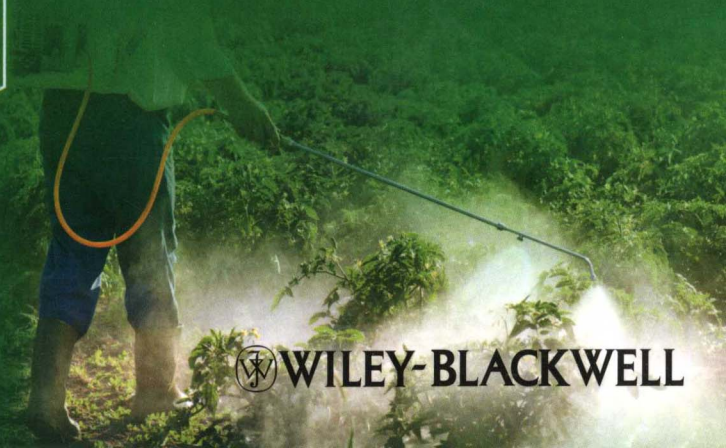
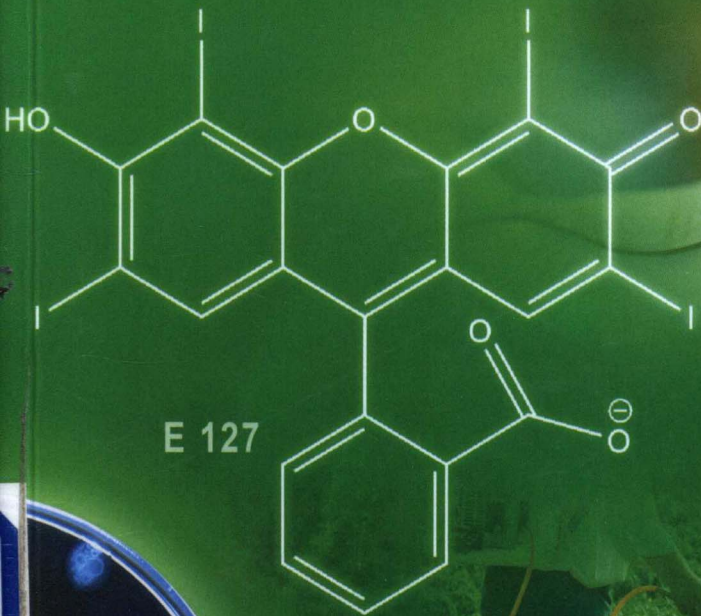


# Food Safety

The Science of Keeping Food Safe

Ian C. Shaw



 WILEY-BLACKWELL

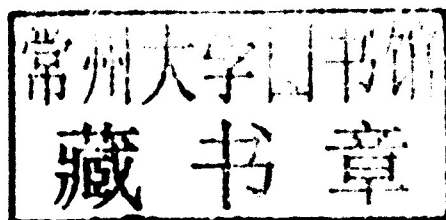
# Food Safety

## The Science of Keeping Food Safe

---

**Ian C. Shaw**

Director of Biochemistry & Professor of Toxicology  
University of Canterbury, Christchurch, New Zealand



 **WILEY-BLACKWELL**

A John Wiley & Sons, Ltd., Publication

## Erratum

*Corrected copyright information:*

This edition first published 2013 © 2013 Ian C. Shaw

Wiley-Blackwell is an imprint of John Wiley & Sons, formed by the merger of Wiley's global Scientific, Technical and Medical business with Blackwell Publishing.

### *Registered Office*

John Wiley & Sons, Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

### *Editorial Offices*

9600 Garsington Road, Oxford, OX4 2DQ, UK

The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

2121 State Avenue, Ames, Iowa 50014-8300, USA

For details of our global editorial offices, for customer services and for information about how to apply for permission to reuse the copyright material in this book please see our website at [www.wiley.com/wiley-blackwell](http://www.wiley.com/wiley-blackwell).

The right of the author to be identified as the author of this work has been asserted in accordance with the UK Copyright, Designs and Patents Act 1988.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, except as permitted by the UK Copyright, Designs and Patents Act 1988, without the prior permission of the publisher.

Designations used by companies to distinguish their products are often claimed as trademarks. All brand names and product names used in this book are trade names, service marks, trademarks or registered trademarks of their respective owners. The publisher is not associated with any product or vendor mentioned in this book. This publication is designed to provide accurate and authoritative information in regard to the subject matter covered. It is sold on the understanding that the publisher is not engaged in rendering professional services. If professional advice or other expert assistance is required, the services of a competent professional should be sought.

