Salt in the Diet and Consideration of its Role in Food Manufacture

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ABSTRACT

The sources of salt, aspects of its quality and its physiological role in human nutrition are reviewed.

Estimates have been made of the contribution of natural foods, processed foods and salt used in cooking and at the table to the total salt content of the diet in the United Kingdom have been made. Accurate assessment of the average total salt intake is not possible because of the large individual variation in diet selection. Approximate estimates arrived at by several methods, including one by diet recall, give a range of total salt (sodium chloride) intake of 10.8 to 12.2 g per head per day. The total sodium intake lies between 4.5 and 5.0 g per day. Salt added in cooking, or at the table, represents approximately 27 percent of the total salt. Calculation of the sodium contributed by functional additives to food other than salt indicates that these represent some 5.5 to 6 percent of the total sodium intake.

The use of salt in food manufacture is partly a physiological necessity, a flavouring, a preservative and a processing aid. These uses form the basis of the technical functions which salt serves in processed foods. Some aspects of these roles in food technology are described.

Apart from its own multi-functional contribution to food processing, salt appears to exercise a particular synergistic influence with other functional food additions. The significance of this behaviour is considered.

INTRODUCTION

It is fair to say that a greater public awareness of general health and human nutrition exists in the Western World today than ever before. Such is the present situation with the subject of salt in the diet, where the interest centres on dietary sodium and its relationship to hypertension.

The body of a healthy 65 kg man contains approximately 92 g of sodium, equivalent to 234 g of salt (sodium chloride). About 50% of this is in the extracellular fluids, 40% in bone, and 10% within the cells. (Davidson, 1979, p. 84).

SOURCES OF SALT

Salt is widely distributed throughout the world. It is found in solution seawater, salt lakes and underground brine streams, and in dry deposits as rock salt.

The bedded deposits are true sedimentary rocks formed from evaporation of large inland seas in the Cambrian and pre-Cambrian periods. Rock salt is a very important source of salt and there are appreciable deposits in the United Kingdom as well as in other parts of the world.

The principal methods of salt recovery are shaft mining, solution mining and solar evaporation. Salt deposits are either mined as rock salt or dissolved underground and brought to the surface as brine. Rock salt is sold mainly for industrial use. Brine is recrystallized to produce food grades of salt. Solar evaporation is the oldest method of recovery.

For ordinary grades of salt the brine requires no treatment other than removal of adventitious insoluble impurities. Special grades of salt for use in food processing may require pre-treatment, generally with lime or caustic soda or soda ash to remove calcium and magnesium salts. In recent years, sea salt and rock salt have become more widely available for use for salt for the table. The various forms of salt differ principally in the quantity and variety of trace minerals that may be present, and it is very unlikely that these forms of salt have any specific health advantage.

A standard for vacuum salt for food uses has been produced in the United Kingdom (British Standard 998: 1969) which specifies a chemical purity of not less than 99.6% of sodium chloride, calculated on a moisture-free basis amongst other parameters. A similar standard exists in the United States (Food Chemicals Codex, p. 282), and other specifications have been proposed for particular salt uses, but there is no internationally accepted standard of purity for food grade salt. It is therefore of relevance to note that a standard for food grade salt is presently being elaborated within the Codex Alimentarius Commission of FAO/WHO. (Kinzel, 1980, p. 447).

PHYSIOLOGICAL ROLE OF SALT

Sodium, which is one of the two ions comprising salt, is an essential nutrient. Its presence is critical to the maintenance of the correct blood volume and blood pressure. The chloride ion is also important in the maintenance of the electrolyte balance of the body, in the transmission of nerve impulses, and in the passage of water across cell walls. It is also essential to the formation of hydrochloric acid in the stomach which has important bactericidal and digestive functions.

Salt is ingested by every living creature and is essential in the nutritional and physiological processes of all animals, including man. Sodium chloride is present in all body tissues and fluids, and is found chiefly in the latter as a watery solution containing sodium and chloride ions. The importance of salt is thus based almost entirely on the properties of its constituent ions.

About 75% of the body water is intracellular and the remainder is extracellular. Approximately one quarter of this is accounted for by the water of the circulating blood plasma and the remaining three quarters occupies the spaces between cells. This fluid is in close contact with individual cell units; the interstitial fluid.

The uneven division of sodium chloride between these fluids is quite marked. Sodium and chloride ions are predominant amongst the inorganic constituents of the extracellular fluid, whilst inside the cell, the intracellular fluid contains little sodium and is almost devoid of chloride.

Little is known about the mechanisms by which this large difference in salt concentrations inside and outside the cell wall is maintained. The cell wall is freely permeable, however, to water, oxygen, glucose and all the other substances necessary for, or produced by, the processes of life. Living cells utilize oxygen, glucose and other nutrients and produce carbon dioxide, urea and other waste products. These are discharged into the interstitial fluid, which has characteristics of temperature, water content, osmotic pressure, acid content, etc., which must remain constant. This is ensured by the continuous interchange of water, salt and many other substances between the interstitial fluid and the blood circulating in the capillaries. As a result of this interchange, new nutrient supplies are brought from the lungs, liver and elsewhere, and waste products are carried away for excretion by the kidneys and respiratory system. This essential control of the constitution of the interstitial fluid involves many physiological mechanisms, and sodium chloride is intimately concerned with all of them.

