A FOOD SCIENTIST LOOKS AT WATER

By

R. B. DUCKWORTH

Professor and Head of Department of Nutrition and Food Science, University of Ghana, Legon

A FOOD SCIENTIST LOOKS AT WATER

By

R.B. Duckworth

Professor and Head of Department of Nutrition and Food Science,
University of Ghana, Legon.

An Inaugural Lecture delivered at the University of Ghana
Legon, on Friday, 24th February, 1978.

GHANA UNIVERSITIES PRESS

ACCRA

1978

Published for the University of Ghana

By

Ghana Universities Press

P.O. Box 4219,

Accra.

Distributed in the United Kingdom and the Commonwealth

By

Rex Collings Limited

6 Paddington Street

London W.1.

Printed in Ghana

By

NEW TIMES CORPORATION

ACCRA

A FOOD SCIENTIST LOOKS AT WATER

Mr. Vice-Chancellor, ladies and gentlemen, it is, I think, one of the more interesting and valuable features of University life that a series of lectures such as the present one can encompass so wide a variety of subject matter. My own contribution as a scientist is, for example sandwiched between a discourse on the legal system in Ghana and another on the foundations of African civilization. Yet in spite of the wide divergence of the topics, it is often surprising I think how many points of contact and mutual interest can emerge.

Compared to Law and Archaeology, my own subject of Food Science is, of course, a relative new-comer to the academic scene. Like all other branches of scientific study it has assumed a separate identity gradually over a considerable period of time and as a result of the activities of many individuals and small groups of specialists.

There was a time, not very long ago, when in the older established Universities the academic mind would no doubt have boggled at the idea of introducing new courses of so specialised and applied a nature into the curricula. However, we live in a relatively enlightened era in which it is now considered respectable to combine the academic challenge with the accumulation of knowledge and of technical expertise in an essentially practical field bearing directly on the provision of man's basic everyday requirements.

It is interesting to look back fleetingly over the history of our academic institutions and on the way in which what we might call the practical arts have become established within the Universities. From the very outset man's preoccupation with himself, with his own body, its function and malfunction, resulted in medicine being accepted as a respectable subject for academic study. Relatively it has been only quite recently, however, that the other practical subjects concerned with the basic needs of man and of his society e.g. agriculture, and engineering received the accolade of full academic respectability.

The emergence of Food Science has been an even more recent development and one which may be said to have finally culminated only in 1962 with the holding in London of the first International Congress of Food Science & Technology.

So young in fact is academic Food Science that I am very pleased to be able to count the first two Presidents of our International Union as personal friends. The first president was Professor George Stewart of the University of California and the second and present president is the Head of my home department at Strathclyde University, Professor John Hawthorn who has visited the University here on a number of occasions.

1962 was indeed really a most significant year in the present context because, not only did it mark the coming of age of Food Science as an academic discipline internationally, but it was also the year in which, I understand, the teaching of Food Science began in this University. The combined department of Biochemistry, Nutrition and Food Science came into being at that time following a recommendation by a joint F.A.O./Ghana Government Committee and the University of Ghana became the first seat of higher learning in West and Central Africa to offer courses in the subject.

Ghana, and this University in particular, can therefore pride itself as having been a pioneer in these developments in this part of the world and in having provided a shining example to the rest of Africa, an example incidentally which was quickly followed. Now, a substantial and progressively increasing number of departments of Food Science and of Food Technology is to be found, scattered widely around the African continent.

The singular importance of providing university education and training in Food Science and Nutrition in a country such as Ghana should, I feel, require no special emphasis from me. The food situation in this country, as we are all too well aware, is a serious one. Nutritionally, the position in the country is far from good, especially among certain particularly vulnerable groups such as young children and expectant and nursing mothers. Yet more important, however, is the fact that for various reasons overall supplies of wholesome food are inadequate. In some areas, food is dangerously short for most if not all of the time, while in many other areas periods of serious shortages are liable to occur at not infrequent intervals. Moreover, a good deal of the shortfall may be accounted for by post-harvest losses.

