

GLOBAL CHEESEMAKING TECHNOLOGY

CHEESE QUALITY AND CHARACTERISTICS



EDITED BY
PHOTIS PAPADEMAS
THOMAS BINTSIS

WILEY

Global Cheesemaking Technology

Global Cheesemaking Technology

Cheese Quality and Characteristics

Edited by

Photis Papademas

Department of Agricultural Sciences, Biotechnology and Food Science,
Cyprus University of Technology, Cyprus

Thomas Bintsis

11 Parmenionos, 50200 Ptolemaida, Greece

WILEY

This edition first published 2018

© 2018 John Wiley & Sons, Ltd

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 law. Advice on how to obtain permission to reuse material from this title is available at <http://www.wiley.com/go/permissions>.

The right of Photis Papademas and Thomas Bintsis to be identified as the author of this work has been asserted in accordance with law.

Registered Offices

John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, USA

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

Editorial Office

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

For details of our global editorial offices, customer services, and more information about Wiley products visit us at www.wiley.com.

Wiley also publishes its books in a variety of electronic formats and by print-on-demand. Some content that appears in standard print versions of this book may not be available in other formats.

Limit of Liability/Disclaimer of Warranty

The publisher and the authors make no representations or warranties with respect to the accuracy or completeness of the contents of this work and specifically disclaim all warranties, including without limitation any implied warranties of fitness for a particular purpose. This work is sold with the understanding that the publisher is not engaged in rendering professional services. The advice and strategies contained herein may not be suitable for every situation. In view of ongoing research, equipment modifications, changes in governmental regulations, and the constant flow of information relating to the use of experimental reagents, equipment, and devices, the reader is urged to review and evaluate the information provided in the package insert or instructions for each chemical, piece of equipment, reagent, or device for, among other things, any changes in the instructions or indication of usage and for added warnings and precautions. The fact that an organization or website is referred to in this work as a citation and/or potential source of further information does not mean that the author or the publisher endorses the information the organization or website may provide or recommendations it may make. Further, readers should be aware that websites listed in this work may have changed or disappeared between when this work was written and when it is read. No warranty may be created or extended by any promotional statements for this work. Neither the publisher nor the author shall be liable for any damages arising here from.

Library of Congress Cataloging-in-Publication Data

9781119046158

Cover Design: Wiley

Cover Image: The cover photo is of Ragusano PDO cheese. For more details see Part II Section 8.8. Courtesy of Photis Papademas

Set in 10/12pt WarnockPro by SPi Global, Chennai, India

10 9 8 7 6 5 4 3 2 1

This book is dedicated to our families and to a great teacher, the late Dr R.K. Robinson.

Contents

List of Contributors *xxv*

Preface *xxix*

Part I *1*

- 1 The History of Cheese** *3*
Paul S. Kindstedt
 - 1.1 Introduction *3*
 - 1.2 Origins of Cheese *3*
 - 1.3 Cheese in Antiquity *7*
 - 1.4 Cheese in the Middle Ages and Renaissance *10*
 - 1.5 Cheese in the Modern Era *12*
 - References *14*

- 2 From Micelle to Melt: The Influence of Calcium on Physico-chemical Properties of Cheese** *20*
Darren R. Cooke and Paul L.H. McSweeney
 - 2.1 Introduction *20*
 - 2.2 Calcium Equilibrium in Bovine Milk *21*
 - 2.2.1 Forms of Calcium in Milk *21*
 - 2.2.2 Colloidal Calcium Phosphate *22*
 - 2.2.3 Modification of Calcium Equilibrium in Bovine Milk *24*
 - 2.3 Calcium Equilibrium in Cheese *25*
 - 2.3.1 Changes in the Calcium Equilibrium of Cheese during Ripening *25*
 - 2.3.2 Methods of Calcium Equilibrium Determination in Cheese *25*
 - 2.3.3 Manipulation of Calcium Equilibrium in Cheese *26*
 - 2.3.4 Mechanisms of Calcium Equilibrium Changes during Cheese Ripening *27*
 - 2.4 The Influence of Calcium on Cheese Rheology and Functionality *31*
 - 2.4.1 The Influence of Calcium Equilibrium on Cheese Microstructure *31*
 - 2.4.2 Determination of the Rheological Properties of Cheese *32*
 - 2.4.3 Influence of Calcium on Rheological Properties of Unmelted Cheese *36*
 - 2.4.4 Influence of Calcium on Cheese Melt and High Temperature Cheese Rheology *37*
 - 2.5 Conclusions *40*
 - References *40*

3	Cheese Flavour Development and Sensory Characteristics	45
	<i>Kieran Kilcawley and Maurice O'Sullivan</i>	
3.1	Introduction	45
3.2	Biochemical Pathways Involved in Cheese Flavour	46
3.2.1	Glycolysis	46
3.2.2	Lipolysis	48
3.2.3	Proteolysis	53
3.3	Sensory Methods	58
3.3.1	Grading Methods	58
3.3.2	Difference Methods	59
3.3.3	Affective Sensory Testing	59
3.3.4	Descriptive Sensory Profiling	60
3.3.5	Rapid Sensory Methods	62
3.4	Data Analysis, Chemometrics and Preference Mapping	63
3.5	Conclusion	63
	References	64
4	Cheese Microbial Ecology and Safety	71
	<i>Antonia Picon</i>	
4.1	Introduction	71
4.2	Source of Microorganisms in Cheese	71
4.3	Factors Influencing the Growth of Microorganisms in Cheese	72
4.4	Cheese Microbiota	72
4.4.1	Starter Bacteria	72
4.4.2	Non-Starter LAB	74
4.4.3	Propionibacteria	75
4.4.4	Micrococci and Staphylococci	75
4.4.5	Moulds and Yeasts	76
4.4.6	Probiotics in Cheese	77
4.5	Cheese Pathogens	77
4.5.1	<i>Listeria monocytogenes</i>	79
4.5.2	<i>Escherichia coli</i>	79
4.5.3	<i>Salmonella enterica</i>	80
4.5.4	<i>Campylobacter</i> spp.	80
4.5.5	<i>Staphylococcus aureus</i>	81
4.6	Other Risks of Microbial Origin	81
4.7	Growth and Survival of Bacterial Pathogens in Cheese	82
4.8	Procedures to Improve Cheese Safety	84
4.8.1	Biopreservatives of Microbial Origin	84
4.8.2	Physical Treatments	86
4.9	Conclusions and Future Trends	89
	References	89
5	Cheeses with Protected Land- and Tradition-Related Labels: Traceability and Authentication	100
	<i>Luiz Javier R. Barron, Noelia Aldai, Mailo Virto and Mertxe de Renobales</i>	
5.1	Introduction: Protected Land- and Tradition-Related Labels	100
5.2	Traceability	103
5.3	Authentication: What Should Be Authenticated?	103
5.3.1	Raw Materials	104
5.3.2	Geographical Location	106

