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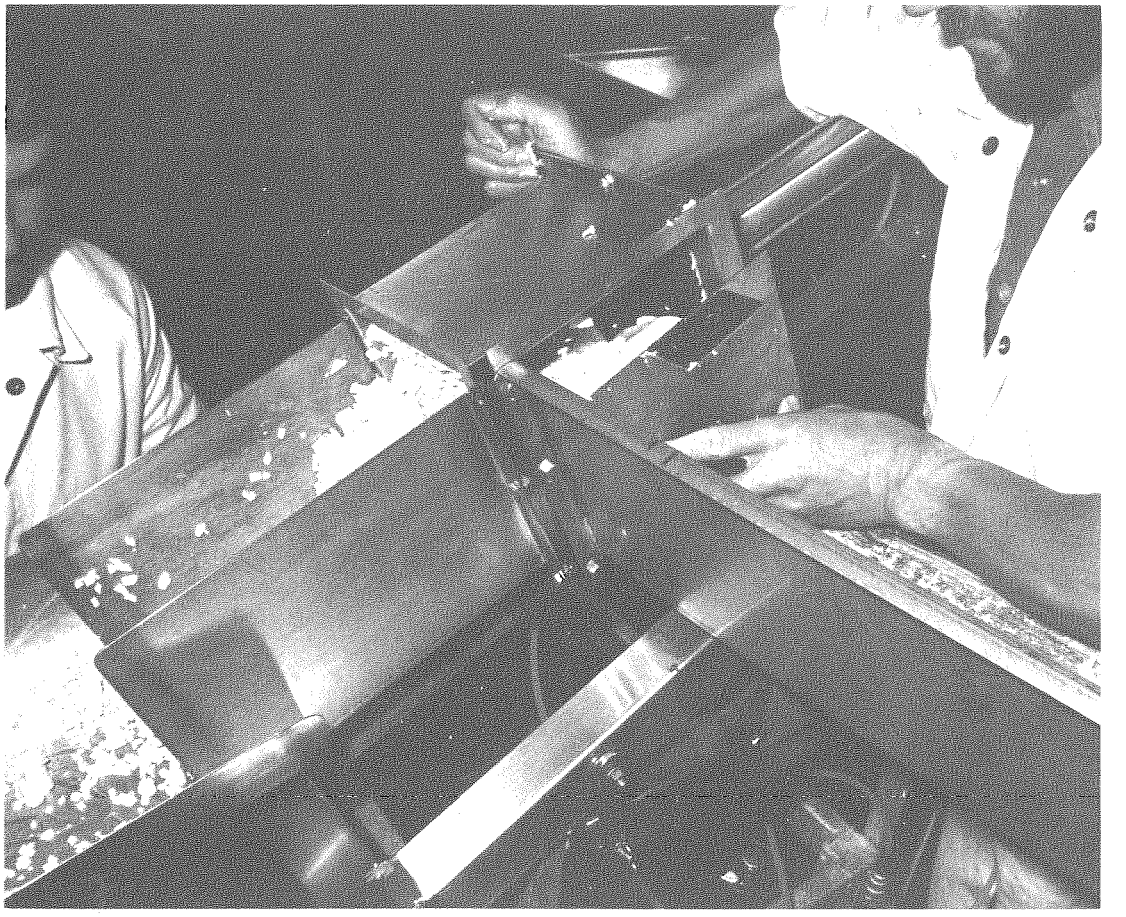

Transmission of viral disease by food

By M. J. Eyles

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There is increasing evidence that our food supply suffers contamination with viruses which can have a significant effect on the health of consumers. Most of this evidence has been obtained either through epidemiological investigations of common-source disease outbreaks or by the detection of viruses infective for man in foods. Food is not generally regarded as the most important vehicle for transmission of any virus and viruses are not the most important group of food-borne pathogens. Nevertheless, viral contamination of food sometimes presents a substantial hazard. This hazard often need not exist. The following discussion is concerned primarily with the viruses presently known to be transmitted by food. Our knowledge of virus transmission by food is inadequate and it has been suggested that many more viruses might be significant food-borne disease agents (Larkin 1978). An understanding of the role of these other agents awaits further investigations.

Viruses transmitted by food

Unlike most other microorganisms found in food, viruses are obligate intracellular parasites; they cannot reproduce outside the living cells of their host. Thus, there cannot be more virus particles present in food than were introduced at the time of contamination. On the other hand, the infective dose of viruses may be much lower than that of many other food-borne pathogens. For a virus to be effectively transmitted by food its mode of release from a host, its stability and other characteristics must be such that it can be found in food in numbers sufficient to cause infection and remain infective until the food is eaten. The virus must also be capable of infecting some part of the alimentary tract when ingested.

Experience suggests that the viruses which have this combination of biological and physical properties are, in the main, viruses found in the faeces of infected humans. The faecal-oral route is an important means of virus transmission and food may act as a vehicle along that route. In most proven instances of contamination of food with viruses infective for man, a human enteric virus has entered food as a result of exposure to water containing human wastes or by contamination directly from an infected food handler. Many of the virus groups found in human faeces are listed in Table 1. Table 1 indicates the virus groups which have either been isolated from foods or shown epidemiologically to be food-borne on occasions. Several of the agents listed in Table 1 have been identified relatively recently and little is known about them. Viruses excreted in faeces may also be excreted by other routes, for example in urine or oropharyngeal secretions.

Viruses transmitted by the faecal-oral route tend to be relatively hardy, surviving well in environments outside their host. The enteroviruses, for example, survive well in aquatic environments, in the presence of some common disinfectants (e.g. 70% ethanol, 5% lysol) and at low pH (pH 3). Hepatitis A virus, which appears to be similar to the enteroviruses, is also relatively stable outside the human body. Although virus stability in foods is influenced by the food composition, storage temperature and other factors, enteroviruses are very stable in many foods, surviving for weeks or months with very little loss of infectivity (e.g. Table 2).

The viruses listed in Table 1 have been associated with a wide range of clinical syndromes. Syndromes associated with infection with various enteroviruses include poliomyelitis, meningitis, myocarditis,

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Table 1. Virus groups represented in human faeces[A]

Enterovirus
includes Polioviruses
Echoviruses
Coxsackieviruses A and B
Hepatitis A virus
Norwalk virus and morphologically similar agents
Reovirus
Mastadenovirus
Rotavirus
Astrovirus
Coronavirus
Calicivirus

[A]Members of groups above the dashed line have been detected in food or have been shown epidemiologically to be food-borne.

conjunctivitis, 'common cold' type illnesses and many others. Infections with enteroviruses are often clinically inapparent. Hepatitis A virus causes hepatitis A, once known as infectious hepatitis. Rotaviruses and Norwalk virus cause gastroenteritis. Feeding trials with human volunteers have shown that members of several groups in Table 1 are infectious by the oral route. These include polioviruses, hepatitis A virus, Norwalk virus and similar agents, and adenoviruses. Epidemiological evidence indicates that others, such as reoviruses, are transmitted by the oral route.

Viruses infective for domestic animals can be found in foods of animal origin when an infected animal is used for production of milk or eggs or slaughtered for meat production. The use of animals with viral infections in food production can have consequences for the health of both domestic animals and man. Several viral diseases of domestic animals can be introduced into areas free of these diseases by importation of contaminated animal products, often with disastrous economic consequences. Foot and mouth disease is one such viral disease which has had an important impact on international trade. With very few exceptions, evidence linking viral infections of food animals and food-borne disease of humans is hard to find and unconvincing, the host specificity of most viruses being an important protective mechanism for man. Some exceptions are discussed later.

Several oncogenic viruses are capable of causing leukaemia and various tumours in animals. Oncogenic viruses have been shown to occur in food as a result of infection of domestic animals or of animals regarded as vermin in environments associated with food production. Bovine leukaemia virus, for example, can be found in raw milk from infected cows. The suspicion that some such viruses may cause tumours in man, and the justifiable sensitivity of consumers to the presence of anything in food that might cause cancer, have prompted several studies of oncogenic viruses in food. However, there is no convincing evidence that these viruses cause tumours in humans.

Viral contamination of food

Contamination by polluted water

Lakes, rivers, estuaries, coastal waters and groundwater play many important roles in food production. There are several routes, some involving food, by which viruses in human wastes can find their way back to man via water. Viruses are frequently introduced into watercourses or coastal waters by the discharge of treated or untreated sewage and by runoff from the land during rain. Although sewage treatment processes reduce virus concentrations in domestic sewage by varying degrees, very few of the processes in current use produce virus-free effluent. Effluents and sludges used in agriculture for irrigation or fertilization may contain viruses. Groundwater can become contaminated with viruses and subsequently contaminate water supplies which come into

Table 2. Survival of poliovirus type 1 on the surface of cooked, peeled prawns during storage[A]

Storage temperature (°C)	Storage time (days)	Mean virus recovery (% of input[B])
4-6	3	64
	8	23
	15	+[C]
−20	8	65
	15	61
	30	42
	180	48
	300	28

[A]Adapted from Eyles (1983).
[B]1.3×10^3 plaque-forming units of poliovirus were added initially to 10-15 g samples of prawns.
[C]Infective virus present.

contact with food.

Bivalve molluscs. — The edible bivalve molluscs (oysters, mussels, clams, etc.) which are harvested from coastal waters, rivers and estuaries in many parts of the world are probably the most significant food vehicles for human enteric viruses. These animals collect their food by filtration of large volumes of water. Thus, the contents of the bivalve digestive system closely reflect the material suspended in the water. Bivalves grown in waters polluted with human wastes may accumulate human enteric viruses to concentrations well above those in the surrounding water (Fig. 1). This problem is exacerbated because bivalves are frequently eaten raw. Even when they are cooked the cooking procedures are often too mild to inactivate all of the viruses which might be present. Cooked shellfish appear to be able to transmit both hepatitis A and viral gastroenteritis.

Human enteric viruses have been detected in bivalves collected from retail or wholesale markets or from waterways approved for shellfish harvesting in several countries, including Australia (Eyles *et al.* 1981). The viruses isolated have included a large number of enterovirus types and reoviruses. The most significant evidence for the role of bivalves as carriers of viral disease has come from epidemiological investigations of common-source outbreaks of hepatitis A or viral gastroenteritis. Many outbreaks of hepatitis A, some involving hundreds of cases, have been attributed to consumption of bivalves harvested from polluted waters. One outbreak, in which mussels were the vehicle, has been reported in Australia (Dienstag *et al.* 1976). Hepatitis A is a distinctive enough disease to be reliably identified on clinical grounds and outbreaks of shellfish-borne hepatitis A were recorded well before the causative virus was identified in the 1970s. Many small outbreaks and sporadic cases of shellfish-borne hepatitis A remain undetected by health authorities because of the many difficulties involved in identifying the source of infection in cases of this disease.

Norwalk virus and a number of similar agents have been associated with gastroenteritis in man in recent years. Although these agents cannot be cultivated in the laboratory, epidemiological and laboratory studies showed that Norwalk virus was the cause of an Australia-wide series of

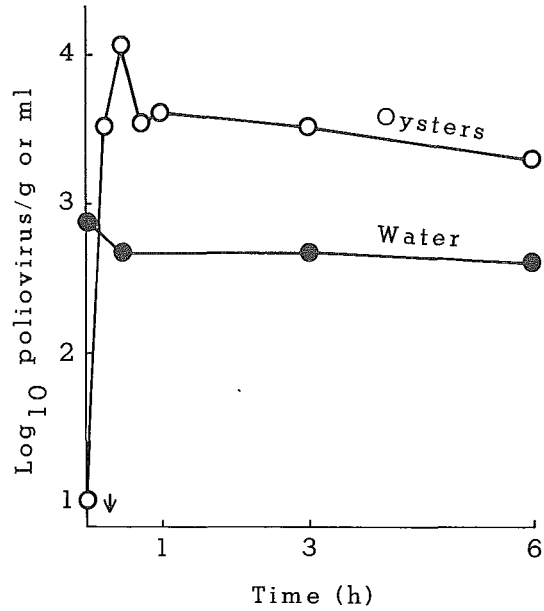

Fig. 1. Uptake of poliovirus type 1 by Sydney rock oysters *(Crassostrea commercialis)* in a laboratory aquarium containing contaminated water.

oyster-borne outbreaks of gastroenteritis involving several thousand people in 1978 (Murphy *et al.* 1979). Since these outbreaks, evidence has been accumulating in several other countries which suggests strongly that shellfish and other foods are vehicles for these viruses.

Other foods. — Foods other than bivalves (e.g. crustaceans, watercress) harvested from polluted waterways may transmit viral disease. The use of contaminated water supplies in food processing environments may also lead to outbreaks of viral disease, as illustrated by several outbreaks of hepatitis A. Viral contamination of crops arising from the application to land of sewage sludges and effluents has been of particular interest in recent years. The water component of effluents is becoming increasingly valued for irrigation in dry areas and the humus and fertilizer content of many wastes are useful agriculturally. Virological studies have indicated that viral disease can be readily transmitted by vegetable crops exposed to such materials and that the agricultural use of human wastes must be very carefully controlled.

Contamination by food handlers

The evidence that infected food handlers may contaminate food with a virus is derived almost exclusively from the many documented food-borne outbreaks of hepatitis A. Although hepatitis A virus has not been detected in food, a number of excellent epidemiological studies have clearly demonstrated the role of food in transmitting hepatitis A from a food handler to consumers. Cliver (1979) summarized the characteristics of 74 outbreaks, in 59 of which the food vehicle was not shellfish. Infected food handlers were the source of the virus in 30 of the latter 59 outbreaks. Most of these food handlers were workers in cafeterias, restaurants, dining rooms, delicatessens, or similar food service establishments. Some were persons who contaminated food served at home or to a social group and others contaminated food at an earlier stage in production and distribution, such as during production of bakery or dairy products.

Most of the implicated foods had been handled fairly intimately and consumed without further cooking. The food vehicles included various kinds of salads, sandwiches and beverages, milk and milk products, fruits, pastries, and meat. It appears that almost any food which comes into contact with human hands may act as a vehicle for hepatitis A virus and other enteric viruses. The contact with food need not necessarily be direct. The source of the virus in one outbreak was a hepatitis sufferer who had not handled food but had worked in the dishwashing area of a school cafeteria (Dull *et al.* 1963).

