

concentrations. The importance of concentration is suggested by the work of Wiseblatt (1960) on the flavour of bread. From baking ovens, he was able to isolate a condensate which did not have the odour of bread until it was diluted by spraying into the atmosphere.

Conclusions

Although it has been possible to identify the causes of some off-flavours in dairy products by use of gas chromatography and mass spectrometry, the components responsible for the characteristic flavours of the most important dairy products have still to be identified. The flavour of Cheddar cheese presents a particularly intriguing problem and the original hopes of attributing this characteristic flavour to a single compound have now faded.

The complex nature of food flavours may not be so surprising now that an insect sex pheromone has been found which consists of four components, all of which must be present in the correct concentration ratio.

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The complex background to the sensory qualities of meat and fish

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The sensory qualities by which a consumer judges a food include appearance and various eating qualities, of which I propose to cover three: taste, odour and texture. In most studies, taste and odour, which are often mingled in a composite sensation, are grouped together under the term 'flavour', and this concept will be used here. The chemistry of the flavourous components of meat (including chicken) and fish has been extensively reviewed in recent symposia and elsewhere (Doty, Batzer, Landmann & Santoro, 1961; Jones, 1961, 1967, 1969; Kazeniac, 1961;

Lineweaver & Pippen, 1961; Watts, 1961; Hornstein, 1967; Pippen, 1967; Solms, 1968, and it would be both inappropriate and unpractical to cover this subject in any detail here. Rather do I propose, as the title indicates, to give a general picture of our present knowledge of the flavour chemistry of flesh foods, to indicate some of the many experimental difficulties involved, and finally to give some examples of the impact of technology on eating quality and acceptability to the British consumer. My own research background inevitably means that I can speak with more assurance about fish than about meat and poultry.

In Britain very little flesh food is eaten raw, so that we have to consider not only the intrinsic flavours of the raw material, but also the flavours developed during cooking. In addition, considerable chemical changes occur between slaughter and cooking. Under good conditions these changes are due solely to the action of tissue enzymes and non-enzymic chemical reactions but with fish, unfortunately, it is only too often evident that bacterial enzymes have also been involved. There are further difficulties with fish; in contrast to meat and poultry, fish are still hunted rather than farmed. Thus, there is no control over their biochemical status at death, and for any one species it is, in fact, extremely variable. Again, most of our fish are brought back to port packed in melting ice, and leaching can be extensive.

An enormous list of flavourous or potentially flavourous compounds have been detected in flesh foods. Thus, Solms (1968) reports that more than 250 have been found in meat. Various authors have commented on the qualitatively, generally similar picture for all forms of flesh food and it is clear that until we can measure these compounds quantitatively we shall not know with any confidence why, for instance, beef, chicken and cod are not only quite different in taste, but why each has the characteristic taste we associate with it. The difficulties of quantitative analysis arise not only from the minute traces in which some of the compounds occur, but in changes in relative proportions and even in the production of artifacts during the course of extraction and concentration. There is a further problem often not sufficiently appreciated; tissue enzymes function extremely well at temperatures a little below the freezing point (e.g. in a laboratory refrigerator) and often are still active at commercial cold-storage temperatures. Thus, supposed reference material is sometimes far from representative of the starting material in studies of changes occurring during processing and storage. This is a particular difficulty with fish, where the intrinsic variability between individual fish really necessitates using reference and experimental material from the same animal.

A word should be said here about the expression 'potentially flavourous'. Many trace components of flesh are present at concentrations below the limit of their detection by taste. There is, however, abundant evidence that when present as mixtures of similar classes of compound, e.g. amino acids or aliphatic ketones, the mixture can be tasted. Again, some substances may be tasteless in the raw flesh, but by participation in reactions occurring during cooking may contribute significantly to the final taste. Some workers call these substances 'flavour precursors'. Finally, for compounds of an acidic or basic nature, flavour is markedly dependent on the pH of the tissue.

All flesh foods contain fat as well as lean muscle. Even muscle free from adipose tissue, e.g. cod, contains enough lipid, mainly phospholipid, to exert a significant effect in flavour development. The fat-free muscle of mammals, birds and fish has a basically similar flavour, as exemplified by that of concentrated aqueous extracts. Fat is discussed separately below, but at this stage it should be mentioned that, apart from any direct role, fat can act as a retaining store of volatile or water-soluble flavours that might otherwise be lost during cooking, while it also contributes to the 'feel' of food in the mouth. It is widely-known that low-fat meat is regarded as inferior by gastronomes and the same is true for fatty types of fish, e.g. herring. There is an unexplained difference in the free amino acid pattern of many fatty versus non-fatty fish. In the former, free histidine is generally present in considerable amounts, whereas in non-fatty species its place is taken by the dipeptide anserine. These compounds occur at levels where they are detectable by taste, and presumably contribute to the different flavours of the two classes of fish.

