

28 APRIL 1956

THE IMPACT OF FOOD TECHNOLOGY ON THE NUTRITION OF MAN AND ANIMALS

Chairman : PROFESSOR G. F. MARRIAN, F.R.S., *Department of Biochemistry,
University of Edinburgh*

Food processing and nutritive value for man

By H. R. BARNELL and DOROTHY F. HOLLINGSWORTH, *Scientific Adviser's Division
(Food), Ministry of Agriculture, Fisheries and Food, Great Westminster House, Horse-
ferry Road, London, S.W.1*

If it is accepted that food processing includes all treatments received by a foodstuff from its point of origin to the point in space and time at which it is consumed then barely 2% of our food, expressed in terms of calories, receives no processing. Most foods are not fully edible (i.e. palatable as well as nutritious) in the form in which they are produced and require at least a heat treatment to transform them from potentially edible to edible materials. Food supplies are normally available, particularly for the industrialized minority of the world's population, from sources distant from the consuming populations. They must therefore be moved and stored in some form which permits them to arrive on the table in a condition both palatable and nutritionally sound.

Processing to render potential foods edible and to preserve foods obtained in times of plenty for use in times of shortage has been practised since before the beginning of recorded history. The difference between early methods of heat treatment, withdrawal of water, pickling and curing, and modern methods is that we now have more control over the treatments, more knowledge of their effects, both chemical and physical, and more certainty of producing foods of consistent palatability and known nutrient content.

Treatments used in food processing

The treatments used in food processing are physical, chemical or mechanical or combinations of these. In order that their effects on nutritive value may be considered it will be convenient to classify the treatments at this stage:

- (1) Physical and chemical
 - (a) Application or removal of heat.
 - (b) Application or exclusion of light.
 - (c) Application or removal of water.
 - (d) Application of γ or β rays.

- (e) Emulsification.
 - (f) The application or removal of air or the use of other oxidizing or reducing agents.
 - (g) Fermentation.
 - (h) Addition of sugar, salt, acid, smoke or other substance as a preservative.
- (2) Mechanical
- (i) Addition of colouring matter (might also be chemical).
 - (j) Addition of nutrients.
 - (k) Grinding or pulverizing.
 - (l) Removal of parts of the original material.

The effects of some of the more important of these treatments will be considered.

Effects of heat on the major constituents of foods

The application of heat to starch in foods is essential for its digestion, and starch is the most important single source of carbohydrate and energy. The application of moderate heat to fat has little effect apart from melting it but excessive heat may cause the production of acrolein, of pungent odour and violent action on the mucous membrane of the eye.

The action of heat on protein is complex. Excessive exposure to heat reduces the nutritive value of protein probably owing, in part at least, to differential destruction of some amino-acids. Thus, lysine is partly destroyed during the baking of bread and may be made totally unavailable by toasting (quoted by Horder, Dodds & Moran, 1954). 'Puffing' of cereals has a measurable effect on the biological value of protein, probably owing to destruction of lysine and cystine, and perhaps of other heat-labile essential amino-acids (Booth, Moran & Pringle, 1945). Drying of meat at 80° has little or no detrimental effect on the nutritive value of its protein, but if the temperature of the meat rises above 90° breakdown occurs with release of free ammonia and, later, hydrogen sulphide (Sharp, 1953). The pasteurizing of milk has no effect on the value of milk protein, but in the preparation of evaporated milk which includes autoclaving at 116° slight loss of digestibility and biological value occurs (Kon, 1944). Dean (1953) has reported that if soya products are autoclaved for 15–20 min at 15 lb. pressure the trypsin inhibitor is destroyed and the nutritive value thereby improved, but if the temperature exceeds 120° the protein is damaged, lysine being particularly liable to heat damage, though it is not the only amino-acid so affected.

Proteins are also sensitive to the removal of heat. Thus fish muscle tends to toughen on freezing (Reay, Banks & Cutting, 1950). The texture of frozen fish depends on speed of freezing, temperature of storage and length of storage.