5.3.3	Animal Management and Feeding Systems	108
5.3.4	Cheesemaking Technologies	111
5.3.5	Sensory Characteristics	112
5.4	Innovation, Modern Technologies and Traditional Cheeses	112
5.5	Conclusions	113
	Acknowledgements	113
	References	113
6	An Overview of the Cheesemaking Process	120
	<i>Thomas Bintsis and Photis Papademas</i>	
6.1	Introduction	120
6.2	Milk Types and Composition	121
6.2.1	Casein	121
6.2.2	Whey Protein	122
6.2.3	Lipids	122
6.2.4	Minerals	123
6.2.5	Lactose	123
6.3	Raw Milk Quality for Cheesemaking	123
6.3.1	Animal Nutrition and the Effect on Milk Composition	123
6.3.2	Microbial Activity of Milk	124
6.3.2.1	Hygienic Raw Milk Production	124
6.3.2.2	Milk Storage and Transport Conditions	124
6.3.2.3	Microbial Contamination	124
6.3.2.4	Raw Milk Cheeses	124
6.3.3	Other Factors Affecting Milk Composition	125
6.3.3.1	Stage of Lactation	125
6.3.3.2	Genetic Variants of Milk Proteins	125
6.3.4	Enzymatic Activity of Milk	125
6.3.4.1	Proteinases	125
6.3.4.2	Lipases	126
6.3.5	Milk Residues	126
6.3.5.1	Antibiotics	126
6.3.5.2	Mycotoxins	126
6.4	Additives in Cheese Milk	126
6.4.1	Calcium Chloride	126
6.4.2	Preservatives	127
6.4.3	Colourings	127
6.5	Milk Standardisation	127
6.6	Treatments of Raw Milk for Cheesemaking	127
6.6.1	Thermisation	127
6.6.2	Pasteurisation	128
6.6.3	Microfiltration	128
6.6.4	Ultrafiltration	128
6.6.5	Bactofugation	128
6.6.6	Homogenisation	129
6.6.7	High-Pressure Processing (HPP)	129
6.7	Acidification	129
6.8	Coagulation	131
6.9	Post-Coagulation Processes	132
6.9.1	Cutting	133
6.9.2	Cooking (Scalding)	133
6.9.3	Cheddaring	134

6.9.4	Curd Washing	134
6.9.5	Stretching	134
6.9.6	Moulding/Drainage	135
6.9.7	Pressing	135
6.9.8	Salting	135
6.10	Control of Cheesemaking Steps	136
6.11	Cheese Maturation	136
6.12	Adjunct Cultures and Acceleration of the Maturation Process	137
6.13	Packaging	138
6.14	Main Cheese Categories	140
	References	152

7 Traditional Wooden Equipment Used for Cheesemaking and Their Effect on Quality 157

Giuseppe Licitra, Margherita Caccamo, Florence Valence and Sylvie Lortal

7.1	Introduction to Traditional Cheeses	157
7.2	Traditional Equipment	158
7.2.1	Wood Characteristics	160
7.3	Biofilms of Wooden Vats	161
7.4	Wooden Shelves	163
7.5	Legislation Concerning Wood in Contact with Milk or Cheeses	164
7.6	Cleaning Systems	165
7.7	Safety Assessment	167
7.8	Conclusions	168
	References	169

Part II 173

Introduction 175

Cheeses from Argentina 175

Acknowledgements 175

References 176

Cheeses from Cyprus 176

Reference 177

Cheeses from Denmark 177

References 178

Cheeses from France 178

Cheeses from Germany 179

Cheeses from Greece 180

Reference 181

Cheeses from Italy 181

Cheeses from Malta 183

Cheeses from the Netherlands 183

Cheeses from Portugal 184

Cheeses from Serbia 185

References 186

Cheeses from Slovakia 186

Cheeses from Spain 187

Acknowledgements 188

Cheeses from Sweden 188

References	189
Cheeses from Switzerland	190
Acknowledgements	190
Cheeses from Turkey	191
References	192
Cheeses from the United Kingdom	192