Transfer of viruses from faeces to food as a result of poor personal hygiene is generally assumed to be the mode of contamination of food with hepatitis A virus by food handlers. Infected food handlers are quite likely to be still at work while hepatitis A virus is apparent in their faeces. The virus is present in large quantities in the faeces late in the incubation period and very early in the clinical course of the illness. The bulk of faecal virus excretion will already have occurred by the time a patient presents with jaundice to a physician. Clinically inapparent infections with hepatitis A virus are also common.

Some authors consider that, in practice, it is relatively uncommon for an infected food handler to contaminate food with hepatitis A virus. Although a food handler could unknowingly be excreting the virus for up to a few weeks during the early stages of the disease, it has often been possible to narrow the time of exposure of victims of food-borne outbreaks to a period of a day or two, perhaps even to a specific meal (Schoenbaum *et al.* 1976). It seems also that individuals ill with hepatitis A are not equally prone to contaminate food items they have prepared (Denes *etal.* 1977). It has been suggested that faecal shedding of hepatitis A virus is not uniform during the early stages of the disease (Denes *et al.* 1977) and that certain persons, or persons at certain stages of the infection, may excrete a large dose of virus concentrated in a small amount of material (Schoenbaum *et al.* 1976). Other factors, especially personal hygiene, also affect the likelihood of disease transmission.

Before poliomyelitis was controlled in developed countries by vaccination, there were several outbreaks of that disease which were probably the result of contamination of food with poliovirus by food handlers. The vehicles for the disease included milk, bakery products and lemonade handled by persons with inapparent infections or in the early stages of infection with poliovirus. Like hepatitis A virus, polioviruses are excreted in faeces very early in the illness, often before the onset of symptoms, and a high proportion of poliovirus infections, like infections with other enteroviruses, remain sub-clinical or inapparent. More recently, a large outbreak of another enterovirus, echovirus type 4, has been reported in which the vehicle was coleslaw served at a picnic (Center for Disease Control 1977). The source of the virus was not stated, although it seems likely to have been an infected food handler. Other human enteroviruses, from unstated sources, have occasionally been isolated from other foods (e.g. milk, meat).

Other mechanisms of contamination

Arthropod pests such as flies and cockroaches are popularly believed to be very important in transmitting viral pathogens to food and, in fact, a variety of human enteroviruses have been isolated from trapped flies and cockroaches. However, there is little direct evidence that arthropods are important in contaminating food with viruses. Poliovirus has been detected in food deliberately exposed to flies in the homes of

victims of a poliovirus epidemic (Ward *et al.* 1945) and the authors considered that such contamination may be a route for transmission of poliovirus. Outbreaks of both hepatitis and poliomyelitis have been blamed on contamination of food by flies which were known to have had access to human faeces.

Tick-borne encephalitis virus of Central Europe is one of the few animal disease viruses known to be significant for human health when present in food. Virus is excreted in the milk of infected goats, sheep, and cows and remains infective for long periods in raw milk and some dairy products. Epidemiological and experimental studies have indicated that human disease may occur as a result of consumption of milk and dairy products containing the virus. Fortunately, pasteurization of milk inactivates tick-borne encephalitis virus.

A macabre example of food-borne transmission of viruses is the theory that cannibalism may have played a fundamental role in the transmission of kuru, a degenerative disease of the central nervous system due to a slow virus infection, among certain tribal groups in New Guinea.

The incidence of food-borne viral disease

The evidence available so far indicates that food is usually relatively unimportant as a vehicle for viral disease. The number of documented food-borne outbreaks of viral disease is small in relation to the incidence of food-borne transmission of many other disease agents. Only 21 food-borne outbreaks of viral disease were reported in the USA in the years 1975-1979, whereas 540 food-borne outbreaks of bacterial illness were reported during the same period (Centers for Disease Control 1981). In addition, food-borne outbreaks of viral disease account for a very small proportion of the reported cases of those diseases. Hepatitis A has been the only viral disease clearly and consistently associated with food over a long period, even though the opportunities for food-borne transmission of other viral diseases demonstrably exist. Human enteric viruses have rarely been isolated from foods other than shellfish.

It is very likely that the incidence of food-borne viral disease is considerably underestimated for several reasons. The majority of infections with enteroviruses and many other viruses in humans are inapparent. Detecting and tracing an outbreak is very difficult if only a small proportion of persons exposed to and infected by an agent suffer overt disease. Outbreaks caused by an agent regularly and frequently associated with an easily recognized clinical syndrome, such as hepatitis, will also be detected more easily than those produced by an agent associated with variable, non-specific clinical signs of disease. The long incubation period of some viral diseases hinders both detection and investigation of food-borne outbreaks, hepatitis A again being a good example. Our knowledge of human enteric viruses is limited; for example, several viral agents of human gastroenteritis have been identified and recognized as important only in the last decade. This lack of knowledge could lead to a failure to recognize food-borne outbreaks of viral disease. Outbreaks of food-borne disease of unknown aetiology are often reported. Recent evidence suggests that viruses might be responsible for some of these outbreaks. These problems are exacerbated by the severe deficiencies which exist in epidemiological surveillance systems both in Australia and overseas.

An important reason for the deficiencies in our knowledge of enteric viruses is the lack of convenient laboratory hosts for cultivation of many of these viruses. Many viruses detectable in human faeces by electron and microscopy and other techniques, including hepatitis A virus and Norwalk virus, cannot easily be cultivated in the laboratory. The human viruses which have been detected in food by laboratory tests have almost all been viruses that are cultivable in cell cultures, predominantly enteroviruses. These problems, together with the epidemiological difficulties discussed above, have led to some anomalies in the evidence for transmission of viruses by food. Hepatitis A and Norwalk viruses have not been detected in food, whereas most of the enteric viruses isolated from food have not been implicated in food-borne disease. Virology is still at an early stage in its development and there is much we do not know about viruses, their means of transmission and their pathogenicity.

Two measures which can reduce significantly the risk of transmission of viral diseases by food are (1) the adoption of safer methods for disposal of human wastes than are frequently used at present and (2) an

improvement in the level of community awareness of the principles of food hygiene. Most known food-borne outbreaks of viral disease can be prevented by keeping human wastes and body secretions out of food.

References

Center for Disease Control (1977). Food-borne and Water-borne Disease Outbreaks. Annual Summary 1976. (US Department of Health, Education and Welfare: Atlanta).

Centers for Disease Control (1981). Food-borne Disease Surveillance. Annual Summary 1979. (US Department of Health and Human Services: Atlanta).

Cliver, D. O. (1979). Viral infections. In 'Food-borne Infections and Intoxications'. (Eds. H. Riemann and F. L. Bryan) pp. 299-342. (Academic Press: New York).

Denes, A. E., Smith, J. L., Hindman, S. H., Fleissner, M. L., Judelsohn, R., Englender, S. J., Tilson, H., and Maynard, J. E. (1977). Food-borne hepatitis A infection: a report of two urban restaurant-associated outbreaks. *Am. J. Epidemiol.* **105**, 156-62.

Dienstag, J. K., Gust, I. D., Lucas, C. R., Wong, D. C., and Purcell, R. H. (1976). Mussel-associated viral hepatitis type A: serological confirmation. *Lancet* **1**, (7959), 561-4.

Dull, H. B., Doege, T. C., and Mosley, J. W. (1963). An outbreak of infectious hepatitis associated with a school cafeteria. *South. Med. J.* **56**, 475-80.

Eyles, M. J. (1983). Assessment of cooked prawns as a vehicle for transmission of viral disease. *J. Food Prot.* **46**, 426-8.

Eyles, M. J., Davey, G. R., and Huntley, E. J. (1981). Demonstration of viral contamination of oysters responsible for an outbreak of viral gastroenteritis. *J. Food Prot.* **44**, 294-6.

Larkin, E. P. (1978). Foods as vehicles for the transmission of viral diseases. In 'Indicators of Viruses in Water and Food'. (Ed. G. Berg) pp. 299-328. (Ann Arbor Science Publishers: Ann Arbor).

Murphy, A. M., Grohmann, G. S., Christopher, P. J., Lopez, W. A., Davey, G. R., and Millsom, R. H. (1979). An Australia-wide outbreak of gastroenteritis from oysters caused by Norwalk virus. *Med. J. Aust.* **2**, 329-33.

Schoenbaum, S. C., Baker, O., and Jezek, Z. (1976). Common-source epidemic of hepatitis due to glazed and iced pastries. *Am. J. Epidemiol.* **104**, 74-80.

Ward, R., Melnick, J. L., and Horstmann, D. M. (1945). Poliomyelitis virus in fly-contaminated food collected at an epidemic. *Science* **101**, 491-3.

News from the Division

Visiting workers

Dr H. Bolin, Western Regional Research Center, U.S. Department of Agriculture, is working for one year from August 1983 with Dr R. J. Steele and Mr E. G. Davis of FRL's Applied Food Science Group on the chemistry of sulphur dioxide interaction with plant tissue and model systems.

Dr S. Andrews, South Australian Institute of Technology, spent six months on study leave from August 1983 working with FRL's Food Safety and Nutritional Quality Group on the identification and physiology of xerophilic fungi isolated from dried foods.

Dr I. Tinsley, Professor, Department of Agricultural Chemistry, Oregon State University, U.S.A., spent eight months at FRL from April 1983 investigating the effect of zinc status on the metabolism of fatty acids in cooperation with Mr A. Fogerty of FRL and Dr I. Dreosti of the CSIRO Division of Human Nutrition.

Some recent advances in cheese technology*

By G. W. Jameson

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During much of the last two decades, the evolution of cheese manufacturing practice has been fairly predictable, with emphasis on mechanization and automation. More recently, an era of change and innovation has begun with the introduction of membrane processing. The concentration of cheese production into fewer and larger factories has continued, albeit at a reduced rate. Milk is now transported over greater distances than previously, and the consequent transport costs are a cause of serious concern. Milk is also stored longer, which can adversely affect cheese quality and yield.

This review covers recent research and development in cheese technology. Mechanization, automation, and the translation of technological developments into commercial practice are reviewed elsewhere.

Treatment of cheesemilk

Cold storage — effects and remedies

Both cheese yield and quality are adversely affected by the rapid cooling of milk upon collection and by its prolonged storage at low temperatures (Harper 1976). A possible chemical basis for these effects is dissociation of micellar casein (especially β-casein) and micellar calcium into the soluble phase on storage of milk at 4°C, followed by partial reversal of these effects on prolonged storage (Ali *et al.* 1980a, b). Cold storage (4°C) of cheesemilk was shown to affect rennet coagulation time and whey expulsion, and to cause cheese yield losses of up to 1.9% (Ali *et al.* 1980a). Addition of calcium reduced the soluble protein levels, showing that it may be a useful remedial measure, but the most effective means of reversing casein dissociation caused by cold storage was found to be heat treatment of the cheesemilk (60°C/30 min or 72°C/30-60s) (Ali *et al.* 1980b).

Cold storage of milk can also selectively permit the growth of psychrotrophic bacteria, with resultant flavour defects and yield losses in cheese (Cousin and Marth 1977; Marshall 1979). These effects have been demonstrated in milk stored at 10°C and shown to be associated with high levels of proteolysis (Ali *et al.* 1980a). However, under the conditions prevailing in good commercial practice (storage below 4°C, and adequate on-farm cooling), it has been claimed that psychrotrophic bacteria are unlikely to grow to levels which adversely affect the yield or quality of Cheddar cheese through their proteolytic activity, although they may give rise to lipolytic rancidity in cheese (Ali *et al.* 1980a; Law *et al.* 1979). By contrast, American studies of cheesemaking from stored milk (temperature unreported) have noted decreasing cheese yields as well as rising moisture levels and declining cheese quality, all changing continuously with milk storage time. Equations for calculating probable cheese yield losses were presented by Hicks *et al.* 1980.

Pre-ripening of cheesemilk with a small inoculum of starter has been advocated for alleviating some effects of modern milk handling practices. Widely studied, it has been found especially beneficial when used after a thermization treatment (Aae 1980).

Coprecipitation

Heat treatments designed to promote

*Review paper delivered at the Second Australian Dairy Technology Review Conference, Glenormiston, 1982, and originally intended as an exhaustive coverage of selected aspects of cheese technology. As such, the bibliography was very extensive, but due to limited space only references to review articles are cited in this publication. Copies of the full bibliography may be obtained by contacting the author.

extensive protein interaction in cheesemilk have been devised by Polish workers (Poznanski *et al.* 1969, 1979; Smietana 1979a).

Homogenization

Nichols (1948) separated cheesemilk, homogenized the cream, and recombined it with the skim milk. From the resulting milk he made Cheddar cheese which was resistant to fat leakage at elevated temperatures. Homogenization of the whole milk was found to be impractical for Cheddar manufacture as it gave a soft rennet curd, but it has recently been found to be beneficial in the manufacture of soft cheeses (Humbert *et al.* 1980). Fat losses in the whey were reduced, and cheese texture was improved by moisture retention. Relatively mild homogenization caused decreased rennet coagulation time and increased curd firmness, but more severe homogenization reversed these trends.

Ultrafiltration

A major innovation in dairy processing, ultrafiltration, is reviewed in a separate section.

Starters

Bacterial starters are reviewed separately. Alternative acidification systems (e.g. direct acidification with mineral acid) have been studied periodically and were reviewed by Fox (1978), but have not been widely accepted in commercial practice. Direct acidification in Cottage cheese manufacture was recently shown to give increased yields (up to 5% increase) together with better flavour and texture (Bassette 1980).

Rennet, rennet substitutes and milk coagulation

Many aspects of these topics have recently been reviewed elsewhere (Green 1977; Koning 1980; Martens and Naudts 1978; International Dairy Federation 1976). Many of the recent developments have related to the use of microbial rennets, prompted by the shortage and cost of calf rennet. Microbial rennets are normally resistant to thermal denaturation, leading to high residual proteolytic activity in cheese whey. To overcome this, enzyme preparations from *Mucor miehei* have been modified to decrease their thermal stability (Branner-Jorgensen, Scheider and Eigtved 1980a, 1980b). The modified enzymes have been tested in the manufacture of many cheese varieties, and are now reported to be widely used (Anon 1981a; Christensen 1979). Reports of cheese yield losses and quality defects associated with the use of microbial rennets were once common but are now rarely seen, due both to development of the enzyme preparations and to better understanding of their mode of use (Green 1977).