### *Library of Congress Cataloging-in-Publication Data*

Shaw, Ian, 1950-

Food safety : the science of keeping food safe / Ian Shaw.

p. cm.

Includes bibliographical references and index.

ISBN 978-1-4443-3722-8 (pbk. : alk. paper) 1. Food-Analysis. 2. Food contamination.

3. Food-Safety measures. I. Title.

TX531.S5848 2013

363.19'26-dc23

2012013710

A catalogue record for this book is available from the British Library.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic books.

Cover image: Bacterial culture - © iStockphoto.com/Linde1; Crop spraying - © iStockphoto.com/fotokostic; Food tasting - © iStockphoto.com/webphotographer

Cover design by Steve Thompson

Set in 9.5/11.5pt Interstate-Light by SPi Publisher Services, Pondicherry, India

Printed and bound in Malaysia by Vivar Printing Sdn Bhd

# Food Safety

This book is dedicated to the memory of two lovely ladies:

My mother

Audrey Shaw

28 November 1928 to 28 May 2009

My mother-in-law

Jeanne Zehms

6 May 1919 to 5 December 2010

They both inspired me in their own special ways.



# Preface

We expect our food to be safe; we certainly don't expect to be ill after eating a meal. However, it is important to remember that this is an affluent Western world expectation and that many undernourished people in the poorer parts of the world simply want to eat - the safety of their food is a secondary, or an even lesser, consideration.

Our desire for safe food, spurred on by food disasters like Mad Cow disease in the UK in the mid 1980s, has led to developed countries introducing legislation to ensure safe food - to make sure that food is fit for purpose.

In order to make food safe, we need to understand what makes it unsafe. Why do some microorganisms (pathogens) in food cause disease in their consumers, while others are harmless - or even beneficial? We need to minimise our exposure to food pathogens in order to minimise consumer risk. We need to understand why chemical food contaminants, like pesticides used in food production, can harm their consumers and we need to know the doses that are harmful so that we can set safe levels for chemical contaminants in food and so further minimise risk.

To store food we often use preservatives, otherwise harmful microorganisms might grow on the stored food; if we use chemical preservatives we must understand their potential toxicity to the consumer and make sure the chemical preservatives don't solve a microbiological problem, but introduce unacceptable chemical toxicity.

As consumers become more picky about their food they want it to look and taste exactly right - and by exactly right I mean how *they* think it should look and taste. To achieve this, colours and flavours are added to many pre-prepared foods. But are these additives safe? What are their effects on their consumers? Is using colours and flavours to enhance our food experience an acceptable risk?

Food is inextricably linked to health. If we eat too much fat or sugar we might become obese and our health will be significantly impacted - this might lead to heart disease or diabetes, both serious diseases. Some bacteria (e.g. *Listeria*) that might contaminate food cause serious diseases, even death. On the other hand, the contaminants and additives present in our food might affect our health in far more esoteric ways following very long-term exposure. For example, some food colours are known to cause cancer in rats at high doses, but what effects might they have on human consumers of infinitesimally tiny doses in food? Are these risks outweighed by the benefits of the chemicals? Is bright red cherryade worth the vanishingly low risk of its consumer contracting thyroid cancer? Do you *need* your cherryade to be bright red? Is any health risk associated with food colour acceptable - however small?

These are all fundamentally important questions - and there are many, many more - to which we should seek answers if we are to make our food safer. We need to understand the science that underpins food safety; we need to tease out the health effects of chemicals in our food and set these risks against their benefits. Is the risk of a bacterium growing in our food greater than the chemical used to kill it? Why is the chemical harmful to its consumer? Could we modify its molecule to make it less toxic, but maintain its bactericidal properties? These are some of the answers we might need to help us to produce and regulate our food and make it as fit for purpose as possible.

Over the last 50 or so years our understanding of food safety has grown to such an extent that we no longer accept food-borne illness as a consequence, albeit rare, of eating. Those responsible for food-borne illness outbreaks can fall foul of strict food legislation and find themselves subjected to heavy fines or, in rare cases, even imprisonment. Just 50 years ago this would not have been thought possible.