Regulation of the Extracellular Fluid Volume

An important property of the extracellular fluid is its osmotic pressure, and this is governed by the quantity of electrolyte dissolved in it. Most of the electrolyte present is sodium chloride and its concentration is regulated by the kidneys. The total amounts of salt and water in the extracellular fluid are therefore mutually dependent.

Thus, if the quantity of salt in the body is increased, a corresponding quantity of water will be retained, so that the salt concentration and the osmotic pressure of the extracellular fluid remain constant. Approximately 120 to 130 ml of extra water is added to the fluid for every 1 g of additional salt. Conversely, a decrease in body salt will produce a decrease in the volume of extracellular fluid.

These volume changes cannot be carried to extremes without resulting in a clinical effect, but in the early stages of salt deficiency or excess, the main disturbance is an alteration in fluid volume outside the cell.

Regulation of Intracellular Water

The intracellular fluid is in equilibrium with the extracellular fluid and in this situation water can pass freely through the cell wall. Sodium and chloride ions cannot pass through the cell wall to any significant degree, and an excess of salt in the interstitial fluid causes migration from inside the cell.

Conversely, diminution in the salt content in the extracellular fluid results in the cell becoming overhydrated.

Regulation of the Neutrality of the Body Fluids

The normal range of pH in the body fluids is between 7.35 and 7.45. They are kept in this range by the excretory action of the lung and the kidneys, by the ability of the red blood cells to carry carbon dioxide and by the stabilising action of the sodium buffer systems in the extracellular fluids. These buffers help to neutralise the weak acidity caused by carbon dioxide, and any stronger acids introduced into the body are rapidly neutralised by the sodium bicarbonate of the buffer systems. Excess alkali is similarly neutralised.

The buffers depend for their action on sodium salts and the presence of these is ensured by the intake of sodium chloride in the diet. Each kidney contains approximately one million glomeruli which act as sieves, forming a glomerular filtrate in their associated collecting tubules. In the adult human, 100 litres of glomerular filtrate containing up to 1 kilogramme of salt may be formed each day. To excrete this enormous volume of fluid as urine each day would be more than inconvenient, and in fact, 99% or more of both fluid and salt may be reabsorbed by the kidney tubules, and it is this mechanism which adjusts the losses of salt in the urine to accommodate the widely varying dietary intakes.

The urinary concentration of sodium may be high or low depending on the selective reabsorption within the kidney tubules, which in turn are dependent on the salt content of the diet and the sodium level within the body. In general it would appear that the healthy body can cope with almost any intake of salt, although for one tenth to one fifth of the population, the body salt balance is disturbed.

Functions Due to Specific Action of Sodium and Chloride Ions

In addition to the "bulk" effects of sodium chloride described above, many other physiological processes require sodium (and sometimes chloride). These ions are required in exact relative proportions to each other and to other mineral salts, such as calcium and potassium. These processes include the operation of the heart, intestinal muscle and the stomach.

DAILY REQUIREMENT FOR SALT

A precise figure for the daily requirement for sodium, and hence for salt, is difficult to establish. In health it will vary according to age, environmental temperature and physical activity. Adequate levels for a daily dietary intake of sodium have been estimated to be between 1.1 and 3.3 g for adults, equivalent to 2.8 and 8.4 g of salt, or 0.04 to 0.13 g salt per kg body weight (NAS, NRC 1980). These figures contain a very large safety margin, and it has been estimated that most adults could remain healthy on less than 0.5 g salt daily, except under conditions where there are substantial losses, for example from excessive sweating or diarrhoea. No known national diets commonly contain such small amounts of salt, although there are largely vegetarian cultures whose normal sodium intake is in the range of less than a half gram of salt per day.

Athletes, those performing heavy manual work, and people visiting countries with very hot and humid climates may initially suffer from salt depletion. However, the body can conserve salt both by reducing its urinary excretion and by secreting a dilute sweat containing reduced amounts of salt. However, additional salt supplements may be needed (Buskirk, 1980, p. 75).

Infants have greater daily faecal losses of salt than adults and have a modest requirement for growth. Therefore, on a body weight basis their need is greater than that of adults and has been estimated to be between 115 and 750 mg of sodium, which is the equivalent of 0.03 to 1.9 g of salt per day, or 0.09 to 0.54 g salt per kg body weight per day (NAS, NRC 1980).

When rapidly ingested in large doses, salt can be lethal. The lethal dose for adults has been estimated to be several grams per kilogramme body weight per day, depending on the length of time for ingestion. However, in newborn infants, because the capacity for excretion of urinary salt is much lower, salt toxicity can occur more easily. (SCOGS, 1979).

DIETARY SALT INTAKE

Before consideration can be given to such topical matters as the effect of varying salt levels on the status of health, or the ways and means of reducing salt levels in specific foods, it is necessary to define an estimate of the average dietary salt intake. As with any item of food which may be added to the diet according to individual taste preference, the range of salt intakes for the population varies greatly. Any calculated estimate is thus at best an approximation.

A number of sources contribute to the daily intake of salt. A small amount of sodium which is in the form of a number of different salts, including sodium chloride, is consumed in drinking water. This generally represents less than 1% of the daily sodium intake. The other 99% is contained in three major sources.