Effects of oxidation and reduction on the major constituents of foods

Starch, sugars and proteins in foods are not normally affected by atmospheric oxygen. However, powerful oxidizing agents may have an effect, for example that of nitrogen trichloride on gluten and other proteins such as zein, casein and egg

albumen caused by its reaction with the methionine residues in the proteins to produce methionine sulphoximine, the factor responsible for hysteria in animals (Bentley, McDermott, Moran, Pace & Whitehead, 1950).

Fats may become rancid on storage, particularly in the presence of air. Rancidity may also be caused by the activities of micro-organisms. No sharp differentiation between the two types is possible, but only oxidative rancidity can be controlled by the addition of antioxidants unless the antioxidant also has antiseptic properties. The development of oxidative rancidity is affected by temperature, light, moisture and by traces of cobalt, copper, iron and manganese. The precise mechanism of the initial chemical changes that occur when fats become rancid is not fully understood, but it appears that free radicals are formed giving rise to a chain reaction in which oxygen is taken up by the fat, resulting in the formation of hydroperoxides. The rate of absorption of the oxygen depends upon the constitution of the fat, glycerides containing unsaturated fatty-acid groups being the more reactive. When the concentration of these peroxide compounds in the fat reaches a certain level further complex chemical changes occur. The volatile and toxic decomposition products then formed are responsible for the unpleasant taste and odour associated with rancidity (Ministry of Food: Food Standards Committee, 1954). The oxidation of vitamin A in fats is retarded by the presence of antioxidants, a very important natural one being vitamin E, which is itself destroyed during the development of rancidity in fats. Thus, rancidity besides reducing the value of the fat has adverse nutritional side-effects.

In the manufacture of hardened fats by hydrogenation the reduction is usually selective. Unsaturated fatty acids are reduced and the highly unsaturated essential fatty acids (linoleic, linolenic and arachidonic) are almost eliminated. Although the significance of essential fatty acids in human nutrition is not yet clear Deuel's (1955) recent summary of the evidence on the essential role of fats and oils in intermediary metabolism contains some striking information. Apparently in animals essential fatty acids are concerned with protection from X-ray injury, the prevention of capillary permeability and of increased cholesterol deposition in the liver and also probably with growth, pregnancy and lactation. Even more far-reaching hypotheses have been put forward recently by Sinclair (1956), and have found support in evidence published by Bronte-Stewart, Antonis, Eales & Brock (1956) on the effects of feeding different fats on serum-cholesterol levels.

Effects of heat, light and air on vitamins

Vitamin A is relatively stable to heat if oxygen is excluded. Both vitamin A and β -carotene are unstable to heat in the presence of oxygen. Light also accelerates oxidation. There is little loss of vitamin A or of β -carotene in stored butter or margarine if they are kept out of the light. Heating of carotenoid-containing materials causes rearrangements of the molecules of both provitamin A carotenes and non-provitamin A carotenes with loss of nutritional value and changes in colouring (Joyce, 1954). Freezing has no known effect on vitamin A or β -carotene.

Of the other common fat-soluble vitamins, vitamin D is moderately stable to heat, light and oxygen. Vitamin E is fairly stable to heat but is destroyed during the development of oxidative rancidity in fats. It is reduced in amount in flours by the action of chlorine dioxide: 70% destruction (Moran, Pace & McDermott 1953), 90% destruction (Horder *et al.* 1954) and almost complete destruction (Moore, 1956) have been reported. A loss of 40% has been reported in the baking of untreated freshly milled flour (Horder *et al.* 1954).

The instability of vitamin C, particularly in relation to oxidation, is well known. Vitamin B₁ is the most heat labile of the B-complex. It is more readily destroyed by heat in an alkaline than in an acid medium. Treatment of vegetables with sulphite in the dehydration process preserves ascorbic acid and colour but results in loss of most of the vitamin B₁ (Allen & Mapson, 1943).

Conventional heat treatments, including cooking, for which an average loss of 25% has been suggested (Medical Research Council: Accessory Food Factors Committee, 1945) all result in losses of vitamin B₁. For example, pasteurizing, drying or condensing of milk causes reductions of 10%; sterilizing or evaporating of 30–50% (Kon, 1944); bread baking of about 20%; cake and biscuit baking of about 30% (Coppock, Carpenter & Knight, 1956). Puffed and flaked breakfast cereals which have been autoclaved and crisped or toasted contain negligible amounts of vitamin B₁ (Booth *et al.* 1945).