My book takes a trip through the world of food safety, from microbiological food pathogens, through chemical contaminants, natural toxins and the chemicals we use to colour, preserve and flavour our food. It grapples with the esoteric prion that causes Mad Cow disease which led to the collapse of the UK beef industry and prevents me as a Brit living in New Zealand from donating blood because of the perceived risk of transferring the prion to my fellow New Zealanders. It uncovers the controversy of 'organic' food and food irradiation. Finally, it looks at the laws that are used to make sure that when we eat our dinner or buy a snack on the street we don't contract a food-borne illness or expose ourselves to chemicals that might compromise our health in the future. This is a long journey flavoured with many examples from around the world; I hope you enjoy it!

*Professor Ian C. Shaw PhD, FRSC, FIFST, FRCPath  
Christchurch, New Zealand  
September 2012*

# Acknowledgements

I thank Wiley-Blackwell for asking me if I would write a textbook on Food Safety, and, in particular, David McDade for steering the idea to contract and Andrew Harrison for trying to keep me on schedule and for gently prompting me by e-mail when I missed deadlines by a country mile. He never once raised his e-mail voice even though this would have been justified on many occasions. In addition, I am indebted to Alison Nick for her supreme proof reading skills and frightening efficiency.

As with any wide-ranging textbook, there are subjects included that the author is less *au fait* with; in my case food legislation was the subject that I needed expert help with. I thank Keith Zehms and Sharon McIlquham for their advice on US law and John Reeves for his help with the New Zealand food legislation.

When I agreed to write the book and signed the contract on 21 January 2010 I could not, in my worst nightmare, have anticipated the devastation that the 4 September 2010, 22 February and 13 June 2011 Canterbury (New Zealand) earthquakes would bring to my life and environment. Much of this book was written during a period of regular and significant aftershocks, telecommunication failures, lack of internet, uncertainty about the stability of buildings, workmen everywhere, continual battles with the New Zealand Earthquake Commission and our insurers, and deep, deep sadness for the loss of our city and some of its people. Throughout this, my partner, David Zehms, gave me unwavering support and provided some semblance of emotional normality that allowed me to retire to my cracked and crumpled study to write this book - thank you David.

As you read, think of the people of Christchurch and Lyttelton, New Zealand, who have lost so much and have a long, hard road ahead.

I hope you enjoy my book.

*Ian C. Shaw*  
*Christchurch, New Zealand*



# Contents

Preface	x
Acknowledgements	xii
<b>1 Introduction</b>	<b>1</b>
A brief history of food safety	1
Evolution of cellular protection mechanisms	2
<b>2 Food Risk</b>	<b>13</b>
Introduction	13
What is risk?	14
Measuring hazard	16
Determining risk	18
Acceptable risk	23
Risk versus benefit	26
Risk perception	27
The precautionary principle	30
Food risk assessment	31
Relative risk and risk ranking	33
Risk management	33
Risk communication	36
Quantitative risk assessment	36
Take home messages	45
Further reading	45
<b>3 Bacteria</b>	<b>46</b>
Introduction	46
The discovery of bacteria	47
The biology of bacteria	52
The bacterial ecology of food	61
Human bacterial pathogens on food	62
Gastroenteritis	63
Food-borne pathogenic bacteria	63
Take home messages	101
Further reading	102
<b>4 Viruses</b>	<b>103</b>
Introduction	103
The discovery of viruses	103
The biology of viruses	105
Diseases caused by viruses and mechanisms of viral transmission	108

Other food-borne viruses	115
Take home messages	116
Further reading	116
<b>5 Parasites</b>	<b>117</b>
Introduction	117
What are parasites?	117
Flatworms - Platyhelminthes	118
Tapeworms - Cestodes	118
Flukes - Trematodes	121
Nematodes	124
Protozoa	130
Take home messages	140
Further reading	140
<b>6 Bovine Spongiform Encephalopathy (BSE)</b>	<b>141</b>
Introduction	141
The history of BSE	141
The epidemiology of BSE in England	142
Spongiform encephalopathies	143
Prions	143
The symptoms of BSE	145
BSE cases in the UK	146
BSE transmission and the origins of PrP <sup>Sc</sup>	146
The risk to human consumers of BSE beef - nvCJD	149
The politics of BSE and implications for food safety worldwide	153
BSE incidence around the world	153
Take home messages	154
Further reading	155
<b>7 Chemical Contaminants</b>	<b>156</b>
Introduction	156
Pesticides	157
Insecticides	164
Herbicides	185
Fungicides	187
Veterinary medicines	192
Growth promoting chemicals	203
Fertilisers	208
Natural environmental chemicals	210
Non-agricultural environmental pollutants	213
Residues monitoring programmes	217
Dietary intake and risk to human consumers	218
Take home messages	219
Further reading	219
<b>8 Natural Toxins</b>	<b>220</b>
Introduction	220
Why produce natural toxins?	221
Natural toxins in the human food chain	222