1	Extra-Hard Cheeses	194
	<i>Giuseppe Licitra, Erica R. Hynes, Maria Cristina Perotti, Carina V. Bergamini, Elisabeth Eugster-Meier, Marie-Therese Fröhlich-Wyder, Ernst Jakob and Daniel Wechsler</i>	
1.1	Parmigiano Reggiano PDO – Italy	194
1.1.1	Introduction	194
1.1.2	Type	195
1.1.3	Milk	195
1.1.4	Description and Sensory Characteristics	195
1.1.5	Method of Manufacture	195
1.1.6	Relevant Research	196
1.2	Reggianito Cheese – Argentina	197
1.2.1	Introduction	197
1.2.2	Type	197
1.2.3	Description and Sensory Characteristics	197
1.2.4	Method of Manufacture	197
1.2.5	Relevant Research	198
	Acknowledgements	199
1.3	Sbrinz PDO – Switzerland	199
1.3.1	Introduction	199
1.3.2	Type	200
1.3.3	Description and Sensory Characteristics	200
1.3.4	Method of Manufacture	200
1.3.5	Relevant Research	201
	References	201
2	Hard Cheeses	204
	<i>Katja Hartmann, Giuseppe Licitra, Elisabeth Eugster-Meier, Marie-Therese Fröhlich-Wyder, Ernst Jakob, Daniel Wechsler, Jean L. Maubois, Kimon-Andreas G. Karatzas, Thomas Bintsis, Efstathios Alichanidis, Maria Belén López Morales, Françoise Berthier, İrem Uzunsoy, Barbaros Özer and Ylva Ardö</i>	
2.1	Allgäu Mountain Cheese – Germany	204
2.1.1	Introduction	205
2.1.2	Type	205
2.1.3	Description and Sensory Characteristics	205
2.1.4	Method of Manufacture	205
2.2	Asiago PDO – Italy	206
2.2.1	Introduction	206
2.2.2	Type	207
2.2.3	Milk	207
2.2.4	Description and Sensory Characteristics	207
2.2.5	Method of Manufacture	208
2.2.5.1	Asiago Pressato PDO	208
2.2.5.2	Asiago d'Allevo PDO	208
2.2.5.3	Asiago 'Prodotto di Montagna'	209

2.2.6	Relevant Research	209
2.3	Berner Alpkäse PDO and Berner Hobelkäse PDO – Switzerland	210
2.3.1	Introduction	210
2.3.2	Type	211
2.3.3	Description and Sensory Characteristics	211
2.3.4	Method of Manufacture	211
2.3.5	Relevant Research	212
2.4	Cantal PDO – France	213
2.4.1	Introduction	213
2.4.2	Milk	213
2.4.3	Description and Sensory Characteristics	213
2.4.4	Method of Manufacture	214
2.5	Cheddar – United Kingdom	214
2.5.1	Type	215
2.5.2	Milk	215
2.5.3	Description and Sensory Characteristics	215
2.5.4	Method of Manufacture	215
2.6	Cheshire – United Kingdom	216
2.6.1	Type	217
2.6.2	Description and Sensory Characteristics	217
2.6.3	Method of Manufacture	217
2.7	Fiore Sardo PDO – Italy	218
2.7.1	Introduction	218
2.7.2	Type	218
2.7.3	Description and Sensory Characteristics	218
2.7.4	Method of Manufacture	218
2.7.5	Relevant Research	219
2.8	Graviera Kritis PDO – Greece	220
2.8.1	Introduction	220
2.8.2	Type	220
2.8.3	Milk	220
2.8.4	Description and Sensory Characteristics	220
2.8.5	Method of Manufacture	221
2.8.6	Relevant Research	221
2.9	Idiazabal PDO – Spain	222
2.9.1	Introduction	222
2.9.2	Type	222
2.9.3	Milk	223
2.9.4	Description and Sensory Characteristics	223
2.9.5	Method of Manufacture	223
2.9.6	Relevant Research	223
2.10	Kefalograviera PDO – Greece	224
2.10.1	Introduction	225
2.10.2	Type	225
2.10.3	Milk	225
2.10.4	Description and Sensory Characteristics	225
2.10.5	Method of Manufacture	225
2.10.6	Relevant Research	225
2.11	Kefalotyri – Greece	226
2.11.1	Introduction	226
2.11.2	Type	226

2.11.3	Milk	226
2.11.4	Description and Sensory Characteristics	227
2.11.5	Method of Manufacture	227
2.11.6	Relevant Research	227
2.12	Le Gruyère PDO – Switzerland	228
2.12.1	Introduction	228
2.12.2	Type	228
2.12.3	Description and Sensory Characteristics	228
2.12.4	Method of Manufacture	229
2.12.5	Relevant Research	230
2.13	Ossau Iraty PDO – France	230
2.13.1	Introduction	230
2.13.2	Description and Sensory Characteristics	231
2.13.3	Method of Manufacture	231
2.13.4	Relevant Research	233
2.14	Tête de Moine PDO, Fromage de Bellelay – Switzerland	233
2.14.1	Introduction	233
2.14.2	Type	234
2.14.3	Description and Sensory Characteristics	234
2.14.4	Method of Manufacture	234
2.14.5	Relevant Research	235
2.15	Tulum Cheese –Turkey	235
2.15.1	Introduction	235
2.15.2	Type	236
2.15.3	Description and Sensory Characteristics	236
2.15.4	Method of Manufacture	236
2.15.5	Relevant Research	237
2.16	Västerbottensost – Sweden	237
2.16.1	Introduction	237
2.16.2	Type	238
2.16.3	Milk	238
2.16.4	Description and Sensory Characteristics	238
2.16.5	Method of Manufacture	238
2.16.6	Relevant Research	239
2.17	Würchwitz Mite Cheese – Germany	239
2.17.1	Introduction	240
2.17.2	Type	240
2.17.3	Description and Sensory Characteristics	240
2.17.4	Method of Manufacture	240
	References	241

3 Semi-hard Cheeses 247

Elisabeth Eugster-Meier, Marie-Therese Fröhlich-Wyder, Ernst Jakob, Daniel Wechsler, Maria Belén López Morales, Giuseppe Licitra, Françoise Berthier, Photis Papademas, Ylva Ardö, Tânia G. Tavares, F. Xavier Malcata, Zorica Radulovic and Jelena Miocinovic