The time required for initial formation of a rennet coagulum in milk and the subsequent rate of curd firming both have important implications for the yield and quality of the cheese produced. Christensen (1979) has discussed their importance in relation to the use of microbial rennets and the problems generated by making cheese to a time schedule in totally enclosed vats. Kowalchyk and Olson (1979) have shown that clotting time and curd firming rate are affected differently by type of enzyme (calf rennet, rennet-pepsin, or microbial rennet), pH and temperature of milk, ionized Ca concentration, season, and by interactions of these factors. Milk protein concentration strongly influenced the rate of curd firming and the degree of firmness ultimately developed, but fat content had little effect (Garnot, Rank and Olson 1981). An oscillating diaphragm curd firmness sensor developed at CSIRO Dairy Research Laboratory (Vanderheiden 1976) was used in these studies. This apparatus is suitable for use in enclosed vats under commercial conditions, and economic benefits could be obtained through its use (Christensen 1979). English workers have modified the instrument and confirmed its usefulness (Marshall, Hatfield and Green 1982). South Australian workers have shown that both curd firmness and syneresis are affected by the casein and mineral content of milk, and that these factors vary seasonally (Zviedrans, Graham and McLean 1982). Swiss workers selectively removed soluble milk components by ultrafiltration and demonstrated that slow renneting behaviour is due to changes in the milk salt balance (Flueler and Puhan 1979).

An important practical point sometimes overlooked in the use of rennet is its destruction by chlorine in the water used for dilution purposes. Pearce (1978) showed that substantial rennet inactivation can take place in 5 minutes with residual chlorine present at levels common in factory-treated water.

Immobilized milk coagulation enzymes

generated much interest several years ago as they initially appeared to be a basis for continuous coagulation processes (Olson and Richardson 1975). Interest has waned and commercial application of the technique now seems unlikely. Beeby (1979) took rigorous precautions to prevent leakage of enzyme from his immobilized preparation, and observed no coagulation after passage of milk through a column of the material. Green (1977) and Beeby (1979) point out that the coagulation of milk by rigidly immobilized enzymes is incompatible with current theories of casein micelle structure and the chemistry of the rennet coagulation process.

The continuous coagulation of milk or retentate has been reviewed by Berridge (1976). A form of continuous coagulation is a commercial reality in the Alpma Coagulator, now in use in Europe for the manufacture of soft cheeses (Hansen 1975).

Addition of whey proteins in cheese manufacture

The addition of denatured whey protein preparations to cheesemilk in order to increase cheese yields usually results in cheese with defective flavour and texture (Bachmann *et al.* 1976; Brown and Ernstrom 1977; Buchheim and Jelen 1978). The addition of dried whey to cheesemilk has also proved unsuccessful (Wingfield *et al.* 1979). When, however, whey proteins are added to cheesemilk in a relatively undenatured form as ultrafiltered whey protein concentrates, more satisfactory results can be obtained. The successful manufacture of Camembert-, Feta- and Gouda-type cheeses by this approach has been reported (Georgakis 1974; Bachmann *et al.* 1976; Nes 1980), while Pien (1976a, b) has discussed the approach in general terms, claiming beneficial effects on the physical properties and rate of flavour development of cheese.

Cheese manufacture from stored forms of milk

The manufacture of cheese from recombined or reconstituted milk powders is of especial interest in countries such as Australia and New Zealand, where pasture feeding of dairy cattle results in marked seasonal fluctuations in the milk supply. Much of the relevant technology has been recently reviewed by Gilles and Lawrence (1981). Polish workers (Smietana 1979b) have reported the use in cheesemaking of milk powder manufactured from milk subjected to the 'Serwit' co-precipitation procedure – 92°C/15s with 3.6 mM $CaCl_2$ added (Poznanski *et al.* 1979; Smietana 1979a). Increased whey protein utilization was claimed together with an absence of adverse effects on cheese body, texture and flavour. However, a recent Australian attempt to use 'Serwit' whole milk powder in the manufacture of Cheddar cheese was unsuccessful (G. W. Jameson and R. M. Shanley, unpublished observations). The curd obtained was too soft for cheesemaking purposes.

Published procedures (drawn from those reviewed by Gilles and Lawrence 1981) for cheese manufacture from recombined milk were evaluated by Shanley and Jameson (1982) for the manufacture of Cheddar cheese. The resulting cheeses had severe body defects and lacked Cheddar flavour. Various procedures intended to remedy these defects were unsuccessful, but mixtures of fresh milk (60% v/v) and recombined low heat skim milk powder yielded satisfactory cheese. It was also possible to obtain satisfactory Cheddar cheese from mixtures of fresh milk and reconstituted medium heat whole milk powder, but the permissible level of the latter component was small (10–20% of solids) (Shanley and Jameson, unpublished observations). A possible opening for future research arises from a report by Kosikowski (1981) that supplementation of low heat recombined skim milk powder with full fat retentate reduced the crumbliness of Cheddar cheese made from the mixture.

Davis (1980) has described an unusual cheesemaking procedure utilizing fermented recombined cream, anhydrous milk fat, skim milk powder and sodium caseinate (or various alternatives). No whey is produced, yields are high, and economic advantages are claimed. However, the procedure has not been used commercially, and it yields cheese with a substantial residual lactose content.

When cheese is manufactured from reconstituted retentate powders, it is possible to retain the whey proteins in the cheese without excessive residual lactose. Some of the technical possibilities have been surveyed by Madsen and Bjerre (1981a). Reconstituted spray-dried retentate was used by Graet and Maubois (1979) to make fresh

soft cheese of satisfactory quality, and by Siapantas (1979) to make Feta. Goat's milk retentate has been stored in both spray-dried and frozen forms (Pierre 1978), and the latter form of storage is now used commercially (Anon 1979a).

Accelerated maturation

Costs associated with maturation contribute substantially to the production costs of hard cheese, accounting for the continuing interest in methods of accelerating maturation without sacrificing cheese quality (Law 1978, 1980). A recent example is a method claimed to yield satisfactory hard grating cheese in 2–6 months, in which the drained curd is incubated at 45 °C for 4–20 hours, milled, dry salted and pressed (Johnson 1981).

The cheese curd slurry system initially appeared to have potential as a source of intense Cheddar cheese flavour for processed cheese manufacture (Sutherland 1975). Subsequent experience with slurries on a larger scale at CSIRO suggested that consistent flavour quality was not compatible with high flavour intensity, and development of the system was terminated (Shanley and Jameson, unpublished observations). American workers have continued to use slurries for studying the chemistry of Cheddar cheese flavour formation in the laboratory, demonstrating, for example, the effects of poly-unsaturated milk fat and the role of sulphydryl groups (Harper and Blaser 1981). In Australia, Dulley (1976) has reported that addition of ripened curd slurry to Cheddar curd at salting accelerates the maturation of the resulting cheese, while a recent Dutch patent (Ruys 1979) claims a similar benefit from the addition of finely divided matured cheese to cheesemilk.

Addition of enzymes (usually proteases and lipases) has long been a favoured method for enhancing cheese flavour production, and cheese flavour concentrates consisting largely of enzyme-modified cheese curd are now commercially available. Sood and Kosikowski (1979a, b, c) optimized the choice and levels of enzymes in a cheese curd slurry system, and then used these enzymes both to accelerate the ripening of natural Cheddar cheese and to develop cheese flavour in retentate which was then incorporated into processed cheese. An alkaline protease was used by Irish workers (O'Keeffe *et al.* 1979) to accelerate Cheddar cheese ripening. Law and Wigmore (1982) reported that addition of bacterial neutral protease accelerated flavour development in Cheddar cheese but rendered cheese body softer and more brittle.

Microencapsulated bacterial cell-free extracts have been incorporated into cheese to accelerate maturation, but microcapsule instability created some difficulties (Magee, Olson and Lindsay 1981). Workers from the same group evaluated the high pressure injection of cheese ripening enzymes, but found that a suitable esterase failed to diffuse in cheese (Lee, Olson and Lund 1978, 1980). The practical utility of these approaches is not yet clear.

A novel treatment of cheesemilk was claimed by Thompson and Brower (1976) to markedly accelerate Cheddar cheese ripening. The procedure involved partial hydrolysis of lactose by 'Maxilact', a commercially available yeast β-galactosidase. This claim generated much interest, but some workers, including those at CSIRO, were unable to verify it (Jameson and Shanley, unpublished observations). Workers in Queensland eventually demonstrated that the accelerated maturation was associated with increased proteolysis (Marschke and Dulley 1978), caused by a contaminating protease in the Maxilact (Marschke *et al.* 1980). Other yeast proteases may be useful for accelerating cheese ripening (Grieve 1982). Claims for increased yield of cottage cheese from lactose-hydrolyzed milk have also been refuted (Fedrick and Houlihan 1981).

An alternative approach to accelerating cheese maturation employs the incorporation of additional but non-acid producing starter bacteria into the cheese. Heat-shocked starters were first used for this purpose by Petterson and Sjostrom (1975), and were shown to accelerate proteolysis and lipolysis in Cheddar cheese by Thompson (1980). Incorporation of additional lactase-deficient starter mutant into Cheddar cheese has been reported to accelerate flavour production (Dulley, Brooks and Grieve 1978).

Some technological factors influencing cheese flavour formation

The mechanisms of cheese flavour production largely fall outside the scope of this paper. They have been intensively studied over the last decade, and recently

reviewed (Hillier and Jago 1978; Forss 1979; Law 1981; Visser 1981). The chemical basis of Cheddar flavour is not yet fully understood, but many factors influencing it are known. Instrumental analysis of cheese flavour compounds and precursors may eventually provide an objective basis for evaluation of cheese flavour (Aston, Durward and Dulley 1982; Horwood, Lloyd and Ramshaw 1982), but many difficulties remain (Aston 1982).

Also ways in which cheese composition affects flavour are reviewed in the section on cheese quality. New Zealand workers have established that both lactose utilization and proteolysis in maturing Cheddar cheese are strongly affected by small changes in salt in moisture (S/M) (Thomas and Pearce 1981). An English study showed that Cheddar cheeses made in open vats matured more rapidly than cheeses made in enclosed vats. Starter strain had little effect on cheese flavour, but high populations of viable starter cells caused bitterness. Maturation temperature was the dominant factor controlling flavour intensity (Law, Hosking and Chapman 1979).

The fat and flavour chemistry of Feta cheeses from different sources has been investigated by a CSIRO group (Horwood, Lloyd and Stark 1981). The group also established that a flavour defect in Feta cheese was due to the application of sorbic acid to prevent mould growth, and pointed out the possible dangers to public health associated with the use of this preservative on low pH products (Horwood *et al.* 1981).

Retarded maturation and preservation

The maturation of cheese may be retarded by storage at low temperature, but freezing usually causes breakdown of the cheese structure, resulting in a short, crumbly or mealy body. Quarg can however be successfully frozen (Luck 1977).

The freezing point of cheese varies widely (from −1 °C to −16 °C) according to variety and degree of maturity. The fat content also has a strong influence on the resistance of cheese body to disruption by freezing. Most varieties of cheese, including Cheddar, can be stored at −2° to −5 °C with very marked retardation of flavour production and proteolysis (Luck 1977; Jameson, Beeby and Shanley 1978). Freezing (at −20 °C) can be used to prevent over-maturity in Cheddar cheese for processing. The general quality of the resulting processed cheese is satisfactory (Thomas, Newell and Abad 1980).

Heat treatment of cheese is the major alternative to cold or frozen storage for retarding maturation, or even for preventing it. Stehle (1980) has reviewed the possibilities with Camembert cheese. Microwave heating is an interesting new method which is claimed not to overheat the cheese interior (Leon, Remars and Tracard 1976). A novel method for treating retail-packaged high moisture foods, such as unripened cheeses or yoghurt, has been patented by Bach (1976), and is in commercial use (Hansen 1977a). High frequency electromagnetic fields operating at two different frequencies are used to separately heat the food product and head space in the container. Improved shelf life and product quality are claimed.

Cheese processing

Mann (1981) has reviewed most of the more recent information available on cheese processing.

Cheese yield

Milk fat and milk protein are expensive raw materials, yet cheese manufacturers often have surprisingly little information on the recovery of these components in their product. The relevant literature, reviewed by Olson (1977), extends back many years, and has recently been supplemented. Banks *et al.* (1981) studied seasonal effects on milk composition and cheese yield in Scotland, and observed a weak positive correlation of casein/fat ratio (C/F) in cheesemilk with fat recovery in cheese, together with a weak inverse correlation between C/F and protein

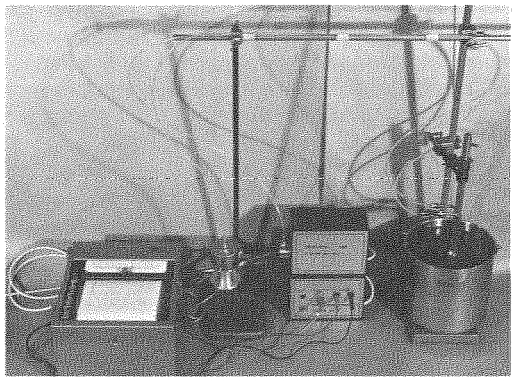

Fig. 1 Curd firmness tester developed at DRL.

recovery. Bynum and Olson (1981) studied the effect of curd firmness at cutting on cheese yield and the recovery of milk constituents. Although the effects were small, milk fat recovery and cheese yield per unit milk fat were greater when curd was cut at slightly greater firmness than normal. Relationships between cheese yield and milk composition, particularly as influenced by seasonal factors, have been discussed by Chapman (1981) and Phelan (1981).

Ultrafiltration in cheese manufacture

The introduction of pressure driven membrane processing — reverse osmosis (RO) and ultrafiltration (UF) — promises to revolutionize dairy manufacturing technology. Cheese yields are increased significantly when cheese is manufactured from milk selectively concentrated by UF, providing a major economic incentive for developing the relevant technology. Research and development associated with this new technology have already generated a substantial literature, reviewed by Glover *et al.* (1978), Maubois (1978), Mocquot (1979), and by Sutherland and Jameson (1980, 1981). The present survey will be confined to significant recent developments.

General

On-farm UF could significantly reduce milk transport costs associated with cheesemaking. Pilot studies have been performed, and from one in France an encouraging preliminary report has been published (Anon 1980a).