Firstly, sodium is present naturally in the food eaten as sodium chloride. The sodium contents of some typical natural foods are given in Table 1. It is therefore impossible not to gain some sodium from food, even if the diet consisted solely of fresh fruits and vegetables.

The second major source of sodium is contained in processed, manufactured foods. Sodium is added to manufactured foods, both in the form of salt and as a large number of other sodium-containing functional additions, examples of which are monosodium glutamate and sodium saccharin. The sodium contents of a selection of processed foods are given in Table 2, which would not normally be considered to be salty to the palate. (The role

TABLE 1

Sodium Content of Some Natural Foods*

Food	mg/100 g	Serving
Apple	2	2 mg per apple
Carrot	50	50 mg per 100 g
Milk	50	295 mg per pint
Plaice, steamed	65	110 mg per 6 oz. fillet
Steak	54	120 mg per 8 oz. steak
Eggs, boiled	140	78 mg per egg
Celery	140	70 mg per 50 g

*Paul and Southgate, 1978.

TABLE 2

Sodium Content of Some Processed Foods*

Food	mg/100 g	Serving
White bread	540	216 mg per slice
Butter, slightly salted	870	44 mg per 5 g
Cheese, Stilton	1150	575 mg per 50 g
Haddock, smoked	1220	2074 mg per 6 oz. fillet
Beef, corned	950	475 mg per 50 g
Tomato ketchup	1120	112 mg per 10 g
Soy sauce	6082	304 mg per 5 ml

*Paul and Southgate, 1978; Inst. of Food Technologists 1980.

of salt in food processing technology will be considered later in this paper).

The third major source of sodium is that which is added as salt at home in cooking or at the table. This is known as "discretionary" salt and varies greatly among individuals.

To complete this review of the sources of sodium intake in the diet, some consideration must be given to the potential contribution of sodium from medicines. Bennett (1973) has concluded that the total amount of sodium consumed in this way is, in most cases, small. However, the continued use of antacids, laxatives and other non-prescribed drugs that are based on sodium salts can increase the daily sodium intake for some individuals.

ESTIMATES OF SALT INTAKE

Several techniques have been adopted to estimate the average daily intake. The FDA "market basket" is based on a dietary survey (SCOGS, 1979). For each of twelve food categories (for example, cereals, dairy foods), numerous individual food items are purchased in four regions and are prepared as they would be for home consumption, but without added salt. Discretionary salt is added into a separate category and the results adjusted for a diet of 3900 Kcal.

A somewhat different approach is used by the National Research Council Subcommittee surveying the use of GRAS substances (1972). Information was obtained from manufacturers on the levels of salt added to processed foods, and in this way estimates of the average salt level of a large number of food categories were prepared. The average salt intake was computed by estimating the frequency and size of portions of these food categories eaten.

Both of these techniques provide good indications of average salt consumption but do not provide data about individual variation of the intake. If individual figures are required, the only reliable method is to measure the sodium excretion of the individual. As has been discussed previously, sodium is excreted from the body almost entirely in the urine, although minor losses do occur in the faeces and sweat. Generally, the faecal loss of sodium is less than 100 mg per day and in non-sweating conditions the loss of sodium through the skin is equally small, so both of these losses may be neglected, provided the subjects do not exercise. The salt excretion is obtained by the collection of 24-hour urine samples under institutional conditions.

METHODS AND RESULTS

Sodium Occurring Naturally and Added to Foods During Processing

Three methods have been used to estimate the contribution of salt to the diet from these sources.

Method 1. The amount of salt ingested per day has been calculated from a list of foods chosen to represent the typical human diet. This is recommended as "A Well Balanced U.K. Diet" in a standard textbook of nutrition (Davidson, 1979). The average portion was estimated, and the sodium content was derived by calculation using nutritional tables. (Paul and Southgate, 1978).

The results are given in Table 3. The total sodium intake is 3.453 g per day which is equivalent to 8.85 g salt per day.

Method 2. Ten adult healthy male and female volunteers, between 15 and 45 years of age, were asked to record in detail the nature and amount of their food intake for a period of 24 hours. The quantity of sodium consumed in this way was calculated using nutritional tables. (Paul and Southgate, 1978).

The individual records are not reported in this paper, but the results obtained have been summarised in Table 4. The average sodium intake per day is 3.63 g, which is equivalent to 9.3 g salt per day.

Method 3. Data relating to food groups, listed in official U.K. consumption surveys (National Food Survey, 1980), were adjusted according to average U.K. estimated intakes. The sodium content was calculated using nutritional tables. (Paul and Southgate, 1978).

The results are given in Table 5. The total sodium intake is 3.29 g per day which is equivalent to 8.4 g salt per day.