Production is primarily the concern of the agricultural specialist; conservation, the maintenance of quality and preservation are very much the concern of the food scientist. The quest for alternative sources of food and for the more effective use of raw materials which are at present or could potentially be, produced locally in quantity is one which perhaps calls for a high degree of interdisciplinary co-operation.

Although Food Science is now firmly established worldwide as an academic discipline, it is my experience that there are still very many people, even among fellow academics, who see the subject as through a glass rather darkly and who remain somewhat confused as to its relationships with other disciplines.

I would go further and say that there are indeed food scientists who still argue and disagree among themselves on points of details. Nevertheless, within the subject there is now a high measure of agreement and today I would like to attempt a modest contribution of my own towards a wider and more complete understanding of what Food Science represents and what it is trying to do.

An all-embracing definition of the subject in the time I have available would be an impossible task to undertake and in any case, I do not wish to bore you with a long recital of subject headings and sub-headings. The most important feature of Food Science to my mind is its interdisciplinary or should I say multidisciplinary character. May I depart for a moment from my main argument to reminisce.

I myself originally trained as a botanist and spent some time in academic botany before I entered food science. I remember on joining the scientific civil service in Britain to work in what was then Scientific Adviser's Division of the Ministry of Food in London, I was expecting that I would be set to work as a botanist. I soon discovered, however, that the title Scientific Officer which was and still is used in the service meant exactly what it said. I had been employed not as a botanist but as a Scientist and I was soon doing all manner of things which called for the application of my general scientific knowledge rather than of my specialist training. The moral of this story, I think, is obvious. Specialists we shall always need, but the specialist who becomes too narrow and who neglects his understanding of related and supporting subjects and allows it to wither away is the less effective as a consequence. Moreover, there are few practical problems in the real world, especially involving the use of biological materials, to which expertise exclusively in one narrow specialisation is sufficient in itself to provide a satisfactory solution.

The little story I told also, I think, draws attention to the distinction between two different kinds of specialist. Firstly, we have the specialist in one of the areas into which academics have traditionally and quite logically classified universal knowledge, and secondly we have the person who specialises in dealing with practical problems of a particular kind by the collective application of knowledge and expertise which the traditionalist (academic) would classify under several or many different headings. The subject matter of academic food science is peculiar to food science itself, but the student of the subject is trained to approach problems in a broadly scientific and interdisciplinary way.

What I propose to do then during the remainder of my address is to take a topic which is important in quite a number of different respects in the scientific study of foods and in which I happen to have a special interest and by discussing some of its ramifications to underline, I hope, the essential interdisciplinary nature of the subject and the way in which it is firmly founded on and overlaps with the older-established, and more basic branches of scientific study. At the same time, I hope that a sense of the identity and wholeness of food science as a separate area of scientific endeavour will also emerge. The topic I have chosen is water and the roles which it plays in relation to food quality, food conservation and food preservation.

As I talk about this I invite you to list the numerous other academic disciplines on which I shall incidentally touch and with which science obviously has some community of interest. I offer no prizes for getting them all right, but it should form an interesting and revealing collection.

Water is, of course, such an important substance in man's environment that, were this an inaugural lecture in almost any other academic field it might still, entirely appropriately, be chosen as a subject. This is, perhaps, a reflection at one and the same time of both the universality of knowledge and of the immense importance of water in this world of ours.

Man's first experiments in civilised living were in fact made in large fertile river basins, notably those of Mesopotamia, Egypt and India, and from the beginning water was accorded a central and almost divine importance by the city dwellers of those ancient times.

The fundamental role attributed to water substance by the early Greek philosophers is well-known alike to both the classical scholar and to the scientist. Indeed, Thales, one of the original seven wise men of ancient Greece, and generally regarded as the first man of science in the western world, went so far as to regard water as the material cause of all things — the original substance from which all other material things were made. While this rather extreme view never won wide acceptance, water nevertheless became firmly established, along with earth, air and fire as one of the "four elements" recognized by the early Greek philosophers whose writings, notably those of Aristotle, were to continue to influence informed thinking on such matters, along with the later pronouncements of the alchemists, right up to the time of Robert Boyle and the emergence of modern Chemistry during the seventeenth and eighteenth centuries.

