of T_1 and T_2 we call simply the *mean gelatinization temperature*. In the second method, the point of steepest descent on the curve was estimated, and we call this *the temperature of most rapid gelatinization*. Examination of over a hundred curves showed that in each case the mean gelatinization temperature and the temperature of most rapid gelatinization were within 2°C of each other. The mean of three runs on a specimen was usually reproducible within ± 1°C.

Results and discussion

The gelatinization of wheat starch in distilled water and in aqueous solutions or suspensions of sugars, milk powder and its constituents, egg powder and its constituents, proteins and soya bean oil has been investigated.

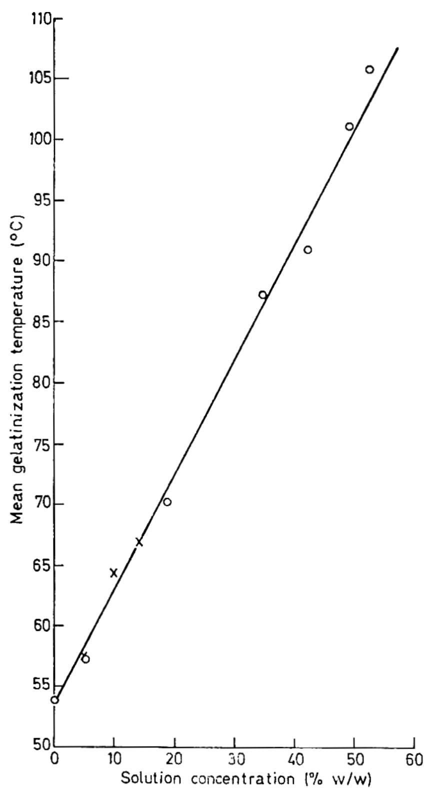

Fig. 3

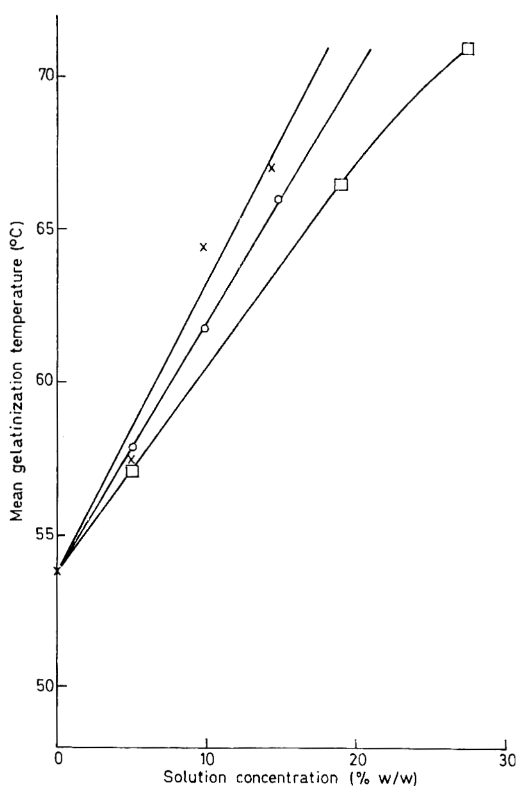

Fig. 4

Fig. 3. Effect of sugars on starch gelatinization temperature. ○, Sucrose solutions; ×, lactose solutions.

Fig. 4. Effect of milk powder and constituents on starch gelatinization temperature. ×, Lactose solutions; ○, casein solutions; □, milk powder solutions.

