PROCEEDINGS OF THE NUTRITION SOCIETY

The Two Hundred and Fifty-first Scientific Meeting (One Hundredth Scottish Meeting) was held jointly with The Institute of Food Science and Technology at the University of Strathclyde on 10 November 1972.

SYMPOSIUM ON
'THE EFFECT OF PROCESSING ON THE NUTRITIVE VALUE OF FOOD'

The effect of processing on the nutritive value of flesh foods

By I. H. BURGER and C. L. WALTERS, *British Food Manufacturing Industries Research Association, Leatherhead, Surrey*

Table 1 shows the nutritional contribution made by flesh foods (i.e. meat, fish, poultry and egg products) to the diet in Britain in 1969 and underlines the importance of these foods in the supply of fat, protein and vitamins A, D and those of the B complex. It will be demonstrated that processing of these foods can cause alterations in protein availability and loss of vitamins, and these aspects represent, therefore, important losses with regard to human nutrition.

Table 1. *Percentage contributions made by flesh foods to nutrient content of household food consumption (from Ministry of Agriculture, Fisheries and Food, 1969)*

	Protein	Fat	Calcium	Iron	Vitamin A*	Thiamin	Ribo-flavin	Nicotinic acid	Vitamin D
Meat	27·6	29·2	2·0	28·8	24·6	17·3	20·3	36·3	0·9
Fish	4·5	1·0	1·6	1·9	0·3	0·8	1·4	4·2	20·8
Eggs	5·2	3·3	1·9	7·3	7·2	3·6	8·1	0·2	17·0
Total	37·3	33·5	5·5	38·0	32·1	21·7	29·8	40·7	38·7

*As retinol equivalent.

The principal problem associated with any evaluation of protein quality is the difficulty in measuring, accurately but meaningfully, the protein damage resulting from a given process. Biological measurements such as biological value (BV), net protein utilization (NPU) and protein efficiency ratio (PER) will reveal changes in nutritional quality only when these changes affect the limiting amino acid. On the other hand, chemical analysis may provide misleading information since the linkages formed in the protein as a result of processing may be resistant to hydrolysis by digestive enzymes in vivo but will be labile to the harsh acid hydrolysis that is included in amino acid analysis.

Miller, Hartley & Thomas (1965) showed that amino acid analysis of protein hydrolysates was a poor indicator of the protein quality of heated cod-muscle preparations, as measured biologically with rats and chicks. The microbiological

assay devised by Ford (1962), which measures available amino acids, and the Carpenter (1960) method for the chemical analysis of available lysine were land-marks in the analysis of protein quality. The peptic digest residue index of NPU devised by Sheffner, Eckfeldt & Spector (1956) uses a method based on enzymic digestion followed by amino acid analysis to compute an index which has very close correlation with NPU values obtained using biological methods. These methods represent an advance on the chemical score method of Mitchell & Block (1946) and, although a comprehensive discourse on methods is clearly out of place here, this particular aspect of food 'quality' is of prime importance in assessing the retention or otherwise of nutritive value.

Effects of processing

Curing. The curing of meat has been reported so far to produce only small reductions in nutritive value. Rice, Beuk & Fried (1947) found small losses (1–5%) of thiamin, riboflavin and nicotinic acid in cured meat. An increased thiamin loss occurred (15–20%) if the product was smoked and no doubt this is attributable to the heat lability of this vitamin, as the losses of riboflavin and nicotinic acid remained low.

In fact, thiamin appears to be the only vitamin consistently lost in the preparation of several types of processed meats and sausages (2–6% loss) (Beuk, Fried & Rice, 1950), although Jackson, Crook, Malone & Drake (1945) reported riboflavin losses of 11–43% together with thiamin losses of 16–26% and nicotinic acid losses of 4–19% in smoked bacon.

The protein quality of cured meat has been reported to be equivalent in BV and digestibility to that of raw beef (Harris & von Loesecke, 1960). However, Dvorak & Vognarova (1965) concluded that cold smoking for 1–2 d caused a 12% reduction in available lysine.

Widespread use is made of sodium nitrite in the curing of meat. Although the concentration of sodium nitrite used is small, it is known that several gases are formed when nitrite interacts with meat under curing conditions (Walters & Casselden, 1972; Woolford, Casselden, Walters, Parke & Gould, 1972), and there are indications that nitrite nitrogen is incorporated into meat. It is possible that these interactions could affect the nutritional quality of the meat protein, although these effects have yet to be fully investigated on a nutritional basis.