TABLE 3

Estimated Average Daily Intake of Food and Drink in Britain*

Food	Average Portion (g)	% Na	Na Intake g/head/day
Pineapple juice	120	0.001	0.001
Bacon (back, fried)	30	2.790	0.837
Egg (fried)	50	0.220	0.110
White bread (toasted)	80	0.635	0.508
Butter (slightly salted)	30	0.223	0.067
Jam (fruit)	20	0.0159	0.003
Biscuits (digestive)	30	0.435	0.131
Shepherd's pie	260	0.351	0.913
Peas (frozen)	100	0.0005	0.001
Yoghurt	150	0.062	0.093
Tomato ketchup	10	1.123	0.112
Doughnut	60	0.060	0.036
Roast chicken	150	0.080	0.120
Carrots (old, boiled)	100	0.050	0.050
Brussel sprouts (boiled)	120	0.008	0.010
Roast potatoes (old)	170	0.009	0.020
Apricots (canned)	150	0.0009	0.001
Cream (double)	25	0.027	0.007
Biscuits (sweet)	30	0.216	0.065
Potato crisps	30	0.0352	0.011
Beer (pale ale)	570	0.0101	0.058
Coffee	600	0.0003	0.002
Tea	450	0.0004	0.002
Milk (fresh, whole)	590	0.050	0.295

*Based on the well balanced U.K. diet.

TABLE 4

Summary of Sodium Intake (excluding discretionary salt) by Ten Volunteers

Subject No.	Description		Total Sodium Intake g/Day
1	Male	Age 24 years	3.726
2	Male	Age 24 years	5.408
3	Male	Age 45 years	5.069
4	Male	Age 28 years	2.968
5	Male	Age 35 years	4.480
6	Female	Age 15 years	3.618
7	Female	Age 20 years	3.626
8	Female	Age 42 years	1.789
9	Female	Age 26 years	2.888
10	Female	Age 28 years	2.693

Discretionary Salt

The calculation of the contribution of discretionary salt has been derived from two approaches to provide a probable range.

Official figures for 1978 (Household Food Consumption, HMSO) for household salt consumption per person provides a figure of 3.1 per day. This figure is considered to be a low estimate, as it fails to include salt used in cooking or added to food consumed outside the home.

In 1978 the packet salt market in the UK was estimated to be about 80,000 tons, which when divided by the approximate population of fifty million gives a consumption figure of 3.6 g salt per day. This amount is undoubtedly high as it takes no account of the salt lost in discarded cooking water, left on the plate or used for other household purposes not associated with food.

Sodium From Sources Other Than Salt

A considerable number of functional food additives, apart from salt, such as sweeteners, emulsifiers, preservatives, colouring and flavouring materials and so on, are added to processed foods. Many of these are sodium-based and their contribution to the total sodium daily intake is therefore of importance and needs delineating from the sodium contribution of salt itself.

The sodium-containing ingredients have been categorised in terms of their most probable function in foods. Using data for 1981, the total tonnage used in the U.K. has been divided by the estimate of the total population of approximately fifty million. The levels of the ingredients or compounds used in their functional role have been taken either as the maximum levels permitted by the U.K. legal regulatory systems, where these levels are applicable, or as an estimate of the average level of use required to give the necessary functional characteristics of colour, flavour and so on, where no legal maxima apply. The official figures for household food consumption were used to determine the levels of consumption of individual types of

TABLE 5

Calculation of Average Sodium Contents of Food Groups Multiplied by Intake Data Provided by Food Facts

Food Group	Average Intake/Person/Day	Sodium Content in Average Portion (mg)
Liquid milk	336 ml	168
Other milk	31 ml	57.7
Cheese	16.3 g	156.6
Butter	15.9 g	138.3
Margarine	15.5 g	124.0
Lard and compound fat	6.9 g	0.14
Eggs (number)	0.5	42
Preserves	8.1 g	4.03
Sugar	43.5 g	—
Beef and veal	28.2 g	18.4
Mutton and lamb	16.8 g	11.95
Pork	17.9 g	11.78
Bacon and ham—uncooked	16.6 g	255.97
Bacon and ham—cooked	4.5 g	64.87
Poultry and cooked chicken	27.3 g	18.65
Other cooked meat, not canned	2.2 g	9.50
Other canned meat	8.1 g	80.54
Offal	4.0 g	4.77
Sausages—uncooked	13.0 g	102.05
Meat pies and sausage rolls, ready to eat	3.1 g	18.76
All others, not frozen	9.9 g	57.70
Fish, fresh and processed	11.5 g	44.40
Canned fish	3.0 g	15.08
Fish and fish products, frozen	5.6 g	3.81
Fresh green vegetables	47.6 g	344.60
Tomatoes, fresh	17.1 g	0.51
Other fresh vegetables	39.2 g	82.08
Frozen vegetables	21.5 g	3.01
Canned tomatoes	6.2 g	1.80
Canned peas	9.4 g	21.62
Canned beans	16.3 g	397.72
Potatoes, excluding processed	140.0 g	19.25
Citrus fruit	25.6 g	0.77
Bananas	13.2 g	0.13
Apples	29.7 g	0.59
All other fresh fruit	15.8 g	0.87
Canned fruit	12.6 g	0.42
Dried fruit, nuts and fruit & nut products	3.7 g	0.48
Pickles and sauces	7.6 g	49.19
Flour	20.4 g	12.41
White bread, standard loaves	85.6 g	462.24
Brown, wholewheat and wholemeal	22.2 g	120.99
Other bread	15.7 g	91.06
Buns, scones and tea cakes	3.3 g	18.89
Cakes and pastries	11.3 g	32.41
Chocolate biscuits	4.7 g	7.52
Other biscuits	18.3 g	72.31
Breakfast cereals	14.7 g	81.04
Oatmeal and oat products	1.2 g	7.58
Canned milk puddings	3.1 g	1.55
Tea	8.4 g	3.78
Instant coffee	2.2 g	0.90
Canned soups	9.2 g	43.47

food. (Household Food Consumption, HMSO) (Food Survey Committee, 1980).