The flavorful components of lean muscle are water-soluble and can be broadly classified into various groups. Thus there are the essentially non-volatile compounds, such as sugars, amino acids, other carboxylic acids, e.g. lactic, and inorganic salts. Although these undoubtedly contribute to taste, they can have little or no effect on odour. Then there are substances which, though possessing little intrinsic flavour, exert a marked effect as flavour 'intensifiers'. Glutamic acid is a well-known example, but probably more generally important in flesh foods is inosine-5'-monophosphate (IMP), derived autolytically from the adenosine-5'-triphosphate (ATP) of the live tissue. Since IMP is only an intermediate in the enzymic degradation of ATP, its concentration first rises and then falls. A product of further autolysis is the bitter-tasting free purine, hypoxanthine. Solms (1968) quotes values for beef held at chill temperature (0.5-1.5°), where IMP reaches a maximum in about 12 h and then slowly falls over a period of up to 4 d, after which the decline is more rapid. For fish, rates vary widely from species to species. In chilled (2.5°) haddock, for instance, IMP concentration reached a maximum at about 4 d after death whereas in plaice IMP decreased rapidly almost from death (Jones, 1963). These values relate to rested fish from aquarium tanks. Free glutamic acid only occurs in very small amounts in fresh tissue, but is formed autolytically from protein and from its monoamide glutamine, e.g. during the hanging period for meat. Incidentally, glutamic acid and IMP have a synergistic effect on each other as flavour intensifiers. A further important group of flavorful components of lean muscle can be described broadly as 'carbonyls'; aldehydes and ketones. Small amounts of these occur in the fresh raw tissue, but the amounts and variety are greatly increased during cooking, as a result of Strecker degradation of amino acids and Maillard reactions between amino acids and sugars. It is notable that with fish, which is normally more lightly cooked than meat, production of additional carbonyl compounds during normal cooking appears to be on a relatively small scale, as judged by the odour of the raw and cooked fish (Jones, 1961). The situation is, however, quite different with more severe heat-processing, e.g. in canned fish.

Many carbonyls have marked flavours, and those derived from lean muscle are

considered to impart a 'meaty' background flavour. However, it is from the fatty substances accompanying the lean muscle in all flesh food that the most significant groups of carbonyl compounds are derived, partly present in the fresh, raw tissue but mainly arising by oxidation during the cooking process. Whereas the composition of the lean portion is broadly similar over a wide variety of species, this is not true for the lipids. In particular, the polyunsaturated components are important. The characteristic differences in the flavour of cooked beef, pork, lamb, chicken and fish can be traced to characteristic differences in lipid composition. The well-known effect of feeding too much fish oil to chicks or pigs is of interest here; in fishy bacon, for instance, it is only the fat of the bacon that is affected, whereas the effect in chicks of ingesting polyunsaturated oils (linseed or fish) affords the only clear example of a dietary influence on flavour in this species (Lineweaver & Pippen, 1961). It should be emphasized that it is apparently quantitative variations within a qualitatively similar picture that account for species-characteristic flavours rather than the presence of unique components.

It will probably have been noted that two types of reaction (Maillard and fat-oxidation) have been mentioned as contributing desirable flavours, and the same reactions are well known sources of pungent, bitter and rancid off-flavours. It is all a question of degree and, I am sure, to some extent of individual consumer preference, as, for example, with grilled steak.

This is an extremely condensed account of flavour chemistry and I have not touched on many interesting compounds, e.g. the sulphides and mercaptans—repulsive in excess, desirable in traces. I should, however, mention the importance of trimethylamine oxide in marine fish. This compound does not occur in meat or poultry, nor in significant amounts in freshwater fish. When bacteria penetrate into the flesh of chilled fish (say, after about 5–6 d in ice), certain organisms progressively reduce the oxide to free trimethylamine. Fish as purchased by many people in Britain has been more than 6 d in ice, and its 'fishiness' is undoubtedly partly due to trimethylamine and is not the characteristic much milder flavour of really fresh fish. It is, however, apparently preferred by some people! Incidentally, it has recently been shown (R. A. Herbert, 1969, unpublished) that the sulphides and mercaptans in much commercially acceptable cod are solely the products of bacterial action, the main sources being cysteine (for H₂S) and methionine (for H₂S, dimethyl sulphide and methyl mercaptan). Curiously, the major free amino acid of cod, the sulphur-containing compound taurine, was not metabolized by any bacterial isolate tested. This same work has shown that if sterile cod fillets are stored aseptically at 2° there is very little odour or flavour development over at least 12 weeks; in fact there is rather a loss of flavour.

Having touched briefly on such factors as autolysis, leaching, bacterial invasion and cooking, what about refrigeration in respect of sensory qualities? Of all the customary forms of processing, including canning and curing, I only propose to deal with freezing and cold storage, since this technique, in contrast to the others, is designed to supply a product equivalent to the good-quality fresh article.

