

Food
The Chemistry of its Components
5th Edition

T.P. Coultate

formerly of London South Bank University

RSCPublishing

Foreword

Like science, cuisine thrives on curiosity.

In 1999 I began visiting the flavour and fragrance company Firmenich in Geneva, to exchange ideas and explore culinary science. On one occasion I was in the office of Dr Alan Parker, at the wonderfully named Laboratory for the Physics of Soft Edible Matter, and noticed a shelf full of RSC books with titles that held a lot of appeal for a chef with a growing interest in the molecular properties of food: *Basic Principles of Colloid Science*; *Carbohydrate Chemistry*; *Fatty Acids* and, of course, *Food: The Chemistry of Its Components*.

As soon as I got back to Bray, I looked up the RSC's publications list and ordered lots of their books. Tom's turned out to be particularly useful. Lucid, accessible and clearly expressed, it was exactly the kind of science primer I was looking for. I read it from cover to cover and then invited Tom over to the Fat Duck to find out more.

In person, Tom is just as entertaining and passionate about his subject as he is on the page. It made for a truly stimulating discussion, during which he talked, among other things, about gellan gum – a versatile gelling agent with superb flavour release that has since become a vital part of the kitchen's resources and a key ingredient in a number of the dishes I've created, including amazingly fresh, smooth purées, salmon poached in liquorice, and a cup of tea that appears to be hot and cold at the same time!

Food: The Chemistry of Its Components is full of similarly valuable, thought-provoking information, guaranteed to spark off all kinds of insights and ideas. It deserves to be on the bookshelf not just of every chef and scientist, but of anyone interested in food or how the world around us works.

Heston Blumenthal, Bray, 2008

The Author

Until he retired from full-time teaching Tom Coultate was Principal Lecturer in Food Biochemistry at London South Bank University, on courses ranging from HNC to MSc and particularly the BSc in Food Science. He has had a professional interest in food ever since leaving school to join Unilever's Colworth laboratories, where he continued with his studies part-time gaining an ONC (in Chemistry), an HNC (in Applied Biology) and an MIBiol (in Biochemistry). Before taking up teaching he gained a PhD at the University of Leicester for studies on the biochemistry of thermophilic bacteria. Dr Coultate is a Fellow of the Institute of Food Science and Technology. From time to time he contributes articles to food magazines and enjoys giving talks to local societies on food topics.

Acknowledgements

In preparing this fifth edition I have been as dependent as ever on the contributions of my family, colleagues, students and readers of previous editions.

My wife Ann has continued to provide the same invaluable encouragement and support she first contributed over 25 years ago. My sons Edward and Ben, keen amateur photographers, have graduated from helping to spend the royalties to contributing valuable artistic advice on the design of the cover.

Ever since I started work on the first edition I have been dependent on the support of colleagues and friends. They have been an indispensable source of encouragement and ideas, details of the latest research (including their own) and expert guidance through controversial or unfamiliar topics. This list of names is intended to include contributors to all five editions and I sincerely apologise to anyone whose name should be here but isn't:

Jenny Ames, Peter Barnes, Alan Beeby, Martin Chaplin, Barbara Crook, Jill Davies, Peter Ellis, Ailbhe Fallon, Paul Gillard, (the late) Pat Hastilow, John Henley, Nick Henson, Mike Hibbs, (the late) Mike Hill, David Ledward, Dominic Man, Neil Morgan, Bryan Reuben, Sibel Roller, Dave Rosie, Tom Sanders, David Shuker, Ken Spears, Melvyn Stevens, Sam Sumar, Graham Sworn, Geoff Talbot, Jan van Mechelen, Dave Walsh and Robin Wyers.

Of course the opinions expressed in this book, and any errors that remain, must be placed at my door, not theirs. Several organisations have provided essential services, notably the libraries of London South Bank University, the Open University at Milton Keynes and King's College, London University. The regular on-line bulletins from Reading Scientific Services, Ltd., have also kept me aware of the latest

developments. The staff of the UK Food Standards Agency have been a constant source of up to date information on legislative issues. What is recorded in this book was correct at the time of writing, but readers should always consult the FSA or other authorities directly when authoritative information is required about what is or is not currently permitted.

Writing a book like this would not be the rewarding task it is without the support, and often blunt criticism, of my students, for many years at London South Bank University and most recently at King's College, London University. Perhaps they will never improve on the mnemonic for the hexose sugars but they still spot errors, especially in diagrams and formulae, with ruthless efficiency.

As with all previous editions I have been able to rely on my friends at the Royal Society of Chemistry, particularly Janet Freshwater, Katrina Harding and Caroline Wain, for their support and encouragement. Special thanks must go to my editor, Don Sanders. He has done great work repairing the infelicities of my English and made me rethink a number of passages that simply did not actually say what I thought they did!

Finally I come to my friend Heston Blumenthal. Much of my readership has always consisted of students and teachers, of chemistry, food science, nutrition, *etc.*, together with scientists and technicians involved in the food industry and its associated organisations. Until I met Heston it had never occurred to me that what I had to say might be of interest to that other food world, of fine dining and internationally renowned chefs. However when Heston introduced me to “molecular gastronomy” my ideas changed, to say the least. That he has consented to write the Foreword will ensure that this book is not entirely without merit and is for me a great honour for which I am exceedingly grateful.