Care has been exercised with the data so that where there are alternatives to sodium-containing additives available to exercise the same function in a food an estimate has been made for the usage of the sodium-bearing one. Thus, as an example, sodium stearoyl lactylate has been assumed to represent 10 percent of the emulsifiers used in bread and flour confectionery. The only sodium chloride sources given in this calculation are hydrolysed vegetable proteins and yeast extracts.

The total sodium intake is 1.9 g person per week, or 0.27 g per person per day (Presented in Table 6).

DISCUSSION OF RESULTS

The results for the sodium intake, both present naturally and added in processing, differ, depending on the method used to estimate the dietary contribution. This is to be expected because there is a considerable individual variation in salt intake. The figures of 3.45 g, 3.63 g and 3.29 g of sodium per person per day that have been obtained provide a reliable series of approximations of sodium intake.

Using the mean result of 3.5 g, the sodium contributed by functional additions to food other than salt, viz. 0.27 g per day that has been calculated (Table 6), represents 7.7% of the sodium contributed to the diet from food. This figure concurs with a statement in the literature that the small quantities of sodium, other than that found in nature and from salt used in food processing constitutes less than 10% of the total resulting from salt (Kare, 1980, p. 223) and is therefore probably a conservative estimate.

If all the sodium in food is assumed to be in the form of sodium chloride, the range of salt intake derived from the results is between 8.4 g and 9.3 g per person per day. On the other hand, if allowance is made for the possible contribution of the 0.27 g of sodium from other functional additions, then the equivalent salt intake falls to between 7.7 g and 8.6 g.

The discretionary salt consumed is between 3.1 g and 3.6 g per person per day. Thus the total salt (sodium chloride) intake derived from these calculations is within the range of 10.8 g to 12.2 g per person per day. The total sodium intake is, of course, between 4.5 g and 5.0 g per person per day, equivalent to a salt intake ranging between 11.5 g to 12.9 g per day. Discretionary salt thus represents some 27% of the total daily salt intake on average, with a range of 25 to 33%, and the sodium derived from other functional food additions represents between 5.5 and 6% of the total intake.

It is of interest to compare the data obtained here with the results of other dietary studies that have been reported.

In the United Kingdom, the sodium content of all items on the National Food Survey has been calculated (Bull, 1980). The total sodium intake was 3.5 g per person per day, comprising 2.23 g from food and 1.24 g from discretionary salt. The total sodium content is considerably lower than the present data provide, but the discretionary intake is comparable.

In a separate study of total diet samples from six areas of the United Kingdom, the average intake of sodium in representative amounts of food, prepared where appropriate in salted cooking water, but excluding salt added at the table, was estimated (Buss, 1978). The average intake of sodium ranged between 2.9 g and 3.7 g, which may be compared with 3.3 g to 3.6 g reported in this study.

The differences that are recorded point to the difficulties encountered in surveying "national" data, since such surveys normally record only food purchased with the intention of home consumption and ignore the sodium from food eaten outside the home.

In the United States, dietary data for 1971 to 1974 are reported for naturally occurring sodium in foods and sodium added by food processors. (U.S. Department of Health and Human Services, 1981). These indicate an average daily consumption of 2.70 g sodium, equivalent to 6.9 g salt for males, and 1.85 g sodium, equivalent to 4.7 g salt for females. The differences reported among various age groups were small. The technique used was based on dietary recall, so discretionary salt is not included in these data.

The difference between the dietary salt intake of males and females is also apparent in the results given in Table 4, but because of the small number of results, the figures are not capable of statistical evaluation.

The most comprehensive contemporary review of dietary sodium intakes in the United States is reported in SCOGS (1979). Using both direct and indirect measurements of discretionary, naturally occurring and processing sodium additions (including salt), many differing estimates of the total salt intake for adults have been made. It is concluded that the best estimate of daily salt intake is not less than 10 g to 12 g. Discretionary use accounts for about one third of the total intake on average. Of the non-discretionary contribution, 3 g of salt is attributed to sodium occurring naturally in foods (when expressed as sodium chloride), and by difference 4 g to 6 g added in both the form of salt and other sodium-based functional additions by the food processor.

The figures relating to both total intakes and discretionary salt use are not dissimilar from the results derived in this study. The contribution made by naturally occurring sodium in foods has, however, not been evaluated as yet.