I have already mentioned that many autolytic processes are, in fact, accelerated

or promoted by freezing and that rates are maximal just below the freezing point—often far higher than in chill-stored tissue. In freezing to the low temperatures of commercial stores (preferably -30°) it is, of course, necessary to pass through the range of maximal autolytic activity, and this occurs again during thawing. There is still room for more research into possible effects of time spent in this temperature-zone on subsequent changes in cold storage, e.g. the possible role of phospholipid hydrolysis on protein stability. Jones (1963) has given some interesting information on the relative rates of the six successive enzymic reactions involved in ATP breakdown in frozen fish. For best flavour retention (maximal IMP) the fish should be frozen immediately post-rigor and stored at -20° or below. They may be thawed moderately slowly but should be cooked rapidly.

Inhibition of bacterial growth and marked slowing of autolysis in cold-stored flesh foods does not mean that all deterioration is suspended. After all, the holding periods are extended, often for many months. Various non-enzymic reactions occur, of which the most significant organoleptically are lipid oxidation and protein polymerization following configurational change (unfolding). Maillard-type reactions can sometimes occur, e.g. in fish a phenomenon known as 'rusting' is sometimes a problem, although its chemistry is obscure. Lipid oxidation can easily lead to objectionable levels of rancidity, but modern vacuum-packaging helps considerably to reduce this defect. Protein polymerization leads to toughness and loss of juiciness occasioned by release of fluid in the form of 'drip'. There are enormous variations from species to species in the rate of this reaction, which often sets the time-limit to successful cold storage, e.g. lemon sole keeps far better than cod. In practice, most serious quality-defects in frozen foods arise through faulty operation, e.g. of retail freezer cabinets, where stock rotation and efficient temperature control are vital.

I have mentioned that, in contrast to farm animals, fish are hunted. Most fish is caught far from the ports of landing and the limitations of chill storage in ice are well known. Freezing at sea is a growing practice on distant-water trawlers and if efficiently carried out can supply fish of far superior eating quality to most of the available iced fish. However, operations aboard a trawler are seldom carried out under ideal conditions; to mention just one problem, the catch rate varies enormously, and whatever it may be the fish must be dealt with. Bleeding of the fish is a necessary process if the flesh is to have the uniformly white appearance desired by the consumer. In British practice this is achieved by evisceration followed by washing with sea-water in special tanks. With hurried operations, occasioned by high catch rates, bleeding may be incomplete, and the position is exacerbated if some of the fish suffers excessive delay before gutting. This does not matter with iced fish, where leaching completes the process, but it does matter with sea-frozen fish, which sometimes suffer from blood discoloration so badly as to be unacceptable to the purchaser. This is an instance where appearance, rather than flavour or texture, is the crucial factor.

British sea-frozen fish is almost all brought back as whole, eviscerated fish in the form of large blocks which then go into cold storage on shore. When needed, blocks are thawed in special equipment, and the fish further processed, e.g. filleted and the

fillets perhaps refrozen for the retail and catering trade. Why not fillet the fish at sea and bring back the frozen fillets? Many attempts have been made to do this, but most of them have ultimately been abandoned.

One difficulty is that blood discoloration due to inadequate bleeding is more obvious in a fillet and no subsequent trimming or washing is possible if the fillet is frozen at sea. But an even more serious problem arises from the muscular contraction accompanying the onset of rigor mortis. In the whole fish, the skeleton prevents any actual shortening of the muscle. True, under certain conditions, sea-frozen whole fish exhibit a torn texture (known as 'gaping') due to the tension set up during rigor mortis, but with fillets actual shrinkage can occur. Thus, if the fish are filleted pre-rigor, as many of them will be, but the fillets are not frozen before the onset of rigor, the fillets will contract. The result is a wrinkled or corrugated appearance and a tough rubber-like texture. It is easy to say that all fillets cut pre-rigor should also be frozen pre-rigor, or that all fish should pass through rigor before filleting, but in practice this is far from easy. Not only does catching rate vary, but the varying biochemical status of the fish at death affects the onset and duration of rigor.

I would like to conclude this very incomplete summary of a highly-complex subject with a word on consumer preference. Again, I choose fish by way of illustration, since I feel on surer ground! Most people in Britain have never tasted fish straight from the sea and quite often, when they first do so, they do not like it. There are species effects here. Sea-fresh cod tastes sweetish, due largely to glucose. Sea-fresh lemon sole has a flavour hard to describe, but often called 'sea-weedy'. Such flavours are lost after about a day in ice, when the flavour usually associated with best-quality fish is evident. Needless to say, most fish bought and eaten in Britain is far different from this! I have already mentioned the apparent preference of some people for fish that smells and tastes 'fishy', and which has undoubtedly been attacked by bacterial enzymes. When freezing of fish was becoming accepted, staff at the Torry Research Station, Aberdeen, co-operated with the research staff of a London firm in tests on high-quality frozen lemon sole. Again and again the London taste panel rejected fish that to the Aberdeen panel were the equal of fresh. Finally, the London panel came up to Aberdeen, and for the first time in their lives tasted fresh lemon sole. They did not like it!

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