Mineral levels influence the physical properties and sometimes the taste of cheese made by UF (Sutherland and Jameson 1981, 1982). Retentate mineral levels, and hence cheese composition may be controlled by adjusting milk pH before UF (acidification reduces Ca and P levels, and changes their ratio). Equipment required for performing this operation commercially has been discussed (Hansen 1981a).

The use of recombined spray-dried retentate powders in cheese manufacture has been reported (Ducruet 1979).

Starter performance

Relatively little has been published on the growth and metabolism of starter bacteria in retentates. Narasimhan and Ernstrom (1977) reported phosphate inhibition of lactic streptococci growing in skim milk retentates, while Covacevich and Kosikowski (1979) quantified the increased buffering capacity of retentates and the rate of pH change with both chemical acidification and lactic fermentation. Starter bacteria have been shown to grow well in retentates after storage, and were not adversely affected by prior growth of adventitious microorganisms (Tayfour *et al.* 1981). Effects on metabolism have however been detected by comparing retentate with skim milk as the growth medium for selected strains of lactic streptococci. Relative rates of acid production changed with the medium to a degree which varied between bacterial strains (K. Nguyen, unpublished observations).

Coagulation

The rennet coagulation of retentate has been intensively studied, and Mocquot (1979) has summarized the main characteristics of the process. The earliest studies showed that the concentration of rennet required to coagulate milk or retentate in a given time varied little with protein concentration. Thus when cheese is made from retentate, the amount of rennet required to make a given amount of cheese is reduced approximately in proportion to the concentration factor of the retentate (Maubois *et al.* 1971). Deviations from this relationship can be reduced by addition of calcium chloride to the retentate (Schmutz and Puhan 1978), but they increase at lower pH (pH <6.7) and at low rennet concentrations (Garnot and Corre 1980; Culioli and Sherman 1978).

More recently, detailed kinetic and chemical studies of the rennet coagulation of retentate have been reported by Reuter, Hisserich and Prokopek (1981), Garnot and Corre (1980), van Leeuwen (1982) and by Culioli and Sherman (1978). The latter authors also studied changes in gel rheology. The coagula formed from renneted retentate differ from milk coagula in rheology (they are much firmer and less elastic), and in the degree of micelle interlinkage.

Less complete cleavage of the rennet-sensitive bond in κ-casein is required for coagulation to commence.

Heat treatment

A potentially useful property of retentate has been noted in the patent literature. It is

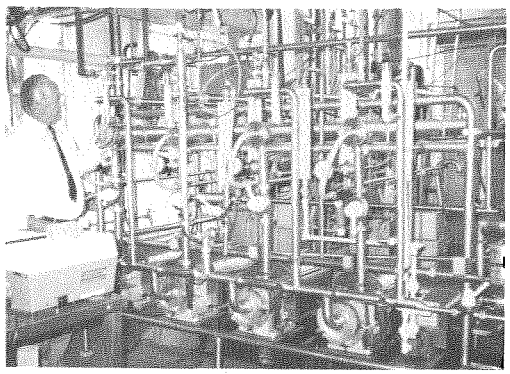

Fig. 2 Pilot-scale ultrafiltration equipment at DRL.

claimed that retentate can still be coagulated by rennet and converted into cheese after prior heating to sterilizationtemperatures of 110°–120°C (Delespaul and Remars 1980; Maubois *et al.* 1976).

Applications to cheesemaking

Quarg and fresh cheese. — Yields of quarg can be increased 25–30% by manufacture using UF. The unacceptable taste due to retention of excess calcium in the product can be eliminated by UF at pH 5.7–5.9, achieved by partial fermentation of the milk (Puhan and Gallmann 1981). An alternative approach is the UF of acid curd (pH 4.4) using mineral membranes (Mahaut *et al.* 1982).

Ricotta. — Introduction of UF makes a continuous manufacturing process possible, allows reduction in heating costs, and yields a product claimed to be of excellent quality. The process involves hot packaging, which is reported to improve product shelf life (Maubois and Kosikowski 1978).

Cottage cheese. — Increased yield has been claimed for the manufacture of Cottage cheese using UF (Jepsen 1979), while Kealey and Kosikowski (1981) have developed a modified manufacturing process designed to overcome problems of soft texture and poor cream absorption encountered earlier. The new process yielded an acceptable product.

Cream cheese. — Cream cheese manufactured by UF was found by Covacevich and Kosikowski (1977) to be excessively hard and brittle, but Jameson (unpublished observations), using a similar manufacturing process, obtained a soft product with a flavour defect due to excessive mineral levels. Ultrafiltration at pH 5.8 reduced the severity of the defect. The yield increase and economic benefits of the process have not yet been established.

Camembert. — This variety was the first to be produced by UF (Maubois *et al.* 1971). The manufacturing process is now operating commercially, with yield increases of 12–18%. A new automatic mechanized plant (the 'Camatic') based on the new process and with a capacity of up to 10 tonnes of cheese in 8 hours has been described (Hansen 1981b; Anon 1979b, 1981b). The product is claimed to differ only slightly from traditional Camembert, notably in body characteristics. However, an earlier study demonstrating significant structural and organoleptic differences between UF and traditional Camembert cheese has yet to be refuted (Prokopek, Knoop and Buchheim 1976). An economic analysis suggests that the entire Camatic plant could be amortized in about 2 years (Anon, 1981b).

Coagulation in the Camatic plant takes place in travelling individual moulds ('micro basins'). An alternative process uses the Alpma coagulator (Hansen 1975), but smaller yield increases are obtained as the milk is less extensively concentrated by UF (Hoffman 1977).

Blue cheese. — The methods reported for manufacturing Blue cheese by UF allow some whey expulsion in order to achieve the desired composition. Yield increases of 5.5–13.5% are claimed, and the product quality is said to be similar to that of conventionally-made cheeses (Jepsen 1977; Mahaut and Maubois 1978).

Mozzarella. — In experimental manufacture, retentate solids levels of 45–50% in the 'pre-cheese' were obtained by blending plastic cream, skim retentate and freeze-dried skim retentate. When the retentate used was prepared with simultaneous fermentation and with adequate diafiltration (to control mineral and lactose levels respectively) Mozzarella cheese of generally good quality was obtained except possibly for melting characteristics (Covacevich and Kosikowski 1978). In a later study of Mozzarella made from milk supplemented with retentate, stretching in hot brine was found to reduce fat losses (Fernandez and Kosikowski 1981). A Mozzarella production process based on UF is offered by an equipment supplier, with

a claimed yield increase of 16% (Friis 1981b).

Feta. — The most successful commercial application of UF in cheesemaking has been in the manufacture of Feta. In Denmark alone, Feta is made by UF in at least nine factories and successfully exported to the Middle East even though the cheese body and texture differ considerably from those of the traditional product (Friis 1981a). The manufacturing method is now well known (Hansen 1977b). The operation of a factory using the process has been outlined (Hansen 1980a), and a complete automatic plant designed to treat 300 000 kg milk/22 h (i.e. 3000 kg Feta/h) has been described in detail (Hansen 1980b). The yield increase obtained is said to be 18% based on skim milk utilization (Hansen 1977b). Pilot-scale experiments by Mahmoud and Kosikowski (1979) suggest that a pouch-ripening technique (plastic lined Al pouches) can increase cheese yield and enhance flavour production.

St. Paulin. — This variety was the first to be manufactured from milk concentrated on the new 'third generation' UF membranes — zirconium oxide in carbon tubes (Anon 1979c; Goudedranche *et al.* 1981). High UF pressures were required, but concentration by factors up to 7.5:1 could be achieved, yielding retentates with solids contents of 45% and protein contents of 20–22%. Ultrafiltration plant performance (average flux 30 $L/m^2/h$) showed some unusual features not encountered at lower concentration ratios. Control of lactose level in the retentate by diafiltration proved to be essential in manufacturing this type of cheese. In cheese manufacture, the retentate was inoculated with starter, salt was added, and then rennet. Coagulation took place in moulds, and little whey was expelled. Some variants of the process produced cheese almost identical with the conventionally-made product. The yield increase obtained was 19% (Goudedranche *et al.* 1981). The economics of using this type of UF plant have not yet been discussed. Capital and energy costs of UF are likely to be higher than previously encountered.

Low-fat semi-hard cheese. — This cheese, with 20% fat in dry matter (FDM) was made by a combination of UF and evaporation (scraped-surface) in order to achieve the desired solids level (42% in final 'pre-cheese'). Control of lactose level was again necessary. Scraped surface heat exchangers were used for adding starter and rennet as well as for adjusting retentate temperature. Whey proteins were largely retained by this process, giving a yield increase of 25%. The product quality was satisfactory, and the most useful feature was that the inclusion of whey proteins gave a softer, smoother consistency than 20% FDM Gouda (Boer and Nooy 1980a, b). Whey proteins were shown to constitute 18.5% of the total cheese protein, and they were resistant to proteolysis during maturation. Concentrations of protein breakdown products were therefore reduced in the UF cheeses, possibly accounting for their lower flavour level (Koning *et al.* 1981).

Swiss-type — Semi-hard cheeses with propionic eye formation were made from retentate (45% solids) prepared using mineral UF membranes and diafiltration. Avoiding air entrainment in the retentate was found to be important. Variation in the surface treatment of the finished cheeses (smear V. rind) gave products with differing flavour, body and eye size (Ducruet *et al.* 1981).

Cheddar. — Freeze-dried and liquid retentate were blended by Covacevich and Kosikowski (1978) to obtain the desired solids level, and the mixture used to make Cheddar cheese without whey formation. The product had serious body and texture defects (corky, crumbly) and lacked flavous, but it processed satisfactorily. Green, Turvey and Hobbs (1981) used retentate (up to 4:1 concentration) in a relatively conventional manufacturing procedure involving whey production. Fat losses were unacceptably high (up to about 55%). The cheeses made using UF lacked flavour, a characteristic tentatively ascribed to reduced rennet activity in the cheese. The cheeses made in these experiments were studied by light microscopy, scanning and transmission electron microscopy, and instrumental textural analysis. Ultrafiltration concentration factor was thereby shown to affect cheese structure and texture (Green *et al.* 1981). By contrast, Sutherland and Jameson (1981) were able to obtain acceptable Cheddar cheeses from 4.8:1 whole milk retentate. The desirable degree of diafiltration was determined, and means of controlling cheese mineral content established, using acidification before UF. The effects of cheese mineral content on rheology of the cheeses were investigated

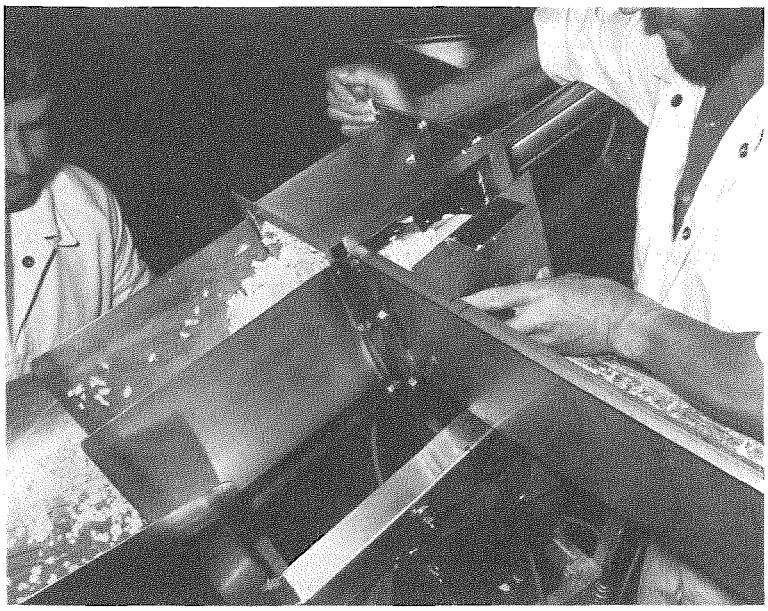

Fig. 3 Pilot-scale cheesemaking plant for the manufacture of hard cheese from ultrafiltered milk.

(Sutherland and Jameson 1982) and an optimum pH of 6.4 during UF established. This manufacturing method is being developed into a commercially viable process at CSIRO Division of Food Research, Highett (van Leeuwen 1982b; van Leeuwen *et al.* 1982).

Cheesebase. — This product is made from whole milk by ultrafiltration, diafiltration, fermentation and then evaporation. It has the composition of Cheddar cheese but lacks its flavour (except for acid) and body characteristics. However, it is obtained in 16–18% greater yield, and is suitable for use in processed cheese manufacture (Ernstrom, Sutherland and Jameson 1980). The economics of cheesebase manufacture appear to be attractive (Sutherland 1982), and it is claimed that the capital outlay involved could be recouped in two years (Madsen and Bjerre 1981b). Retentate can also be used in cheese processing without further modification (Kumar and Kosikowski 1977).

Cheese quality and quality prediction

The four factors that largely determine the quality of Cheddar cheese (composition, rate and extent of acid production, curd structure before salting, and maturation temperature) have been reviewed by Lawrence and Gilles (1980). Composition is of great importance (Pearce and Gilles 1979), and the optimum ranges of the most significant parameters were established for Cheddar cheese as: FDM 50% minimum, moisture in non-fat substance (MNFS) 52–56%, pH 4.95–5.20, and salt in moisture (S/M) 3.7–6.3%. MNFS was shown to be the most important single parameter, but manufacturing conditions must also be considered. The time curd is held in the whey and the acid development during this period have important influence on cheese quality (Czulak *et al.* 1969). Curd structure (influenced, for example, by extent of cheddaring and curd particle size) influences salt uptake. The effects of salt content on cheese quality are well known. Excessive salt levels inhibit proteolysis and lactose fermentation by starters (Thomas and Pearce 1981), while inadequate salt levels may permit growth of undesirable microorganisms. Milk quality, other manufacturing parameters, and maturation temperature are also known to affect cheese quality (Lawrence and Gilles 1980).

The foregoing discussion refers to Cheddar cheese, but the principles apply to other varieties. For example, many of the same

points are made in a discussion of compositional effects on Gouda quality (Vries 1979). Differences arise mainly with respect to control of lactose level by water addition to the whey, and in the brine salting process.