TABLE 6

Sodium from Sources Other Than Salt

Additive/Ingredient	Function	% Na	Intake (mg/ person/week)	Food Types/Levels of Use	Assumptions	Significance in Diets
Sodium ascorbate	Antioxidant	11	<10	Cooked meats, bakery products, pickles—0.2% (approx.)	Asorbic acid generally preferred	Low
Sodium nitrate	Preservative	27	20	Bacon and ham—500 ppm	Consumption = 5.39 oz. per week	Low
Sodium nitrite	Preservative	33	10	Bacon and ham—200 ppm	Consumption = 5.39 oz. per week	Low
Sodium propionate	Preservative	24	<10	Bread, processed cheese—0.3% max.	Propionic acid and calcium salt more commonly used	Low
Sodium sulphite	Preservative	37	5	Dried fruit (<350 ppm) and jams (<100 ppm)	Consumption = 1 oz. per week	Low
			10	Dried veg., instant potato (<2000 ppm)	Consumption = 0.5 oz. per week for each	
Sodium benzoate	Preservative	16	10	Jams, marmalade, pickles, sauces (<1000 ppm)	Present in 50% of products (1.75 oz.)	Low
Sodium stearate	Emulsifier	14	<10	Dutch crispbreads only	—	Low
Sodium stearoyl lactylate (SSL)	Emulsifier	6	30	Bread and bakery products—0.5% max.	Used in 10% of bread and cakes at maximum level	Low
Dyestuffs: Tartrazine, Sunset yellow FCF, Indigo carmine	Artificial Colour	10 (ave)	7	Numerous types, 0.1%	U.K. usage = 2% of caramel usage = 176 tons/annum	Low
Caramel	Colour	0.2	5	Gravy browning, numerous types	U.K. usage = 7000 tons/annum	Low
Sodium nucleotides	Flavour	13	17	Savoury products, dried soups <0.2%	U.K. usage = 35 tpa	Low
Monosodium glutamate	Flavour Enhancer	12	280	Savoury products, <3% in dry soup mix	U.K. usage = 6000 tons/annum	Medium
Hydrolysed Vegetable Protein						
—sodium chloride	Flavour	16	245	Savoury products	U.K. usage = 4000 tons/annum	Medium
—natural MSG		1.3	20			Low
Yeast Extract (mostly NaCl)	Flavour	4	120	Savoury products <10%, Marmite	U.K. usage = 8000 tons/annum	Medium
Saccharin	Artificial Sweetener	12	30	Soft drinks, hot beverages	Consumption = 25% of WHO recommended maximum ADI.	Low Low
Sodium citrate	pH Controller	11	40	Ice cream, evap. milk 0.5%	Consumption = 2.35 oz. per week	Low
Sodium acid pyrophosphate $Na_2H_2P_2O_7$	Sequestering Agent	21	110 20	Canned beef, canned poultry, other canned meats <0.5% Canned fish <0.5%	Consumption = 2.35 oz. per week Consumption = 0.51 oz. per week	Medium Low
Tetra sodium pyrophosphate $Na_4P_2O_7$	Coagulating Agent	35	120	Milk puddings <1%	Consumption = 1.2 oz. per week	Medium

TABLE 6 (cont.)

Sodium from Sources Other than Salt

Additive/Ingredient	Function	% Na	Intake (mg/ person/week)	Food Types/Levels of Use	Assumptions	Significance in Diets
Sodium tripolyphosphate	Water Binding	34	30	Fish products < 0.2%	One third of fish eaten is phosphate treated (= 3.4 oz/wk)	Low
			130	Chicken, cooked ham, bacon, poultry 0.4%	One half of products are phosphate treated (= 3.4 oz/wk)	Medium
Sodium pectate Sodium CMC Sodium alginate (edible gums)	Thickener, Stabiliser, Gelling Agent	10 (ave)	95	Cereal convenience foods (0.5%) ice cream (0.3%) jellies (0.4%) dressings (0.5%) milk puddings (1%)	Consumption = 6.6 oz. per week	Low
Sodium bicarbonate	Chemical Leavening	27	310 + 80	S.R. flour—1% cakes and buns—0.3%	S.R. flour = 2/3 of flour consumed (= 4 oz) Consumption of cakes and buns = 3.5 oz.	High
Sodium aluminium phosphate (Levair)	Chemical Leavening	2.4	3	S.R. flour, cakes & buns 1.5%	Used in 25% of cakes and pastries (0.25 oz) oz. per week	Low
Sodium acid pyrophosphate $Na_2H_2P_2O_7$	Chemical Leavening	21	90 + 40	S.R. flour—1.3%, cakes and pastries—0.4%	Used in 50% of cakes and pastries and 20% of S.R. flour	Medium

SALT IN FOOD TECHNOLOGY

Salt has an essential role to play in food technology, as a flavouring, preservative and textural ingredient, and it is used widely and in varying amounts in the processing and manufacture of many foods. Its use in particular foods is well documented and it is not proposed to provide details here. It is appropriate, however, to describe the more important principles involved in its multifunctional attributes, and to illustrate them with references to foods that owe their viability to these properties.

Salt in Flavouring

One of the most universal and demanding appetites is that for sodium chloride, and salt has been called the "primordial narcotic." (Multhauf, 1978, p. 4).

Interaction of sodium and chloride with the taste cell membranes excites an innervating sensory nerve. When salt is taken into the mouth, salivary secretions increase, and the oral stimulation broadly serves to initiate anticipatory digestive activity (Strong, 1968), and it is possible that even at very early ages, salt increases the palatability of food (Kare, 1978).

References to the use of salt in cooking can be traced for over five thousand years (Kaufmann, 1971, p. 397), and the lack of the proper amount of salt causes many foodstuffs to be flat, tasteless and undesirable. Thus bread from which salt has been omitted has been reported to be unsaleable because of its insipid taste (Pyler, 1952) and salt affords the best means of correcting blandness or absence of flavour.