Heat processing including canning. Heat processing is known to be responsible for reductions in protein value as a result of the destruction or unavailability of the constituent amino acids. Broadly speaking, three types of reaction are responsible for the nutritional changes which occur (Donoso, Lewis, Miller & Payne, 1962):

(1) Maillard reactions in which amino groups (notably the ϵ-amino group of lysine) react with aldehyde groups of reducing sugars or carbonyls from oxidized fat. These reactions render the lysine metabolically unavailable to the body. This subject has been reviewed extensively (Schonberg & Moubacher, 1952; Ellis, 1959).

(2) Cross-linkage reactions, i.e. protein–protein interactions, an example of which

is the formation of $=CH-N=$ links (instead of normal peptide bonds) which are resistant to enzymic hydrolysis in the gut.

(3) Damage to sulphur amino acids by oxidation or desulphydration.

As expected, the heat treatments involved in canning result in higher losses of nutrients, than do the relatively mild conditions of curing. Nevertheless, thiamin is, generally speaking, the only vitamin lost in appreciable amounts. Table 2 shows the percentage losses of thiamin, riboflavin and nicotinic acid in tinned flesh foods. Apart from tinned bacon the retention of riboflavin and nicotinic acid is high, but thiamin can be lost in considerable amounts from virtually all of the foods.

Table 2. *Percentage loss of certain B vitamins in tinned flesh foods (from Harris &* *von Loesecke*, 1960)

		Percentage loss during processing		
	Food	Thiamin	Riboflavin	Nicotinic acid
Beef:	chopped	79	6	0
	corned	56	12	0
	roast	75	0	0
Veal:	diced	79	0	0
Pork:	chopped	55	0	16
	bacon	59	29	52
	sausage	55	0	0
Lamb:	strained	84	0	13
Poultry:	light meat	67		
	dark meat	77		
Fish		75		

There is little information on the fate of other vitamins in processed flesh foods, but it has been reported that 30–40% of pantothenic acid is destroyed in the commercial heat processing of flesh foods. (Waisman, Henderson, McIntire & Elvehjem, 1942) and that the dehydration of swordfish destroyed most of the biotin (Lopez-Matas & Fellers, 1948).

On the evidence of Nielands, Strong & Elvehjem (1947) pteroylmonoglutamic acid is almost totally destroyed during canning. More recently Korobkina, Danilova & Kalinina (1969) reported 68% destruction of pyridoxine and 72% destruction of nicotinic acid when mussels were blanched for 10 min in boiling water. Polansky & Toepfer (1969) have demonstrated an increased formation of pyridoxamine in fully cooked or tinned products, but presumably this will have little effect on the nutritional value of the food since pyridoxine, pyridoxamine and pyridoxal (the active form of the vitamin) are interconvertible during normal metabolic processes.

Mayfield & Hedrick (1949) reported small decreases in the digestibility (from 0·98 to 0·94) and BV (from 0·86 to 0·79) of beef protein processed at 121° for 85 min. Pork processed at 110° for 24 h lost 44% cystine, 34% available lysine and up to 20% of other amino acids (Donoso *et al.* 1962). In addition, the NPU was seriously lowered (49%), and it was suggested that the losses of amino acids underestimated the true degree of nutritional damage. Harsher heat treatment in which pork was

processed at 112° for 24 h resulted in losses of 70% cystine and 50–65% of other essential amino acids as assayed by enzymic hydrolysis (Beuk, Chornock & Rice, 1948).

It is important to appreciate that, although prolonged heating at high temperatures can cause extensive damage to the protein of flesh foods, these particular conditions are often irrelevant as regards normal commercial processing where the most severe conditions involve temperatures of 115° and processing periods of 4–5 h. For example, Rubin (1972) has reported that luncheon meat has PER values (2·76, 2·66) which compare favourably with that for fresh pork muscle (3·0 approx.) In contrast, Bender (1962) states that the corning of beef reduced its NPU from 0·75 to 0·55.