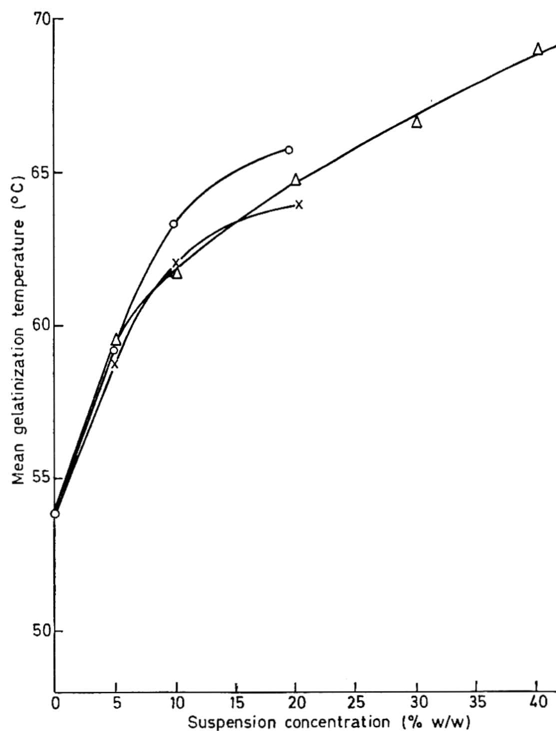

FIG. 5

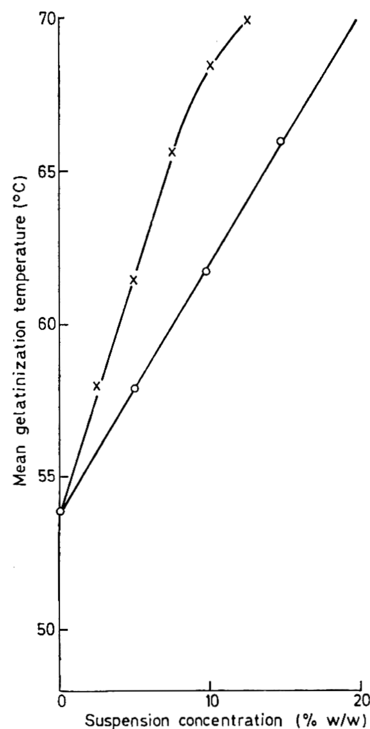

FIG. 6

FIG. 5. Effect of egg powder and constituents on starch gelatinization temperature. ○, Freeze-dried egg white suspensions; ×, freeze-dried egg yolk suspensions; △, spray-dried egg powder suspensions.

FIG. 6. Effect of proteins on starch gelatinization temperature. ○, Casein suspensions; ×, gluten suspensions.

Using 1 part of starch plus 2 parts of distilled water by weight, a mean gelatinization temperature of $53{\cdot}8 \pm 2{\cdot}0$°C was observed. In this case the results were more variable than usual because the low viscosity of water allowed the specimen to flow. The effect of sugars in raising the gelatinization temperature was next investigated, using sucrose and then lactose solutions. The results are shown in Fig. 3 where the mean gelatinization temperature is plotted against solution concentration. Both sets of results lie close to the same straight line.

Fig. 4 shows the effects of skim milk powder and its constituents. The curve for milk powder does not lie between those for its two major constituents; the deviation cannot be accounted for by the fact that milk salts are included in the weight of milk powder taken. This suggests some loss in the hydrophilic properties of the milk powder as a result of spray drying.

The effects of egg powder and its constituents are illustrated in Fig. 5. Fresh liquid

egg gave exactly the result (65·4°C) predicted from its solids content. Similar agreement with the egg powder curve of Fig. 5 was obtained when a 40% (w/w) egg suspension, reconstituted from 5 parts of freeze-dried egg white and 3 parts of freeze-dried egg yolk, was used. The reason for the decrease in slope of the egg curves at about 10% concentration is not understood. Other substances such as milk powder and gluten also show this effect to a smaller extent.

Fig. 6 compares the effects of two different types of protein. Of all the substances examined in this investigation, gluten had the greatest effect in raising the gelatinization temperature. A flour sample with a gluten content of 14% was mixed with the appropriate weight of water to give a starch–suspension ratio of 1 : 2; this suspension had a gluten content of 5·9% and gave a gelatinization temperature of 63·6°C, which is very close to the 63·1°C predicted from Fig. 6.

The effect of soya bean oil-in-water emulsions, with no added emulsifier, is shown in Fig. 7. A possible reason for the elevation of the gelatinization temperature, in this

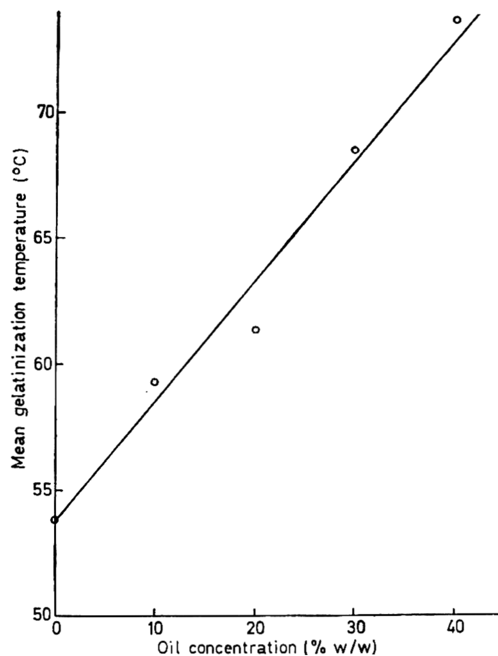

FIG. 7. Effect of soya bean oil-in-water emulsions on starch gelatinization temperature.

case, is the physical reduction in water content as the percentage of oil phase is increased. This was confirmed by showing that the increase in gelatinization temperature, for a given starch–water ratio, was not changed when the oil phase was omitted.