Plant toxins	224
Mycotoxins	237
Phytohaemagglutinins in beans	241
Bacterial toxins	243
Phytoestrogens	243
Take home messages	243
Further reading	243
<b>9 Endocrine Disrupting Chemicals</b>	<b>244</b>
Introduction	244
The first observations of xenoestrogens' effects	245
Estrogen receptors - ERs	246
Molecular requirements for estrogenicity	247
Estrogens are present in both males and females	247
Xenoestrogens	248
Population level effects of exposure to xenoestrogens	261
The positive health effects of xenoestrogens	264
Take home messages	265
Further reading	265
<b>10 Genetically Modified Food</b>	<b>266</b>
Introduction	266
A brief introduction to nucleic acids, genetics and molecular biology	267
Nucleic acids	267
Converting the genetic code into a protein	268
The history of GM crops	271
The tools of the genetic engineer	272
Glyphosate-resistant crops	274
Insect-protected crops - BT toxin	275
GM crops with enhanced flavour or nutritional properties	276
What happens if humans eat GM crops or foods made from them?	277
Changed biochemistry in GM crops	278
What is the effect of eating DNA and RNA?	278
GM animals	279
Take home messages	279
Further reading	279
<b>11 Colours, Flavours and Preservatives</b>	<b>280</b>
Introduction	280
Food colours	282
Flavours	290
Preservatives	305
Take home messages	319
Further reading	319
<b>12 Food Irradiation</b>	<b>320</b>
Introduction	320
Different types of radioactivity	321
How irradiation kills cells	323

The history of food irradiation	324
The effect of radiation on microorganisms	325
How is food irradiated?	326
The effects of irradiation on food chemistry	326
The effects of irradiation on vitamins	327
Radiation dose	331
Does irradiation make food radioactive?	332
Health effects of food irradiation	332
The use of food irradiation around the world	333
Take home messages	334
Further reading	334
<b>13 Food Safety and the Unborn Child</b>	<b>335</b>
Introduction	335
'You are what your mother ate'	335
Growth and development of the embryo and fetus	337
Effects of food chemical contaminants	344
Effects of microbiological contaminants	345
Effects on ova and sperm	346
Take home messages	347
Further reading	347
<b>14 Organic Food</b>	<b>349</b>
Introduction	349
What does 'organic' mean?	350
The history and philosophy of organic farming	351
Demand for organic food	352
Organic farming methods	352
Organic farming legislation	353
Organic fertilisers	354
Organic pest control	355
Organic weed control	355
Animal health remedies	356
Food processing	356
Is organic food better for you?	357
Myths and facts about organic food	361
Take home messages	364
Further reading	365
<b>15 Food Allergy</b>	<b>367</b>
Introduction	367
What is an allergy?	368
The basics of immunology	368
Immunity and the immune response	368
Sensitisation	371
Food allergies	373
The genetics of allergy	373
Food allergens	374
Milk allergy	375
Peanut allergy	377

Soy allergy	380
Nut allergies	381
Seafood allergies	383
Gluten allergy (coeliac disease)	386
Allergy to eggs	389
Allergen cross-reactivity	390
Banana/latex allergy	390
Food additives allergy	392
Why is the incidence of food allergies increasing?	392
A cautionary note	393
Take home messages	393
Further reading	394
<b>16 Food Legislation</b>	<b>395</b>
Introduction	395
Legal processes - how laws are made	397
A very brief history of food law	398
Food legislation around the world	399
Food legislation in the USA	399
Food legislation in the UK	402
Food legislation in New Zealand	405
Policing food legislation	407
Does food legislation reduce risks to consumers?	410
Case example - non-compliance follow-up	410
The relevance of national food legislation in a global food market	411
Take home messages	412
Further reading	412
Index	413

A colour plate section falls between pages 52 and 53



# Chapter 1

## Introduction

### Introduction

Food safety is a relatively recent 'invention'. It was introduced in the developed world to increase confidence in food. In our modern world it simply is not acceptable to have food that might make us ill. Sadly even now a good proportion of the world's people are very much more concerned about getting food and stemming their unrelenting hunger than they are about whether they might get a stomach upset as a result of eating the food. We must always remember these horrifying facts when we study food safety. Food safety and the legislation emanating from it are for the relatively rich countries that have the luxury of having sufficient food to allow them to make rules about what is safe to eat.