Salt gives food a flavour which is distinctly salty, and its applications as a flavour, and with spices as seasoning, are legion. In addition it acts to accentuate the flavour of other major and minor constituents, as well as flavours induced by fermentation. For example, the sweetness of sugar can be emphasised by the contrasting taste of salt, thus, about 15 to 20 g salt is added to 10 kg sugar to improve the taste sensation in meringues.

Salt as a Preservative

The microbiological stability of a food, or the likelihood of spoiling, is related to the state of the constituent water and not just the water content. There is a correlation between the thermodynamic water activity a_w and microbial growth under certain circumstances (Scott, 1957). a_w is the ratio of vapour pressure of water in the food to the vapour pressure of pure water at the same temperature and is numerically equal to one hundredth of the relative humidity generated by the food in a closed system.

The a_w of a food influences of multiplication and metabolic activity of microorganisms, including toxin production, as well as their survival and resistance. This is true not only for organisms that cause spoilage and food poisoning but also for those which are desirable for the fermentation of certain foods. Most organisms occurring in foods proliferate at a high a_w and only a few require a low a_w for growth.

For every different microorganism there is a value of a_w required for the growth of a number of genera of bacteria, yeasts and moulds which are recovered from foods (Leistner, 1976, p. 126), many of which are based on the sodium chloride tolerences of the organisms. Substrates with a_w of less than 0.95 inhibit multiplication of most Gram-negative bacteria as well as spore forming bacteria of the genera Bacillus and Clostridium and also apparently inhibit germination of bacterial spores. Some Gram-positive bacteria which are desirable for the fermentation of meats, e.g., representatives of the genera Lactobacillus, tolerate a much lower a_w than 0.95 and well adapted strains of bacteria, for example, those found in curing brines, are able to grow at an a_w at which most representatives of their genera would be inhibited.

In traditional processes, in order to obtain an extension of the shelf life of products, decreases in the a_w of a food are accomplished by drying, freezing or the addition of a hydrophilic chemical (a humectant). Some of these processes are applied in combination, and the object is to decrease the a_w below a level where most pathogenic microorganisms cannot grow but still have enough water in the product for palatability.

Both sugar and salt are examples of hydrophilic chemicals, and sodium chloride allows the highest moisture contents at a_w of between 0.7 and 0.9 because its molecular weight is low and its solubility is high. Unfortunately it presents taste problems when used in high concentrations.

Butter is a typical example of a product whose shelf life can be extended considerably by the addition of between 1 and 4 percent of salt (even though salt is added primarily as a flavouring).

Salt in Processing

Salt plays an important role in affecting the texture of many products.

In bakery products, it has a strengthening effect on gluten in bread doughs, thereby improving the handling properties of dough and reducing water absorption. This may be due to direct action on the gluten or it may be due to an inhibitory action on the proteolytical enzymes.

A similar explanation may account for the effectiveness of salt in controlling the development of bitter flavour in Cheddar cheese, where it has been shown that salt exercises an inhibitory effect on the proteolysis of beta casein (Fox, 1971, pp. 165–170).

In meat products texture is affected by the capability of salt to solubilise the myofibrillar and sarcoplasmic proteins which have both hydrophilic and hydrophobic properties enabling them to act as emulsifiers. Its use therefore serves to bind water through electrostatic interactions and retain product yields. The solubilised meat protein and water form a matrix which encapsulates globules of fat. When the raw emulsion is cooked, the fat is melted and held within the matrix of heat coagulated protein, thereby diminishing losses of fat and water, for example, in frying comminuted meat products like sausages.

Fermentive Texturising

The principle of using selective fermentation to alter the flavour, texture and other properties of basic food has been applied to a wide variety of commodities, vegetable dairy and meat.

Vegetables rapidly lose their turgidity and are prone to quality deterioration unless they are processed immediately after harvesting. The production of processed vegetables relies heavily on brining or salting. Unfermented products are usually stored in 15% brine, thereby inhibiting the growth of all the surface microflora and extending the shelf life by several months.

Fermented vegetable products, on the other hand, have an almost indefinite shelf stability when maintained in anaerobic conditions, and their organoleptic attributes are also considerably altered by the physical and chemical changes brought about by the fermentation, including the maintenance of turgidity.

Raw vegetables have an extensive flora of microorganisms, the majority of which are inhibited when the vegetables are slightly salted (2%–3%). The salt, through its osmotic effect, provides an aqueous environment from the vegetable tissues which contain fermentable sugars and other nutrients. This is between 8 and 11 percent equilibrium salt content overall. This selective reduction in a_w allows bacteria, particularly the lactobacillus and aerobacter types, to ferment the natural sugar present (or added sugar if no natural sugar is available). Some convert the sugars almost exclusively to lactic acid, others produce lactic acid, carbon dioxide and traces of alcohols and acetic acid.

Spoilage microorganisms include yeasts, some of which may ferment the sugars to carbon dioxide and alcohol. Other yeasts act oxidatively at the surface of the brine, and ferment and destroy lactic acid, thereby reducing the level present. These therefore need controlling, since the remaining salt-tolerant organisms are putrifactive bacteria which are inhibited by lactic acid.