3.1	Appenzeller® – Switzerland	247
3.1.1	Introduction	248
3.1.2	Type	248
3.1.3	Milk	248
3.1.4	Description and Sensory Characteristics	248
3.1.5	Method of Manufacture	248

3.1.6	Relevant Research	250
3.2	Arzúa-Ulloa PDO – Spain	250
3.2.1	Introduction	250
3.2.2	Type	251
3.2.3	Milk	251
3.2.4	Description and Sensory Characteristics	251
3.2.5	Method of Manufacture	252
3.2.6	Relevant Research	253
3.3	Castelmagno PDO – Italy	253
3.3.1	Introduction	254
3.3.2	Type	254
3.3.3	Description and Sensory Characteristics	254
3.3.4	Method of Manufacture	254
3.3.5	Relevant Research	256
3.4	Comté PDO – France	256
3.4.1	Introduction	256
3.4.2	Description and Sensory Characteristics	257
3.4.3	Method of Manufacture	258
3.4.4	Relevant Research	258
3.5	Flaouna Cheese – Cyprus	259
3.5.1	Introduction	259
3.5.2	Type	259
3.5.3	Description and Sensory Characteristics	259
3.5.4	Method of Manufacture	260
3.6	Formaggio di Fossa di Sogliano PDO – Italy	260
3.6.1	Introduction	261
3.6.2	Type	261
3.6.3	Description and Sensory Characteristics	261
3.6.4	Method of Manufacture	261
3.6.5	Relevant Research	262
3.7	Havarti – Denmark	263
3.7.1	Introduction	263
3.7.2	Type	263
3.7.3	Description and Sensory Characteristics	263
3.7.4	Method of Manufacture	264
3.7.5	Relevant Research	264
3.8	Herrgård – Sweden	264
3.8.1	Introduction	265
3.8.2	Type	265
3.8.3	Milk	265
3.8.4	Description and Sensory Characteristics	265
3.8.5	Method of Manufacture	265
3.8.6	Relevant Research	266
3.9	Mahón-Menorca PDO – Spain	267
3.9.1	Introduction	267
3.9.2	Type	267
3.9.3	Milk	268
3.9.4	Description and Sensory Characteristics	268
3.9.5	Method of Manufacture	268
3.9.6	Relevant Research	269

3.10	Majorero PDO – Spain	269
3.10.1	Introduction	269
3.10.2	Type	270
3.10.3	Milk	270
3.10.4	Description and Sensory Characteristics	270
3.10.5	Method of Manufacture	270
3.10.6	Relevant Research	271
3.11	Manchego PDO – Spain	271
3.11.1	Introduction	272
3.11.2	Type	272
3.11.3	Milk	272
3.11.4	Description and Sensory Characteristics	272
3.11.5	Method of Manufacture	273
3.11.6	Relevant Research	273
3.12	Murcia al Vino PDO – Spain	274
3.12.1	Introduction	274
3.12.2	Type	274
3.12.3	Milk	274
3.12.4	Description and Sensory Characteristics	275
3.12.5	Method of Manufacture	275
3.12.6	Relevant Research	275
3.13	Präst – Sweden	276
3.13.1	Introduction	276
3.13.2	Type	277
3.13.3	Milk	277
3.13.4	Description and Sensory Characteristics	277
3.13.5	Method of Manufacture	277
3.13.6	Relevant Research	277
3.14	Raclette du Valais PDO – Switzerland	278
3.14.1	Introduction	278
3.14.2	Type	279
3.14.3	Description and Sensory Characteristics	279
3.14.4	Method of Manufacture	279
3.14.5	Relevant Research	280
3.15	Raclette Suisse®-Switzerland	280
3.15.1	Introduction	280
3.15.2	Type	281
3.15.3	Description and Sensory Characteristics	281
3.15.4	Method of Manufacture	281
3.15.5	Relevant Research	282
3.16	San Simón da Costa PDO-Spain	282
3.16.1	Introduction	283
3.16.2	Type	283
3.16.3	Milk	283
3.16.4	Description and Sensory Characteristics	283
3.16.5	Method of Manufacture	284
3.16.6	Relevant Research	284
3.17	Svecia PGI – Sweden	285
3.17.1	Introduction	285
3.17.2	Type	285

3.17.3	Milk	285
3.17.4	Description and Sensory Characteristics	285
3.17.5	Method of Manufacture	286
3.17.6	Relevant Research	286
3.18	Serpa – Portugal	286
3.18.1	Introduction	287
3.18.2	Milk and Rennet	287
3.18.3	Description and Sensory Characteristics	287
3.18.4	Method of Manufacture	288
3.18.5	Relevant Research	288
3.19	Sombor Cheese – Serbia	289
3.19.1	Introduction	289
3.19.2	Type	289
3.19.3	Milk	290
3.19.4	Description and Sensory Characteristics	290
3.19.5	Method of Manufacture	290
3.19.6	Relevant Research	290
3.20	Tuma Persa PDO – Italy	291
3.20.1	Introduction	291
3.20.2	Type	292
3.20.3	Milk	292
3.20.4	Description and Sensory Characteristics	292
3.20.5	Method of Manufacture	292
	References	293

4 Soft Cheeses (with Rennet) 301

Maria Belén López Morales, Thomas Bintsis, Efstathios Alichanidis, Karol Herian, Paul Jelen, Erica R. Hynes, Maria Cristina Perotti, Carina V. Bergamini, Everaldo Attard, Anthony Grupetta, Stefania Carpino, Tânia G. Tavares and F. Xavier Malcata