### A brief history of food safety

---

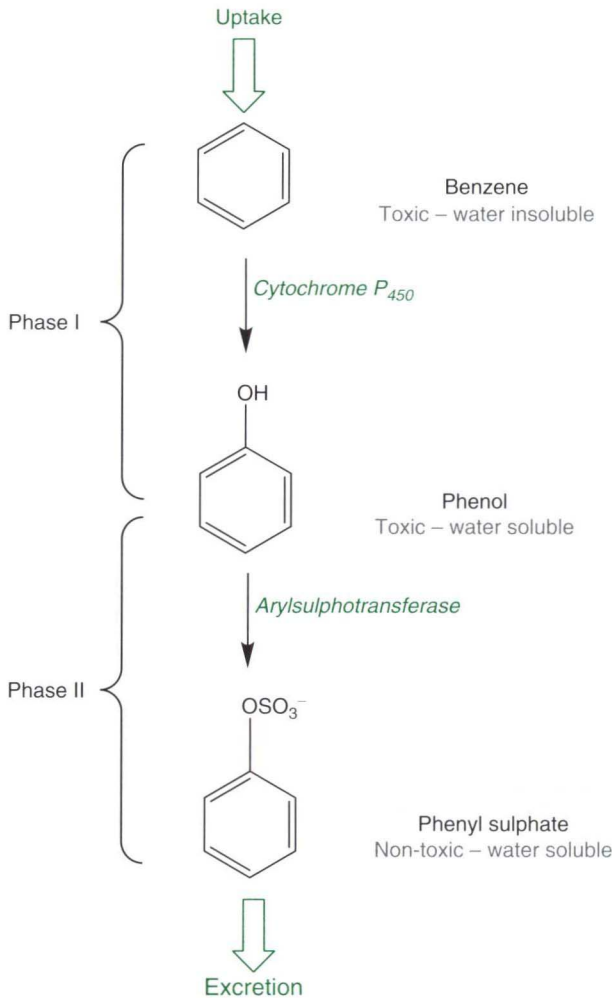
#### Prehistoric times

The risk of eating in prehistoric times was very much more an issue of the dangers of catching the beast to eat than the ill effects suffered after eating it. To survive, cavemen had to eat and their animal instincts dominated their behaviour with respect to food. These instincts, no doubt, made them avoid food they had learned made them sick, but their overriding instinct was 'eat to live'. Some foods, however, might have been so toxic that they threatened the early man's survival. Behaviour that minimised consumption of toxic food would have been selected in because individuals that succumbed to toxins in their food simply did not survive. This is the raw material of Darwinian evolution and could be considered a very early manifestation of food safety issues! Whether this happened or not thousands of years ago is impossible to know, but we do know that modern-day animals avoid toxic plants in their diet. This might be because some of the toxins (e.g. alkaloids) have a bitter taste that warns the would-be consumer of the risk. Prehistoric man probably behaved in exactly this way which is why he was able to survive in such a harsh environment in which every day posed new and unknown food challenges.

This is hardly prehistoric food safety policy, but it illustrates our inborn survival instinct that extends to the food we eat. We have an innate desire not to eat something that will make us ill. This has not changed over the millennia.

## Evolution of cellular protection mechanisms

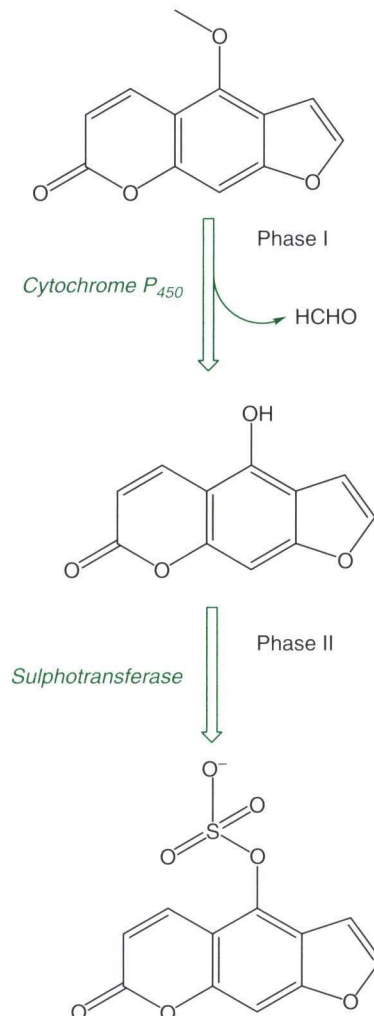
It is important to remember too that our metabolic systems (and avoidance strategies) evolved during the tens of thousands of years of prehistoric times. Metabolism of toxins from food in order to reduce their toxicity and so make the food 'good' developed over millions of years. There are highly complex metabolic systems 'designed' to detoxify ingested toxins that evolved long before man, but the enzyme systems from the primitive cells