The initial slopes, $(\Delta T_g/\Delta c)$, of all the gelatinization temperature–concentration curves are given in Table 1.

TABLE 1. Elevation of starch gelatinization temperature by various substances in 1 : 2 starch-solution mixtures

Substance	Initial slope ($\Delta T_g/\Delta c$) (°C per unit increase in concentration)
Gluten	1·587
Egg powder	1·140
Egg white	1·086
Egg yolk	0·996
Lactose	0·950
Sucrose	0·937
Casein	0·821
Milk powder	0·674
Soya bean oil	0·477

The smallest slope (0·477) represents the effect of physically reducing the water available to the starch, so that the increase in slope for the other substances may be taken as a measure of their water-binding capacity.

A few runs have been made with a cake batter containing starch, sucrose, egg solids and water in the ratios 1, 1·15, 0·25 and 1·07 (by weight). The mean gelatinization temperature was found to be 93·6°C. This figure is thought, from experience, to be fairly typical of cake batters of this type, but is much lower than might be expected from the results of Figs. 2–7. Thus the gelatinization temperature in a cake batter cannot be calculated simply from the composition.

The present investigation shows that under restricted moisture conditions many substances, in solution or suspension, inhibit the gelatinization of wheat starch.

In the case of soya bean oil-in-water emulsions, it is thought that the increase in starch gelatinization temperature, as the oil phase is increased, is due to the physical reduction in available water per unit weight of starch. The greater effect of the other substances in raising the gelatinization temperature indicates that, in addition to physically reducing the amount of water present, these substances also bind a certain amount of water. When these substances are present the temperature must be raised to a higher level to supply sufficient energy to break the internal starch granule bonds; only then can gelatinization occur.

These results show how complex is the competition for water by the various ingredients present in cake batters. It is clear that the effects of mixtures of ingredients on starch gelatinization temperature merit much further study. These effects are thought to be of practical importance in relation to the ultimate cake volume achieved on baking.

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PROCEEDINGS OF THE INSTITUTE OF FOOD SCIENCE AND TECHNOLOGY

The evolution of the food technologist

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An abridged version of a paper read to a joint meeting of the Institute of Food Science and Technology and the Procter Society at Leeds University, 17 *February* 1966

Introduction

Any study of the evolution of food science and technology must of course properly be based on internal evidence.

There are, however, certain external 'indicators' that food science and technology have come of age. The two most obvious are:

(1) That practitioners have recognized the need to establish a professional institution.

(2) That the nation has recognized that it is no longer adequate to rely only on practitioners educated in one or another of the scientific disciplines involved, and that it is now necessary also to provide a substantial body of people trained on a broad basis of food science and technology.

There is a third and important indicator of professional maturity and awareness; namely an intense interest in the historical background and origins, and in the chain of cause and effect whereby the profession has eventually come into being—in order the better to determine what should be its present role and function, and its future lines of development.

Techniques or technology

The manufacture of foods, their conversion to more desirable or more readily preserved forms, goes back into the mists of antiquity. Food preservation dates back to man's first primitive effort to put by a surplus of the day's kill for an otherwise probably hungry morrow; food conversion goes back to his earliest attempts to vary an otherwise monotonous diet by converting basic food materials to more interesting, more palatable or more attractive forms.

But empirically-based techniques and practices, however extensively and skilfully carried out, do not properly constitute technology.

Axiomatically, a technology is science-based. Today we know of industries, such as

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the manufacture of antibiotics, synthetic chemicals, electronic computers, plastics —the list could be extended widely —which are truly the children of science. These industries and their products were conceived by science and brought forth by technology, and had, from the moment of their birth and at their very core, a built-in scientific and technological basis.

Food manufacture had very different origins, arising simply from man's necessity to eat at fairly frequent and regular intervals in order to survive. For each type of food, an empirical art, and often indeed a mystic art, gradually came into being.

Some of those practices can now be seen, with present knowledge and hindsight, to have had a sound scientific basis, but they were not based on scientific understanding.