4.1	Afuega'l Pitu PDO – Spain	301
4.1.1	Introduction	302
4.1.2	Type	302
4.1.3	Milk	302
4.1.4	Description and Sensory Characteristics	302
4.1.5	Method of Manufacture	303
4.1.6	Relevant Research	303
4.2	Anevato PDO – Greece	304
4.2.1	Introduction	304
4.2.2	Type	304
4.2.3	Description and Sensory Characteristics	304
4.2.4	Method of Manufacture	304
4.2.5	Relevant Research	305
4.3	Bryndza – Slovakia	305
4.3.1	Introduction	305
4.3.2	Type	306
4.3.3	Description and Sensory Characteristics	306
4.3.4	Method of Manufacture	306
4.4	Cremoso – Argentina	307
4.4.1	Introduction	308
4.4.2	Description and Sensory Characteristics	308
4.4.3	Method of Manufacture	308

4.4.4	Relevant Research	309
	Acknowledgements	309
4.5	Galotyri PDO – Greece	310
4.5.1	Introduction	310
4.5.2	Type	310
4.5.3	Description and Sensory Characteristics	310
4.5.4	Method of Manufacture	310
4.5.5	Relevant Research	311
4.6	Kopanisti PDO – Greece	311
4.6.1	Introduction	311
4.6.2	Type	311
4.6.3	Milk	311
4.6.4	Description and Sensory Characteristics	312
4.6.5	Method of Manufacture	312
4.6.6	Relevant Research	312
4.7	Maltese Ġbejna – Malta	312
4.7.1	Introduction	313
4.7.2	Type	314
4.7.3	Description and Sensory Characteristics	314
4.7.4	Method of Manufacture	314
4.7.5	Relevant Research	315
4.8	Serra da Estrela PDO – Portugal	316
4.8.1	Introduction	316
4.8.2	Milk	317
4.8.3	Rennet	317
4.8.4	Description and Sensory Characteristics	317
4.8.5	Method of Manufacture	318
4.8.6	Relevant Research	319
4.9	Torta del Casar PDO – Spain	319
4.9.1	Introduction	320
4.9.2	Type	320
4.9.3	Milk	320
4.9.4	Description and Sensory Characteristics	320
4.9.5	Method of Manufacture	320
4.9.6	Relevant Research	321
	References	321
5	Dutch-Type Cheeses	326
	<i>Eva-Maria Düsterhöft, Wim Engels and Thom Huppertz</i>	
5.1	Edam Cheese – The Netherlands	326
5.1.1	Introduction	326
5.1.2	Type	327
5.1.3	Description and Sensory Characteristics	327
5.1.4	Method of Manufacture	327
5.2	Gouda – The Netherlands	329
5.2.1	Introduction	329
5.2.2	Type	329
5.2.3	Description and Sensory Characteristics	329
5.2.4	Method of Manufacture	330
5.2.5	Relevant Research	332
5.3	Hollandse Geitenkaas (Dutch Goat's Cheese) PGI – The Netherlands	332

- 5.3.1 Introduction 333
- 5.3.2 Type 333
- 5.3.3 Milk 333
- 5.3.4 Description and Sensory Characteristics 333
- 5.3.5 Method of Manufacture 334
- References 334

6 Swiss-Type Cheeses (Propionic Acid Cheeses) 336

Katja Hartmann, Elisabeth Eugster-Meier, Marie-Therese Fröhlich-Wyder, Ernst Jakob, Daniel Wechsler, Ylva Ardö, Eva-Maria Düsterhöft, Wim Engels, Thom Huppertz, Erica R. Hynes, Maria Cristina Perotti and Carina V. Bergamini

- 6.1 Allgäu Emmental PDO – Germany 336
 - 6.1.1 Introduction 336
 - 6.1.2 Type 337
 - 6.1.3 Description and Sensory Characteristics 337
 - 6.1.4 Method of Manufacture 337
- 6.2 Emmentaler PDO – Switzerland 338
 - 6.2.1 Introduction 338
 - 6.2.2 Type 339
 - 6.2.3 Description and Sensory Characteristics 339
 - 6.2.4 Method of Manufacture 339
 - 6.2.5 Relevant Research 340
- 6.3 Grevé – Sweden 340
 - 6.3.1 Introduction 340
 - 6.3.2 Type 341
 - 6.3.3 Description and Sensory Characteristics 341
 - 6.3.4 Method of Manufacture 341
 - 6.3.5 Relevant Research 341
- 6.4 Maasdammer – The Netherlands 342
 - 6.4.1 Introduction 342
 - 6.4.2 Type 342
 - 6.4.3 Description and Sensory Characteristics 342
 - 6.4.4 Method of Manufacture 343
 - 6.4.5 Relevant Research 344
- 6.5 Pategrás Cheese – Argentina 344
 - 6.5.1 Introduction 344
 - 6.5.2 Type 344
 - 6.5.3 Description and Sensory Characteristics 345
 - 6.5.4 Method of Manufacture 345
 - 6.5.5 Relevant Research 346
- Acknowledgements 346
- References 346

7 White-Brined Cheeses 349

Thomas Bintsis, Efstathios Alichanidis, İrem Uzunsoy, Barbaros Özer, Photis Papademas, Zorica Radulovic and Jelena Miocinovic

