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Food research in the 1980s*

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We are all well aware that there is probably enough food produced in the world to provide the minimum requirements of every man, woman and child on earth. At the same time, at least one-eighth of the world's population can be described as 'existing on the razor edge of starvation'. This problem of food distribution is largely economic and societal. Whether, even if equitable distribution were achieved, production could continue to meet demand is by no means certain, but progress in research, particularly in the plant sciences, certainly promises great increases in productivity.

Production of food materials is, of course, the province of agriculture, fisheries and animal husbandry. The various branches of the food industry then have the responsibility of processing, transporting and storing these foods. It is for food research to solve the problems that arise in these various areas and to ensure that knowledge is available to enable the cheapest, safest, most acceptable and most nutritious foods to be produced. Food research leads not only to the maintenance of desirable properties in existing foods but also to the development of new food forms.

I do not intend to dwell on the developmental aspects. The food industry is notoriously conservative, largely because we, its customers, are conservative and because our political masters are rightly concerned with the health and safety aspects of the food we eat. There is not a great deal that a food manufacturer can do with his raw material, if the product is to be accepted as suitable for human consumption. Compare his few options with those available to the manufacturer whose raw material is iron ore, timber or even wool. Consequently, changes in the nature of our foods tend to be gradual – evolutionary rather than revolutionary.

What follows is a very personal view of food research in the 1980s which relates primarily, but by no means entirely, to the research program of the CSIRO Division of Food Research.

I will consider five areas, frequently overlapping, of research into foods. These relate to processes, costs, organoleptic quality, nutritional quality, and safety.

Costs

Major contributors to the cost of foods are the costs of raw materials, labour, energy and waste.

The search for cheaper raw materials leads to continuing research on the substitution of one material by another. Recent years have seen extensive replacement of milk fat by other animal fats in many food applications, and efforts to replace cocoa butter by cheaper fats in confectionery. Milk and plant proteins will become increasingly interchangeable as food scientists learn to modify the properties of one to mimic the other. This does more for the industry than it does for poetry – to describe a lady's complexion as 'peaches and non-dairy coffee whitener' may be construed as less than a compliment.

Much of the food industry is mechanized, but some is labour intensive. Many inspection procedures are being automated as suitable equipment is developed. Perhaps Australia's most important labour intensive food processing activity takes place in abattoirs – there is great scope for reducing the labour required for the dressing and boning of beef carcasses in particular. Last year, an experimental slaughter facility in which to undertake this research was opened

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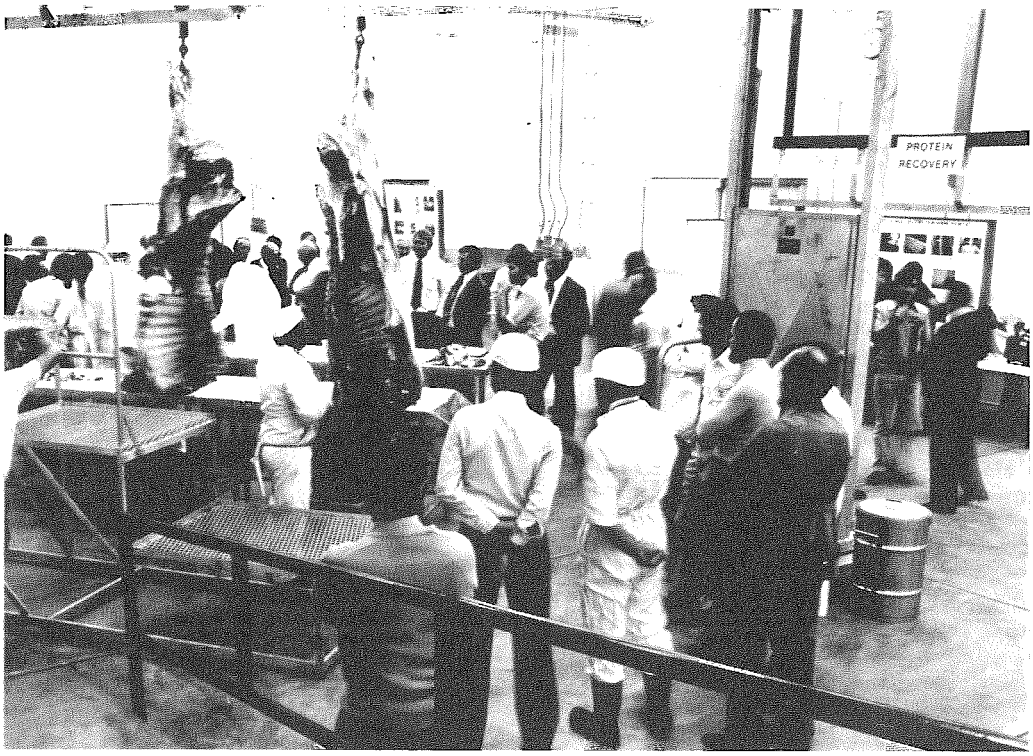

Fig. 1. New processing facility at the Meat Research Laboratory, Division of Food Research, CSIRO, Cannon Hill, Qld.

at the Division's Meat Research Laboratory in Brisbane.

Increases in energy costs have had major impacts on all manufacturing processes. It is worth noting that different forms of food processing have very different energy requirements. The storage of frozen foods is enormously more costly than storage of foods preserved by other methods. Can-manufacture requires twice the energy needed to produce flexible pouches. Hot-air drying is, in energy terms, by far the cheapest method of drying foods but might be, in organoleptic terms, the least attractive. These considerations will become increasingly important and I will now mention some developing processes aimed at energy conservation.

Many foods have very high water contents (75–95%) and the cynics say that for most foods the profit comes from the amount of water the vendor can sell. However, transportation of this water is expensive in terms of energy. Concentration of milk and of fruit juices greatly reduces transport costs and hence energy input *at this stage*. To be economical, the costs of water removal before transportation must be minimized. With milk, in particular, research on concentration by ultrafiltration and reverse osmosis close to the production point will increase. Along with this will go research into the utilization of this concentrate — how can processes be modified to utilize the concentrate direct? If it is reconstituted, are its properties different from fresh milk? If so, how can they be treated?

There are other food processes which conserve energy in not requiring extreme dehydration, not possessing high water contents and not requiring high level thermal processing. These are the Intermediate Moisture Foods (IMF) which have equilibrium humidities in the range 85–60% (0.85–0.60 water activity). Their water activities are such that the growth of pathogenic bacteria is prevented, although for some products an antimycotic agent may

be required to control fungi. Some traditional foods are in this IMF group, e.g. dry sausages, fruit cake, honey and much confectionery. The most important recent commercial application of IMF has been the intermediate moisture pet foods, which have proved a great success with dogs and cats. This development was foreseen in the limerick:

'There was a young lady of Malta,
Who strangled her aunt with a halter.
She said 'I won't bury her,
She'll do for the terrier.
She should keep for a month if I salt her.'

The very sweet or salty humectants that have been used in these pet foods are not acceptable to humans, but there are other combinations that will give stable IMF and research on these, particularly involving mixtures of animal protein and cereals, is sure to increase.

There is, in addition, an interest in what have been termed Shelf Stable Products (SSP). These are predominantly meat products, in hermetically sealed containers, which, because of reduced water activity (a_w), require very mild heat treatments to ensure microbiological stability. Traditional SSP exist, e.g. Italian Mortadella and German Speckwurst. This is another promising line of research which would also lead to savings in processing energy.

There is also a contrary view on the influence of energy costs on food processing. This is that lower energy costs in Australia will give this country's products a price advantage on world markets, which would justify the continued use of high energy requiring processes.

Costs are also involved in the avoidance of environmental pollution and in wastes — these two are generally linked, the wastes causing the pollution. The disposal of many of our food-processing wastes is, in addition, very expensive and pressures to dispose of wastes acceptably and profitably are growing. Within the Division of Food Research there are interests in silage production from trash fish and abalone wastes in Tasmania, the fermentation of fruit and vegetable-processing wastes to produce methane gas in New South Wales, making available an alternative fuel, the concentration and utilization of whey solids from cheese manufacture in Victoria, and the treatment and utilization of abattoir wastes. At a more sophisticated level, the processing of some byproducts into high value materials may also be practicable. Research in the Meat Research Laboratory of the Division of Food Research is leading to the conversion by bacteria of the bile acids of cattle to compounds readily transformed chemically into steroid hormones for medical use. Research on the exploitation of wastes will undoubtedly increase.

Processes

I have confined my remarks largely to processes that appear to have particular relevance to costs. There are, of course, many other processes which are important, including packaging, storage and transport, and I shall mention a selection of these in relation to future research products.

A trend in future food-processing research will certainly be towards the development of continuous processes. Recent research at the Food Research Laboratory of the Division of Food Research has made continuous diffusion extraction of juices a very attractive proposition. A commercial counter current extractor developed from the CSIRO prototype has undergone successful trials, and more applications for this machine will be sought.

Research into food preservation by control of water activity will continue and increase. As well as the IMF and SSP products referred to earlier, improvements should continue in the quality of foods preserved by dehydration. This may be achieved by a better understanding of the effects of heating and drying on the properties of food constituents and on the integration of different drying techniques into a single dehydration process. The cost of freeze-drying is likely to continue to restrict the use of this process to high value foods.

Research into heat sterilization has led to the hydrostatic cooker, to the flame sterilizer, which employs direct flame heating of cans, to aseptic processing, all of which are continuous processes, and to the use of retortable pouches. Much more development can be expected in the last two areas in particular. Retortable pouches offer advantages of a flat thin shape and hence improved heat penetration and reduced heat damage to the product, although further research will undoubtedly be devoted to machinery for filling and sealing pouches at

much greater speeds than are now attainable and to improved packaging materials. An interesting development is the sterilizing of food in pouches by microwave heating, permitting much shorter processing times and again enhanced product quality. The application of microwave technology to food processing generally is already being researched extensively in many laboratories.