Thus, looking back to the beginning of the nineteenth century, the pioneer work of Nicholas Appert, the father and founder of the canning industry, can be seen, with our present knowledge, to have had a sound scientific basis; but at the time, while Appert and the early canners observed facts empirically, they had no conception or understanding of the underlying physical, chemical and microbiological considerations.

Without denying the skill and craftsmanship that developed in traditional, pre-technological food manufacture, it is hardly surprising that the products were frequently of indifferent and widely variable quality; of unreliable stability and shelf-life, and subject to frequent sporadic, and at the time inexplicable, outbreaks of serious defects and spoilage.

Food science and food technology

What precisely do we mean by 'food science' and 'food technology'? If we regard a technology as an application of scientific knowledge and understanding to some group of practical activities in meeting man's needs, a definition of any technology must involve two essential elements, namely: the science or sciences applied, and the practical objectives and activities to which they are applied.

In considering 'food technology', all the disciplines involved can be summarized in the general term 'food science', which can be defined without actually listing all the contributing disciplines. Likewise, the practical ends to which 'food science' is applied can be expressed in brief general terms without listing the individual activities involved.

Food science is a coherent and systematic body of knowledge and understanding of the nature and composition of food materials, and their behaviour under the various conditions to which they may be subject.

Food technology is the application of food science to the practical treatment of food materials so as to convert them into food products of such nature, quality and stability, and so packaged and distributed, as to meet the requirements of the consumer and of safe and sound practice.

Food technology implies the causing of food materials to undergo desirable changes

of nature and/or form, while inhibiting and if possible preventing undesirable changes of nature and/or form. The application of food science to these ends involves a knowledge and understanding of the chemical composition of food materials; their physical, biological and biochemical nature and behaviour; human nutritional requirements and nutritional factors in food materials; the nature and behaviour of enzymes and of micro-organisms and their action on foods; the interaction of food components and the effect on these of additives and contaminants; any pharmacological and toxicological considerations; the reactions of food materials with atmospheric oxygen and with substances with which they may come in contact during handling, processing and packaging; and the effects of various manufacturing operations, processes and storage conditions on all the foregoing. It also requires the application of statistical methods for the design of experimental work and evaluation of these results.

For the sake of completeness it should also be mentioned that development of food technology draws heavily on developments in other technologies, such as those in steel, tinplate, glass, aluminium, plastics, engineering, instrumentation, electronics, chemicals, and agriculture.

The historical background

Having defined food science and food technology, and referred to the essential features involved and implied, we can look for the origins of food technology, in the period before those features existed. However, not necessarily before any of them existed, but before enough of them existed to a sufficient extent to constitute at any rate the basis of a coherent and systematic body of knowledge and understanding. This directs our attention to the middle of the nineteenth century.

The Industrial Revolution had divorced large numbers of the population from the land, whence they had previously derived much of their food, and simultaneously created, for the first time, the problem of feeding large urban populations. Thus the general trend of industrialization, and the creation of a large 'captive' consuming public conveniently concentrated, had a double impact on food manufacture. Furthermore, ignorance and unscrupulousness, and the absence of any restraining force, combined to result in the widespread adulteration of food; deliberate and fraudulent adulteration as a very lucrative procedure; and the use, in ignorance, of dangerously toxic substances, such as the colouring of cheese with red lead.

The steel roller mill revolutionized flour-milling, but resulted in vitamin deficiencies in flour and bread, which were, of course, not realized because vitamins were unknown.

Microbiology was unknown in the field of food manufacture and distribution and in wider terms of public health. Foods, including milk, and water were vehicles for poisoning and disease, which were widespread.

The importance of these circumstances lies mainly in the reaction they evoked during

the period 1820–60 and the consequences which followed. Two separate but immensely significant advances had been taking place during the same period. Liebig and his school had been applying classical methods of analytical chemistry to foods, showing that foods were composed of identifiable and measurable chemical substances, thus laying the basis for food chemistry.

Simultaneously, Pasteur was carrying out his work which was firmly to establish the science of microbiology in general, and food microbiology in particular.

Food legislation

The period 1820–60 had seen mounting efforts by analytical chemists like Frederick Accum and John Mitchell, and a number of doctors, especially Dr A. H. Hassall, through his microscopy and his notable series of articles in the *Lancet*, to expose the nature and extent of adulteration which called for reform and legislation. This movement eventually led to the Adulteration Act of 1860, a weak piece of permissive legislation. It permitted the appointment of Public Analysts, but only seven were appointed, of whom only one, Dr Cameron of Dublin, was in any sense effective (Burnett, 1960).