- 7.1 Batzos PDO – Greece 349
 - 7.1.1 Introduction 349
 - 7.1.2 Type 350

7.1.3	Description and Sensory Characteristics	350
7.1.4	Method of Manufacture	350
7.1.5	Relevant Research	350
7.2	Beyaz Peynir – Turkey	351
7.2.1	Introduction	351
7.2.2	Type	351
7.2.3	Description and Sensory Characteristics	352
7.2.4	Method of Manufacture	352
7.2.5	Relevant Research	352
7.3	Feta PDO – Greece	353
7.3.1	Introduction	353
7.3.2	Type	353
7.3.3	Milk	354
7.3.4	Description and Sensory Characteristics	354
7.3.5	Method of Manufacture	354
7.3.6	Relevant Research	355
7.4	Halitzia – Cyprus	356
7.4.1	Introduction	356
7.4.2	Type	356
7.4.3	Description and Sensory Characteristics	356
7.4.4	Method of Manufacture	356
7.5	Halloumi – Cyprus	357
7.5.1	Introduction	357
7.5.2	Type	357
7.5.3	Milk	358
7.5.4	Description and Sensory Characteristics	358
7.5.5	Method of Manufacture	358
7.5.6	Relevant Research	359
7.6	Mihaliç – Turkey	359
7.6.1	Introduction	359
7.6.2	Type	359
7.6.3	Description and Sensory Characteristics	359
7.6.4	Method of Manufacture	360
7.6.5	Relevant Research	360
7.7	Sjenica – Serbia	361
7.7.1	Introduction	361
7.7.2	Type	361
7.7.3	Milk	361
7.7.4	Description and Sensory Characteristics	362
7.7.5	Method of Manufacture	362
7.7.6	Relevant Research	362
7.8	Urfa – Turkey	363
7.8.1	Introduction	363
7.8.2	Type	363
7.8.3	Description and Sensory Characteristics	363
7.8.4	Method of Manufacture	364
7.8.5	Relevant Research	364
	References	365

8	Pasta-Filata Cheeses	368
	<i>Giuseppe Licitra, Zorica Radulovic, Jelena Miocinovic, İrem Uzunsoy, Barbaros Özer, Thomas Bintsis, Efstathios Alichanidis, Karol Herian and Paul Jelen</i>	
8.1	Caciocavallo Podolico PDO – Italy	368
8.1.1	Introduction	368
8.1.2	Type	369
8.1.3	Description and Sensory Characteristics	369
8.1.4	Method of Manufacture	369
8.2	Kachkaval (Kačkavalj) – Serbia	370
8.2.1	Introduction	371
8.2.2	Type	371
8.2.3	Description and Sensory Characteristics	371
8.2.4	Method of Manufacture	371
8.2.5	Relevant Research	372
8.3	Kashar (Kaşar Peyniri) – Turkey	372
8.3.1	Introduction	372
8.3.2	Type	373
8.3.3	Description and Sensory Characteristics	373
8.3.4	Method of Manufacture	373
8.3.5	Relevant Research	374
8.4	Kasseri PDO – Greece	374
8.4.1	Introduction	375
8.4.2	Type	375
8.4.3	Milk	375
8.4.4	Description and Sensory Characteristics	375
8.4.5	Method of Manufacture	375
8.4.6	Relevant Research	376
8.5	Mozzarella di Bufala Campana PDO – Italy	376
8.5.1	Introduction	376
8.5.2	Type	377
8.5.3	Description and Sensory Characteristics	377
8.5.4	Methods of Manufacture	377
8.5.5	Relevant Research	379
8.6	Parenica – Slovakia	379
8.6.1	Introduction	379
8.6.2	Type	380
8.6.3	Description and Sensory Characteristics	380
8.6.4	Method of Manufacture	380
8.7	Provolone Valpadana PDO – Italy	382
8.7.1	Introduction	382
8.7.2	Type	382
8.7.3	Description and Sensory Characteristics	382
8.7.4	Methods of Manufacture	382
8.8	Ragusano PDO – Italy	383
8.8.1	Introduction	383
8.8.2	Type	384
8.8.3	Description and Sensory Characteristics	384
8.8.4	Methods of Manufacture	384
8.8.5	Relevant Research	386
8.9	Vastedda della Valle del Belice PDO – Italy	386
8.9.1	Introduction	386

8.9.2	Type	387
8.9.3	Description and Sensory Characteristics	387
8.9.4	Method of Manufacture	387
8.9.5	Relevant Research	388
	References	389
9	Mould Surface-Ripened Cheeses	392
	<i>Katja Hartmann and Jean L. Maubois</i>	
9.1	Altenburger Goat Cheese PDO – Germany	392
9.1.1	Introduction	392
9.1.2	Type	393
9.1.3	Description and Sensory Characteristics	393
9.1.4	Method of Manufacture	393
9.2	Camembert de Normandie PDO – France	394
9.2.1	Introduction	394
9.2.2	Milk	394
9.2.3	Description and Sensory Characteristics	394
9.2.4	Method of Manufacture	394
	References	395
10	Bacterial Surface-Ripened (Smear) Cheeses	397
	<i>Ylva Ardö, Françoise Berthier, Katja Hartmann, Elisabeth Eugster-Meier, Marie-Therese Fröhlich-Wyder*, Ernst Jakob and Daniel Wechsler</i>	
10.1	Danbo – Denmark	397
10.1.1	Introduction	397
10.1.2	Type	398
10.1.3	Description and Sensory Characteristics	398
10.1.4	Method of Manufacture	398
10.1.5	Relevant Research	399
10.2	Epoisses PDO – France	399
10.2.1	Introduction	399
10.2.2	Description and Sensory Characteristics	400
10.2.3	Method of Manufacture	400
10.2.4	Relevant Research	401
10.3	Esrom PGI – Denmark	401
10.3.1	Introduction	402
10.3.2	Type	402
10.3.3	Description and Sensory Characteristics	402
10.3.4	Method of Manufacture	402
10.4	Hohenheim Trappisten – Germany	403
10.4.1	Introduction	403
10.4.2	Type	403
10.4.3	Description and Sensory Characteristics	403
10.4.4	Method of Manufacture	403
10.5	Maroilles PDO – France	404
10.5.1	Introduction	404
10.5.2	Description and Sensory Characteristics	405
10.5.3	Method of Manufacture	406
10.5.4	Relevant Research	406
10.6	Reblochon PDO – France	407
10.6.1	Introduction	407