Cheese quality prediction is a matter of great commercial importance. If the skills of a professional grader are used together with knowledge of the manufacturing parameters, composition and intended storage conditions, it is possible to predict the maturation potential of young (2–3 week-old) cheese. Such predictions usually give useful guidance in choice of the appropriate market and stage of maturation at which the cheese should be sold. There is, however, a significant lack of correlation between the quality of Cheddar cheese as assessed by professional graders and acceptability of the cheese as perceived by consumers (McBride and Hall 1979). The preferences of consumers were found to be unrelated to cheese grade, although there were some differences detected when the consumers were split into age groups (e.g. the older consumers preferred second grade cheese). The results suggest that most types of cheese can find a niche in the market place. Pre-requisites for successful marketing of the range of cheese types encompassed by a single variety such as Cheddar are identification and reliability. The cheese type should be made readily identifiable by suitable packaging and labelling, and its organoleptic attributes should exhibit minimal variation.

References

Berridge, N. J. (1976). *J. Dairy Sci. Res.* 43, 337.

Forss, D. A. (1979). *J. Dairy Res.* 46, 691.

Fox, P. F. (1978). *Bull. Int. Dairy Fed.* Doc. 108, 33.

Gilles, J., and Lawrence, R. C. (1981). *N.Z. J. Dairy Sci. Technol.* 16, 1.

Glover, F. A., Skudder, P. J., Stothart, P. H., and Evans, E. W. (1978). *J. Dairy Res.* 45, 291.

Green, M. L. (1977). *J. Dairy Res.* 44, 159.

Hillier, A. J., and Jago, G. R. (1978). *CSIRO Food Res. Quart.* 38, 1.

International Dairy Federation (1976). *Ann. Bull., Int. Dairy Fed.* (91), 38 pp.

Koning, P. J. de (1980). *Bull. Int. Dairy Fed.,* Doc. 126, 11.

Law, B. A. (1978). *Bull. Int. Dairy Fed.,* Doc. 108, 40.

Law, B. A. (1980). *Dairy Ind. Int.* 45 (5), 15.

Law, B. A. (1981). *Dairy Sci. Abstr.* 43, 143.

Lawrence, R. C., and Gilles, J. (1980). *N.Z. J. Dairy Sci. Technol.* 15, 1.

Madsen, R. F., and Bjerre, P. (1981a). *Nordeurop. Mejeri-Tidsskr.* 47, 120.

Mann, E. J. (1981). *Dairy Ind. Int.* 46 (2), 13.

Martens, R., and Naudts, M. (1981). *Bull. Int. Dairy Fed.,* Doc. 108, 51.

Maubois, J. L. (1978). *XX Int. Dairy Congr., Conf.* 10ST.

Mocquot, G. (1979). *Proc. first Bienn. Marschall Int. Cheese Conf.* Miles Labs. Inc., Madison, Wis., USA, p. 603.

Olson, N. F. (1977). *Dairy Ind. Int.* 42 (4), 14.

Sutherland, B. J., and Jameson, G. W. (1980). CSIRO Dairy Res. Rep. 29, 12 pp.

Sutherland, B. J., and Jameson, G. W. (1981). *Aust. J. Dairy Technol.* 36, 136.

Visser, S. (1981). *Neth. Milk Dairy J.* 35, 65.

News from the Division

Transfer

Dr A. J. Evans, Senior Research Scientist, transferred to the Division in July 1983 and is now working on the properties of dietary long chain unsaturated fatty acids in FRL's Food Safety and Nutritional Quality Group.

He was previously leader of the Duck Program at the Institute's Project for Animal Research and Development, PARD, in Indonesia. Dr Evans graduated in Science from the University of W.A. and obtained the M.Sc. from the University of Sydney and his Ph.D. from Edinburgh University.

Changes to FRQ Editorial Committee

In July 1983 Mr J. F. Kefford, Chairman of the Editorial Committee since 1977 and Dr D. L. Ingles, FRL, resigned their membership. Mr K. C. Richardson, leader of FRL's Liaison Group, was appointed the Committee's new Chairman and Drs W. B. McGlasson and R. W. Sleigh of FRL also joined the Committee.

The structure and quality of meat

By R. W. D. Rowe

CSIRO Division of Food Research, Cannon Hill, Queensland, 4170

The importance to meat science of understanding meat structure is reflected in the current theories of the underlying causes of variability of meat toughness. Even though the structure of meat has been investigated by numerous workers for many years, there are still some important areas where information is not available. Surprisingly, these gaps in our knowledge of meat structure occur at all levels, from the macroscopic through to the finest ultrastructural level of organization. As these gaps are recognized and eliminated, our ability to develop a more comprehensive understanding of the reasons for variability of meat quality increases.

This paper points out some of the structural features of meat which, in the author's opinion, need further investigation and consideration in developing updated explanations of the variability of meat toughness.

Introduction

Ultimately, meat quality is assessed by the person eating the meat. It is a personal judgement of how closely the meat corresponds to their idea of what meat should be like. Qualities taken into consideration include flavour, odour, appearance, juiciness and texture. Of these, texture i.e. the toughness/tenderness rating is probably the most important. Almost everyone who eats meat is aware of the variability to be found in its eating quality, particularly its tenderness.

Scientists have been looking for the causes of meat toughness since they first started investigating meat. Our understanding of the factors influencing meat toughness is improving all the time. Even so, within a group of meat scientists there would still be argument as to which components of meat are responsible for causing a particular piece of meat to be tough. The argument is a consequence of the complex structure of meat; it does not mean that meat scientists have not come up with a number of useful and valuable findings. 'Tenderstretch' and electrical stimulation are two recent examples of procedures which can be successfully used to improve tenderness. However, the underlying mechanisms whereby the tenderness is improved are still open to debate.

In simple terms, the assessment of meat toughness is an assessment of its physical strength. As with any material, the strength depends on both the chemical and the physical structure of the material. For example, most of us are aware of the differences between the properties of a plain piece of wood and a piece of plywood of the same size. The strength of the material is changed by reorganizing its structure. Unfortunately, the physical structure of meat is very complex. Even though it has been investigated by numerous people it is still not completely known. There are gaps in our knowledge of meat structure at all levels of organization from the macroscopic level to the high levels of magnification obtained by electron microscopy. Consequently, there are a number of unknowns when it comes to explaining rheological data in structural terms.

Structurally, there are two major components in meat, the muscle fibres and the connective tissue. Majority opinion would have us believe that the influence of connective tissue on meat toughness is determined by the history of the live animal. This connective tissue toughness is usually called background toughness and is regarded as not being substantially influenced by treatment of the meat from the point of slaughter up to the point of cooking the

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meat.

The contribution made to meat toughness by the muscle fibre component is termed myofibrillar toughness. It is this myofibrillar toughness which is thought to respond to the handling procedures from the time of slaughter onwards. It is the component thought to be responsible for changes in meat toughness resulting from cold shortening, ageing, tenderstretching and electrical stimulation.

This division of meat toughness into a relatively fixed background toughness and a variable myofibrillar toughness stems directly from the state of knowledge of meat structure and behaviour at the time the theories of meat toughness were developed. It has been known for a long time that muscle fibres are excitable and respond to stimulation by contracting. This results in a change in the muscle fibre structure. Naturally this change in structure has been used to develop theories of the cause of the variability of meat toughness. Connective tissue on the other hand has long been regarded as a fairly passive tissue and its structure in meat has been unknown until very recently. This lack of knowledge has resulted in connective tissue being regarded as rather unresponsive and contributing only a background toughness to meat.

More and more meat scientists are now realizing that it is no longer wise to regard these two major components independently and are becoming aware of the considerable interactions between them. As our knowledge of meat structure increases, particularly of the connective tissue component, our theories of the underlying causes of the variability of toughness are expanding and becoming more comprehensive. Without going into great detail about either the structure of meat or theories of meat toughness, the structure of meat will be reviewed briefly and those factors that are thought to contribute to meat toughness will be discussed.

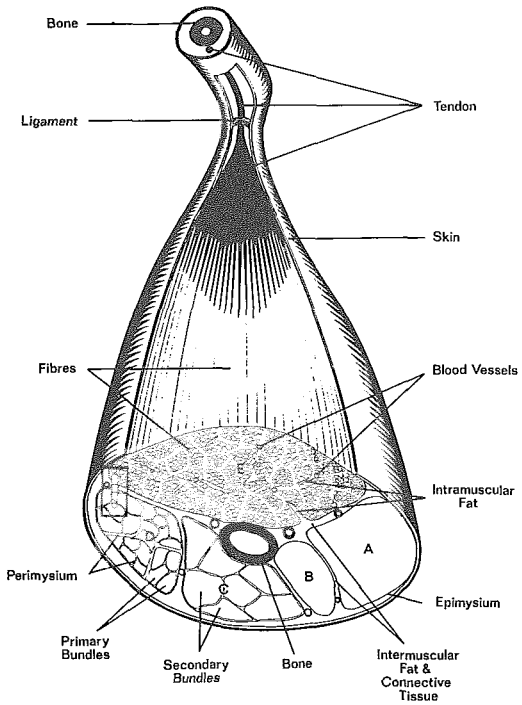

Fig. 1. Structural details of a joint of meat which are visible to the naked eye.

Structural features revealed by macroscopic examination

Macroscopic examination of meat enables us to see a number of important structural features (Fig. 1):

- The whole muscle is covered in a connective tissue wrapping (the epimysium)
- The muscle fibres run a roughly parallel course but not necessarily along the length of the muscle
- Towards the end of a muscle there is a tendon attaching the muscle to the bone
- If a cut is made across the grain of the meat then it can be seen that the muscle fibres are divided up into bundles by connective tissue sheets (the perimysium)
- In some instances tendons can run up through the interior of the muscle, e.g. in shin meat.

A meat scientist looks for the following when studying meat toughness:

- The relative proportions of connective tissue, including tendons within the body of the meat, and muscle fibres
- The course taken by the muscle fibres, in other words, whether they are straight or wavy. This can give clues about the contraction state of the meat.

Even at this macroscopic level, careful examination of the connective tissue component reveals that there is a complex network of collagen fibres running throughout the muscle (the perimysium, see

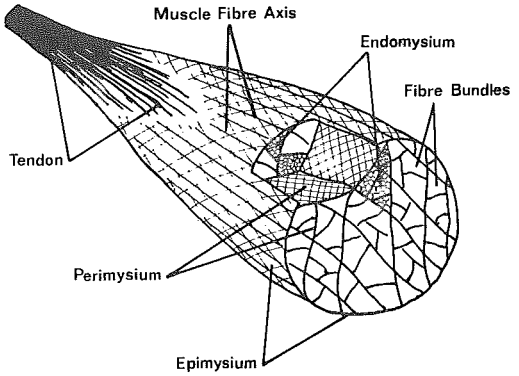

Fig. 2. Structural details of the connective tissue of meat which, with care, are visible to the naked eye.

Fig. 2). It is possible, even at very low magnification, to see that the angle of these collagen fibres relative to one another and to the muscle fibres varies depending on the contraction state of the muscle.

The big gaps in our structural knowledge at this level of organization relate to the connective tissue component of the meat. The pattern of subdivision of the muscle fibres into bundles by the connective tissue sheets is not known. There is no reliable information about the sizes of the fibre bundles, or if there is order to the pattern of subdivision.

For example, if you visualize a brick wall where the bricks are equivalent to the muscle fibre bundles and the mortar between the bricks is equivalent to the connective tissue, then there are a number of patterns in which the bricks could be put together. Obviously this can have an influence on the strength of the wall. Similarly, the strength of the meat could be influenced by its pattern of subdivision.

There is no comparative information, for meat from animals of different ages or for different cuts of meat within an age group, for the angle between these collagen fibres and the axis of the muscle fibres. Similarly, there is no comparative information for ages or cuts, for the crimp seen in these collagen fibres — all features which could have a great deal of bearing on the comparative physical properties of pieces of meat.

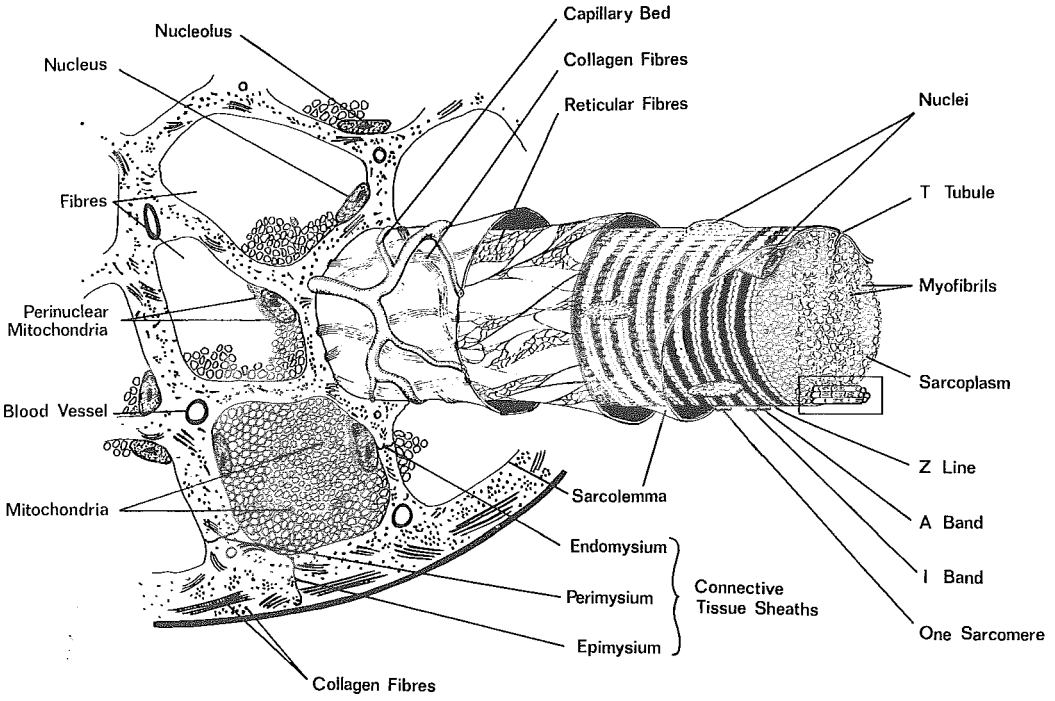

Fig. 3. Structural details which are visible when meat is examined by light microscopy (N.B. The structure of the connective tissue is not entirely correct).