It was not until the much more effective Adulteration Act of 1872, and then the Sale of Food and Drugs Act of 1875, that Public Analysts became well enough established —and in sufficient numbers —to be an effective force.

The entry of scientists into the food industry

The introduction of analytical chemists into the food industry was a direct reaction. For any food manufacturer of consequence, it would be an obvious form of insurance and self-protection, to employ someone (whether as a consultant or as an actual employee) who could examine samples in the same way as the Public Analyst, and, equally important, 'talk the same language' as the Public Analyst on level terms of knowledge, ability and standing. But, like the payment of insurance premiums, this would be regarded as a necessary evil and an unproductive charge on industry.

It is, however, one thing to conjure up spirits, but another thing entirely to confine their activities to those the conjurer had in mind! So it proved when analysts were brought into food manufacture. They were initially ignorant of the empirical craft and techniques used in the manufacture of the particular products with which they were concerned. Furthermore, in general they were narrow specialists. But they were men with analytical minds, scientific curiosity, and trained in the scientific method.

Initially, they would concern themselves with sampling techniques, examination of samples, and dealing with matters raised by Public Analysts. Before long, however, in the course of their work they would become aware of variations, inconsistencies, anomalies, quality defects, and various kinds of deterioration after manufacture, and would be self-impelled to try and discover the reasons and the influence of various factors. They would note that different batches of raw material gave finished products

of markedly different characteristics, and would try to establish what factors were responsible; and, having done so, would try to establish what kind of raw material gave the 'best' finished product. Likewise, noting product variations coincident with fortuitous variations in processing, they would seek to determine optimum processing conditions.

Thus they were going far beyond their terms of reference, and were incidentally putting to the test of properly designed scientific experiment various traditional, long-cherished and time-hallowed 'principles'.

The evolving pattern

As they gradually gained fundamental knowledge of factors affecting product quality and stability and processing efficiency, they would seek to have this knowledge applied. No doubt this was far from easy. One can picture the analyst being told by his Victorian employer to stay in his laboratory, and leave production matters to the 'practical men who know all about them'.

Nevertheless, a developing pattern began to emerge, in which we can discern several significant strands.

Firstly, the newly-gained knowledge did become applied, with consequent improvements in the rational control of food manufacture and the quality and consistency of its products.

Secondly, the industry slowly began to realize that science could play a valuable part far beyond the confines of dealing with Public Analysts.

Thirdly, an influx of larger numbers of scientists occurred, still mainly analytical chemists, but accompanied as time went on by organic chemists, physical chemists, biochemists, chemical engineers, physicists, microbiologists and nutritionists.

Fourthly, an increasing body of knowledge and understanding was being established to form the basis of a food science. This was to be greatly added to as a result of governmental interest and government-sponsored research, stimulated by two world wars and the twin problems of feeding armed forces and feeding an island population in wartime.

Fifthly, developments in other technologies were opening-up new possibilities in the way of materials, processes, processing equipment, instrumentation and packaging. The impact of these depended in turn on the presence, in the food industry, of people capable of appreciating their potentialities and developing their effective utilization.

Sixthly, there was a process of change taking place in the scientists in the industry, who found themselves increasingly evolving from narrow specialists into technological experts applying scientific method and an increasing body of scientific knowledge and understanding to every aspect of food.

Out of the intricate interweaving of these six main strands has evolved food science and technology, and the modern food technologist in the industry. But evolution is,

of course, a continuing process. New tasks, or new forms of old tasks, and new attitudes in recent years add further strands to the pattern.

New attitudes, new tasks

In the highly industrialized countries, the affluent society has resulted in an emphasis on new products, on products with improved quality and improved keeping properties, and on greater consumer convenience.

At the same time, primarily centred on the work of the World Health Organization and the Food and Agriculture Organization and, more recently, the joint FAO/WHO Codex Alimentarius Commission, there are world-wide efforts to ensure sufficient supplies of adequately nutritious food to large sections of the world's population that have always gone short; and to establish world-wide food standards to give greater protection and information to consumers, while facilitating and promoting international trade in food.

In all these connections, food science and technology has important tasks to perform. It has to establish a much closer unity with the sources and production of its raw materials. It has to supply the expertise required for the furthering of the work of the international bodies already mentioned. It has, as always, to discover new knowledge and new understanding. It has to develop new and more efficient applications of new and existing knowledge. Finally, it has to ensure that science pervades the outlook and activities of the food industry and those responsible for its direction and management.