As the true nature of matter and of the chemical elements came to be realised, it was the work of Cavendish and Lavoisier in the 1780s which first demonstrated that water is in fact a compound of the two elements hydrogen and oxygen. A further hundred and fifty years were to pass, however, before the unique structure and dipolar nature of the water molecule were to be discovered and before the important influence of these on the physico-chemical properties of water substance began to be fully appreciated.

Today, we tend to take water very largely for granted, thinking of it merely as the most abundant and ubiquitous of chemical compounds in our immediate environment. For it does in the liquid form cover some three fifths of the earth's surface, quite apart from the immense quantities occurring as water of hydration within the rocks of the earth's crust, as vapour and liquid droplets in the earth's atmosphere, and making up well over 50 per cent of the weight of all living organism — a not inconsiderable part of the total water in the inhabitable regions of the earth, sea and sky, and the part we shall be concerned with mainly in talking about foods.

Water is, however, from the chemical point of view, a most interesting compound, being uniquely capable of forming complex multimolecular structures which cause it to exhibit quite unusual physico-chemical properties.

In spite of its abundance and ready availability it has always proved a very challenging and difficult material for scientific study.

Allow me to quote from a chemical treatise by Herman Boerhaave, a Professor of Chemistry at Leyden in Holland during the 18th century:

"As water is common to be met with and comes to be used on every occasion, men are apt to imagine they thoroughly understand its nature: but those who have carefully applied themselves to the examination thereof, find it one of the difficult subjects in all natural philosophy to be acquainted with. A principal cause of the difficulty is the labour required to separate water from other bodies or, other bodies from water; which continually mixes itself with chemical subjects and especially with the air, wherein all chemical operations are performed, so that it is scarce anywhere excluded." (First published in English in 1753).

Although these words were written so long ago, present-day physical chemists, who have themselves undertaken studies on water, agree readily with the sentiments expressed and there is still today continuing controversy concerning the precise structure of pure liquid water itself.

More important in the present context is that water formed the cradle of biological evolution. Without water there could have been no life on earth, or certainly no life as we know it, and the very properties of water which made life possible and which continue to be paramount in the biological sphere are also those which are especially important in my own subject of Food Science.

Not only has water been so essential to the evolution of man but it has also been a most important factor in his social history. It has, for example, played a major role in relation to the rise and fall of civilisations and, pausing for a moment to do a little crystal-gazing, the efficiency with which the water resources available to man are managed in the future will no doubt determine, to a greater and greater extent, the availability of future human food supplies and the fortunes and quality of life of large number of human beings yet unborn. Increasingly already, it is lack of water rather than lack of land that is limiting world food production.

I think I have probably said enough already to illustrate that it is difficult to talk generally about water without trespassing on the preserves of other academic disciplines, both scientific and non-scientific. Even when one turns to consider water more specifically in relation to food there are large areas, notably those concerned with food production — the growth of crops and the rearing of animals — which have traditionally formed a part of agriculture and agricultural science. This is one area where it has been difficult to draw sharp lines of demarcation between disciplines, because agricultural practices inevitably affect agricultural in products qualitative ways, as well as in yield, and the quality of harvested crops and of the edible parts of animal carcasses is appropriately an interest of the food scientist. It used to be suggested that food science should properly concern itself with food from the time of harvest or slaughter to that of consumption but for the reasons I have outlined, it is a mistake to attempt to apply this guideline too strictly.

Following this general train of thought and moving across to the other end of the spectrum, we find that food science merges almost imperceptibly into nutritional science and medical science. Undeniably, the nutritional quality of foods is a very important aspect, some would say the most important aspect, of food quality, while freedom from toxins of either microbiological or purely chemical origin and from potentially disease-producing organisms as yet another important aspect of quality which must be the concern alike of both the food scientist and of the medical practitioner.

Returning, however, to our theme subject, water to the medical man, as to the food scientist, is in fact a food and traditionally the responsibility for monitoring the safety of local supplies of drinking water has rested with the medical profession. In these days, it is arguable that this is a responsibility which could more appropriately be shared with the food scientist or even transferred to him in its entirety.