Tom Coultate, 2008

Preface to the Fifth Edition

When the Royal Society of Chemistry originally invited me to write this book in 1980 the proposed readership was clearly delineated, namely teachers of GCE Advanced Level Chemistry in school sixth forms. Apparently they were badly in need of background information to help them prepare their students for the new topic of Food Chemistry which had appeared in some of their syllabuses. By the time the first edition actually appeared a few years later the need for an up to date textbook of introductory food chemistry to support my own BSc Food Science students, at what was then the Polytechnic of the South Bank, London, was also becoming obvious. The favourable response to the first edition told me that for once two birds had been killed with one stone! As new editions have appeared over the years the original objective has, perhaps inevitably, suffered from what I believe is known in military circles as “mission creep”. This edition is over twice the size of the first, as interesting new topics have demanded attention and chapters devoted to water, minerals and “undesirables” have been added.

My determination to ensure that chemical formulae are included for virtually every food substance mentioned in the text may make the contents look a little intimidating. However, I continue to try to make the actual words as approachable as possible, lending themselves to being read as well as “looked up”. Despite appearances, readers with only the vaguest recollection of school chemistry should find most of it within their grasp, especially in the later chapters. The separate inclusion of more advanced material begun in the fourth edition has now been further developed with the Special Topics included at the end of most chapters.

As in previous editions, a selection of Further Reading is also included with each chapter, wherever possible restricted to 21st century material. Extensive references to research literature are not provided, but each chapter ends with a selection of articles, headed Recent Reviews. These will be available to most university students and can provide a route to advanced literature. The temptation to include addresses of relevant and authoritative websites has been resisted since, unlike the traditional scientific literature, they tend to be ephemeral and are unlikely to survive through the lifetime of a textbook.

The internet can provide a wealth of information—but it must be used with considerable caution. It has always been the rule that one should not necessarily believe something just because it has appeared in a book, but such scepticism is absolutely essential when exploring websites. For example, an internet search using “choline” and “vitamin” as keywords will locate the official statement that choline is not a vitamin (*see* Chapter 8), followed by innumerable commercial sites which claim the exact opposite, as a means of boosting sales of choline as a “dietary supplement”.

Information on nutrient consumption, exposure to pesticides and similar material is largely based on British sources, a limitation for which I apologise to readers elsewhere in the world. Similarly, where legislation is mentioned, for instance regarding what additives are or are not permitted, the situation in Britain and the European Community is reported for illustrative purposes. The appropriate authorities such as the UK Food Standards Agency must always be consulted for an authoritative view of the legal position.

A BRIEF NOTE ABOUT CONCENTRATIONS

The concentrations of chemical components are expressed in a number of different styles in this book, depending on the context and the concentrations concerned. Readers may find the following helpful.

- (a) However they are expressed, concentrations always imply the amount *contained*, rather than the amount *added*. Thus “5 g of X per 100 g of foodstuff” implies that 100 g of the foodstuff contains 95 g of substance(s) other than X.
- (b) The abbreviation ppm means parts per million, *i.e.* grams per million grams, or more usually milligrams per kilogram. One ppb, or part per billion, corresponds to one microgram per kilogram.
- (c) Amounts contained in 100 g (or 100 cm³) are often expressed as simple percentages. Where necessary the terms w/w, v/v or w/v

are added to indicate whether volumes or weights or both are involved. Thus “5% w/v” means that 100 cm³ of a liquid contains 5 g of a solid, either dissolved or in suspension. Note that millilitres (ml) and litres (l) are no longer considered acceptable. Although the replacement for the ml, the cubic centimetre (cm³), is widely recognised, there is little sign that the cubic decimetre, or dm³, has yet taken over from the litre—except in teaching laboratories, which of course must always endeavour to toe the party line.

- (d) Very often a strictly mathematical style is adopted, with “per” expressing the power of minus one. Since mathematically:

$$x^{-1} = 1/x$$

5 μg kg⁻¹ becomes a convenient way of writing 5 micrograms per kilogram. This brief but mathematically rigorous style comes into its own when the rates of intake of substances such as toxins have to be related to the size of the animal consuming them, as in “5 milligrams per day per kilogram body weight”, which abbreviates to:

$$5 \text{ mg kg}^{-1} \text{ body weight per day}$$

A quantity, say 10 mg, per cubic centimetre, cm³, would be written: 10 mg cm⁻³.