In carrying out these tasks, alongside the injection and assimilation into industry of the products of the new trends in food technological education, and alongside the further building-up of the profession and its professional institute, the achievements can be far-reaching, and the evolution of the food technologist will be carried an important stage further.

In conclusion, while the profession of food technologist can only in recent years be said to have come of age, it has been in the process of so doing for the past century. Not a long time, but long enough to claim that as a profession it is not entirely without roots or tradition. The evolutionary forefathers of the modern food technologists, the analytical chemists who entered the food industry a century ago, represented, as it were, the foot of science in the door of the food industry. If today it is possible to see much farther than they did, and view much wider prospects and perspectives, it is because, in an historical sense, the modern technologist is standing on the shoulders of his predecessors who achieved so much.

Reference

BURNETT, J. (1960) *Fd Manuf.* **35**, 479.

Book Reviews

Fish Handling and Processing. Ed. by G. H. O. Burgess, C. L. Cutting, J. A. Lovern & J. J. Waterman.

Edinburgh: Her Majesty's Stationery Office, 1965. Pp. 390. 40s. net.

The text of the book consists of contributions from the scientists at Torry Research Station and its outstation the Humber Laboratory. In 1929 Torry Research Station was set up to examine the problems of fish handling and processing. This traditional industry employed crude methods, and it is not surprising that the fish, one of our most perishable foods, suffered in quality. Even in 1959 a survey of wet fish purchased in shops throughout England indicated that only 15% of the samples merited a good quality rating.

Since 1929 numerous problems of importance to the fish industry have been studied at Torry Research Station, and as a result instead of the original situation of empiricism, rule of thumb, and at times ignorance, we have available now a considerable fund of precise knowledge, though unfortunately still applied in far too few areas. The advance that has been made is aptly defined in the words of one of our most eminent scientists, Lord Kelvin: 'When you can measure what you are speaking of and express it in numbers you know that on which you are discoursing. But when you cannot measure it and express it in numbers your knowledge is of a very meagre and unsatisfactory kind'. Even a cursory study of this book will indicate the great strides that have been made in measuring and expressing in numbers the various parameters of importance; even that elusive concept of fish quality is not omitted.

It is therefore proper that all efforts should be made to apply this 'knowhow' on a wider scale in the industry. Scientific textbooks on the subject are available, and at learned meetings subjects of importance to the industry are often discussed, but the information is not intelligible except to the scientist. In this present book we have probably the first authoritative text written in a simple fashion specifically for those who are actively engaged in the fish industry and who have little or no scientific training.

The subject matter is broken down into a logical series of chapters and the essential features of operations between the handling of fish at sea and retailing are discussed from the practical aspect. Drying, canning and fish meal manufacture, together with a few chapters which explain some basic principles involved in fish technology, are included.

The style of the authors is generally lucid, and the information is conveyed with the minimum of scientific jargon. It is inevitable that some sections will prove more

difficult for the person with no scientific training to assimilate. However considerable assistance is provided to the reader in the form of numerous illustrations, diagrams and tables. Without doubt the book is a useful basic work of reference and warrants careful study by those for whom it was specially written.

The binding and quality of the paper is good, and the type is easily read. The book is astonishingly cheap and will make useful and interesting reading to everyone concerned with or interested in the fish industry.

E. ROLFE

Principles of Sensory Evaluation of Food. By M. A. AMERINE, R. M. PANGBORN & E. B. ROESSLER.

New York and London: Academic Press, 1965. Pp. vi + 602, 82 tables, 88 figures £7 16s.

This important book will undoubtedly remain the authoritative text on the principles and practice of sensory evaluation for a number of years to come. The authors are members of different departments (Viticulture and Enology, Food Science and Technology, and Mathematics) at Davis, California. They have brought together for the first time an extensive review under the following headings (abridged): Sense of taste, Smell, Other senses, Factors influencing sensory measurements, Laboratory studies (Types and principles; Difference and directional tests; Quality and quantity evaluation), Consumer acceptance, Statistical procedures, and Physical and chemical tests on foods. Each chapter is followed by a bibliography, the longest of which follows the one dealing with the sense of taste and covers some fifteen pages. Relevant statistical tables, and extensive glossary and an effectively cross-referenced index are included.