Structural features revealed by light microscopy

At a higher magnification we can start to see more structural details (Fig. 3). The muscle fibres can be seen to be filled with smaller fibrous elements, the myofibrils. They have a banded appearance which results from the periodic distribution of different proteins along their length. This banding pattern changes when the muscle fibre contracts. All the muscle fibres are bound together by connective tissue but the pattern shown here (Fig. 3) is wrong. When the diagram was drawn the structure of this connective tissue was not clearly understood. The true structure will be dealt with when we consider electron microscopy.

The sort of information relevant to meat toughness to be gained from examination at this level includes:

- The size of the muscle fibres and therefore of surface areas etc.
- Better assessment of the relative proportions of connective tissue and muscle fibres
- The contraction state of the muscle gained by measuring the spacing of the band pattern of the myofibrils (this is known as the sarcomere length).

It can be seen from Fig. 3 that different regions of connective tissue have been given different names. Originally this was for convenience and described finer and finer sheets of connective tissue. Recently, however, it has been shown that these are distinct tissues which differ both chemically and structurally. At this level of examination the gap in our knowledge is again in relation to the connective tissue component. So far, we do not have data on the distribution of collagen types for animals of different ages or for different cuts of meat.

Structural features revealed by electron microscopy

By using electron microscopy we can magnify the structure enough to see most of the fine structure needed for explaining meat toughness in structural terms (see Fig. 4). There are two types of electron microscopy.

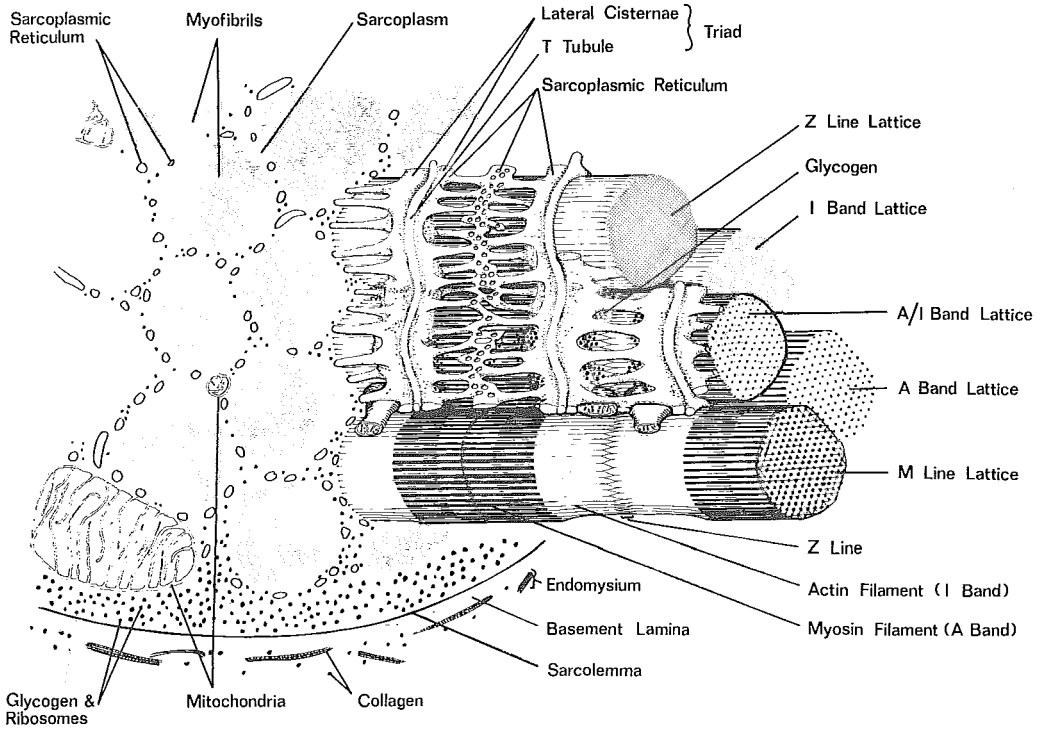

Fig. 4. Detailed structure which is visible when meat is examined by transmission electron microscopy.

Firstly transmission electron microscopy which uses very thin, small slices of tissue much less tham 0.001 mm thick. Technically it is therefore difficult to get information about features which have a three dimensional structure extending over distances of millimetres and even centimetres, as does the connective tissue component of meat. The myofibrillar structure of meat is much more suited to studies using transmission electron microscopy. It has a repeating structure with a unit cell not much bigger than 0.001 mm.[3] Just one section of a muscle fibre gives many views of this repeat structure, from which it is possible to build up a three-dimensional-picture of the whole structure. This means that there is an enormous amount of information available about the structure of the muscle fibres of meat and, once again, relatively little on the connective tissue.

The sort of information useful to meat toughness studies includes:

- The contraction state, showing the overlap of the different protein filaments
- Monitoring the structure for loss of integrity as a result of such things as ageing
- Looking for the point of rupture in the structure when it is subjected to loads.

The data on intramuscular connective tissue that have been obtained from transmission electron microscopy are very sparse. Although such things as fibril diameters of the collagen can be obtained, the structural organization of collagen fibres is nearly impossible to determine. New data, at this level, which could be important to the meat toughness story involve the specific localization of new proteins which have been identified as part of the muscle fibre structure.

The second type of electron microscopy is scanning electron microscopy. With this technique it is possible to examine the surfaces of large pieces of tissue. Scanning electron microscopy is ideal for looking at the connective tissue component of meat and certain aspects of the muscle fibre component. Very recent information is available concerning the structure of connective tissue within meat using this technique (Fig. 5). Because some of this information is so very recent and as yet incomplete, it has not been fully integrated into theories of meat toughness, but promises to be worthy of detailed consideration.

Obviously, all the important features to be seen in meat have not been dealt with in this

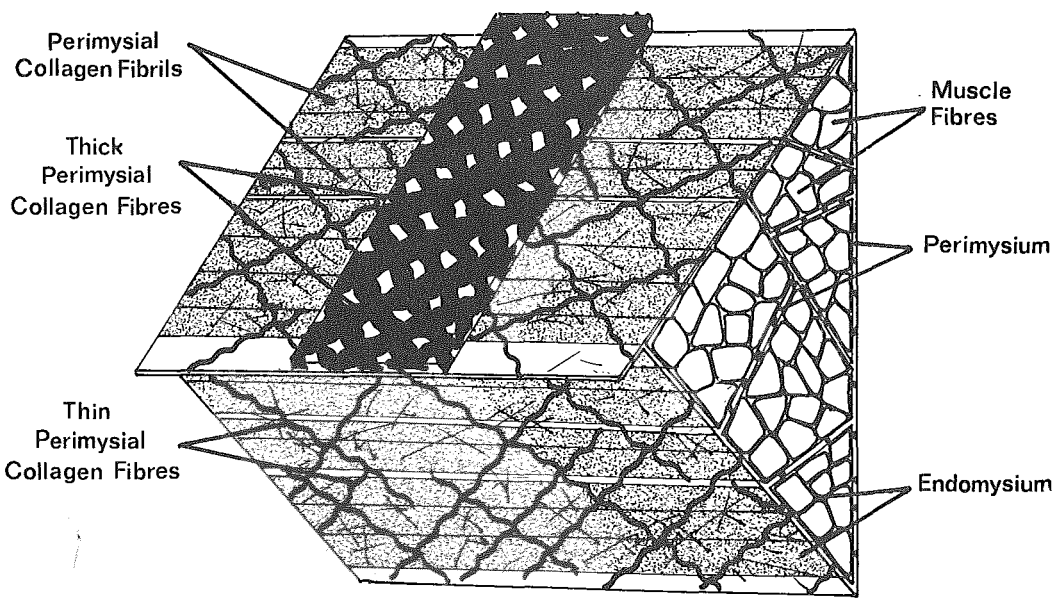

Fig. 5. Details of the connective tissue which are visible by scanning electron microscopy. The thick perimysial sheet is shown cut away to reveal the more delicate thin perimysial sheet beneath.

article, e.g. changes in structure following cooking. Cooking obviously can have an effect on meat toughness and this is a consequence of the structural and chemical changes brought about by the heating time and temperature employed.

There are two conclusions that may be drawn from the foregoing. Firstly, that although the structure of meat is very complex, studies of it at almost any level are very rewarding in that they give an insight into many aspects of the behaviour of meat, particularly in relation to meat toughness. Secondly, that even today there is still a vast amount of new structural information to be extracted and put to use in the meat industry.

News from the Division

Awards

Study Award

A CSIRO Study Award has been granted to Miss Ailsa Hocking of the Food Safety and Nutritional Quality Group at FRL. She will be spending four months overseas, gaining expertize in identification of an important group of potentially mycotoxigenic fungi — *Fusarium* and *Trichoderma*, and in detection methods for the toxins they produce, known as trichothecenes. She will spend six weeks at The Fusarium Research Center, Pennsylvania State University, U.S.A. working with Dr P. E. Nelson on methods of isolation and identification of *Fusarium* species from foods, followed by six weeks at The Commonwealth Mycological Institute in Kew, England, where she will study the taxonomy of other trichothecene-producing fungi such as *Trichoderma* and *Gliocladium* species. The final six weeks will be spent at the National Research Institute for Nutritional Diseases at Tygerberg, near Capetown in South Africa, working with Dr W. Marasas and his group. There she will learn methods currently being used, and those being developed, for the detection and quantification of trichothecene toxins.

Miss Hocking's award is the sixth made to staff of the Division of Food Research (the others being Mr I. R. McDonald of Headquarters, Mr P. J. Rutledge and Mr G. R. Chaplin of FRL, Mrs S. M. Collins of DRL, and Mr D. R. Smith of MRL). The Division thus becomes 'top scorer' in CSIRO, which currently has 39 Divisions and seven smaller research Units. The Award, named 'Jubilee Award' in 1976, the year the first award was made in commemoration of the Organization's fiftieth year, is funded by the Executive as one of its functions under the Science and Industry Research Act, requiring it '. . . to make grants and award fellowships and studentships relevant to the Organization's research'.

Hicks Prize — 1982

The 'E. W. Hicks Memorial Prize' for 1982 was won by Mr David Medlin, Apprentice Fitter and Turner, for 'The most meritorious academic record leading to the award of a first post-secondary qualification by part-time study'.

Mr Medlin completed a three-year Fitting and Machining Course, gaining consistently high marks throughout his apprenticeship.

On the advice of the Hicks Prize Selection Committee, the FRL Staff Club recently amended the conditions for award to require that the greater portion of the qualifying course be undertaken whilst the candidate was on the staff of FRL and, in addition, that the course be relevant to the work of the Laboratory.

Fellowship — Australian Academy of Technological Sciences

Mr Lawrie Muller, Officer-in-charge, CSIRO Dairy Research Laboratory, has been elected a Fellow of the Australian Academy of Technological Sciences.

Election to the Fellowship requires clearly demonstrated achievements in the technological sciences to the benefit of the community.

Lawrie Muller is well known in the dairy industry for his outstanding contributions over many years in the field of technological research and industry application. It is a fitting tribute that his efforts for the dairy industry are recognized by the Australian Academy of Technological Sciences.

Retirements

D. McG. McBean

Mr Don McBean, Principal Research Scientist and Leader of FRL's Applied Food Science Group, retired from CSIRO in July 1983 after 41 years' service.

On graduating in Science from the University of Queensland Don McBean joined the Division in 1943 to undertake research and development on vegetable dehydration. After the war he expanded his research interests to include work on the drying, dehydration and sugaring of fruits. His work on the application of sulphur dioxide to foods for drying and its retention during drying and storage markedly improved the technology of the Australian industry. He also became an authority on processed potato products and for many years carried out varietal assessments for plant breeders in the departments of agriculture. His work on the processing of high-moisture prunes and on many other practical problems was of great assistance to an industry which frequently sought his advice on technical matters.

During a year's study leave at the Western Regional Laboratory of the US Department of Agriculture in 1968 he worked on methods for increasing the drying rate of fruits with waxy cuticles such as grapes and prunes. This work was continued on his return and also led to improved technology in our industry. In 1976 he visited Sri Lanka, India and Nepal to advise on the use of solar energy for drying foods.

Don was keenly interested in the welfare of the Division and supervised the gardens and grounds of the North Ryde site. He was also an author of part of the history of the Division which was prepared for its 50th anniversary. For the last two years of his career he led with distinction the Applied Food Science Group.

PWB/GF

Fig. Mr Don McBean planting a silky oak in the grounds of FRL on the occasion of his retirement.

B. M. P. Keogh

Ms Barbara M. P. Keogh (Principal Research Scientist) joined CSIRO in 1955 after an eight year period as Senior Demonstrator at the Microbiology Department, University of Melbourne. Whilst on leave from the University, Ms Keogh spent 1953 at the Central Public Health Laboratories, Colindale, London, researching the cause of infantile diarrhoea.

During her time at DRL, Ms Keogh published numerous papers on cheese starters and their bacteriophages, antibiotics, pathogens in dairy products, and psychrotrophic organisms in relation to quality of dairy products. Ms Keogh developed a simple test for penicillin in milk which was widely used by milk testing authorities in Australia.

Since joining CSIRO, Ms Keogh has been involved with the Standards Association of Australia, the National Association for Testing Authorities (NATA) and has served on a number of International Dairy Federation committees. She is a foundation member of the Australian Society for Microbiology.

P. E. Bouton

Paul Edward (Ed) Bouton, Experimental Officer, retired from MRL on 5 August 1983, after 32 years' service. When he joined the Meat Research Laboratory it was housed in the Brisbane Metropolitan Regional Abattoir and staff numbers were about 10; he saw these grow to about 90, now accommodated in modern laboratories a short distance from the abattoir.

Although Ed is a chemist by professional training, during the early part of his career as a member of a small team, he was expected to be versatile and he had to acquire some of the skills of a statistician, biochemist, slaughterman and carcass boner. He maintained his interest in statistics throughout his career and his expertize in statistical design and analysis remained in great demand up to the time of his retirement. His main interest was meat quality, in particular the causes of variability in meat tenderness and methods for the control of tenderness. He participated in pioneerine investigations into various processing techniques for the tenderization of meat. These included injection of enzymes into animals or carcasses pre- or post-slaughter respectively, hanging of carcasses from the aitch bone (tender-stretching), electrical stimulation of carcasses and high pressure treatment of meat. The results of these, and other studies in which he participated, are recorded in 59 research publications of which he is author or co-author.