10.6.2	Description and Sensory Characteristics	408
10.6.3	Method of Manufacture	408
10.6.4	Relevant Research	409
10.7	Vacherin Mont-d'Or PDO – Switzerland	409
10.7.1	Introduction	410
10.7.2	Type	410
10.7.3	Description and Sensory Characteristics	410
10.7.4	Method of Manufacture	410
10.7.5	Relevant Research	411
	References	412
11	Blue-Veined Cheeses	415
	<i>Maria Belén López Morales, Ylva Ardö, Françoise Berthier, Kimon-Andreas G. Karatzas and Thomas Bintsis</i>	
11.1	Cabrales PDO – Spain	415
11.1.1	Introduction	415
11.1.2	Type	416
11.1.3	Milk	416
11.1.4	Description and Sensory Characteristics	416
11.1.5	Method of Manufacture	417
11.1.6	Relevant Research	417
11.2	Danablu PGI – Denmark	418
11.2.1	Introduction	418
11.2.2	Type	418
11.2.3	Description and Sensory Characteristics	418
11.2.4	Method of Manufacture	419
11.2.5	Relevant Research	419
11.3	Fourme d'Ambert PDO – France	420
11.4	Fourme de Montbrison PDO – France	420
11.4.1	Introduction	420
11.4.2	Description and Sensory Characteristics	422
11.4.3	Method of Manufacture	422
11.4.4	Relevant Research	423
11.5	Gamonedo PDO – Spain	423
11.5.1	Introduction	424
11.5.2	Type	424
11.5.3	Milk	424
11.5.4	Description and Sensory Characteristics	424
11.5.5	Method of Manufacture	425
11.5.6	Relevant Research	425
11.6	Roquefort PDO – France	426
11.6.1	Introduction	426
11.6.2	Description and Sensory Characteristics	427
11.6.3	Method of Manufacture	427
11.6.4	Relevant Research	428
11.7	Stilton PDO – United Kingdom	429
11.7.1	Introduction	429
11.7.2	Type	430
11.7.3	Milk	430
11.7.4	Description and Sensory Characteristics	430
11.7.5	Method of Manufacture	430

11.7.6	Relevant Research	431
	References	432
12	Acid-Coagulated Cheeses	436
	<i>Katja Hartmann, Françoise Berthier and Giuseppe Licitra</i>	
12.1	Acid Curd (Harzer) – Germany	436
12.1.1	Introduction	436
12.1.2	Type	436
12.1.3	Description and Sensory Characteristics	437
12.1.4	Method of Manufacture	437
12.2	Crottin de Chavignol PDO – France	438
12.2.1	Introduction	438
12.2.2	Description and Sensory Characteristics	439
12.2.3	Method of Manufacture	439
12.2.4	Relevant Research	440
12.3	Quark – Germany	441
12.3.1	Introduction	441
12.3.2	Type	441
12.3.3	Milk	441
12.3.4	Description and Sensory Characteristics	441
12.3.5	Method of Manufacture	442
12.4	Robiola di Roccaverano PDO – Italy	442
12.4.1	Introduction	443
12.4.2	Type	443
12.4.3	Milk	443
12.4.4	Description and Sensory Characteristics	443
12.4.5	Method of Manufacture	443
12.4.6	Relevant Research	444
	References	444
13	Whey Cheeses (Heat Coagulated)	446
	<i>Photis Papademas, Thomas Bintsis, Efstathios Alichanidis and Ylva Ardö</i>	
13.1	Anari – Cyprus	446
13.1.1	Introduction	446
13.1.2	Type	447
13.1.3	Description and Sensory Characteristics	447
13.1.4	Method of Manufacture	447
13.2	Anthotyros – Greece	447
13.2.1	Introduction	448
13.2.2	Type	448
13.2.3	Description and Sensory Characteristics	448
13.2.4	Method of Manufacture	448
13.2.5	Relevant Research	448
13.3	Manouri PDO – Greece	449
13.3.1	Introduction	449
13.3.2	Type	449
13.3.3	Whey	449
13.3.4	Description and Sensory Characteristics	449
13.3.5	Method of Manufacture	449
13.3.6	Relevant Research	450
13.4	Mesost and Messmör – Sweden	450

- 13.4.1 Introduction 450
- 13.4.2 Type 451
- 13.4.3 Whey 451
- 13.4.4 Description and Sensory Characteristics 451
- 13.4.5 Method of Manufacture 451
- References 451

- Index 453**

List of Contributors

Noelia Aldai

Food Technology and Biochemistry and
Molecular Biology
Faculty of Pharmacy – University of the
Basque Country/EHU, Vitoria-Gasteiz
Spain

Efstathios Alichanidis

Department of Food Science and
Technology, School of Agriculture
Aristotle University of Thessaloniki
Thessaloniki
Greece

Ylva Ardö

Department of Food Science
University of Copenhagen, Frederiksberg
Denmark

Everaldo Attard

Division of Rural Sciences and Food
Systems, Institute of Earth Systems
University of Malta
Malta

Luiz Javier R. Barron

Food Technology and Biochemistry and
Molecular Biology
Faculty of Pharmacy – University of the
Basque Country/EHU, Vitoria-Gasteiz
Spain

Carina V. Bergamini

Facultad de Ingeniería Química
(Universidad Nacional del Litoral)
Santa Fe
Argentina

and

Instituto de Lactología Industrial (Universidad
Nacional del Litoral – Consejo Nacional de
Investigaciones Científicas y Técnicas)
Santa Fe
Argentina

Françoise Berthier

Unité de Recherches en Technologie et
Analyses Laitières Rue de Versailles
France