It has been suggested that the losses of sulphur amino acids represent the most serious aspect of these changes because it is these amino acids which are limiting in the vast majority of flesh foods (Donoso et al. 1962). Nevertheless, a great deal of research has been devoted to the effects of processing on available lysine and it is likely that the observed reductions in nutritional quality are, in large measure, the result of reactions of lysine with oxidized fat (Osner & Johnson, 1968).

Maillard-type reactions can also occur in flesh foods when carbohydrate is present. Karakas, Dinic & Bern (1969) reported that minced pork or fat-trimmed chopped beef, when processed at 110° for 50 min or 130° for 30 min, showed reduced peptic digestibility and free amino acid content if 30 g starch/kg was added. The presence of small amounts of ribose (4 g/kg) in certain species of fish was sufficient to cause Maillard browning on heating. Meats generally contained less sugars than fish but could be similarly affected (Tarr, 1954). In a comprehensive study on the effect of heat-treatment on cod muscle, Miller, Carpenter & Milner (1965) reported that the presence of glucose (100 g/kg) causes damage to lysine and that digestibility falls with heat-treatment. Up to two-thirds of the cystine was destroyed and methionine was made unavailable. Once more it should be noted, however, that some of the heat-treatments studied were extremely harsh and atypical of normal industrial practice.

The dehydration of eggs involved a 'desugaring' process which removes glucose from eggs and subsequently improves the stability of dried egg during storage (Hawthorn & Brooks, 1944),

Freeze-drying. This process represents a useful realm of food technology, especially for those foodstuffs which are particularly heat-labile.

De Groot (1963) showed that freeze-drying did not significantly alter the BV or digestibility of a variety of flesh foods including beef, fish, chicken and eggs. In this study the freeze-dried products were compared with undehydrated cooked foods so that only the effect of dehydration *per se* was measured. Sauvegeot (1968) has reported that freeze-drying causes a deterioration of protein quality in meat as a result of protein or amino acid aggregation or the Maillard reaction.

Freezing and storage. Lehrer, Wiese, Harvey & Moore (1951) reported that pork chops stored for 6 months at −18° and −26° retained 60% of thiamin, 69% of riboflavin and all of the nicotinic acid. There were no significant differences in retention between the two temperatures studied. Similar results were obtained by

Westerman, Oliver & MacKintosh (1955), who studied the retention of thiamin, riboflavin and nicotinic acid in pork loins stored at $-18°$.

Little or no loss of nutrients occurs during the storage of tinned meat products. Rice & Robinson (1944) reported that at temperatures of up to $37°$ there was little or no loss of riboflavin, nicotinic acid or pantothenic acid, after 31 weeks storage. However, after 43 weeks storage at $27°$ thiamin retention had decreased to 52%.

A 9-year storage period had no effect on the NPU of tinned corned beef but two extremely aged samples of tinned meat (veal 110 years old and mutton 136 years old) had NPU values of 29 and 27 respectively (Bender, 1962) which represents a considerable reduction in nutritive value compared with that of fresh meat.

The problem of fat oxidation during storage is a serious defect that develops in many cold-stored fishery products. The oxidation products have a marked destructive effect on vitamins A and E and may exert a direct toxic action on certain enzyme systems (Kaunitz, 1967). Several measures have been taken to overcome this problem and very low storage temperatures $(-30°)$ have been found to be particularly useful (Harris & von Loesecke, 1960). One of the most successful methods of preventing fat oxidation is the rigorous exclusion of oxygen, and it has been reported that vacuum-dried sardine meal stored at $28-33°$ for 2 months has a nutritive value similar to that of the fresh product (Moorjani, Lahiry, Nair, Upadhye & Rao, 1965). Regier & Tappel (1956) reported that the PER of freeze-dried meat products did not fall after 30 d of storage under nitrogen. Antioxidants such as BHT (butylated hydroxytoluene) and ethoxyquin (6-ethoxy-1,2-dihydro-2,2,4-trimethylquinoline) have been found to improve the nutritive quality of herring meal after storage at warehouse temperatures for several months (March, Biely, Tarr & Claggett, 1965).

The method of freezing can also influence fat oxidation. It has been reported that slow freezing of beef or pork inhibits oxidation more than rapid freezing and that the absence of air circulation during freezing aided this inhibition (Nestorov, Vasilyev, Lilov, Tyutyundgiyev, Ivanov, Dgevisov & Miteva, 1969). These researchers reported that pork fat was less resistant to oxidation than beef fat.