**Figure 1.1** Phase I and II metabolism for a simple compound, benzene, showing how the molecule is detoxified, made water soluble and excreted (e.g. in urine).

in which they evolved were selected into the human genome through the evolutionary process and were inevitably expressed by the earliest hominids. These detoxification systems gave man an advantage because he could eat food that contained chemicals which if not detoxified would make the food too toxic to eat. These enzyme systems are now very well understood; they include the cytochromes  $P_{450}$  mixed function oxidases (termed Phase I metabolism) and the conjugating enzymes (termed Phase II metabolism) (Figure 1.1).

There are many food toxins that are detoxified by these systems, so making the food safe to eat (this will be discussed further in Chapters 7 and 8); for example, parsnips contain bergapten, a photosensitising toxin that also causes cancer (see Chapter 8, *Furocoumarins in parsnips, parsley and celery*); bergapten is detoxified by Phase I and II metabolism (Figure 1.2)



**Figure 1.2** A proposed metabolic pathway for bergapten.

thus making parsnips safe to eat. These metabolic processes are the cell's internal food safety mechanisms and broaden the range of foods we can eat without suffering the ill effects that some of their components would cause.

There are significant differences in the susceptibility of different animal species to toxic chemicals; these are due to the evolutionary selective pressures under which the particular species developed. This means that safe foods for some species might be highly toxic to others. For example, the toxin in the swan plant (*Asclepias fruticosa*), labriformidin, is very toxic to birds but harmless to the monarch butterfly (*Danaus plexippus*) (see Chapter 8, *Why produce natural toxins?*).

The monarch butterfly uses this differential toxicity as a means of protection. Its caterpillar eats swan plant leaves and incorporates labriformidin into its body; this makes it toxic and unpalatable to predatory birds. This interesting means of survival is by no means unique amongst animals. Indeed, some plants that are eaten by animals are very toxic to humans. For example, it would only take a few leaves of hemlock (*Conium maculatum*) to kill a person, but the skylark (*Alauda arvensis*) is unaffected by its toxin (Figure 1.3). Indeed, there have been cases of human poisoning in Italy following consumption of skylarks which (strange as it may seem) are a delicacy in that country. The toxin in hemlock is coniine (Figure 1.3) - it is very toxic; about 200 mg would be fatal to a human. Hemlock was the poison used to execute Socrates in 399 BC for speaking his mind in the restrictive environment of ancient Greece.

### **Tudor England (1485–1603)**

In the 1500s I doubt whether many people thought about illness being linked to what they had eaten, but I imagine food-borne illness was prevalent in that rather unhygienic society. In fact spices were introduced into Tudor England to mask the putrid taste of some foods particularly meat - this is a 'head in the sand' approach where masking the bad taste was thought to take away the bad effects. Whether the Tudors thought that masking the taste of putrefying meat stopped them getting ill I cannot know, but they certainly thought that masking the terrible smells of putrid plague-ridden London prevented them catching fatal diseases like the Plague. The gentry used, amongst other things, oranges stuck with cloves, and ornate necklaces with receptacles for sweet-smelling spices and resins (pomanders - derived from the French *pomme d'ambre* meaning apple of amber; ambergris, a sweet-smelling substance produced by sperm whales was often used to scent pomanders) to waft in front of them to take away the evil smells as they walked the streets. This is hardly food safety legislation, but it might just be the beginning of people connecting off-food with illness - a key step in making food safe.

### **The times of King George III of England (1760–1820)**

The Georgian era was a time of great social division. The rich ate well, if not exuberantly, and the poor just about found enough food to keep them alive. The idea that bad smells were associated with disease prevailed as