The ordinary man in the street, instinctively recognizes that food and water, which he usually thinks of as two separate and distinct entities, are essential requirements for his own well-being and, accepting for a moment the distinction between them, it can be said that in a very real sense water is the more important of the two. This is certainly so over the short-term. If a man is deprived of food but supplied with water he may continue to live for a considerable period of time. During this time he will progressively lose a great deal of weight, including practically all his body fat and up to 50 per cent of his body protein, but he may nevertheless survive for several weeks. Completely deprived of water, he will die within a few days, after losing between 10 and 20 per cent of his original total body water. It can therefore be said that water is the most important essential nutrient in man's diet since the symptoms of deficiency develop so rapidly and have such a catastrophic outcome.

This kind of illustration is, however, rather artificial and contrived because as a food scientist one cannot draw this sharp distinction between food and water. The fact is that practically all foods, and certainly all natural foods, contain water as an essential part of their constitution. Indeed, most fresh foods contain a much greater proportion of water than they do of all their other constituents put together.

A useful and revealing way of looking at the proportions of constuents in foods is to express them in molecular terms i.e. as relativetimolalities or numbers of molecules of each constituent as a proportion of the total number of molecules. These values may then be compared with the contents of the same constituents expressed as simple proportions by weight. An interesting point to emerge from such an exercise is that generally, even in foods which are usually thought of as 'dry', the molecules of water clearly outnumber those of other constituents, this of course being related to the low molecular weight of water as compared with those of other major food components. The expression of water content as a mole fraction, which is what has in effect been done here, is also highly significant in connection with the resistance of foods to spoilage by micro-organisms, as I shall discuss later.

Because of its physico-chemical peculiarities, water interacts very readily with the solid substances present in foods. The water molecule itself forms a tiny magnet or dipole with two small concentrations of positive charge and two of negative charge directed approximately out through the apices of an imaginary tetrahedron of which the oxygen atom of the molecule forms the centre.

This is the underlying reason for the regular tetrahedral arrangements of the molecules in crystals of ice and for the beautifully ornamental hexagonal structures which occur in snow flakes and in deposits of frost. Similarly, even in liquid water the molecules form clusters of basically tetrahedral pattern and by the same token, any sites on the surfaces of the molecules of other food constituents which show even the faintest of electrical charges can also attract and bind water molecules. The result is that an appreciable fraction of water in foods is modified in its properties due to this interaction with the solids. This phenomenon which is common to all biological materials is referred to as water-binding and it has important consequencies in many areas of biological science.

A useful criterion for the determination of the amount of bound water in a material is non-freezability, since the restriction on the bound water molecules prevents them from undergoing a normal freezing process when the temperature is lowered. In this way the quantity of bound water in a food may be measured.

A parameter which provides a very useful index of the degree of restriction of the water in a food due to, among other things, this water-binding phenomenon, is the vapour pressure which the constituent water exerts as a proportion of the pressure that pure water could exert at the same temperature i.e. what we call the relative vapour pressure.

This same value is commonly (if rather loosely) also referred to as the Water Activity and should, in turn, according to basic physico-chemical theory, at least for a simple solution, be numerically equal to the mole fraction of water to which I have already referred. A plot showing the relationship between water content and water activity for a given food is referred to as a water sorption isotherm and characterises the water relations of the particular material.

Now, the relative amount of water in a given type of food and, more particularly, the condition of this water in terms of the degree of water-binding and the Water Activity are important in a number of different ways in relation to the quality and acceptability of the food and even more in relation to its keeping properties and resistance to spoilage. I need hardly say that water, as the universal biological solvent and transport and reaction medium, influences the quality of fresh foods in many different ways. The solution of pigments and of sapid and odoriferous compounds respectively affects colour and flavour, while the involvement of water in various kinds of chemical reaction can also have very profound effects on both the colour and flavour of foods.