Riboflavin and nicotinic acid are more stable to heat than vitamin B₁. Riboflavin is not, however, stable to heat and light (Williams & Cheldelin, 1942). Periodic exposure of milk to room daylight does not appreciably affect its riboflavin content but exposure to direct sunlight may cause a loss of 30% in half an hour and 80% in 2 h. Vitamin C in milk is also destroyed in sunlight: complete oxidation has been reported in 10–30 min in clear glass bottles. A characteristic 'sunlight' or 'activated' flavour develops on direct exposure, apparently resulting from a reaction between photo-excited riboflavin and methionine. The effects of light on milk have recently been reviewed by Stull (1953).

Effects of water on the constituents of foods

In various forms of food processing water may be added or removed.

The effects of the removal of water are related to the extent of heating involved, the amount of water left and the length of storage of the dried product. All these factors affect the ability of the protein to rehydrate satisfactorily in a dehydrated product. The amount of water remaining in a dried product has important effects on its keeping quality, e.g. dried skim milk with 3 or 5% moisture keeps longer in good condition than a product with 7½% (Henry, Kon, Lea & White, 1948). These workers showed the free amino-nitrogen content of the protein to fall during storage, while lactose became bound to protein in the proportion of one molecule of lactose for each free amino-group destroyed, a change greatly accelerated by increasing the moisture content from 3 to 7½% and the temperature of storage from 20° to 37°. Insolubility of the protein, a characteristic brown discoloration and

flavour changes developed after a time lag, and were attributed to secondary reactions involving the protein-lactose complex. Milk that has suffered such changes is also likely to show serious loss in the nutritive value of its protein. Badly deteriorated powder was found to possess a biological value of 65–70 for the young rat as compared with an average of 85 for the unstored control. The fact that it could be restored nearly to the original value by supplementing the diet with lysine demonstrated that a deficiency in this essential amino-acid had developed during storage. It was also shown that stored dried milk became distinctly unpalatable before the deficiency in lysine could be demonstrated.

It has also been shown that dehydrated cabbage with 3% moisture will keep much longer in an inert gas under tropical temperatures than one with 7–8% moisture. The latter turns brown after a short time and loses vitamin C and flavour (Gooding, 1954, 1955). The nature of the browning reaction in dehydrated carrot and potato has been investigated by Wager (1955), and the findings on dehydrated cabbage, carrot and potato have been summarized by Barnell, Gooding & Wager (1955). In brief, it appears that 95% of the browning of dried carrot, cabbage and potato is caused by the Maillard reaction between amino-groups and sugars, though some browning occurs on heating extracts which contain no sugars. The rates of browning of extracts of dried cabbage have been shown to be much greater than those of extracts of dried carrot or potato although the pH and total nitrogen of the samples from all the vegetables and the sugar content of the carrot and cabbage were approximately the same. It will be apparent that these browning reactions are very complex and that many of their aspects, including the role of moisture, remain to be explained.

Uri (1956) has postulated that the level of moisture content plays a decisive part in the development of oxidative rancidity. He suggests that rancidity which sets in below a certain moisture level in dehydrated foods is due to the partial dehydration of trace metals, which produces profound changes in their oxidation—reduction potentials. His experiments indicate that in certain complex forms trace metals can be active oxidation catalysts at concentrations as low as 0.005 p.p.m. and that this activity is greatly affected by the polarity of the environment.

Effects of irradiation on the constituents of foods

This method of preventing microbiological decomposition of foods is not yet in commercial application. It is, however, under investigation both in the U.S.A. and in the United Kingdom. The most promising application appears to be with foods such as meats which require long exposures to high temperatures to obtain sterility. It is possible that a combination of light heat treatment and a radiation—sterilization treatment will eventually give more attractive products than those produced by present methods. Progress cannot be expected until a great deal of work has been done on the methods of irradiating the materials uniformly, on the effects of radiation on the constituents of food and on the potential acute and chronic toxicity of substances produced under radiation and in the stored products.