JJM

W. McC. Bailey

Also in July 1983 Mr Wilf Bailey retired as a Senior Technical Officer from FRL after 17 years' service.

Wilf was appointed to assist with investigations into the storage and transport of fresh fruits and was largely responsible for the conduct of storage experiments, but also involved in complex analyses and the development of new techniques. He made valuable contributions, particularly in the search for new chemical inhibitors for the fruit disorder known as 'scald' and his contributions were recognized in several research papers.

Fig. At the DRL gathering to farewell Barbara and Gordon. Left to right: Dr J. H. B. Christian, Ms Barbara M. P. Keogh, Mrs Dorothy Vanderheiden, Mr Gordon J. Vanderheiden and Mr L. L. Muller.

G. J. Vanderheiden

Mr Gordon J. Vanderheiden (Senior Technical Officer) began his career with CSIRO at the then Division of Meteorological Physics in 1949. He joined DRL in 1961.

Mr Vanderheiden was involved with a variety of research projects, being responsible for the instrumentation/engineering aspects. He developed a micro-structural recorder for providing an objective assessment of cheese body during maturation. This allowed comparisons of consistency between different cheese types to be made. Mr Vanderheiden was also connected with the mechanized cheesemaking process.

Publications

D. McG. McBean

McBean, D. McG. (1950). The dehydration of apricots and peaches. *CSIRO Food Preserv. Q.* **10**, 59-63.

McBean, D. McG. (1950). Preparation of sugared fruits. *CSIRO Food Preserv. Q.* **10**, 64-8.

McBean, D. McG. (1951). Factors affecting the colour of potato crisps. *CSIRO Food Preserv. Q.* **11**, 46-7.

McBean, D. McG. (1953). Further aspects of the preparation and storage of sugared fruit. *CSIRO Food Preserv. Q.* **13**, 70-2.

McBean, D. McG. (1956). Dehydrofreezing: a new method of preservation. *CSIRO Food Preserv. Q.* **16**, 16-7.

McBean, D. McG., and Kuppuswamy, S. (1957). Effect of coating with starch and starch fractions on storage of dehydrated carrot. *Food Technol.* **11**, 262-5.

McBean, D. McG., and Johnson, A. A. (1957). Control of spoilage in high-moisture prunes. *CSIRO Food Preserv. Q.* **17**, 48-51.

McBean, D. McG. (1962). Drying of tree fruits with particular reference to dehydration and pre-treatment with sulphur dioxide. U.N. Conf. Appl. Sci. Technol. Less developed Areas. Paper E/CONF. 39/D147.

McBean, D. McG. (1962). Instant mashed potatoes. *CSIRO Food Preserv. Q.* **22**, 68-72.

McBean, D. McG., Johnson, A. A., and Pitt, J. I. (1964). Absorption of sulphur dioxide by fruit tissue. *J. Food Sci.* **29**, 257-65.

McBean, D. McG., and Pitt, J. I. (1965). Preservation of high-moisture prunes in plastic pouches. *CSIRO Food Preserv. Q.* **25**, 27-32.

McBean, D. McG. (1965). Recommendation for Prevention of White Centres in Dried Apricots. (Aust. Dried Fruits Assoc.: Melbourne).

McBean, D. McG., Pitt, J. I., and Johnson, A. A. (1965). Retention of absorbed sulphur dioxide in fruit tissue during drying. *Food Technol.* **19**, 141-5.

McBean, D. McG., Miller, M. W., Pitt, J. I., and Johnson, A. A. (1966). Prune drying in Australia — a reappraisal of methods. *CSIRO Food Preserv. Q.* **26**, 2-11.

McBean, D. McG. (1966). Recommendation for Sulphuring Cut Fruit Before Drying. (Aust. Dried Fruits Assoc.: Melbourne).

McBean, D. McG. (1967). Desiccation in the pit cavities of apricots — the cause of white centre in dried fruits. *Food Technol.* **21**, 420-3.

McBean, D. McG. (1967). Levels of free and combined sulphur dioxide in fruits during sulphuring and drying. *Food Technol.* **21**, 1402-6.

McBean, D. McG., and Wallace, J. J. (1967). Stability of moist-pack apricots in storage. *CSIRO Food Preserv. Q.* **27**, 29-35.

McBean, D. McG., and Bain, J. M. (1967). The structure of the cuticular wax of prunes, plums and its influence as a water barrier. *Aust. J. Biol. Sci.* **20**, 895-900.

McBean, D. McG., Miller, M. W., Johnson, A. A., and Pitt, J. I. (1967). Sulphur dioxide levels for sulphuring tree fruits before drying. *CSIRO Food Preserv. Q.* **27**, 22-7.

McBean, D. McG., Casimir, D., and Shipton, J. (1968). Fluidization techniques in food processing. *Food Technol. Aust.* **20**, 466-9.

McBean, D. McG., and Singhagajen, S. (1968). Foam-mat drying of bananas. *CSIRO Food Preserv. Q.* **28**, 43-5.

McBean, D. McG., Lynch, L. J., Mitchell, R. S., and Shipton, J. (1968). Process for producing improved frozen peas. *Aust. Pat.* 286, 440. *Brit. Pat.* 1076, 769.

McBean, D. McG. (1968). Sulphuring cut fruits before drying. *Food Technol. Aust.* **20**, 113.

McBean, D. McG. (1969). Improved dried pears. *CSIRO Food Preserv. Q.* **29**, 49-52.

McBean, D. McG., and Bain, J. M. (1969). The development of the cuticular wax layer in prunes, plums and the changes occurring in it during drying. *Aust. J. Biol. Sci.* **22**, 101-10.

McBean, D. McG., Outhred, N. L., Johnson, A. A., and Coote, G. G. (1969). The prediction of maturity in plums for prune production. *Aust. J. Exp. Agric. Anim. Husb.* **9**, 648-54.

McBean, D. McG., and Ponting, J. D. (1970). Temperature and dipping treatment effects on drying rates and drying times of grapes, prunes and other waxy fruits. *Food Technol.* **24**, 85-8.

McBean, D. McG., Joslyn, M. A., and Nury, F. S. (1971). Dehydrated fruit. In 'Biochemistry of Fruits and Their Products' Vol. 2 (Ed. A. C. Hulme) (Academic Press: New York). pp. 623-52.

McBean, D. McG. (1971). Recent advances in dehydration processes. *CSIRO Food Res. Q.* **31**, 41-6.

McBean, D. McG. (1972). Equipment and processes for drying foods. *Aust. Chem. Process. Eng.* **25**, 20-3, 26, 27, 29.

McBean, D. McG. (1972). Trends, developments and requirements for potato processing. Aust. Potato Agronomy Conf., Burnie, Tasmania.

McBean, D. McG., Coote, G. G., and Christie, E. M. (1973). Quality tests of some new and standard potato varieties. CSIRO Div. Food Res. Tech. Pap. No. **37**.

McBean, D. McG., and Wilson, B. W. (1973). The final stages of drying sultana grapes. CSIRO Div. Chem. Eng. Memo. CE/M37.

McBean, D. McG., Davis, E. G., Rooney, M. L., and Gipps, P. G. (1973). Mechanisms of sulphur dioxide loss from dried fruits in flexible films. *J. Food Technol.* **8**, 391-405.

McBean, D. McG. (1974). Packaging of Dehydrated Foods. Proceedings Food and Food Packaging Winter School 1974. Section 8, 1-7.

McBean, D. McG., and Coote, G. G. (1974). Quality tests of potato varieties in Australia. *Am. Potato J.* **51**, 165-9.

McBean, D. McG. (1975). Sun drying of foods. *Food Technol. Aust.* **27**, 449-500.

McBean, D. McG., Davis, E. G., and Rooney, M. L. (1975). Packaging foods that contain sulphur dioxide. *CSIRO Food Res. Q.* **35**, 57-62.

McBean, D. McG. (1976). Drying and processing tree fruits. CSIRO Div. Food Res. Circ. No. 10.

McBean, D. McG., and Stekly, V. (1976). Sorbate

treatment of moist prunes. *CSIRO Food Res. Q.* **36**, 31-5.

McBean, D. McG. (1976). Basic principles of drying processes and particular features of sun-drying methodology. In 'Sun-Drying Methodology'. (National Science Council of Sri Lanka: Colombo, Sri Lanka). pp. 6-16.

McBean, D. McG. (1976). The use of solar energy in the drying of foods. Report of a visit by Donald McG. McBean to Sri Lanka, India and Nepal, 14 May-9 June, 1976.

McBean, D. McG. (1978). Preservation of low moisture foods. In 'Processing of Fruits and Vegetables'. (Ed. P. W. Board) (Hawkesbury Agricultural College: Richmond, N.S.W.). pp.15.1-15.6.

McBean, D. McG., Smith, M. B., and Bastian, J. M. (1979). Fifty Years of Food Research. *(Collected from CSIRO Food Res. Q. Vol. 36 Nos. 3 & 4 and Vol. 37 No. 4)* CSIRO Division of Food Research: Sydney).

B. P. Keogh

Keogh, B. P. (1956). The sensitivity of some cheese starter cultures to penicillin and nisin. *Aust. J. Dairy Technol.* **11**, 104-6.

Czulak, J., and Keogh, B. P. (1956). Trials of phage-resisting medium. *Aust. J. Dairy Technol.* **12**, 54-5.

Keogh, B. P. (1958). Variations in lactic acid production in milk. *Aust. J. Dairy Technol.* **13**, 132-8.

Keogh, B. P. (1959). Effect of Hibitane (Chlorhexidine) on cheese starter cultures. *Aust. J. Dairy Technol.* **14**, 148.

Keogh, B. P. (1960). Failure of a blend of mixed starter cultures in the vat. *Aust. J. Dairy Technol.* **15**, 121.

Keogh, B. P. (1961). Simple test for the detection of penicillin. *Aust. J. Dairy Technol.* **16**, 19-21.

Keogh, B. P., and Hansen, R. R. (1963). Incidence of coagulase-positive staphylococci and coliforms in Australian Cheddar cheese. CSIRO Dairy Research Laboratory Internal Report No. 3.

Keogh, B. P. (1964). Comment on the hydrogen peroxide-catalase treatment of milk for cheese manufacture. *Aust. J. Dairy Technol.* **19**, 86-7.

Keogh, B. P. (1964). Factors limiting microbial growth in dairy products. *Food Technol. Aust.* **16**, 556-61.

Keogh, B. P. (1965). Application of fundamental principles in microbiology to the dairy industry. Aust. Soc. Dairy Technol. Tech. Publ. No. 16, 39-41.

Keogh, B. P. (1966). Bacteriological problems in the condensing and drying of milk. *Food Technol. Aust.* **18**, 126-33.
Also Aust. Soc. Dairy Technol. Tech. Publ. No. 16, 42-4.

Keogh, B. P., and Pettingill, G. (1966). Long-term storage of bacteriophages of lactic streptococci. *Appl. Microbiol.* **14**, 421-4.

Keogh, B. P. (1968). Growth of psychrotrophic organisms and the associated effects on cream, butter and ice cream. Int. Dairy Fed. Seminar on Psychrotrophic Organisms, Univ. Sussex, Brighton, Doc. SEM-SUSSEX 7.

Keogh, B. P. (1969). Freezing of bacteria. Proc. Symp. Dairy Fermentation Technol., Univ. N.S.W., Kensington, 98-101.

Keogh, B. P. (1969). Factors interfering with microbial growth in the manufacture of fermented dairy products. Proc. Symp. Dairy Fermentation Technol., Univ. N.S.W., Kensington, 175-8.

Keogh, B. P., and Shimmin, P. D. (1969). An inducible antibacterial agent produced by a strain of *Streptococcus cremoris*. *J. Dairy Res.* **36**, 87-92.

Keogh, B. P. (1970). Survival and activity of frozen starter cultures for cheese manufacture. *Appl. Microbiol.* **19**, 928-31.

Keogh, B. P. (1970). Nutritional deficiencies of co-precipitate for the growth of a strain of *Lactobacillus acidophilus*. *J. Dairy Res.* **37**, 461-4.

Keogh, B. P. (1970). Bacteriological quality of milk products. *Aust. J. Dairy Technol.* **25**, 35-7.

Keogh, B. P. (1971). Survival of pathogens in cheese and milk powder. *J. Dairy Res.* **38**, 91-111.

Keogh, B. P. (1972). A re-assessment of the starter rotation system. *Aust. J. Dairy Technol.* **27**, 86-7.

Keogh, B. P. (1973). Adsorption, latent period and burst size of phages of some strains of lactic streptococci. *J. Dairy Res.* **40**, 303-9.

Keogh, B. P. (1973). The setting of microbiological standards for foodstuffs. *Food Technol. Aust.* **25**, 21.

Keogh, B. P. (1974). Starter rotation and phage monitoring Proc. Conf. Cheese Starter Problems, Dairy Research Laboratory, Highett, 11-20.

Keogh, B. P., and Shimmin, P. D. (1974). Morphology of the bacteriophages of lactic streptococci. *Appl. Microbiol.* **27**, 411-5.

Keogh, B. P. (1975). Studies on staphylococcal enterotoxins. Part I. Investigation of methods for the detection of enterotoxin in cheese. Dairy Research Report No. 17A; Part II. The determination of staphylococcal enterotoxigenicity. Dairy Research Report No. 17B; Part III. The extraction of enterotoxins from artificially contaminated cheese and slurries. Dairy Research Report No. 17C, and Part IV. Bibliography. Dairy Research Report No. 17D.

Keogh, B. P. (1976). Appraisal of the developments in the selection of cheese starters and their utilization in cheese manufacture. Abstr. 2nd Aust. Biotechnol. Conf., Melbourne, 1976, 10-2.

Keogh, B. P. (1976). Cheese starter organisms: the origin and types of starters. Proc. Workshop on Cheese Starter Cultures, Dairy Research Laboratory, Highett, 1976, 17-20.