Aseptic processing of liquid products has some great advantages – as well as being a continuous process, the product can be given the necessary heat treatment, then cooled immediately and rapidly to give maximum quality retention, before filling aseptically into containers. Presently, the process is widely applied to dairy products in retail packs and to the bulk storage of tomato and fruit pulps. Work is in progress overseas to extend this process to some of the foods that cannot be handled so readily through heat exchangers and pumps. I refer to foods that are mixtures of discrete units in a fluid medium. Very precise heating schedules are necessary to ensure that the solid phase particles are adequately but not excessively heated. There are, undoubtedly, both potential and problems in the aseptic processing of particulate materials.

Food irradiation, by either electrons or gamma rays, has had a chequered career as a preservation method, with real organoleptic and suspected health problems giving concern. However, recent recommendations by the World Health Organization should clear the way to at least selective use of the process. Apart from very low dose applications for control of insects in grain and other crops and for inhibition of sprouting in potatoes, its use will most likely be at pasteurization doses to destroy certain pathogens, especially salmonellae, in raw meat and poultry. I expect that we shall see some resurgence of research on food irradiation. Reservations are being expressed about the safety of some chemicals used to sterilize spices to eliminate viable bacterial spores and high radiation doses are seen as acceptable substitutes.

One should not ignore progress in biotechnology when discussing food research. Biotechnology has been defined as 'the devising, optimizing and scaling-up of biochemical and cellular processes for the industrial production of useful compounds and related applications'. Certainly, biotechnology is no novelty to the food industry as the classical products of this branch of technology are the fermented foods and beverages. The majority of the possible applications of biotechnology probably do not relate to foods, but a great many do. I refer particularly to the production of single-cell protein (which, despite enormous capital investment, does not yet appear to be viable as a source of human food), to the production of enzymes, vitamins, amino acids and gums and to the use of immobilized cells and enzymes. What has made biotechnology more exciting recently is the prospect that by genetic manipulation the microorganisms used in these transformations can be changed, greatly increasing their productivity and the selectivity through which they produce a desired product. Research in this area is in its infancy, but many of the techniques are available now.

Research on food storage and transport continues to be stimulated by advances in other areas of technology. The use of containers has markedly changed the conditions under which many food products, e.g. fruits and vegetables, are exported, producing new problems and new opportunities. There are greater opportunities for control of the storage atmosphere and of product temperature but perhaps also greater problems where these factors are not controlled adequately. At the other end of the scale, the plastic wrapping of perishable foods, such as fresh and cured meats, has entirely changed the microbiological spoilage pattern, introducing, again, substantial opportunities as well as significant problems, both of which call for continuing research. The Meat Research Laboratory has major research interests here. The Division's newest foray into this arena is a recently commenced research program in Hobart on the packaging and retail distribution of fish.

Aspects of refrigerated storage and transport will continue to be researched. In Tasmania the project referred to above includes comparative studies of various systems for chilling fish at sea. In the meat industry, chilling and freezing regimes may be changed as the hot boning of beef becomes widely practised and as electrical stimulation post-slaughter avoids the problems of cold shortening. While the cool storage of many fruits is well developed, major problems

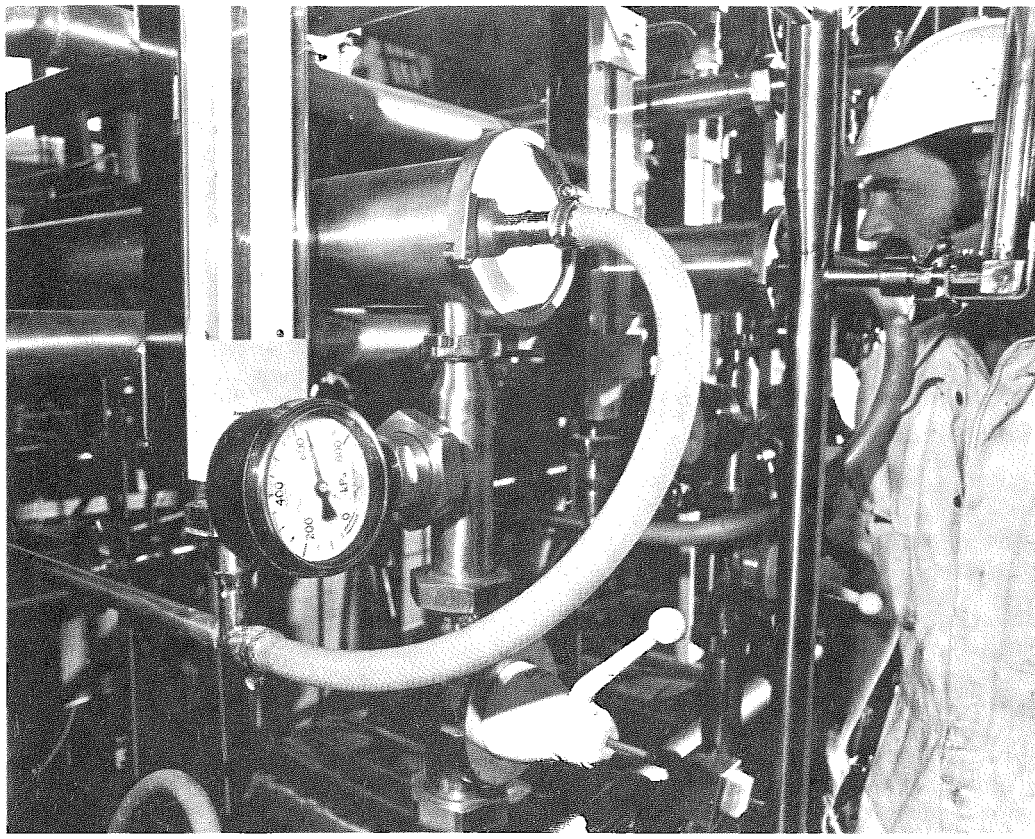

Fig. 2. Pilot-scale ultrafiltration plant, Dairy Research Laboratory, Division of Food Research, CSIRO, Highett, Vic.

remain in storing chill-sensitive tropical fruits. Techniques to delay ripening by means other than low temperatures are being developed, based on absorbance of the ripening hormone and on surface coatings.

Organoleptic quality

Here I refer to the sensory acceptability of a food. The components of sensory acceptability include flavour (taste and odour), appearance and texture. A great deal is yet to be learnt of both flavour and texture.

From the consumer's point of view, we have two types of flavours — desirable flavours and off-flavours.

Flavours, both good and bad, are chemical substances, many of them of extraordinary activity. Many can be detected by the consumer at concentrations below one part in 10^{10}. This is 1 in 10 thousand million, which I find very difficult to visualize. One part in a million is equivalent to one ounce of sand in 28 tons of concrete, or, for the more fluid minded, one ounce of vermouth in 6250 gallons of gin. I am talking of concentrations ten thousand times less than these! Obviously very sensitive instruments are necessary to detect such levels and gas chromatographs coupled to mass spectrometers are used for this purpose. Work to identify natural flavours will continue, partly to make possible the chemical duplication of the active components, because most natural flavours are complex mixtures of many substances. More important may be the use of such knowledge to help protect desirable flavours from the effects of processing, etc. At present there is much emphasis on taints in foods, especially those due to contamination by chemicals in the environment, such as agricultural sprays, compounds in packaging materials and products of microbial activity.

There are also taints of animal and marine foods that come from the diet of the live organism.

There is increasing interest, particularly in industrial laboratories, in substitute flavourings, notably in sweeteners. The objects in the search for sugar substitutes are twofold – to reduce the energy value of the diet and to reduce the tendency to dental caries. Substances under development include modified and substituted sugars, naturally occurring sweet proteins and synthetic peptides.

Although we can now isolate and identify flavour compounds that are present in such very low concentrations, we know very little of how the human animal perceives flavours or how flavours interact. The Division of Food Research is involved both in research on the influence of odours on the behaviour of animals and in psychophysical studies of human responses to odour mixtures. Almost no olfaction research has yet been done with mixtures of odorants.

Texture can be of great importance in the acceptability of many very different foods – consider toughness of meat, crispness of apples, lettuce and celery, lumps in gravy, smoothness of chocolate. For plant foods, texture is generally related to the turgidity of cells which is, in turn, largely under membrane control. Studies of membrane properties will help to explain these effects as will research on the components of the muscles of meat animals lead to a better understanding of toughness and its avoidance. Gums and other macromolecular food components are under increasing study as interest grows in the contributions of gels and colloids to food texture.

Nutritional quality

About nutrition, I have very little to say. It is the responsibility of the health professions to establish the consumer's nutritional requirements and of the educational system to teach the elements of satisfying these requirements by choosing an appropriate diet. The food researcher is then left with the job of determining the contribution that various foods make to these requirements and the extent to which processing and storage affect the levels of nutrients, their availability, digestibility and so on.

Although CSIRO has a Division of Human Nutrition, it is still appropriate for the Division of Food Research to be involved in some nutritional research, much of it in collaboration with its sister Division. One such area is the influence of dietary fibre on the level of serum cholesterol, another is the influence of diet on the microflora of the gut (of which more later) and a third is the bioavailability of particular nutrients.

Food safety

The safety of food is of growing concern. The hazards are broadly of two types – chemical and microbial – although there is overlap, some microorganisms elaborating toxic chemicals in the foods. Some, like saxitoxin and ciguatera toxin in fish, derive from the organism's diet; others, like solanin in green potatoes and cyanogenic glycosides in cassava, are natural components.