Special attention is given to work originating from Davis, the remaining literature having been sampled on an international basis. A rapid inspection of relative frequency of origin of the various references reveals that, according to the topic involved, American sources predominate over other countries (taken individually) in the ratio of between 3 and 9 : 1. The question immediately arises, how reasonable is this preponderance in a comprehensive text. With certain exceptions, and without arguing precisely about the ratio involved, inspection of the reviewer's own bibliographies confirm this emphasis. These exceptions include consumer acceptance and physico-chemical tests on foods to which reference is made below.

The various chapters are not uniform in comprehensiveness and authority and different classes of users may evaluate these differently, according to their own personal interests and needs. The sections on Taste, Smell, and the various aspects of Laboratory studies are particularly valuable. So too, for different reasons, is the section dealing

with 'Factors affecting sensory measurements'. The section on 'Consumer acceptance' and related topics forms a valuable review at a fairly introductory level. It is mostly confined to American experience and could be extensively supplemented from other sources. However, the material assembled still forms a unique collection. To deal with Consumer acceptance at an advanced level would be out of place here and would require a book to itself, rather than a single chapter. The section on 'Physical and chemical tests relating to sensory properties of foods' again provides a useful review, but will probably not satisfy all those actually working in the field. There are some highly pertinent general comments on such topics as odour and gas chromatography. However, the treatment of texture and consistency omits reference to much of the pioneer work in the United Kingdom. For example, there is no *specific* reference to the extensive programme of work initiated by Scott Blair in the late 1930s. In fact, contributions on texture from the United Kingdom are predominantly restricted to papers presented at the Symposium on *Texture in Food* published in 1960 by the Society of Chemical Industry. Other expert readers may also find a few key references omitted on this and other topics. This state of affairs could easily have been rectified by a trivial reduction in the number of American references and the inclusion of a slightly higher proportion from other sources.

The chapter on 'Statistical methods' includes most of the relevant procedures, with many worked examples. The subject is inevitably highly compressed (52 pages) and must be rather awe-inspiring to the beginner. One-tailed and two-tailed *t*-tests, Sequential analysis, as well as Analysis of variance, Correlation and Regression, are among the subjects dealt with. Several of the sections are inevitably too short to do more than draw attention to the particular methods (e.g. Factor analysis and Response surface procedures).

Further observations should now be made about potential uses of this volume. As a source of general reference on particular topics it is of unquestionable value. There is no other comparable collection yet available. As already indicated, different sections are of rather different weight and must be selected for different purposes. The lengthier sections could well form the basis of advanced courses, although critical integration might be improved. Supplementary discussion is likely to be almost essential. Other sections, such as those on Consumer acceptance or Physical and chemical tests, provide admirable introductory reviews. There is obviously much of value to the practical user provided he searches in a number of places referred to in the index. In general, he will still have to work out the details as they apply in his own context. However, to this reviewer at least, that is to be desired, for one of the most crucial problems in this complex field is how to ask the right questions, which take on rather different forms with different foods. This skill very much depends upon experience and its rules are rarely made explicit, here or anywhere else. Much depends upon insight which can be facilitated, for example, by a knowledge of the principles of perception and the

practices of experimental psychology which underly many of the procedures discussed. However, that is a separate question upon which many readers will also require additional guidance.

Finally, these minor criticisms must not be allowed to detract from the very considerable accomplishments achieved in a highly complex field which needs to be developed, both academically and in practice, to the same degree in the United Kingdom.

R. Harper

JOURNAL OF FOOD TECHNOLOGY

Papers to be published in future issues

Nutritional effects of food processing. By A. E. Bender.

The measurement of cake crumb strength. By A. H. Robson.

Thermal conductivities of muscles, fats and bones. By M. J. Morley.

The dielectric constant of foods and other materials with high water contents at microwave frequencies. By G. P. de Loor and F. W. Meijboom.

The effect of phosphate solutions on the denaturation of frozen cod muscle. By R. M. Love and G. Abel.

The relationship between the toughness of cod stored at −29°C and its muscle protein solubility and pH. By W. P. Cowie and W. T. Little.

Cannery retort operation and procedure to cope with modern can-handling methods. By J. D. Felmingham and R. J. Leigh.

Note on the difference between smooth and wrinkled peas after processing. by S. B. Thung and L. Gersons.

Note on a modified device for headspace evaluation of cans. By R. Hoenig D. Reznik and H. C. Mannheim.