By contrast, the rate of freezing appears to have no significant effect upon the thiamin, riboflavin, nicotinic acid, pantothenic acid or pyridoxine values in beef (Lee, Brooks, Pearson, Miller & Volz, 1950) or pork (Lee, Brooks, Pearson, Miller & Wanderstock, 1954).

In precooked frozen poultry, fat oxidation can also be a problem, and Lineweaver, Anderson & Hanson (1952) demonstrated the value of addition of antioxidant during cooking to prevent deterioration during storage.

There appears to be no significant nutritive loss during the freezing of eggs.

Domestic handling

As might be expected, the domestic cooking and treatment of food can affect the nutritive quality, and the results very much mirror the changes observed in industrial handling.

Pearson, Burnside, Edwards, Glasscock, Cunha & Novak (1951) reported losses

of 12% thiamin, 10% riboflavin, 14% nicotinic acid, 32% pyridoxine and 8% folic acid in the thaw juice of a beef carcass. Nevertheless, comparison of the nutritive value of meat cooked from the frozen state with that of the meat cooked after thawing suggested little, if any, difference in total retention of thiamin or riboflavin (Westerman, Vail, Tinklin & Smith, 1949).

Losses of thiamin can be fairly high during the cooking of flesh foods and losses of 15–40% on broiling, 40–60% on frying and 30–60% on roasting have been reported. Nicotinic acid, although stable to heat, can be lost in the meat juices during these cooking procedures (Hawley, 1971). Losses of thiamin have been reported for meat dishes stored in isothermic closed steel containers for up to 6 h. A 13–23% loss was observed after 3 h storage and a 29–40% loss after 6 h (Swiderski, 1969).

Losses of vitamin A during frying of meat at 200° have been demonstrated by Maqsood, Haque & Khan (1963), who reported a 40% loss after 5 min, 60% after 10 min and 70% after 15 min. This vitamin is particularly unstable at high temperatures, if exposed to atmospheric oxygen. Even moderate cooking of meat results in the loss of about one-third of thiamin, pyridoxine and cyanocobalamin and one-tenth of riboflavin, and nicotinic and pantothenic acids (Hawley, 1971).

The available lysine content of beef as been reported to fall as the cooking temperature is increased and ranged from 92% at 70° to 50% at 160° (Dvorak & Vognarova, 1965). Deep-fat frying decreased the available lysine of fish fillets by about 17% and by 25% when the fish oil had been used for continuous frying for 48 h (Tooley, 1972). This is undoubtedly an indication of interactions between the ∈-amino group of lysine and carbonyl compounds. However, the frying of sardines for 15 min at 180° did not reduce the BV or digestibility (Bender, 1972) and it is possible that the small losses of available lysine are not sufficient to alter the total nutritive value of the food.

In conclusion, it is appropriate to consider the action of microwave cooking on the retention of nutrients, especially thiamin, in flesh foods. Thiamin is particularly sensitive to heat and it is conceivable that the rapid heat penetration in microwave cooking might be less destructive than the slower rise in temperature in conventional ovens. Goldblith, Tannenbaum & Wang (1968) showed that microwave radiation *per se* had no destructive effect on thiamin and that loss of the vitamin was the result

Table 3. *Retention of thiamin in meat cooked by microwave heating (M) or conventional methods (C) (from Kylen, McGrath, Hallmark & Van Duyne, 1964)*

Meat	Internal temperature		Thiamin retention meat and drippings (%)
	(°F)	(°C)	
Beef, roast: C	148	65	81–86
M	160	71	70–80
Pork: C	185	85	80
M	185	85	91*
Beef loaves: C	185	85	76
M	185	85	80
Ham loaves: C	185	85	91
M	185	85	87

*Significantly higher than conventional cooking.

only of heat. However the differences between the two methods of cooking are not particularly marked (Table 3) and it is pertinent that the conventional methods scored better on palatability (Bender, 1966). Nevertheless it has been reported that thiamin retention was better in frozen meals (including beef, chicken and shrimp dishes) reheated in a microwave oven than in freshly prepared food held at 82° (Kahn & Livingston, 1970). The difference in thiamin availability could be equivalent to as much as 18% of the recommended daily intake for certain age groups.