Metal contamination of oysters was the subject of a most important investigation in Tasmania several years ago, in which it was demonstrated that the shellfish had accumulated emetic levels of zinc. You will be aware of the controversy surrounding the extent to which the lead from motor vehicle exhausts contributes to the lead content of our food supply.

More difficult is research into carcinogens in foods. Many food components have been claimed to cause cancer in the human consumer, claims usually based on experiments with animals or bacteria. The field is extremely complex and the testing most expensive. More important, definitive results are very difficult to obtain. Both saccharine and nitrite have been nearly full circle from acceptable to unacceptable and almost back again. In the case of saccharine, an injunction has been given in the United States to prevent banning it for 2 years while further research is conducted.

The seriousness of the problem of carcinogens in food led in the United States to the Delaney amendment which, in effect, prohibited the presence of such substances at any concentration in foods. I have already mentioned the great sensitivity of analytical methods and many of the advances in analyses arose from the incorporation of computers into g.c.-m.s. systems some 10 years ago. Thus a suspected carcinogen which could not be detected in food 10 years ago might be readily identified now. So a food that was safe before is now unsafe, although there has been no change in the content of

the offending chemical. This will remain a controversial and difficult field of research.

Another important area of food toxicology relates to mycotoxins, the poisons formed by certain moulds that may grow on foods. Fortunately much less of a problem in Australia, because of our climate, than in many other countries, they are nonetheless important in the peanut industry and in animal feeds, from which they may pass to humans via meat or milk. This is a wide field for research in the 1980s. We need to know much more about the conditions under which mycotoxins are elaborated, how to control their elaboration and, if we fail, how to remove them from foods.

Interest in food hygiene and in the control of food-poisoning microorganisms is increasing world-wide. Improved reporting and diagnostic services are revealing an ever-increasing food-poisoning problem almost everywhere. The classic food-poisoning bacteria — *Clostridium botulinum, Salmonella, Staphylococcus aureus* and *Clostridium perfringens* — are still with us, but are being joined by many others as suspect or certain contributors to the problem — *Vibrio parahaemolyticus, Escherichia coli, Bacillus cereus, Campylobacter, Yersinia* and many others. For all of these 'newer' organisms we need to know a great deal more about their ecology and how they fit into the food scene. Previously unknown viruses are being implicated, particularly in oysters, which are now seen also as a vehicle for the cholera vibrio. This organism was considered, until a connection with airline catering was established several years ago, to be exclusively a water-borne pathogen, but is now known to grow well in some foods. We found it last year in the Sydney oyster leases but as a non-toxic strain causing no illness. A similar situation appears to exist on the east coast of the U.S.A.

The answer to the problem of food poisoning is, of course, to attack it at its source. The major source of salmonella in our community is poultry, followed by red meats. Research is continuing world-wide to achieve resistance to infection of young chicks by feeding them the caecal contents of mature birds, or bacteria derived from them. Studies at the Food Research Laboratory on the effects of food constituents on the microflora of the gut indicate that the food dye erythrosin fed to poultry a day or two before slaughter may strip the salmonella from the intestine and result in a salmonella-free carcass. The process is undergoing commercial trials.

If this approach fails, then some form of chemical, heat or irradiation may be necessary to provide a salmonella-free raw product. There are growing moves in Europe to insist on this and work will continue to define the most acceptable process. Until some such process is developed for flesh foods, only education in the principles of food hygiene can reduce the level of salmonella food poisoning in the community.

My topic has been future food research, and it is worth remembering that research is of little value if it is not passed on — to the scientific or technical journal, to the manufacturer or to the consumer. I would like to mention that the Division of Food Research complements its research program with an extension service to the food industry to assist in technology transfer and in trouble-shooting. An additional service informs the consumer, chiefly through pamphlets on the handling of foods. These are now available in three languages with several more translations waiting in the wings. I believe that the food-processing industry must keep up to date and informed of the results of research and that it will also benefit from having well-informed customers.

The chemistry of food acceptance*

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Introduction

Consumer acceptance of a food often depends more upon its visual presentation, texture and flavour than on its nutritional value. In simple terms, if the food has an attractive appearance, aroma and taste then, irrespective of its nutritional value, it will be eaten and enjoyed. The aroma and taste of a food, in effect its flavour, is therefore one of its most important characteristics.

The flavour of a food is determined by its chemical composition and the response that these chemicals evoke in the taste buds of the tongue and the epithelium of the olfactory bulb. The majority of chemicals that affect the senses of taste and smell are volatile organic compounds. Food flavours are made up of many hundreds of these compounds, and whether a flavour is acceptable or not depends on the qualitative and quantitative composition of the volatile components. The modern consumer is very sensitive to flavour quality and the presence in a food of a particular compound in a lower concentration than usual, even though the difference may be small, or the presence of a foreign compound even in minute concentrations, may lead to the rejection of that food.

The study of the chemistry of volatile food flavours only became possible with the development of the high resolution gas chromatographic column and the coupling of such columns to the mass spectrometer. The column allowed the fractionation of the highly complex mixtures, and the mass spectrometer, through its sensitivity, provided information on the structure and identity of the individual compounds.

*This paper was presented to the Chemistry Section of the 52nd ANZAAS Congress held at Macquarie University, Sydney, 12 May 1982.

Passionfruit flavour

The complexity of food flavours is demonstrated by the gas chromatograms (Fig. 1) of the volatile components of the juices of two varieties of passionfruit, *Passiflora edulis* (Sims) and its mutant *P. edulis f. flavicarpa* (Degener) (Whitfield *et al.* 1982*a*). In these chromatograms peaks due to compounds present in the juices at concentrations of 10 μg kg^{-1} (10 p.p.b.) are visible. The quantitative differences in the chemical composition of the volatile fraction of these two juices are quite apparent. Not so obvious are the qualitative differences which are principally responsible for the *flavicarpa* juice being considered less acceptable to the Australian consumer than the juice of the *edulis* variety. The most important qualitative differences involved the so-called ionone related compounds (Whitfield *et at.* 1982*a*). Each juice contains a different series of compounds (Fig. 2). In the *edulis* variety this class is represented by β-ionone, the megastigma-4,6,8-trienes, the edulans, dihydro-β-ionone and dihydroionone, and it is these compounds that are believed to be responsible for the desirable floral aroma of this juice. The juice of *P. flavicarpa*, which is deficient in this aroma, by comparison contains the theaspiranes, dihydro-β-ionone and geranyl acetone. β-Ionone may also be detected in this variety but, when present, exists in only minute concentrations (below 10 μg kg^{-1}).

During the 1950s, Australian plant breeders set out to combine, through cross-breeding, the desirable fruit qualities of the *edulis* and the hardiness and juice yield of the *flavicarpa* variety. Today, *edulis* is no longer grown commercially in Australia; the variety has been replaced by four purple-skinned hybrids which crop better and are more resistant to viral attack than their *edulis*