Similar mechanisms are involved in the production of fermented sausages (where a lactic acid starter culture may have to be added), and in cheese making where salt is added to the curd to retard the growth of microorganisms and to develop texture and flavour (Zaika, 1978, pp. 186–189). Blue cheeses are more heavily salted to inhibit bacterial growth, allowing the growth of salt-tolerant moulds. "Swiss" cheeses and soft curd cheeses are only slightly salted.

In bakery products, salt serves to control the rate of fermentation in yeast leavened products, and its presence can prevent the growth of undesirable organisms and the development of undesirable wild yeasts.

THE SYNERGISTIC EFFECT OF SALT WITH OTHER FUNCTIONAL ADDITIONS

So far, the intrinsic functional roles of salt in food technology have been considered, but it is evident that it also enhances its efficiency in these roles when used in combination with other functional additives. This phenomenon will assume much significance when consideration is given to the reduction of salt and other sodium-based functional additives in processed foods, especially if replacement of sodium by other anions proves to give rise to other nutritional imbalances.

Inhibitory and Antimicrobial Activity

Salt/nitrite mixtures in meat curing. Salt alone does not destroy pathogenic organisms with certainty and has a limited preservative effect. In the absence of oxygen, as in canned or in vacuum packed meats, the organism *C. botulinum* can grow unless adequate control measures are taken. This organism is responsible for the often fatal food poisoning known as botulism.

The combination of salt and nitrite (curing mixture), as well as producing the required colour and flavour, has a unique preservative effect. Sodium nitrite, or the nitric oxide it generates, is the only single substance that selectively prevents botulism toxin formation in the presence of salt (Baird-Parker, 1974). The effectiveness of the action is dependent on the pH of the system and the rate of diffusion of salt into the meat muscle and is not related to the a_w.

The "hurdle effect" relates the interaction of the several parameters that may influence the inhibition of microorganisms in such systems (Leistner, 1976, pp. 126–128), and this concept might also explain why canned cured meat products, such as canned hams, can be rendered shelf-stable by a heat process which is less intense than that required for canned meat products that are not cured.

Salt in combination with other antimicrobial agents. The inhibition of Staphylococcus aureus growth by combinations of sodium chloride with buylated hydroxyanisole (Stern, 1979), with potassium sorbate (Robach, 1980) and of Moraxella-Acinetobacter cells by combinations of sodium chloride with sodium phosphates (Firstenberg-Eden, 1981) is reported, but as yet no technical applications have specifically resulted.

Yeasts are normally protected against heat inactivation by sodium chloride. The sensitivity of yeast cells to heat can be increased by adding potassium sorbate or sodium benzoate. It has been suggested that the time/temperature requirements for pasteurisation of food products containing relatively high levels of sodium chloride could be reduced, thus maintaining more desirable sensory and nutritional qualities (Beuchat, 1981).

Salt in combination with spices and essential oils. The inhibitory action of cinnamon and cloves and other spices on the germination of mould spores and the synergistic effect of the addition of salt has been observed (Anand and Johar, 1957) in mango pickle. The synergistic antimicrobial effects of sodium chloride with several essential oil components have also been reported (Kurita, 1982).

Salt in combination with sodium lactate. Several humectants appear to produce more depression of the a_w than expected. Of these, sodium lactate shows particularly remarkable behaviour and is further particularly effective in synergistic combinations with sodium chloride (Loncin, 1975).

Rehydration (Cereal)

The use of phosphates and polyphosphates for improving rehydration and cooking times by cereal grains and pasta is reported in the literature. The use of sodium chloride in conjunction with phosphates is less well known. It has been shown that a synergistic effect exists for salt-phosphate mixtures and the ratio in which they are used in combination has been shown to be of particular significance (Personal communication, Bale, 1982).

Autolysis (Yeast)

The addition of sodium chloride to compressed baker's yeast induces strong plasmolysis of cells. The simultaneous addition of ethanol and sodium chloride activated some intracellular proteinases, which accelerated autolysis following plasmolysis. Addition of ethanol alone causes a lesser activation of these enzymes, but with the development of a bitter flavour. The synergistic effect allows the preparation of food grade yeast with acceptable flavour (Sugimoto, 1974).

Emulsification

The addition of phosphate to sodium chloride solutions increases the amount of extractable protein from deboned turkey meat and there is a synergistic effect on the water holding, binding and emulsification capacities (McMahon, 1976). In pork, combinations of salt and sodium tripolyphosphate were synergistic in improving "drip" loss and colour in restructured pork and decreased losses on cooking (Schwartz, 1976).

CONCLUSION

The availability of a wide variety of foods, marketed nationally on an ongoing basis clearly depends upon their processing with salt, among other sodium containing substances, to provide and enhance flavours and to develop and maintain specific characteristics of foods such as texture and durability. The levels of salt in processed foods have evolved to meet these needs, and the consumer has become accustomed to the salt flavour produced by these levels. The significant reduction of salt content could, therefore, not only make some products unacceptable but seriously impair the essential nature of others, and it is impracticable to do so at present.

The synergistic behaviour of salt in conjunction with other additives in food is thus not only of considerable interest but is worthy of further study and evaluation in its application to food processing technology. This would allow for the reduction of salt level in foods, yet offer the maintenance of quality and shelf stability. The gradual reduction of the level of salt in foods would permit the consumers to adjust their established taste preferences.

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