Conclusions

This literature survey has revealed few causes for serious concern about the nutritional damage to flesh foods resulting from processing, but it has also revealed that wide gaps still remain in the knowledge and understanding of commercial practice and that some techniques used for nutritional evaluation leave much to be desired.

For example, it would be useful to investigate more closely the destruction of sulphur amino acids in tinned or cured products, particularly in relation to BV and NPU measurements. In addition, further studies on the nutritional evaluation of freeze-dried products and microwave cooking would be welcome.

With the increasing use of convenience foods, it is important that meaningful techniques are extended to new forms of processing. Similarly, the introduction of substitutes for and alternatives to flesh foods must be examined in relation to alterations in nutritional status introduced both with and without the application of processing procedures. For example, little information is available in the literature on the effects of processing on the nutritional attributes of poultry meat, and this flesh food represents an increasingly important portion of the national diet.

Furthermore, the survey suggests that the care which may be exercised by the processor to protect food from excessive nutritional damage can be undone by the housewife, restaurant or canteen, and it will be increasingly important in an era of consumer scrutiny to make available sufficient information to educate the 'domestic handler', thereby reducing deleterious changes in food to a minimum.

Quite apart from the proposed requirement for the declaration of nutritional standards in some 'enlightened' countries, the increasing concern on the part of the US Institute of Food Technologists to adopt a responsible attitude and to maintain the public image of its industry, has resulted in the formation of an expert panel on food safety and nutrition (Hall, 1972). This committee will issue public pronouncements on several topics, one of which will be nutritional changes in processed foods.

REFERENCES

Bender, A. E. (1962). *Proc. int. Congr. Fd Sci. Technol.* 1. *Lond.* Vol. 3, p. 449.
Bender, A. E. (1966). *J. Fd Technol.* **1**, 261.
Bender, A. E. (1972). *PAG Bull.* **2**, 10.
Beuk, J. F., Chornock, F. W. & Rice, E. E. (1948). *J. biol. Chem.* **175**, 291.
Beuk, J. F., Fried, J. F. & Rice, E. E. (1950). *Fd Res.* **15**, 302.
Carpenter, K. J. (1960). *Biochem. J.* **77**, 604.
De Groot, A. P. (1963). *Fd Technol., Champaign* **17**, 339.
Donoso, G., Lewis, O. A. M., Miller, D. S. & Payne, P. R. (1962). *J. Sci. Fd Agric.* **13**, 192.

Dvorak, Z. & Vognarova, I. (1965). *J. Sci. Fd Agric.* **16**, 305.

Ellis, G. P. (1959). *Adv. Carbohyd. Chem.* **14**, 63.

Ford, J. E. (1962). *Br. J. Nutr.* **16**, 409.

Goldblith, S. A., Tannenbaum, S. R. & Wang, D. I. C. (1968). *Fd Technol., Champaign* **22**, 1266.

Hall, R. L. (1972). *Fd Technol., Champaign* **26**, 11.

Harris, R. S. & von Loesecke, H. (1960). *Nutritional Evaluation of Food Processing.* New York and London: John Wiley.

Hawley, H. B. (1971). *Fd Mf.* **46**, 37.

Hawthorn, J. R. & Brooks, J. (1944). *J. Soc. chem. Ind., London* **63**, 232.

Jackson, S. H., Crook, A., Malone, V. & Drake, T. G. H. (1945). *J. Nutr.* **29**, 391.

Kahn, L. N. & Livingston, G. E. (1970). *J. Fd Sci.* **35**, 349.

Karakas, R., Dinic, J. & Bern, Z. (1969). *Proc. Eur. Mtg Meat Res. Workers* **15**, 413 (Summary III, p. 107).

Kaunitz, H. (1967). *Fd Technol., Champaign* **21**, 278.

Korobkina, G. S., Danilova, E. N. & Kalinina, N. N. (1969). *Vop. Pitan.* **28**, 85 (*Fd Sci. Technol. Abstr.* (1970), **2**, Abstr. 4R118).

Kylen, A. M., McGrath, B. H., Hallmark, E. L. & Van Duyne, F. O. (1964). *J. Am. diet. Ass.* **45**, 139.

Lee, F. A., Brooks, R. F., Pearson, A. M., Miller, J. I. & Volz, F. (1950). *Fd Res.* **15**, 8.