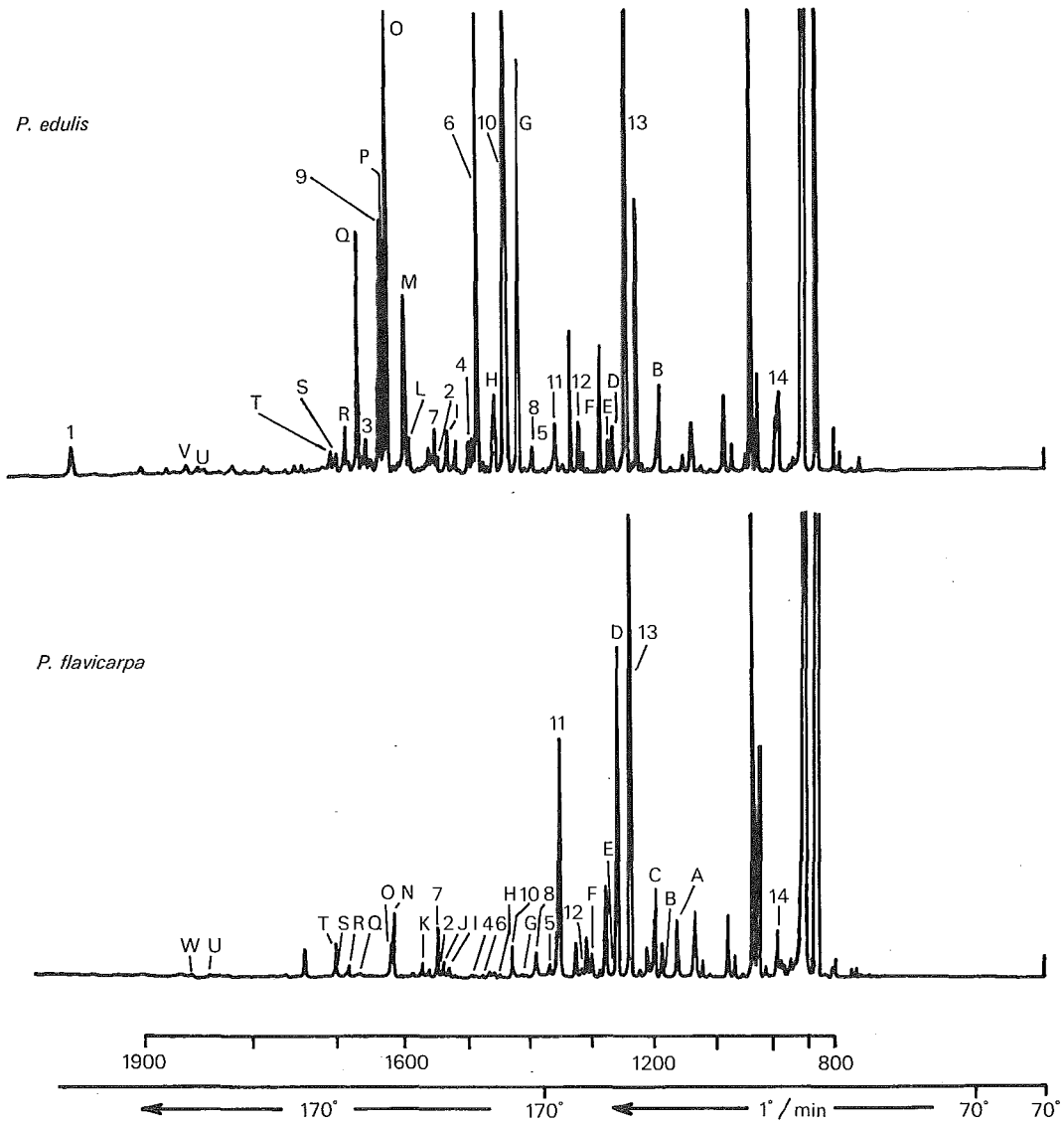

Fig. 1. Gas chromatograms of headspace vapours from purple (upper) and yellow (lower) passionfruit juices. Conditions: Juice sample 10 g, temperature 40°C, collection time 1 hour. Stainless-steel column (150 m, 0.75 mm internal diameter) wall-coated with Carbowax 20M, programmed 70°C for 16 minutes, 70° to 170°C at 1°C/min, 170°C for 2 hours. Peaks (the name compounds are the major components in each peak): A, Myrcene; B, Heptan-2-one; C, Limonene; D, *trans*-β-Ocimene; E, 2-Heptyl acetate; F, α-Terpinolene; G, 2-Heptyl butanoate; H, Ethyl octanoate; I, Ethyl 3-hydroxybutanoate; J, and K, the Theaspiranes; L, *cis*-Hex-3,5-dienyl butanoate; M, 2-Heptyl hexanoate; N, Unknown M.W. 154; O, Hexyl hexanoate; P, Octyl butanoate; Q, *cis*-Hex-3-enyl hexanoate; R, and S, the 2-(3-Hydroxybutyl)-butanoates; T, α-Terpineol; U, Dihydro-β-ionone; V, Dihydroionone; W, Geranyl acetone; 1, β-Ionone; 2, Ethyl *cis*-octa-4,7-dienoate; 3, Megastigma-4,6,8-triene; 4, Ethyl *cis*-oct-4-enoate; 5, Rose oxide; 6, *cis*-Hex-3-enyl butanoate; 7, Linalool; 8, *cis*-Hex-3-enol; 9, Edulan I; 10, Hexyl butanoate; 11, Hexanol; 12, Heptan-2-ol, 13, Ethyl hexanoate; 14, Methyl butanoate.

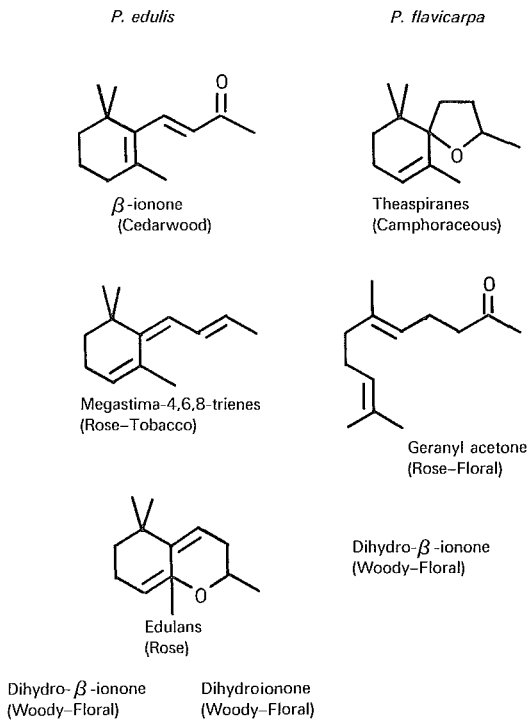

Fig. 2. Ionone related compounds in passionfruit.

parent. Some hybrids, however, lack the characteristic *edulis* flavour and a partial explanation for this lack of flavour is the low concentration — and in some instances the complete absence — of the ionone-related compounds. The consumer may well ask why passionfruit no longer tastes like it once did.

Vegetable flavours

The 3-isopropyl-, 3-sec-butyl- and 3-isobutyl-2-methoxypyrazines are an important class of vegetable flavours (Fig. 3) (Murray and Whitfield 1975). The best known of this class is the 3-isobutyl-derivative which is mainly responsible for the characteristic aroma and flavour of *Capsicum grossum* or green pepper (Buttery *et al.* 1969). The absence of this compound from this vegetable would render it unacceptable to the consumer. The sec-butyl-derivative plays an important role in the flavour of the carrot (*Daucus carota sativa*) and the beetroot (*Beta vulgaris*) (Murray and Whitfield 1975), where it introduces a desirable galbanum or thistle-like flavour. The role of the isopropyl-derivative in the flavour of garden peas (*Pisum sativum*) is less clear-cut (Murray *et al.* 1976). This compound is present in pea pods in relatively high concentrations but in the pea seed its concentration is low. Its aroma is characteristic of crushed pea pods, and in the days when peas were shelled in the kitchen this fresh green aroma was a gratifying presence. It is believed that this compound played a key role in the flavour of freshly cooked peas and the former domestic practice of adding a few pods during cooking to enhance the flavour of the peas may be explained by the adsorption of this compound from the added pea pods.

Avocado flavour

The avocado (*Persea americana*) is a highly priced salad fruit which is greatly prized for its smooth creamy texture. It is, however, generally considerd to be rather bland with only a slight green or nutty flavour. The fruit becomes unacceptable when this changes to a fatty-tallow and putty-like flavour. The volatile fractions obtained from normal and off-flavoured fruit are qualitatively essentially the same in chemical composition; quantitatively, however, they are quite different. The compounds responsible for the off-flavour are principally the aliphatic carbonyls *trans*-pent-2-enal, heptanal, *trans*-hept-2-enal, nonanal, *trans*-oct-3-en-2-one, *cis*, *cis*-octa-2,5-dienal, *trans*-oct-2-enal, *trans*, *cis*-

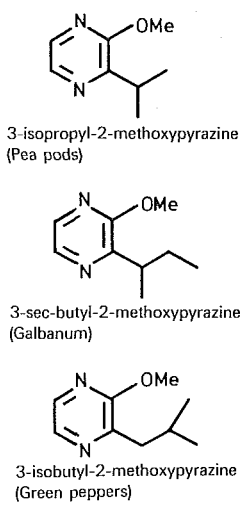

Fig. 3. 3-Alkyl-2-methoxypyrazines in vegetables.

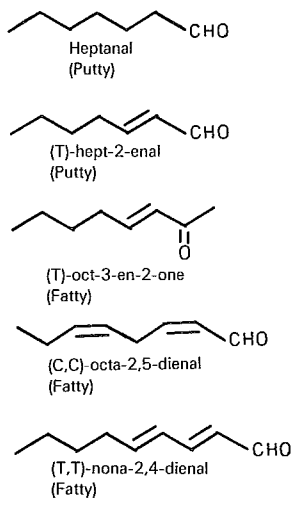

Fig. 4. Carbonyls in avocadoes.

hepta-2,4-dienal and *trans*, *trans*-nona-2,4-dienal (Whitfield *et al.* 1982*b*). The structures of several of these compounds are illustrated in Fig. 4. However, the avocado is an extremely oily fruit in which the lipid fraction is made up of a high proportion of unsaturated fatty acids, and the carbonyl compounds are formed by the oxidative breakdown of these unsaturated acids as a normal part of the ripening process. It is interesting to note that avocadoes, in which these compounds could not be detected, received a low-rating from consumers because they apparently lacked the full flavour. The concentration of a compound can therefore be quite critical; either too little or too much can lead to the rejection of the food.

Off-flavours and taints

Off-flavours can be introduced into a food by the breakdown or chemical interaction of normal food components or by the sorption of foreign compounds from the environment. Objectionable earthy flavours occasionally encountered in some root vegetables such as carrots, potatoes and beets may be due to the presence of geosmin and/or 2-methylisoborneol (Fig. 5) (Buttery and Garibaldi 1976). These compounds are normal metabolites of the soil organisms *Actinomycetes* and are believed to be introduced into the vegetable through cuts and other surface wounds. However, unless the earthy flavour is particularly strong, consumers do not usually reject root vegetables for this reason alone.

Some potato products rejected immediately by Australian consumers have been shown to be contaminated with skatole, indole and *para*-cresol (Fig. 5) (Whitfield *et al.* 1982*c*). These compounds when present impart, in the worst examples, an aroma reminiscent of a pig sty and the product if eaten has a nauseous flavour. These compounds are derived from the bacterial breakdown of the amino-acids tryptophan and tyrosine. Occasionally, bacteria, capable of these transformations, are associated with some forms of soft rot. Furthermore, whole tubers in contact with infected material can absorb these compounds during storage. Consequently, the processor cannot exclude all suspect tubers from the production line. Fortunately, the industry is now aware of the problem and strict quality controls have kept incidences of this off-flavour to a minimum.