Goldblith (1955) has reviewed some of the effects of radiation on nutrients. He has reported that when vitamins or amino-acids are exposed in pure solution some destruction is observed, dependent on the sensitivity of the compound itself, the amount of energy to which it is exposed and the nature and physical state of the medium in which it is present. Nutrients are affected indirectly by radiation which produces in the solvent free radicals which react with them. The effect is influenced by dilution, temperature and the protection of one nutrient by the presence of another. A good example is given by the irradiation of vitamin C and riboflavin in pure solution and in evaporated milk. In milk the energy required to deactivate 63% of the vitamin C is approximately ten times that required to deactivate the same quantity in pure solution, and the corresponding ratio for riboflavin is approximately one hundred times. The same phenomenon has been demonstrated for ascorbic acid in pure solution and in orange juice.

Conclusion

A brief review such as this of the effects of processing on the nutrients in foods must leave an impression of losses of nutrients whenever a food is given any form of treatment. On the whole this is true, but it must be emphasized that the processing of foods is to a large extent a necessity to make them edible and palatable. It is also necessary for their transport from their sources to their points of consumption and also for their carry-over from time of production to time of use. The final result is therefore greatly to increase the supply of nutrients to the world's populations.

REFERENCES

- Allen, R. J. L. & Mapson, L. W. (1943). *Dehydration*. United Kingdom Progress Reports. Section VI Part 4. London: H.M. Stationery Office.
- Barnell, H. R., Gooding, E. G. B. & Wager, H. G. (1955). *Food Tech., Lond.*, **9**, 168.
- Bentley, H. R., McDermott, E. E., Moran, T., Pace, J. & Whitehead, J. K. (1950). *Proc. roy. Soc. B*, **137**, 402.
- Booth, R. G., Moran, T. & Pringle, W. J. S. (1945). *J. Soc. chem. Ind., Lond.*, **64**, 302.
- Bronte-Stewart, B., Antonis, A., Eales, I. & Brock, J. F. (1956). *Lancet*, **270**, 521.
- Coppock, J. B. M., Carpenter, B. R. & Knight, R. A. (1956). *J. Sci. Fd Agric.* **7**, 457.
- Dean, R. F. A. (1953). *Spec. Rep. Ser. med. Res. Coun., Lond.*, no. 279.
- Deuel, H. J. Jr. (1955). *Fed. Proc.* **14**, 639.
- Goldblith, S. A. (1955). *J. Amer. diet. Ass.* **31**, 243.
- Gooding, E. G. B. (1954). Private communication.
- Gooding, E. G. B. (1955). *Food Manuf.* **30**, 311.
- Henry, K. M., Kon, S. K., Lea, C. H. & White, J. C. D. (1948). *J. Dairy Res.* **15**, 292.
- Horder, Dodds, C. & Moran, T. (1954). *Bread*. London: Constable.
- Joyce, A. E. (1954). In *Color in Foods*, p. 136. [K. T. Farrell, J. R. Wagner, M. S. Petersen and G. Mackinney, editors.] Washington: National Research Council.
- Kon, S. K. (1944). *Proc. Nutr. Soc.* **2**, 149.
- Medical Research Council: Accessory Food Factors Committee (1945). *M.R.C. (War) Memor.* no. 14.
- Ministry of Food: Food Standards Committee (1954). Report on Antioxidants. London: H.M. Stationery Office.
- Moore, T. (1956). *Brit. med. Bull.* **12**, 44.
- Moran, T., Pace, J. & McDermott, E. E. (1953). *Nature, Lond.*, **171**, 103.
- Reay, G. A., Banks, A. & Cutting, C. L. (1950). *Leaf. Fd Invest. Bd, Lond.*, no. 11.
- Sharp, J. G. (1953). *Spec. Rep. Fd Invest. Bd, Lond.*, no. 57.
- Sinclair, H. M. (1956). *Lancet*, **270**, 381.
- Stull, J. W. (1953). *J. Dairy Sci.* **36**, 1153.
- Uri, N. (1956). *Nature, Lond.*, **177**, 1177.
- Wager, H. G. (1955). *J. Sci. Fd Agric.* **6**, 57.
- Williams, R. R. & Cheldelin, V. H. (1942). *Science*, **96**, 22.