Keogh, B. P., and Hull, R. R. (1976). Phage detection and monitoring. Proc. Workshop on Cheese Starter Cultures, Dairy Research Laboratory, Highett, 1976,

A/1-A/6.
Keogh, B. P. (1978). Microorganisms in dairy products: friends and foes. *Aust. J. Dairy Technol.* **33**, 41-5. Revised version of paper first published in CSIRO *Fd Res. Q.* **36**, 35-41, 1976, and reprinted in *PAG Bulletin* 6, 34-41, 1976.
Keogh, B. P., and Dick, M. I. B. (1978). Microbial spoilage of dairy foods: the Australian scene. *Food Technol. Aust.* **30**, 377-80.
Keogh, B. P. (1978). Bacteria pathogenic to man in milk and cheese. Int. Dairy Fed. **F-Doc 70**, 2-13. Revised version entitled "Bacteria pathogenic to man in cheesemilk and cheese" published without acknowledgement to author as Int. Dairy Fed. **F-Doc 78**, 2-14, 1979. Final version issued as Bull. Int. Dairy Fed. **Doc. 122**, 4-16, 1980.
Keogh, B. P. (1979). Pathogens in dairy products. Prog. Abstr., Ann. Sci. Mtg., Aust. Soc. Microbiol., Adelaide, p. 35.
Keogh, B. P. (1980). Appraisal of media and methods for assay of bacteriophages of lactic streptococci. *Appl. Environ. Microbiol.* **40**, 798-802.
Keogh, B. P., and Peterson, J. E. (1981). Aberrant forms of *Streptococcus cremoris* HP *Appl. Environ. Microbiol.* **41**, 1003-9.
Keogh, B. P. (1982). Differences in the nutritional requirements of lactic streptococci. Brief Commun., XXI Int. Dairy Congr., Moscow **1**, (2), 204-5.
Keogh, B. P., and Pettingill, G. (1982). Possible role of coryneform bacteria in the age gelation of UHT processed milk. *Appl. Environ. Microbiol.* **43**, 1495-7.
Keogh, B. P. (1983). Longevity of the bacteriophages of lactic streptococci. *Aust. J. Dairy Technol.* **38**, 32-3.
Keogh, B. P., and Pettingill, G. (1983). Adsorption of bacteriophage eb7 on *Streptococcus cremoris* EB7. *Appl. Environ. Microbiol.* **45**, 1946-8.
Keogh, B. P., and Pettingill, G. (1983 or 1984). Influence of enzyme activity of bacteria and leucocytes in raw milk on age gelation after UHT processing. *J. Food Prot.*, (in press).

P. E. Bouton

Bouton, P. E., Brown, A. D., and Howard, A. (1954). Export of chilled and frozen beef. *CSIRO Food Preserv. Q.* **14**, 62-7.
Bouton, P. E., and Howard, A. (1956). Quality of pre-wrapped frozen meat cuts. *CSIRO Food Preserv. Q.* **16**, 50-4.
Bouton, P. E., Howard, A., and Lawrie, R. A. (1957). Studies on beef quality. 6. Effects on weight losses and eating quality of further pre-slaughter treatment. Tech. Pap. Div. Food Preserv. CSIRO Aust. **6** Spec. Rep. Gt. Br. D.S.I.R. Fd. Invest. **66**.
Bouton, P. E., Howard, A., and Lawrie, R. A. (1958). Studies on beef quality. 7. The influence of certain holding conditions on weight losses and eating quality of fresh and frozen beef carcasses. Tech. Pap. Div. Food Preserv. CSIRO Aust. **8**. Spec. Rep. Gt. Br. D.S.I.R. Fd. Invest. **67**.
Bouton, P. E. (1963). Post slaughter changes in meat protein properties. Presented at Div. Meat Res. Conf., CSIRO Div. Food Preserv., Ryde N.S.W.
Pattie, W. A., Godlee, A. C., and Bouton, P. E. (1964). Effects of castration and of the poll gene on prime lamb production. *Aust. J. Exp. Agric. Anim. Husb.* **4**, 386-91.
Bouton, P. E., Howard, A., and Naumann, H. D. (1966). Consumer reactions to steak beef. *CSIRO Food Preserv. Q.* **26**, 12-8.
Bouton, P. E. (1968). Ageing of beef. *CSIRO Food Preserv. Q.* **28**, 52-4.
Bouton, P. E., and Shorthose, W. R. (1969). Correlations between ultimate pH and some quality traits of sheep meat. Proc. 15th European Meat Res. Workers' Mtg. Helsinki, 1969, All, 78-83.
Bouton, P. E., Harris, P. V., and Shorthose, W. R. (1971). Effect of ultimate pH upon the water-holding capacity and tenderness of mutton. *J. Food Sci.* **36**, 435-9.
Bouton, P. E., and Harris, P. V. (1972). The effects of cooking temperature and time on some mechanical properties of meat. *J. Food Sci.* **37**, 140-4.
Bouton, P. E., and Harris, P. V. (1972). A comparison of some objective methods used to assess meat tenderness. *J. Food Sci.* **37**, 218-21.
Baxter, R. I., Bouton, P. E., Fisher, A. L., and Harris, P. V. (1972). Evaluation of hanging methods for improving the tenderness of beef and mutton. CSIRO Meat Research Report 2/72.
Bouton, P. E., Harris, P. V., and Shorthose, W. R. (1972). The effects of ultimate pH on ovine muscle: Water-holding capacity. *J. Food Sci.* **37**, 351-5.
Bouton, P. E., Harris, P. V., and Shorthose, W. R. (1972). The effects of ultimate pH on ovine muscle: Mechanical properties. *J. Food Sci.* **37**, 356-60.
Bouton, P. E., and Harris, P. V. (1972). The effects of some post-slaughter treatments on the mechanical properties of bovine and ovine muscle. *J. Food Sci.* **37**, 539-43.
Shorthose, W. R., Harris, P. V., and Bouton, P. E. (1972). The effects on some properties of beef of resting and feeding cattle after a long journey to slaughter. Proc. Aust. Soc. Anim. Prod. **9**, 387-91.
Bouton, P. E., Carroll, F. D., Harris, P. V., and Shorthose, W. R. (1973). Influence of pH and fiber contraction state upon factors affecting the tenderness of bovine muscle. *J. Food Sci.* **38**, 404-7.
Bouton, P. E., Fisher, A. L., Harris, P. V., and Baxter, R. I. (1973). A comparison of the effects of some post-slaughter treatments on the tenderness of beef. *J. Food Technol.* **8**, 39-49.
Bouton, P. E., Carroll, F. D., Fisher, A. L., Harris, P. V., and Shorthose, W. R. (1973). Effect of altering ultimate pH on bovine muscle tenderness. *J. Food Sci.*

38, 816-20.
Bouton, P. E., Harris, P. V., Shorthose, W. R., and Baxter, R. I. (1973). A comparison of the effects of ageing, conditioning and skeletal restraint on the tenderness of mutton. *J. Food Sci.* 38, 932-7.
Bouton, P. E., Harris, P. V., Shorthose, W. R., and Ratcliff, D. (1974). Changes in the mechanical properties of veal muscles produced by myofibrillar contraction state, cooking temperature and cooking time. *J. Food Sci.* 39, 869-75.
Bouton, P. E., Harris, P. V., and Shorthose, W. R. (1974). A technique for producing ovine muscles of predetermined ultimate pH. Proc. Aust. Soc. Anim. Prod. 10, 227-31.
Bouton, P. E., Harris, P. V., Shorthose, W. R., and Smith, M. G. (1974). Evaluation of methods affecting mutton tenderness. *J. Food Technol.* 9, 31-41.
O'Shea, J. M., Harris, P. V., Shorthose, W. R., and Bouton, P. E. (1974). Changes in the thermal stability of intramuscular connective tissue and mechanical properties of bovine muscle concomitant with changes in myofibrillar contraction state. *J. Food Sci.* 39, 1221-3.
Bouton, P. E., Ford, A. L., Harris, P. V., and Ratcliff, D. (1975). Objective assessment of meat juiciness: A research note. *J. Food Sci.* 40, 884-5.
Bouton, P. E., Harris, P. V., and Shorthose, W. R. (1975). Changes in shear parameters of meat associated with structural changes produced by ageing, cooking and myofibrillar contraction. *J. Food Sci.* 40, 1122-6.
Bouton, P. E., Harris, P. V., and Shorthose, W. R. (1975). Possible relationships between shear, tensile and adhesion properties of meat and meat structure. *J. Texture Stud.* 6, 297-314.
Bouton, P. E., Harris, P. V., and Shorthose, W. R. (1976). Peak shear-force values obtained for veal muscle samples cooked at 50 to 60°C: Influence of ageing. A Research Note. *J. Food Sci.* 41, 197-8.
Bouton, P. E., Harris, P. V., and Shorthose, W. R. (1976). Factors influencing cooking losses from meat. *J. Food Sci.* 41, 1092-5.
Bouton, P. E., Harris, P. V., and Shorthose, W. R. (1976). Thermal contraction of meat during cooking and its possible influence on tenderness. *J. Texture Stud.* 7, 193-203.
Bouton, P. E., Harris, P. V., and Shorthose, W. R. (1976). Dimensional changes in meat during cooking. *J. Texture Stud.* 7, 179-192.
Bouton, P. E., Ford, A. L., Harris, P. V., MacFarlane, J. J., and O'Shea, J. M. (1977). Pressure-heat treatment of post-rigor muscle: Effects on tenderness. *J. Food Sci.* 42, 132-5.
Ratcliff, D., Bouton, P. E., Ford, A. L., Harris, P. V., MacFarlane, J. J., and O'Shea, J. M. (1977). Pressure-heat treatment of post-rigor muscle: Objective-subjective measurements. *J. Food Sci.* 42, 857-9, 865.
Snowden, J. McK., Bouton, P. E., and Harris, P. V. (1977). Influence of constraint during heating and cooling on the mechanical properties of collagenous tissue. *J. Food Sci.* 42, 890-4.
Shaw, F. D., Bouton, P. E., and Harris, P. V. (1977). Electrical stimulation of beef carcasses. CSIRO Meat Research Report 16/77.
Bouton, P. E., Harris, P. V., MacFarlane, J. J., and Snowden, J. McK. (1977). The effects of long term cooking on shear force-deformation curves. *J. Texture Stud.* 8, 297-310.
Bouton, P. E., Harris, P. V., MacFarlane, J. J., and O'Shea, J. M. (1977). Effect of pressure treatments on the mechanical properties of pre- and post-rigor meat. *Meat Sci.* 1, 307-318.
Bouton, P. E., Harris, P. V., and Snowden, J. McK. (1978). Effects of restraint during cooking on the shear properties of cooked meat. *J. Food. Sci.* 43, 175-7, 196.
Snowden, J. McK., Bouton, P. E., and Harris, P. V. (1978). Influence of animal age on the mechanical properties of restrained, heat-treated collagenous tissue. *J. Food Sci.* 43, 178-81, 201.
Bouton, P. E., Harris, P. V., MacFarlane, J. J., O'Shea, J. M., and Smith, M. B. (1978). Pressure-heat treatment of meat: Effect on connective tissue. *J. Food Sci.* 43, 301-3, 326.
Bouton, P. E., Harris, P. V., Ratcliff, D., and Roberts, D. W. (1978). Shear force measurements on cooked meat from sheep of various ages. *J. Food Sci.* 43, 1038-9.
Bouton, P. E., Harris, P. V., Shorthose, W. R., and Ellis, R. W. (1978). Comparison of some properties of meat from normal steers and steers heterozygous for muscular hypertrophy. *Meat Sci.* 2, 161-7.
Kerr, D. T., Bouton, P. E., Harris, P. V., and Shaw, F. D. (1979). Extra low voltage stimulation of beef carcasses using a rectal probe. CSIRO Meat Research Report No. 8/79.
Bouton, P. E., Weste, R. R., and Shaw, F. D. (1980). Electrical stimulation of calf carcasses: Response of various muscles to different waveforms. *J. Food Sci.* 45, 148-9.
Bouton, P. E., Ford, A. L., Harris, P. V., and Shaw, F. D. (1980). Electrical stimulation of beef sides. *Meat Sci.* 4, 145-55.
Bouton, P. E., Harris, P. V., and MacFarlane, J. J. (1980). Pressure-heat treatment of meat: Effect of prior aging treatments on shear properties. *J. Food Sci.* 45, 276-8.
Bouton, P. E., Shaw, F. D., and Harris, P. V. (1980). Electrical stimulation of beef carcasses in Australia. Proc. of 26th European Meeting of Meat Research Workers, Colorado Springs, Colorado, U.S.A. 2, 23-5.
Shaw, F. D., and Bouton, P. E. (1980). The use of electrical stimulation in conjunction with hot boning of beef. *Food Technol. Aust.* 32, 530-2.
Bouton, P. E., and Harris, P. V. (1981). Changes in the

tenderness of meat cooked at 50-65°C. *J. Food Sci.* 46, 475-8.

Bouton, P. E., Harris, P. V., and Ratcliff, D. (1981). The effect of cooking temperature and time on the shear properties of meat. *J. Food Sci.* 46, 1082-7.

Bouton, P. E., Kerr, D. T., McPhail, N. G., and Powell, V. H. (1981). Electrical stimulation of beef sides. CSIRO Meat Research Report 4/81.

Bouton, P. E., Harris, P. V., MacFarlane, J. J., and Shorthose, W. R. (1982). Influence of pH on the Warner-Bratzler shear properties of mutton. *Meat Sci.* 6, 27-36.

Bouton, P. E., Harris, P. V., and Shorthose, W. R. (1982). The effect of temperature and ultimate pH on the increase in meat toughness resulting from restraint during cooking. *Meat Sci.* 6, 235-241.

Bouton, P. E., Harris, P. V., and Shorthose, W. R. (1982). Comparison of some properties of beef from animals homozygous or heterozygous for muscular hypertrophy. *Meat Sci.* 6, 309-318.

Bouton, P. E., Harris, P. V., and Shorthose, W. R. (1982). A comparison of the meat properties of pasture-fed steers, heifers, pregnant heifers and spayed heifers. *Meat Sci.* 6, 301-8.

Møller, A. J., Bouton, P. E., Harris, P. V., and Jones, P. N. (1982). A comparison between two different shear systems used for measuring meat tenderness. *J. Food Sci.* 47, 1354-7, 1364.

Møller, A. J., Bouton, P. E., Harris, P. V., and Jones, P. N. (1983). Effect of electrical stimulation on the tenderisation of mutton by ageing. *J. Food Sci.* (In press).