In recent experience in the Australian food industry, the synthetic chemicals – the chlorophenols, and their metabolites, the

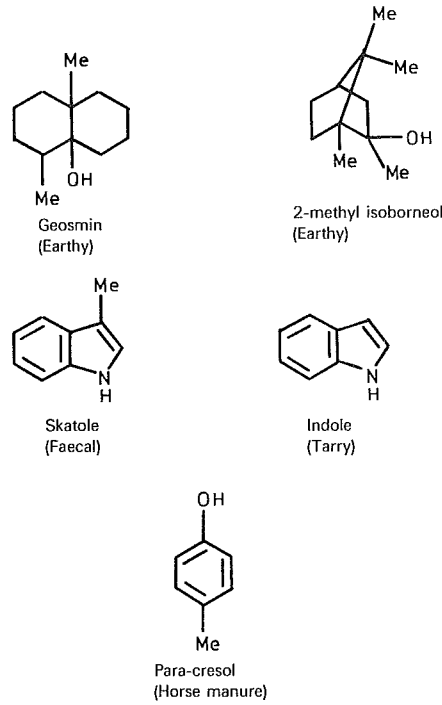

Fig. 5. Off-flavour compounds in potatoes.

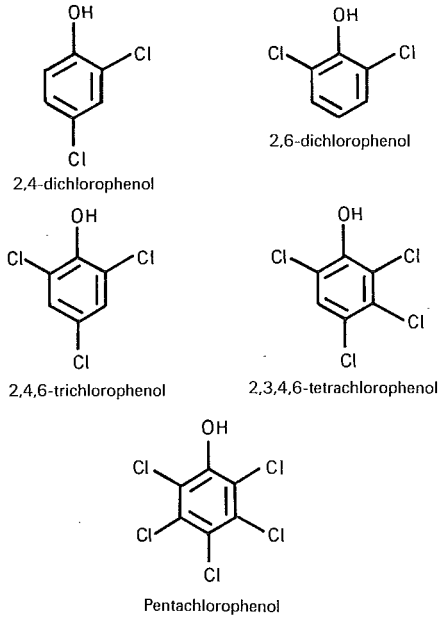

Fig. 6. Chlorophenols encountered as taints in foods.

chloroanisoles, are the most frequent cause of off-flavours. The chlorophenols induce medicinal flavours in foods and beverages at concentrations of the order of 1 μg kg^{-1} (Dietz and Traud 1978). These compounds can be accidentally introduced into the food by either direct or indirect contact since they are used in algacides, fungicides and anti-sapstain preparations. Commercial preparations of these compounds contain 2,4,6-trichloro-, 2,3,4,6-tetrachloro- and pentachlorophenol (Fig. 6). Chlorophenols can also be introduced into the food as a consequence of the reaction of chlorinated water supplies with phenol (Burttschell *et al.* 1975). Compounds formed in this reaction are 2,4- and 2,6-dichloro- and 2,4,6-trichlorophenol (Fig. 6). The dichloro-, trichloro- and tetrachlorophenols all have low taste thresholds and are the major causes of local complaint. Taints that can be ascribed to these compounds have been reported in Australia over recent years in such diverse products as canned vegetables and fruit, soft drinks, fruit juices, milk powders and meat pies. Chlorophenols and their precursors are now environmentally ubiquitous and, although industry is ever vigilant, these compounds are so insidious that for the foreseeable future, foods contaminated by them will continue to be the cause of many consumer complaints.

The methylated derivatives of the chlorophenols are potentially an even greater problem for the industry since chloroanisoles can be detected in food by their musty-mouldy flavours at concentrations well below 1 μg kg^{-1} (Griffiths 1974). These compounds are formed during the detoxification of chlorophenol-based anti-mould preparations by numerous microorganisms (Fig. 7) (Curtis *et al.* 1974). The most potent of these compounds are 2,3,6- and 2,4,6-trichloro- and 2,3,4,6- tetrachloroanisoles. 2,3,6-Trichloroanisole can be detected in aqueous solutions at a concentration of 3×10^{-7} μg kg^{-1}. Over the past 2 years food products exported to Northern America and Europe have been rejected because of the presence of minute quantities of 2,4,6-trichloro- and 2,3,4,6-tetrachloroanisoles.

The compounds which affect our acceptance of a food are therefore many, and their structures varied. Some of these compounds are constantly recognized by consumers as off-flavours; others can either impart a desirable flavour to the food or lead to its rejection depending on their environment and concentration.

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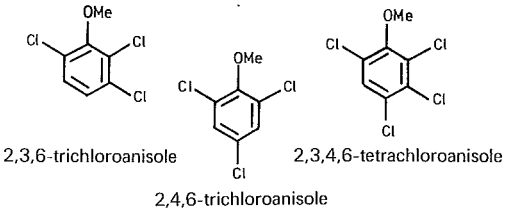

Fig. 7. Chloroanisoles encountered as taints in foods.

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The fatty acids of kangaroo and wallaby meat

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In recent years kangaroo meat has been processed in Australia for human consumption as well as for pet food and other uses. Most of the meat for human consumption is exported as 'game meat' from licenced processing plants. In 1981 over 1 million kg of kangaroo meat was exported from Australia.

Among the nutritional advantages claimed for kangaroo meat are its low fat content and the high levels of polyunsaturated fatty acids within that fat. Sinclair and Slattery (1980) compared the polyunsaturated fatty acids of kangaroo meat with those of beef cattle, sheep, goats, buffalo, deer, horses, and pigs, and showed that the content of polyunsaturated fatty acids in the fatty acids of kangaroo meat was about 38%. Only horse meat fatty acids were richer in polyunsaturated acids (43%). Redgrave and Jeffery (1981) recently compared the lipids of lean meat of kangaroos with those of lean meat of sheep and beef cattle. Kangaroos were obtained from an area near Deniliquin, a relatively arid inland region of New South Wales. The results were similar to those obtained for meat from kangaroos taken near Yan Yean Reservoir, Victoria, where the annual rainfall is much higher (Redgrave and Vickery 1973). Lean kangaroo meat contained more phospholipid and less triacylglycerol than lean beef or sheep meat, and the ratio of polyunsaturated fatty acids to saturated fatty acids (P/S ratio) was much higher for kangaroo meat lipid (1.1) than for sheep (0.3) or beef meat lipids (0.3).

The data published by Redgrave and co-workers (1973, 1981) were obtained from the eastern grey kangaroo, *Macropus giganteus*, collected from two different regions of Australia. The report by Sinclair and Slattery (1980) does not indicate which species of kangaroo were analysed. Kangaroo meat for human consumption is derived from several species, mainly the red kangaroo *(M. rufus = Megaleia rufa)*, the eastern grey kangaroo *(M. giganteus)*, the western grey kangaroo *(M. fuliginosus)*, and some of the larger species of wallaby. *M. rufus* is identifiable by its shape and by the characteristic texture of its short woolly fur,

which is usually red-brown in the male and blue-grey in the female. A distinction between the somewhat grey-coloured carcasses of eastern grey and the generally browner ones of the western grey kangaroo is not readily made by the inexperienced at the processing plant but the area where the animal was found may be a strong indication of its species, though there is some overlap in the distribution of the two species (Kirsch and Poole 1972; Poole 1975).

Recently, samples of kangaroo meat were obtained from a Sydney processing plant to determine whether there were any obvious differences in fatty acid composition between species. Meat was taken from two specimens of *M. rufus* (one male, one female, both obtained from Hay, in N.S.W.), two specimens of grey kangaroo (most probably *M. giganteus*, one from Hay and the other from Roma, in Queensland), and one specimen described as 'Queensland Wallaby' from Roma which, judged by the uniformly dark fur, was probably *Wallabia bicolor* (Swamp wallaby).

Experimental procedure

Lipid was extracted from 100 g meat, cut from the hind leg and free of visible fat, by the method of Bligh and Dyer (1959). The total lipid was recovered and weighed, and the fat content of the meat was calculated. Part of the lipid was transmethylated using the procedure of Glass and Christopherson (1969). The crude mixture of the methyl esters of the fatty acids was purified by column chromatography on 7% hydrated Florisil (Carroll 1961). Aliquots of the purified methyl esters were analysed by gas-liquid chromatography (g.l.c.) using a Pye Model 104 chromatograph with a flame ionization detector and a 4-m by 2-mm coiled glass column containing 10% Silar 10C on 100/120 Gas-Chrom Q (Applied Science Laboratories, State College, Pa.) operated at 200°C. A Hewlett Packard 3390A Integrator was used to measure peak areas.

The methyl esters were separated initially into three fractions by low temperature argentation thin layer chromatography (t.l.c.) using Kieselgel GF_{254}, type 60 (layer thickness 0.5 mm) containing 30% silver nitrate. Development of the ester mixture was carried out twice in the same direction at −20°C using toluene/hexane (90 : 10 v/v) as solvent. After development, the plates were examined under u.v. light to detect conjugated dienes, and then visualization of the remaining components was achieved by spraying with a 0.2% w/v solution of 2′, 7′-dichlorofluorescein in methanol followed by examination under u.v. light.

The fractions collected were, respectively, saturated plus branched-chain plus *trans*-mono-unsaturated methyl esters; *cis*-mono-unsaturated esters; and di- and poly-unsaturated esters. After removal of each zone from the t.l.c. plate, the esters were recovered from the adsorbent by extraction with ether. In each case the ether extract was passed through a 10 mm long column of Florisil to remove traces of dichloro-fluorescein. Each residual methyl ester fraction was then analysed by g.l.c. Argentation t.l.c. in combination with g.l.c. enables the resolution of overlapping or coincident peaks in the original gas chromatogram of the methyl esters of the total fatty acids from the sample. Since the above procedure gave high results for the *trans*-mono-unsaturated methyl esters, these were subsequently determined by repeating the argentation t.l.c. and analysing the recovered *trans* esters separately from all the remaining esters, using methyl behenate as an added internal standard for each of the two fractions.

Results and discussion

The results of the fatty acid analyses are shown in the table. The results for the grey kangaroos are similar to those of Redgrave and Jeffery (1981) and Sinclair and Slattery (1980), though the presence of *trans*-octadecenoic acids was not reported by these workers. P to S ratios in all cases appear to exceed 1.1, but values calculated from the data in the table do not take into account minor polyunsaturated or saturated and branched-chain fatty acids.