Tom Coultate, 2008

Contents

The Author	xvii
Acknowledgements	xviii
Chapter 1 Introduction	
Further Reading	5
Chapter 2 Sugars	
Monosaccharides	7
Oligosaccharides	20
Sugars as Solids	26
Sugars in Solution	27
Decomposition	30
The Maillard Reaction	33
Special Topics	41
1. Reducing Group Reactions	41
2. Sugar Cane, Sugar Beet and Tequila	42
3. Monosaccharide Conformations	43
4. Acrylamide	44
Further Reading	48
Recent Reviews	48
Chapter 3 Polysaccharides	
Starch	51
Pectins	60
Seaweed Polysaccharides	67
Cellulose, Hemicelluloses and Fibre	72

Gums	80
Special Topics	85
1 Chemically Modified Starches	85
2 Syrups from Starch	87
3 Glycaemic Index	89
4 Further Details of Pectin Structure	92
Further Reading	95
Recent Reviews	95

Chapter 4 Lipids

Fatty Acids: Structure and Distribution	97
Conjugated Linoleic Acids	105
Essential Fatty Acids	106
Fatty Acids and Coronary Heart Disease	108
Reactions of Unsaturated Fatty Acids	112
Hydrogenation, Margarine and <i>trans</i> Fatty Acids	113
Rancidity	115
Antioxidants	123
Triglycerides	127
Melting and Crystallisation	130
Cocoa Butter and Chocolate	133
Fractionation	135
Interesterification	137
Polar Lipids	139
Milk Fat, Cream and Butter	147
Synthetic Emulsifiers	148
Phytosteroids	150
Special Topics	152
1 Hydrogenation in Detail	152
2 Singlet and Triplet Oxygen	153
3 Triglyceride Crystals	154
Further Reading	157
Recent Reviews	158

Chapter 5 Proteins

Amino Acids	160
Protein Structure	163
Essential Amino Acids and Protein Quality	168
Analysis	173
Food Protein Systems	176
Milk	176
Cheese	182
Egg	184

Meat	187
Bread	198
Special Topics	208
1 Myoglobin and Free Radicals	208
2 Wheat Genes and Chromosomes	210
3 Further Details of Gluten Proteins	211
Further Reading	212
Recent Reviews	213

Chapter 6 Colours

Chlorophylls	214
Carotenoids	218
Anthocyanins	227
Betalaines	234
Melanins	236
Tea	239
Turmeric and Cochineal	243
Artificial Food Colorants	244
Inorganic Food Colorants	249
Restrictions on the Use of Colours in Foodstuffs	249
The Molecular Basis of Colour	251
Special Topics	255
1 Flavonoids, Tannins and Health	255
2 Colour Measurement	258
Further Reading	263
Recent Reviews	263

Chapter 7 Flavours

Taste	268
Sweetness	268
Bitterness	278
Saltiness	282
Sourness	282
Astringency	284
Pungency	285
Meatiness	290
Odour	294
Meat	295
Fruit	297
Vegetables	301
Herbs and Spices	305
Synthetic Flavourings	306
Special Topics	309

1 Off-Flavours in Meat	309
2 Taints	310
Further Reading	310
Recent Reviews	311

Chapter 8 Vitamins

Thiamin (Vitamin B ₁ , Aneurine)	315
Riboflavin (Vitamin B ₂)	318
Pyridoxine (Vitamin B ₆ , Pyridoxol)	321
Niacin (Nicotinic Acid, Nicotinamide)	323
Cobalamin (Cyanocobalamin, Vitamin B ₁₂)	326
Folic Acid (Folacin)	328
Biotin and Pantothenic Acid	330
Ascorbic Acid (Vitamin C)	332
Retinol (Vitamin A)	338
Cholecalciferol (Vitamin D, Calciferol)	343
Vitamin E (α -Tocopherol)	346
Vitamin K (Phylloquinone, Menaquinones)	350
Special Topics	352
1. Details of the Coenzyme Functions of Thiamine and Pyridoxine	352
2. Further Details of the Role of Ascorbic Acid	353
3. Non-Vitamins	355
Further Reading	357
Recent Reviews	358

Chapter 9 Preservatives

Sodium Chloride	361
Nitrites	362
Smoke	366
Sulfur Dioxide	367
Benzoates	370
Other Organic Acids	372
Nisin and Natamycin	373
Irradiation	375
Further Reading	380
Recent Review	380

Chapter 10 Undesirables

Endogenous Toxins in Foods Derived from Plants	382
Endogenous Toxins in Foods of Animal Origin	394
Mycotoxins	398

Bacterial Toxins	404
Allergens	407
Toxic Agricultural Residues	412
Toxic Metal Residues	421
Lead	421
Mercury	424
Arsenic	426
Cadmium	426
Tin and Aluminium	427
Toxins Generated During Heat Treatment of Food	428
Packaging Residues	430
Environmental Pollutants	432
Special Topics	434
1. Favism	434
2. Total Intake of Undesirable Metals	436
Further Reading	437
Recent Reviews	438

Chapter 11 Minerals

The Bulk Minerals	440
Sodium	440
Potassium	441
Magnesium	442
Calcium	442
Phosphorus	444
The Trace Minerals	446
Iron	446
Copper	449
Zinc	450
Selenium	450
Iodine	451
Other Trace Minerals	453
Further Reading	454
Recent Reviews	454

Chapter 12 Water

Water Structure	456
Interactions of Water with Food Components	461
Interactions of Water with Food Materials	466
Water Binding	468
Water Determination	470
Further Reading	474
Recent Reviews	474

Appendix

Nutritional Requirements and Dietary Sources	475
Further Reading	478

Subject Index	480
----------------------	-----