British Journal of Nutrition

Vol. 20, No. 4, 1966. Shortened versions of titles of articles

Dependence on protein quality of protein: calorie ration in a freely selected diet
Microbiological evaluation of protein quality with *Tetrahymena pyriformis*. W 4
Studies on the composition of food. 1 and 2
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Binding of magnesium and calcium in the calf small intestine
Measurement of fat thickness in man: comparison of methods
Dietary phosphorus intake and rate of bone metabolism in sheep
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TENTATIVE PROGRAMME, 1966–67

Date	Place and time	Subject	Speakers
5 October	College of Technology Blackpool	Symposium: 'Developments in Production, Processing and Packaging of Meat'	N. of England Branch Meeting
28 October	Grimsby College of Technology, Grimsby, Yorks. (9.30 a.m.)	Symposium: 'Transport of Frozen Food'	
3 November	Borough Polytechnic, Borough Road, London, S.E.1 (Tea 6.30 for 7.00 p.m.)	Automation in the Food Industry'	L. Simmens, M.SC., F.R.I.C.
28 November	The University of Strathclyde, Glasgow	Film and Talk 'Spices'	H. B. Heath and T.S.E. Powell (Bush, Boake, Allen Ltd)
29 November		A.G.M. North of England Branch	
6 December	Borough Polytechnic, Borough Road, London, S.E.1 (Tea 6.15 for 6.45 p.m.)	Annual General Meeting	W. Rowan Hare (President, F.M.F.)
February	The University, Reading		
February	The University, Leeds (N. of England Branch Meeting)	Film and Talk 'Spices'	H. B. Heath and T.S.E. Powell (Bush, Boake, Allen Ltd)
2 March	(Joint Meeting: Institute of Packaging)	'Vacuum and Gas Packaging of Foodstuffs'	
15 March	Carlow, Ireland (Joint Meeting: Carlow Scientific Council)		
5–6 April	Church House, London, S.W.1.	Symposium: 'Quality Control in the Food Industry'	
April	Gas Showrooms, Manchester (N. of England Branch Meeting)	Wine/Cheese Tasting Meeting	Dr Buckle (Coates Ltd) Mr Peacock
18 May	(Joint Meeting: Royal Society of Health)	'Man and his Food'	Sir William Slater

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Arrangement. Papers should normally be divided into: (a) Summary, brief, self-contained and embodying the main conclusions; (b) Introduction; (c) Materials and methods; (d) Results, as concise as possible (both tables and figures illustrating the same data will rarely be permitted); (e) Discussion and conclusions; (f) Acknowledgments; (g) References.

References. Only papers closely related to the author's work should be included; exhaustive lists should be avoided. References should be made by giving the author's surname, with the year of publication in parentheses. When reference is made to a work by three authors all names should be given when cited for the first time, and thereafter only the first name, adding *et al.*, e.g. Smith *et al.* (1958). The '*et al.*' form should always be used for works by four or more authors. If several papers by the same author and from the same year are cited, a, b, c, etc., should be put after the year of publication, e.g. Smith *et al.* (1958a). All references should be brought together at the end of the paper in alphabetical order. References to articles and papers should mention (a) name(s) of the author(s); (b) year of publication in parentheses; (c) title of journal, underlined; (d) volume number; number of first page of article. References to books and monographs should include (a) name(s) and initials of author(s) or editor(s); year of publication in parentheses; (b) title, underlined; (c) edition; (d) page referred to; (e) publisher; (f) place.

Standard usage. The *Concise Oxford English Dictionary* is used as a reference for all spelling and hyphenation. Verbs which contain the suffix ize (ise) and their derivatives should be spelt with the z. Statistics and measurements should always be given in figures, i.e. 10 min, 20 hr, 5 ml, except where the number begins the sentence. When the number does *not* refer to a unit of measurement, it is spelt out except where the number is greater than one hundred.

Abbreviations. Abbreviations for some of the commoner units are given below. The abbreviation for the plural of a unit is the same as that for the singular unless confusion is likely to arise.

gram(s)	g	second(s)	sec
kilogram(s)	kg	cubic millimetre(s)	mm^3
milligram(s) (10^{-3} g)	mg	millimetre(s)	mm
		centimetre(s)	cm
microgram(s) (10^{-6} g)	μg	litre(s)	l
		millilitre(s)	ml
nanogram(s) (10^{-9} g)	ng	pound(s)	lb
		gallon(s)	gal
hour(s)	hr	milliequivalent	mEq
minute(s)	min	R_F values	R_F

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. Letters and numbers must be written lightly in pencil. 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'.

Tables. There should be as few tables as possible and these should include only essential data; the data should not be crowded together. The main heading should be in capitals with an Arabic number, e.g. TABLE 2. Each table must have a caption in small letters. Vertical lines should not be used.

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