Even in this preliminary survey it is evident that some differences in fatty acid composition may occur within a species e.g. meat from the female red kangaroo contained less linoleic acid (18:2 ω6) than the male, though both animals came from the same area. The two grey kangaroo samples showed similar differences, but the sex of the animals was not known. The data for the wallaby are similar to those obtained from the kangaroos.

Small amounts of conjugated dienoic acids

Fatty acid composition of kangaroo meat

Species	Red kangaroo (female, N.S.W.)	Red kangaroo (male, N.S.W.)	Grey kangaroo (N.S.W.)	Grey kangaroo (Qld)	Wallaby Qld
Fat (%)	1.2	1.1	1.4	1.1	1.0
	Major fatty acids [A] *(% of total fatty acids by g.l.c)*				
16:0	14.4	13.5	17.1	14.6	17.0
16:1	1.0	0.8	1.0	0.7	1.3
18:0	10.6	10.4	11.5	12.1	11.1
18:1 *trans*	3.7	1.7	2.6	2.9	2.3
18:1 *cis*	29.0	22.7	28.1	17.9	23.0
18:2 ω6	16.3	24.5	13.4	20.7	17.1
18:3 ω3	4.0	4.1	4.2	5.2	6.0
18:2 conjugated diene	0.7	0.7	0.9	0.4	0.6
20:3 ω6	1.2	1.2	1.3	1.5	1.7
20:4 ω6	7.6	8.1	7.4	8.5	8.2
20:5 ω3	3.6	1.7	3.3	2.2	3.0
22:5 ω3	3.2	3.3	2.8	3.3	3.2
22:6 ω3	0.8	0.8	0.7	0.9	0.6

The shorthand notation gives the number of carbon atoms before the number of double bonds. The notation 3 or 6 refers to the number of carbon atoms between the last double bond and the methyl end of the carbon chain, i.e. 3 or 6.

were detected by the presence of the characteristic dark band when the argentation t.l.c. plates were examined under u.v. light before spraying. The g.l.c. analysis suggested that these were octadecadienoic acids, which are present at low levels in the milk and depot fats of ruminants. In the ruminant, conjugated acids are believed to be formed by isomerization of dietary di- and tri-unsaturated fatty acids during biohydrogenation in the rumen (Bartlet and Chapman 1961). This would suggest that some biohydrogenation of dietary polyunsaturated fatty acids may occur in the digestive tract of the kangaroo.

Further evidence for biohydrogenation is the presence in all the meat samples of *trans*-octadecenoic acids. During the g.l.c. analysis of the methyl esters of the total lipids, these appeared as an unresolved shoulder on the leading edge of the *cis*-octadecenoate (oleate) peak. However, during argentation t.l.c. the *trans* esters were isolated either as a part of the saturated ester fractions or separately. Further g.l.c. analysis suggested that both *trans*-11-octadecenoate (methyl *trans*-vaccenate) and *trans*-9-octadecenoate (methyl elaidate) were present, with the former predominating. The analysis of the saturated ester fractions also reveals a number of minor fatty acids in all species. These have been tentatively identified as branched-chain fatty acids, with chain lengths of 15 to 19 carbon atoms.

In 1955, Hartman *et al.* reported the presence of high levels of *trans* acids in the perinephric fats of some New Zealand marsupials, including a species of wallaby *(Thylogale eugenii)*. Their findings supported those of Moir *et al.* (1954), who suggested that a ruminant type of digestion was evident in marsupial macropods. The present findings indicate that Australian species of kangaroo and wallabies have the same ability as their New Zealand relatives to biohydrogenate dietary polyunsaturated fatty acids. It is of interest that tree-dwelling marsupials such as the brush-tail possum *(Trichosurus vulpecula)* and koala *(Phascolarctos cinereus)* do not have *trans* fatty acids in their depot fats (Bolliger and Shorland 1963).

It is clear from this brief survey that g.l.c. analyses of meat lipids would be of little use in deciding from which species of kangaroo the meat had been derived. The identities of the *trans* and conjugated fatty acids require further study. The low level of fat containing high levels of essential fatty acids in kangaroo meat make it an attractive alternative to conventional red meats.

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Energy consumption in different food processing technologies*

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Introduction

In the past, energy considerations have had little or no influence on the primary decisions concerning how a food was to be processed. But then the sudden increase in the price of fuel oil sparked off widespread critical examination of energy usage in the food industry (Crawford and Elson 1982), including many studies of comparative energy consumption in different methods of food processing. In some instances these were comparisons of the basic food preservation process, e.g. canning *v.* freezing; in other situations energy consumption was compared for different methods of performing the same basic process e.g. different methods of drying foods; then again some workers compared energy use in a particular industry (Overview 1982), and others in the whole system from primary production to home consumption.

One particular study by Olabode *et al.* (1977) may be taken as a framework for discussion. These workers calculated the energy consumption in the processing, storage, and distribution of potatoes in 10 different ways. Their calculations are summarized and simplified in Table 1, which shows comparative energy inputs for five different ways of processing potatoes. The numerical values provide a basis for comparisons, but the original paper should be examined in order to assess their probable reliability.

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Table 1. Processed potatoes — comparative energy inputs[A]

	Hot-air dried	Freeze dried	Canned	Retort-pouched	Frozen
Processing	8	42	6	4	5
Packaging	1	2	14	7	7
Storage	0.1	0.1	0.1	0.1	32
(Home)	0	0	0	0	(24)
Transport	2	2	8	8	8
Total	11	46	28	19	52

[A]Abbreviated from Olabode *et al.* (1977). Energy values in Btu per 4 oz serving of mashed potatoes x 10^{-2}, rounded.

Among the processing procedures, drying requires the highest energy input, and especially freeze-drying. But when the total system for the various products is examined, the dried product comes out best because the loss of weight in drying permits economies in packaging and transport. The major energy input for the canned product is in making the can, while the energy input for frozen storage causes frozen potatoes to have the highest energy input. This total would be increased still further if energy consumption in domestic freezer storage was counted.

It is instructive to look more closely at different processing technologies from the point of view of energy consumption.

Water removal from foods

Removing water from foods is a very common step in food processing and a large consumer of energy, e.g. in the dairy industry 50% of the total energy consumed is in the removal of water (Hallstrom 1980). Water removal processes may be catalogued as follows:

- Mechanical dewatering: pressing, filtration, centrifuging.
- Concentration — the term generally applied to removal of water from liquid foods to produce products that are still liquid: evaporation, freeze concentration, membrance processes.
- Drying or dehydration — the removal of water to produce substantially dry solid products.

Concentration

Energy consumptions for different methods of concentration are compared in Table 2. These values were put together by Hallstrom (1980) from a number of sources. He did not include mechanical dewatering in his analysis, but Sivik (1980) in the same symposium showed that mechanical pressing would fall at the bottom of the table with still lower energy consumption per kg of water removed. However, the extent of water removal by pressing is strictly limited, and whether the process is applicable at all depends on the nature of the system.

Indeed, with regard to all the procedures in Table 2, many other factors besides energy consumption must generally be taken into consideration before a choice of process is made.

In the removal of water from liquid foods by evaporation, the practical limit of concentration depends on the nature of the product but is generally around 80% solids. The energy efficiency of evaporation can be dramatically increased (Table 2) by increasing the number of effects, where the vapours from one effect heat the next effect. The number of effects is limited by engineering considerations such as the total temperature difference that is possible and the temperature of available cooling water, and also by considerations of quality and nutritive value. As the number of effects is increased, so are the residence time of product in the evaporator and the likelihood

Table 2. Energy consumption in concentration processes[A]

Process	Energy[B]
Evaporation: 1 effect	0.93
2 effect	0.51
3 effect	0.31
4 effect	0.23
5 effect[C]	0.12
7 effect	0.08
Freeze concentration	0.25–0.50
Membrane concentration	0.012–0.048

[A]From Hallstrom (1980).

[B]Consumption in kWh per kg water removed.

[C]With recompression.

of heat damage, burning on, and fouling.

Energy efficiency can be increased still further by vapour recompression, but application to a particular food system must be analysed in detail to determine whether recompression is worthwhile. Kelso *et al.* (1980) present such an analysis of mechanical vapour compression in comparison with multiple effect evaporation in the concentration of orange juice; only in defined circumstances is recompression likely to be advantageous.

Freeze concentration, where water is removed as ice, shows an intermediate level of energy consumption (Table 2). There is no heat damage to quality and nutritive value but the practical concentration limit is about 30% solids.

Membrane processes embrace reverse osmosis, where the membrane is permeable only to water, and ultrafiltration, where the membrane is permeable to molecules with molecular weights up to about 500. The energy consumption is low but so are the practical concentration limits, e.g. with whey, about 25% solids. Capital costs are high, e.g. in Australian experience about $500 000 per 1000 t whey solids per year. Heat damage to quality and nutritive value is minimal.

Some years ago Casimir and Kefford (1968) demonstrated that optimal quality in orange juice concentrates was achieved by using a single-pass, single-effect evaporator with a very short residence time, which, however, required slightly more than 1 kg steam to evaporate 1 kg water. A number of such evaporators were installed in Australian plants but they are now being removed, or converted into the final effects of multiple evaporators, because of energy costs. Multiple effect evaporators achieve much better steam economy but they have longer residence times and cause more heat damage. Hence this change for the sake of energy economy has been detrimental to the quality of concentrated orange juice.

Drying

To achieve higher levels of water removal by drying we must provide greater amounts of energy per kg of water removed. Some comparative data on drying processes reported by Trägårdh (1981) are set out in Table 3. Different products were processed so that the data should be regarded only as showing the comparative order of energy consumption. The baking of cakes involves, of course, rather more than removal of water.