It is however in relation to the textural quality of foods, how they feel as they are eaten, that water has the greatest effects. Apart from exerting an indirect effect on texture through its involvement in certain chemical changes, the water content of a food product has a direct effect on measurable physical properties such as hardness and resistence to shear which are obviously directly related to texture. In the special case of fresh vegetables and fruit, which are of course composed largely of living tissues, water loss leads to lack of tissue turgor and to wilting which is generally regarded by the consumer as a textural defect. Again, many examples can also be cited of manufactured food products in which physical intereactions between water and other chemical constituents are necessary for the attainment of an acceptable texture and in which relatively small alterations in water content can have very deleterious effects. This applies to products as diverse as chocolate, cheese, bread doughs and vaiious kinds of food emulsion.

Quality can of course mean different things to different people. If, for example, a food material is to be processed in a factory, then the requirements of the processor may well be quite different from those of the consumer of the raw food. Normally, a food material undergoing processing will need to be handled on a relatively large scale. This will probably involve mechanical handling (including perhaps peeling and/or some degree of size reduction) and the physical properties of the food, dependent as these are on water content, assume considerable practical importance in relation to the manufacturing process itself.

Where heat treatments or refrigeration or freezing are to be applied to the food, the processor will be concerned about the thermal properties of his material. Now, because of its physico-chemical peculiarities, water has exceptionally high values of specific heat and latent heats of fusion and evaporation and, since water is usually a major constituent, the thermal properties of foods generally are dominated by water and by changes in water content.

This week has seen the presence in Accra of a number of experts from various countries to discuss the present state of knowledge relating to the uses of ionising radiations in food preservation. In this field again water is important because both the susceptibility if micro-organisms to irradiation and the extent of the largely undesirable chemical changes which can accompany irradiation are greatly dependent on the proportion of water in the target material.

Most food processing and food manufacturing operations involve the use of a great deal of what we might call extrinsic water, i.e. water additional to that which was originally part of the raw food materials themselves. This additional water usually needs to be obtained from public supplies and it may be used for operations such as steam-generation, plant-cleaning etc., as an aid to processes such as washing, blanching, cooling, etc. which may be carried out on the food materials themselves, or it may actually enter into the recipe of a manufactured food and become part of the product. In all such cases, the food scientist must be concerned not only with the condition of the constitutional water of the food material itself but also with various aspects of the quality of the water used for these other purposes. One particular problem is that of the type and degree of hardness of the water which is caused by the presence of small amounts of calcium or magnesium salts. Apart from the obvious disadvantages of scale formation in boilers and pipes and the wastage of soaps, the use of hard water in the processing of fruit and vegetable materials can produce problems of quality due to textural changes resulting from the chemical interaction of calcium and/or magnesium with parts of the food materials themselves. Depending on the kind of material being processed, either greater or lesser degrees of hardness may be desirable.

Other aspects of the condition of processing water which can influence product quality are the presence of undesirable odours due to sulphur compounds, or to chlorinated hydrocarbons in water supplies treated with chlorine, of toxic heavy metals in significant amounts, of nitrates which, apart from possible toxicological effects, can cause detinning of tinplate in canned foods and finally, of course, the microbiological condition of the water which may affect both safety and subsequent resistance to spoilage.

It can therefore safely be said that there are few, if any, aspects of quality in fresh and processed foods which are not in some way influenced by either the constituent water of the food itself or by extrinsic water used in processing operations.

In the final analysis, however, the most fundamentally significant way in which water influences foods is in relation to their keeping properties and their storage stability. From the dawn of civilisation and even earlier, man has needed to rely, in order to survive, on the preservation of edible biological materials through periods of scarcity and one of the main processes that he has exploited, depending in the first place solely on natural agencies to produce the required effect, has been that of drying. The process of drying is effective because it removes water that would otherwise be available to support the growth of micro-organisms — bacteria, yeasts and moulds — which are the primary agents of spoilage of fresh foods. The paramenter which has been shown to be most significant in relation to the effect of water on the susceptibility of foods to microbial spoilage is the water activity or relative vapour pressure. Bacterial growth is easiest to inhibit by reducing the water activity, followed by that of yeasts and finally that of moulds, but no organisms are capable of growing if the water activity is reduced to Aw 0.6 or below. This does not mean that a food will not spoil at lower water activities, but merely that it will only do so much more slowly and by different mechanisms, notably by certain kinds of purely chemical change. Broadly speaking, we can say that the bound water that I referred to earlier is largely unavailable to micro-organisms. This bound water, however, appears to be capable of supporting quite rapid rates of chemical change and a particular question to which I have applied myself in recent years has been that of the solvent properties of the water within the bound fraction. Using the technique of wide-line nuclear magnetic resonance, it has been possible to study the solubility relations of many types of soluble food constituent as influenced by the water content of the food material itself. It has been shown that considerable control can be exercised over the relationship between water level and chemical reaction rate by introducing additives which influence the pattern of solution of the substances involved in producing undesirable changes. In this way, a means is provided of adjusting this pattern so as to improve the keeping quality of a product. It may then be possible, without reintroducing the danger of microbiological spoilage, to utilise higher final water levels than have previously been necessary in foods preserved primarily by drying or water activity reduction.