Lee, F. A., Brooks, R. F., Pearson, A. M., Miller, J. J. & Wanderstock, J. J. (1954). *J. Am. diet. Ass.* **30**, 351.

Lehrer, W. P. Jr, Wiese, A. C., Harvey, W. R. & Moore, P. R. (1951). *Fd Res.* **16**, 485.

Lineweaver, M., Anderson, J. D. & Hanson, H. L. (1952). *Fd Technol., Champaign* **6**, 1.

Lopez-Matas, A. & Fellers, C. R. (1948). *Fd Res.* **13**, 287.

Maqsood, A. S., Haque, S. A. & Khan, A. H. (1963). *Pakist. J. scient. ind. Res.* **6**, 119.

March, B. E., Biely, J., Tarr, H. L. A. & Claggett, F. (1965). *Poult. Sci.* **44**, 679.

Mayfield, H. L. & Hedrick, M. T. (1949). *J. Nutr.* **37**, 487.

Miller, E. L., Carpenter, K. J. & Milner, C. K. (1965). *Br. J. Nutr.* **19**, 547.

Miller, E. L., Hartley, A. W. & Thomas, D. W. (1965). *Br. J. Nutr.* **19**, 565.

Ministry of Agriculture, Fisheries and Food (1969). *Rep. natn. Fd Surv. Comm.*, 1969 p. 115.

Mitchell, H. H. & Block, R. J. (1946). *J. biol. Chem.* **163**, 599.

Moorjani, M. N., Lahiry, N. L., Nair, R. B., Upadhye, A. N. & Rao, S. V. (1965). *Fd Technol.* **19**, 212.

Nestorov, N., Vasilyev, T., Lilov, L., Tyutyundgiyev, N., Ivanov, L., Dgevisov, S. & Miteva, K. (1969). *Proc. Eur. Mtg Meat Res. Workers* **15**, 110. (Summary III, p. 129).

Nielands, J. B., Strong, F. M. & Elvehjem, C. A. (1947). *J. Nutr.* **34**, 633.

Osner, R. C. & Johnson, R. M. (1968). *J. Fd Technol.* **3**, 81.

Pearson, A. M., Burnside, J. E., Edwards, H. M., Glasscock, R. R., Cunha, T. J. & Novak, A. F. (1951). *Fd Res.* **16**, 85.

Polansky, M. M. & Toepfer, E. W. (1969). *J. agric. Fd Chem.* **17**, 1394.

Regier, L. W. & Tappel, A. L. (1956). *Fd Res.* **21**, 630.

Rice, E. F. & Robinson, H. E. (1944). *Am. J. publ. Hlth* **34**, 587.

Rice, E. E., Beuk, J. F. & Fried, J. F. (1947). *Fd Res.* **12**, 239.

Rubin, L. J. (1972). *Fd Can.* **32**, 23.

Sauvegeot, F. (1968). *Industrie aliment.* **7**, 122.

Schonberg, A. & Moubacher, R. (1952). *Chem. Rev.* **50**, 261.

Sheffner, A. L., Eckfeldt, G. A. & Spector, H. (1956). *J. Nutr.* **60**, 105.

Swiderski, F. (1969). *Przem. Spozyw.* **23**, 448 (*Fd Sci. Technol. Abstr.* (1970) **2**, Abstr. 4G195).

Tarr, H. L. A. (1954). *Fd Technol., Champaign* **8**, 15.

Tooley, P. J. (1972). *Proc. Nutr. Soc.* **31**, 2A.

Waisman, H. A., Henderson, L. M., McIntire, J. M. & Elvehjem, C. A. (1942). *J. Nutr.* **23**, 239.

Walters, C. L. & Casselden, R. J. (1972). *Z. Lebensmittelunters. u.-Forsch.* **150**, 335.

Westerman, B. D., Vail, G. E., Tinklin, G. L. & Smith, J. (1949). *Fd Technol., Champaign* **3**, 184.

Westerman, B. D., Oliver, B. & MacKintosh, D. L. (1955). *J. agric. Fd Chem.* **3**, 603.

Woolford, G., Casselden, R. J., Walters, C. L., Parke, D. V. & Gould, B. J. (1972). *Biochem. J.* **130**, 82P.