Table 3. Energy consumption in drying processes [A]

Process	Energy [B]
Roller drier (starch)	1.25
Pneumatic flash drier (starch)	1.8
Spray drier (whey)	2.5
Fluid bed drier (starch)	3.5
Gas-fired oven (cakes)	9.3

[A] From Trägårdh (1981).

[B] Consumption in kWh per kg water removed.

There are other methods of drying that were not included in Trägårdh's comparison. A drying procedure combining hot-air drying with microwave heating is advocated by Smith (1979) of the Microdry Corporation. Microwave heating is used to greatest advantage during the stage of drying when the rate is falling owing to restricted movement of water from the interior of the product to the surface. By heating the interior of the product, microwave radiation drives the water outwards. Typically, microwave energy is applied when the moisture content has been reduced to 10–20%. Such a combined operation applied to the drying of pasta and onions is claimed to cut drying times substantially and energy consumption by 20–30% as compared with conventional hot-air drying.

In Table 1, from Olabode *et al.* (1977), freeze drying showed a very high energy consumption. In a recent analysis Judge *et al.* (1981) made an interesting comparison of freeze drying and freezing for the preservation and distribution of meat (Table 4). The freeze drying process required 40 times as much energy as freezing, while transport and storage of the frozen product on a hypothetical delivery required only 3.5 times as much energy as for freeze-dried meat. The authors calculated that the two systems would break even in energy use only after transport over 26 000 miles — Australia to Europe and back again!

Canning and freezing

The comparison of energy consumption between processing methods that appears to have received the most attention is that between canning and freezing. Löndahl and Lindborg (1980) prepared a figure showing how this comparison worked out in seven different investigations of the processing of

Table 4. System energy requirements (Btu per lb) for the preparation of meat raw materials for sausage manufacture [A]

Process	Preservation system		
	Fresh	Frozen	Freeze-dried
Carcass chilling	77	77	32
Carcass boning	32	32	32
Freezing		134 [C]	207 [B]
Freeze-drying			5187
Transportation	1624 [E]	4840 [D]	1493 [D]
Storage		288 [F]	
Tempering		30	
Grinding	51	51	51
Packaging		160	140
Total	1784	5552	7110

[A] From Judge *et al.* (1981).
[B] 39 °C to -40 °C.
[C] 4 °C to -20 °C.
[D] 16 000 miles round trip, 25 days via transoceanic vessel.
[E] 3000 miles round trip via cargo truck with 2 days of refrigeration.
[F] 30 days.

peas and corn (Fig. 1). Looking at this figure, one would say that there is little difference in energy consumption between canning and freezing. Olsson (1980), making the same comparison, found that the energy consumed in processing peas was 1.9 MJ kg^{-1} for canning and 1.4 for freezing. But when he calculated the energy consumption for the total system from growing to consumption he came up with the identical value (22.6 MJ kg^{-1}, 6.3 kWh kg^{-1}) for canned peas and frozen peas (Fig. 2).

When we look at the canning process itself, the steps that consume most energy are lye peelers, blanchers (Olsson 1980) and retorts, e.g. in tomato canning 18% of the energy consumed is in lye peeling and 81% in retorting (Singh *et al.* 1980). Accordingly, there are powerful incentives for examining methods of energy conservation in retorting. The efficiency of steam usage in atmospheric retorting with steam injection heating is only 10–30%; a two-fold improvement in this efficiency is possible by recycling the hot water through an external heat exchanger (Griffith *et al.* 1979).

Flame sterilization is more economical in energy usage than retorting (Casimir 1975).

A claim for substantial energy savings has been frequently made for processing in retort pouches rather than cans, and this procedure showed up better than canning in the table of Olabode *et al.* (1977). In a detailed analysis of this comparison, Lund (1979) agrees that the energy required to make the pouch (1934 Btu per 8 oz pouch) is about half that to make the can (3560 Btu per 211 × 300 can). However, from reported experience in retort pouch processing in Japan, he concludes 'that the pouch system appears to offer no net reduction in steam requirements compared to cans even though there is a significant reduction in process time'. In transport and distribution the pouch may again show an energy advantage: the weight of empty pouches is only one-ninth of that of equivalent cans, and filled pouches weigh 20% less than cans, but they occupy 30% more volume.

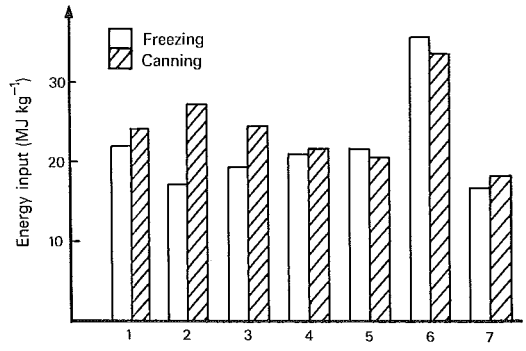

Fig. 1. Energy consumption in freezing and canning of vegetables (peas and corn) according to different investigations (1–7).

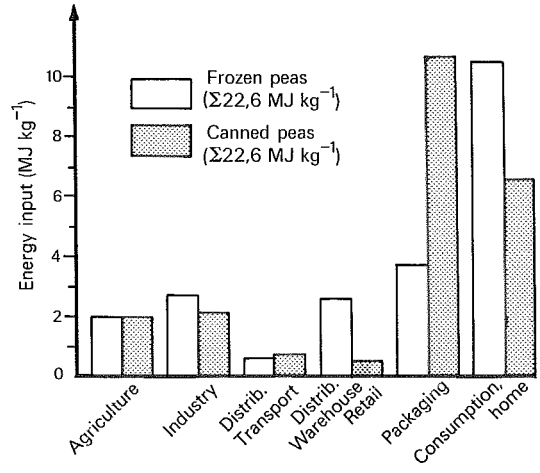

Fig. 2. Energy inputs for canned and frozen peas.

Conclusion

It is not easy to draw worthwhile general conclusions from the very diverse observations that have been reviewed. Going back to the paper first mentioned, Olabode *et al.* (1977) classified their model systems into three categories: low, intermediate and high energy processes, and this broad classification could be extended to other processes that have been discussed, thus:

- *Low energy consumption*
  mechanical pressing, e.g. dewatering, juice extraction; multiple effect evaporation; freeze concentration; membrane concentration.
- *Intermediate energy consumption*
  hot air drying; canning; freezing.
- *High energy consumption*
  freeze drying; retorting; oven cooking; blanching; single effect evaporation; and frozen storage.

The point should be made, however, that in the food industry, more than in most industries, it is not wise to optimize processes on the basis of energy economy alone; the safety and quality of the product must be prime considerations, and they may conflict with energy economy.

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News from the Division

Retirements

Dr Keith Murray

Dr K. E. Murray retired from the Division of Food Research on 21 May 1982 after 43 years' service with CSIRO and its predecessor, CSIR, the last 20 years being spent with the Division at North Ryde. His interests for most of this period were in the development and application of techniques for the study of natural organic compounds, culminating in the coupling of gas chromatography (g.c.) and mass spectrometry (m.s.) in the identification of volatile food flavours. His reputation in this field is world-wide and he has, with justification, been called the father of g.c.-m.s. in this country.

Even as an undergraduate at the University of Western Australia, Keith Murray showed a flair for natural product research, and his experiences in the distillation and analysis of essential oils led to a continuing interest in this field as shown by his chairmanship of the Standards Association of Australia, Committee on Essential Oils, as late as 1981. After graduation as a Bachelor of Science with Honours in 1939, he spent a brief period with the Division of Plant Industry before becoming a foundation member of the Division of Industrial Research in 1940, initially to work with Dr H. H. Hatt on the alcohols of wool wax. War, however, interrupted his study of natural products with the diversion of his efforts into synthetic industrial chemistry and he became involved in the large-scale preparation of C_2 and C_5 intermediates required for the manufacture of such diverse products as novocaine and oil-soluble resins.

With peace, Murray returned to wool wax as a possible source of cetyl alcohol and hence a possible raw material for the manufacture of flotation agents. With his amplified low pressure distillation procedure involving his modified spinning band column, he was able to separate the high boiling components of this complex mixture of high molecular weight compounds and he went on to apply this technique to the separation of the alcohols, diols and acids of carnauba wax. About this time, A. J. P. Martin introduced the technique of gas liquid chromatography for the separation of organic compounds, but it was not generally applicable to such large molecules as the wax components. By modifying Martin's g.c. detector based on a gas density meter and employing temperature programming, Murray was among the first to apply this technique to high molecular weight compounds. His final improvement came with a standard procedure in which the wax was separated chromatographically into fractions representing various classes of compounds (alcohols, diols, fatty acids, hydroxy fatty acids, etc.), each fraction was chemically reduced, and the hydrocarbons so formed were separated and identified by g.c. Murray used this procedure in definitive studies of wool wax, carnauba wax, beeswax and sugar-cane wax.

These g.c. procedures provided information on the molecular weight of long-chain compounds but not always on their complete structure. The location of methyl

side chains was still a problem, and the structure of the branched chain acids of the tubercle bacillus and the preen gland of the goose awaited identification of the site of their methyl branches. Murray developed a rapid technique for locating these chains based on permanganate oxidation but, although successfully applied to the above acids, it was soon replaced, like other chemical methods for elucidation of structure, by procedures based on mass spectrometry. Murray now played an important role in the development of such m.s. methods following his transfer to the Division of Food Research (then Food Preservation and Transport) at the invitation of its Chief, Dr J. R. Vickery, to head a new team to work on food flavours.