The advantage of this approach is that products may be prepared which are sufficiently moist not to require reconstitution with water before eating and yet which retain in general the advantages of dried dehydrated products. They do not, for example, require refrigerated storage, while on the other hand they are generally cheaper to prepare than heat—processed (canned) or frozen foods. To describe this kind of preserved food product the new term "Intermediate Moisture Food" has been introduced.

Taking a broad look at the development of food processing methods during the period since the beginning of the nineteenth century, there has been a progressive trend in the developed countries towards the use of methods which are more and more sophisticated and more and more prodigal in terms of energy expenditure. Canning, artificial freezing and artificial drying, which are the most costly in terms of energy utilisation, are themselves notable products of this industrial era. We are frequently warned in those days, however, that the age of plentiful and cheap supplies of energy has gone for ever and that we must be constantly on the look out for means of energy conservation. What better way of contributing to this need than by concentrating our efforts on improving, extending and diversifying available methods of preserving foods which make relatively small demands on our unsecured and increasingly expensive supplies of artificially-generated energy. What more worthwhile activity in the local Ghanaian context where such large amount of much needed food are lost each year because effective methods of conservation and preservation are not widely enough applied.

Available methods of food preservation, other than canning and irradiation, both of which are relatively sophisticated and expensive, all depend primarily for their effectiveness on rendering the environment within the food less suitable for the growth of micro-organisms.

It is my considered view that of all the controllable factors influencing the susceptibility of foods to microbiological and chemical spoilage the one offering the greatest scope for beneficial manupulation in the forseeable future is water activity. Fortunately, the prospects of progress in this field have been greatly enhanced in recent years by substantial advances in our knowledge of the ways in which water interacts with other food constituents and therefore of the physico-chemical environment within which micro-biological and chemical activity must take place in foods. In addition there have been recent advances in our knowledge of the effects of water activity on the growth of micro-organisms capable of causing food spoilage. Food Science is therefore currently poised to move forward in this vital area and it is to be hoped that the next decade will see the development of new or improved techniques of food preservation which will make a highly significant contribution towards the conservation of much needed food supplies.

That Ghana could derive disproportionate benefit from any such developments is an unfortunate reflection on the present situation, but it strengthens the argument for intensifying the effort locally towards the production of appropriately trained graduates and the building up of the level of post-graduate research activity in Food Science.

I started out to look at water from a professional food scientists point of view. I hope that in doing so I have helped to explain more fully what food science is all about. If I have done nothing else, I think that I have probably said enough to illustrate the essentially interdisciplinary origins of the subject while at the time making, I hope, a good case for the training of graduates with the necessary breadth of background to be able to make an integrated scientific approach to the problems of food spoilage. For these problems will undoubtedly remain among the most important with which man has to contend into the indefinite future.

Earlier in this address, I pointed out that water could quite readily be selected as a subject by a specialist from almost any academic field. I would like to finish off by looking at water from an entirely different point of view.

I have a slide of Loch Lomond in Scotland. This is the nearest thing that Scotland has to Lake Volta here in Ghana. The point of showing this is simply to emphasise that while we might find water a fascinating substance scientifically, it is also in the appropriate context a material of great beauty which can help to cater for man's spiritual and aesthetic needs as well as for his insatiable scientific curiosity.