The major tool for the analysis of food flavours was and still is the gas liquid chromatograph, and from his arrival at North Ryde in 1960, Murray devoted his energies with the assistance of Mr B. H. Kennett and Mr G. Stanley, to modifications in the design of g.c. equipment, then in a fairly primitive state. A standard improved model was developed which was used in all Divisional studies for the next 10 years. Even more significant, however, was the coupling of g.c. to m.s. so that the separated components passed directly to this instrument for measurement of molecular weight and fragmentation patterns. The Division was the first laboratory to use coupled g.c.-m.s. in Australia and it was applied to studies of the volatile flavours of diverse food products: first of all, peas (with Dr F. B. Whitfield and Mr J. Shipton) and then bananas, passionfruit, lamb, beef, pork and mullet (with various associates). In collaboration again with Dr Whitfield, identifications were made of the complex structures of several novel compounds such as the methoxy-pyrazines (in many green vegetables) and edulans (restricted to passionfruit). The very small amounts of these compounds involved in flavour perception required the development of submicro-procedures for the collection of volatiles, their separation into components, and identification of the structure of these components by chemical and mass spectral methods. Further improvements resulted from the coupling of the g.c.-m.s. to a computer for rapid treatment of the results and from the development of high resolution m.s. techniques.

Despite the importance of these isolation and identification studies, Murray became convinced that flavour research also required knowledge of the odour characteristics of the compounds involved. Following the appointment of Dr D. G. Laing, he and Murray collaborated for a while to establish a basis for research on odour perception. This work is still proceeding, to Murray's great satisfaction, alongside the chemical studies at North Ryde.

Murray's interest in food flavours did not reduce his interest in those natural products that provided the basis for his early research. In collaboration with Dr F. E. Huelin and Mr J. B. Davenport, he investigated farnesene, a very unstable component of apple wax believed to be involved in physiological disorders in the stored fruit and with Dr A. R. Johnson, Mr F. S. Shenstone and Mr A. C. Fogerty, he investigated the cyclopropenoid fatty acids responsible for quality defects in eggs from hens consuming plants and plant products in which these acids occur. Indeed, Murray found applications for his techniques in a number of fields, such as studies of the pheromones of the rabbit anal gland (with the Division of Wildlife Research), the smog-forming hydrocarbons in Sydney's atmosphere (with the Division of Process Technology), and the cause of the 'fishy' body odour emanating from some children.

Murray's ability to apply his techniques to a wide variety of problems became even more apparent after the Division acquired in 1976 a MAT 311A mass spectrometer, which possessed a field desorption ionization facility, enabling its use in the study of unstable and high molecular weight molecules. Murray enjoyed a profitable collaboration with Professor Hans-Rolf Schulten of Bonn University in which novel field desorption m.s. techniques were used to obtain new information about the constituents of several natural waxes. With the assistance of Mr K. J. Shaw, he also became involved in short term but very productive collaborative studies with a number of research groups (Waite Agricultural Research Institute, Roche Research Institute of Marine Pharmacology, and CSIRO Division of Animal Health, to name but a few), all working on unstable natural products with important

physiological activities. One of these collaborative ventures, taken up in his last years in service, was with the Royal Alexandra Hospital for Children and concerned the production of neuro-active amines and toxic phenols in the intestinal tract of children suffering from gastro-enteritis. Murray developed such a personal interest in this project that it will occupy most if his time in the first year of his retirement, since he has accepted the Executive's invitation of an Honorary Research Fellowship to enable him to continue these studies at North Ryde.

So, one more year to add to his 43 years' service with CSIRO, and during all this time, Murray has pursued perfection in the application of his techniques to the study of natural products. An enthusiast for each of the new developments he has been involved in – the spinning band column distillation, gas chromatography in the separation of mixtures, mass spectrometry and, especially more recently, field desorption mass spectrometry in the identification of unknown structures – he has actively sought problems which he considered to represent a challenge to his techniques – and to himself. In meeting these challenges, Murray established a secure position for himself in his chosen field of research, recognized first in 1964 by the award of a D.Sc. in Organic Chemistry by the University of Western Australia for his thesis on the chemistry of waxes and then in 1977 by his election as Honorary Life Member of the Australian Society of Perfumers and Flavorists and in the same year by another election as Member of the Australian Academy of Technological Sciences, fitting tributes to a long and productive career.

B.V.C.

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Dr Joan Maud Bain

Joan Bain retired from the Division of Food Research on 16 July 1982 after just over 30 years' service. She joined the CSIRO Division of Food Preservation and Transport, as it then was, on 10 March 1952. She took her Honours degree in Botany at the University of Sydney in 1943, and then taught and carried out research in the Botany School at Sydney University when Professor Eric Ashby (now Lord Ashby) was Head of Department. Those were the days before extreme specialization — she lectured or demonstrated in algae, anatomy, ecology and plant hormones and plant physiology. Her research on the morphological

development of apple fruit was supervised by Dr (now Emeritus Professor Sir Rutherford) R. N. Robertson of the Division. In 1948 she went to Royal Holloway College, University of London as an Assistant Lecturer in Botany to widen her experience. There she taught an equally wide range of courses and developed research interests in the effects of plant hormones on the development of a green alga. This work led to her M.Sc. degree. Her strong desire to return to Australia resulted in her sailing from England in the *Stratheden* in 1952 without a definite job offer in Australia. However, her application for a Research Officer position with the Division was under consideration so that by the time the ship reached Colombo she had a positive indication of interest from the Division and she was appointed to work at Homebush in the Fruit Section soon after her arrival in Sydney. Being a woman in CSIRO at that time carried a financial penalty — a female research officer was paid £105 per annum less than a male. Her initial research work with the Fruit Section was on the histology of postharvest storage disorders of fruit, but this was soon extended to include the morphological, anatomical and physiological changes occurring during fruit development and maturation, a field of study in which she had begun with R. N. Robertson during her early years at the Botany Department, Sydney University. This was a productive field and she published several papers.

In 1961 she spent about 8 months overseas, at East Malling Research Station in England, a notable centre for all aspects of temperate fruit research, studying the relationship between cell size in apples and the storage disorders of fruit. Part of her time overseas was spent in acquiring information and skills for the operation of the new electron microscope which the Division had purchased in 1960 and which it shared with the CSIRO Animal Genetics group in the Zoology School at Sydney University. On her return she moved from the Fruit Section to the Botany School, Sydney University and worked towards her Ph.D. with the then Associate Professor F. V. Mercer as supervisor. She was awarded her doctorate in 1965 for a thesis entitled 'The Physiology of Aging in Plants'.

She learned a great deal of her electron microscopy skills from Edgar Mercer of the Chester Beattie Cancer Research Institute, and brother of F. V. Mercer, when he spent a sabbatical at Sydney University. Joan Bain and D. F. Ohye rapidly became the Division's experts in electron microscopy, a technique which opened up new avenues for many of the research problems being tackled by the Division. During the 1960s she became increasingly associated with the Division's Plant Physiology Unit which was then located also in the Botany School at Sydney University. The P.P.U. became one of her best 'customers' and she did prodigious numbers of high quality electron micrographs, especially for the work on chloroplast development. However, following her Ph.D. and the setting up of the electron

microscope at the Division's new laboratories at North Ryde, Joan Bain and a small group of assistants became increasingly involved in the wide range of microscopical studies, mainly using electron microscopy, necessary in a Food Science laboratory. These included aspects of plant and animal materials as widely different as chloroplast structure and development, many studies of plant cell structure ranging from unicellular algae to higher plants, cuticular waxes of dried fruit, ultrastructure of zooxanthellae from giant clams, structural changes in milk during processing, vitelline membrane of egg, egg yolk structure and beef muscle. During these years the microscopical work was organized into the Electon Microscope Section, with Joan Bain in charge from 1970. Further organizational changes ensued with the E. M. group joining the Plant Physiology Unit in 1977. Since the Fruit Section had been amalgamated with the P.P.U. in 1974, virtually all the plant work of the Division came together, though electron microscopy was still provided for all other research groups in the Division. Her final two papers in 1982 prove a fitting finale covering a wide range of her activities – microscopical studies of postharvest disease-causing organisms in litchi fruit and an electron micrographic study of membranes in hen eggs.

Joan Bain thus collaborated with an unusually wide range of colleagues. She maintained very high standards in her work and that of her group. It was always a source of admiration that she could quickly find a particular photographic plate or print of work done perhaps 15 or 20 years ago. Her records were comprehensive and obviously effective for the retrieval of information. She provided a wide-ranging service to the Division over many years, sacrificing her own personal interests in structural and ultrastructural botany to the service of Divisional interests. Her electron microscope was claimed by the distributor to be the best maintained in Australia. In was unfortunate that time inevitably took its toll of that machine – it is still functional but should have been replaced by a more modern instrument years ago. Joan Bain's retirement marks the demise of the E. M. group.

Among personal idiosyncrasies which must be recorded is her love of cats. Some of these she kept at the Division. A number of beautiful (Snowy) and not so beautiful (Tom) strays came into her loving care. Many was the time that a sick or injured animal was taken to the vet. Not all of the Division's administration approved of such activities and eventually her 'refuge' was disbanded.

Joan Bain was a long-time supporter of the FRL Staff Club, serving on the Committee from 1956 to 1959, in 1966–67 and as President in 1970–71.

Joan had a notable band of loyal friends both inside and outside the Division. Included among them through her professional work are a former President of the Australian Academy of Science, a Master of a Cambridge College and a bevy (if that is the correct term) of professors of biology. Many of these were able to attend her farewell dinner held at Macquarie University. For the future, Joan is studying bridge and bowls and no doubt will not be able to resist her other love – far-off places. We all wish her well in her retirement.

D. G.

J. M. Bain: list of publications

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