Thomas Bintsis

11 Parmenionos
50200 Ptolemaida
Greece

Margherita Caccamo

CoRFiLaC
Ragusa
Italy

Stefania Carpino

CoRFiLaC – Consorzio Ricerca Filiera
Lattiero Casearia, Ragusa
Italy

Darren R. Cooke

School of Food and Nutritional Sciences
University College Cork, Cork
Ireland

Eva-Maria Düsterhöft

NIZO Food Research
The Netherlands

Wim Engels

NIZO Food Research
The Netherlands

Elisabeth Eugster-Meier

Bern University of Applied Sciences
School of Agricultural, Forest and Food
Sciences HAFL
Zollikofen, Switzerland

Marie-Therese Fröhlich-Wyder

Agroscope, Research Division Food
Microbial Systems
Federal Department of Economic Affairs
Education and Research EAER
Bern, Switzerland

Anthony Grupetta

Veterinary Regulations Directorate, Marsa
Malta

Katja Hartmann

Anton Paar GmbH
Germany

Karol Herian

Slovak Dairy Research Institute
Slovakia

Thom Huppertz

NIZO Food Research
The Netherlands

Erica R. Hynes

Facultad de Ingeniería Química
(Universidad Nacional del Litoral)
Santa Fe
Argentina

and

Instituto de Lactología Industrial
(Universidad Nacional del Litoral – Consejo
Nacional de Investigaciones Científicas
y Técnicas)
Santa Fe
Argentina

Ernst Jakob

Agroscope, Institute for Food Sciences IFS
Federal Department of Economic Affairs
Education and Research EAER, Bern
Switzerland

Paul Jelen

Department of Agricultural, Food and
Nutritional Science, University of Alberta
Canada

Kimón-Andreas G. Karatzas

Department of Food and Nutrition Sciences
The University of Reading
United Kingdom

Kieran Kilcawley

Teagasc Food Research Centre
Moorepark, Fermoy, Co. Cork
Ireland

Paul S. Kindstedt

Department of Nutrition and Food Sciences
University of Vermont
United States

Giuseppe Licitra

Department of Agriculture, Nutrition and Environment
University of Catania, Catania
Italy

Sylvie Lortal

INRA, Agrocampus Ouest, Science et Technologie du lait et de l'oeuf
Rennes
France

F. Xavier Malcata

Laboratory of Engineering of Processes, Environment Biotechnology and Energy (LEPABE)
Portugal

and

Department of Chemical Engineering
University of Porto
Portugal

Paul L.H. McSweeney

School of Food and Nutritional Sciences
University College Cork, Cork
Ireland

Jelena Miocinovic

Department of Food Microbiology, Faculty of Agriculture, University of Belgrade
Serbia

Maria Belén López Morales

Food Science and Technology Department
International Excellence Campus for Higher Education and Research 'Campus Mare Nostrum', Veterinary Faculty
University of Murcia
Spain

Maurice O'Sullivan

School of Food and Nutritional Sciences
University College Cork, Cork
Ireland

Barbaros Özer

Ankara University
Faculty of Agriculture
Department of Dairy Technology
Ankara, Turkey

Photis Papademas

Department of Agricultural Sciences
Biotechnology and Food Science
Cyprus University of Technology, Limassol
Cyprus

Maria Cristina Perotti

Facultad de Ingeniería Química
(Universidad Nacional del Litoral)
Santa Fe
Argentina

and

Instituto de Lactología Industrial
(Universidad Nacional del Litoral – Consejo Nacional de Investigaciones Científicas y Técnicas)
Santa Fe
Argentina

Antonia Picon

Department of Food Technology
National Institute of Agricultural and Food Research and Technology (INIA)
Madrid
Spain

Zorica Radulovic

Department of Food Microbiology, Faculty of Agriculture, University of Belgrade
Serbia

Mertxe de Renobales

Biochemistry and Molecular Biology
Faculty of Pharmacy – University of the Basque Country/EHU, Vitoria-Gasteiz
Spain

Tânia G. Tavares

Laboratory of Engineering of
Processes, Environment Biotechnology and
Energy (LEPABE)
Portugal

and

REQUIMTE/Department of Chemical
Sciences
Faculty of Pharmacy
University of Porto
Portugal

İrem Uzunsoy

Bülent Ecevit University Caycuma
Vocational High School
Department of Food Technology
Zonguldak
Turkey

Florence Valence

INRA, Agrocampus Ouest, Science et
Technologie du lait et de l'oeuf
Rennes
France

Mailo Virto

Biochemistry and Molecular Biology
Faculty of Pharmacy – University of the
Basque Country/EHU, Vitoria-Gasteiz
Spain

Daniel Wechsler

Agroscope, Institute for Food Sciences IFS
Federal Department of Economic Affairs
Education and Research EAER, Bern
Switzerland

Preface

The history of cheese goes back to the Neolithic era, parallel to the origins of livestock domestication and dairying, and since then, more than 1000 cheese varieties have evolved. Although cheese is industrially produced in large quantities with a high degree of automation and totally controlled processes, the techniques are very similar to those produced with the traditional methods. Based on the same principles and following basic steps, cheesemakers blend science with 'art', producing a great variety of cheeses.

It is not clear whether cheesemaking is a simple or a complicated process. What is well known is that the impact of a number of different factors in each cheesemaking step is critical, and this is the main reason for the great variability in the characteristics of the final cheese. Thus, the regulation of each factor is vital for producing a cheese with the specific quality characteristics of its variety.

The purpose of this book is to describe (1) the manufacturing process of the most significant cheeses of the world and (2) the quality characteristics of the corresponding individual cheese. In addition, attention is paid to the scientific justification of the development of the final cheese characteristics, and the study of the impact of critical parameters on the development of cheese flavour and texture throughout maturation.

In Part I of the book, some fundamental topics are discussed in order to give a background for a better understanding of cheesemaking and the factors affecting cheese quality. Thus, the history of cheese is presented in Chapter 1; the behaviour of calcium in cheesemilk, during manufacture and during ripening and its impact on the rheological and functional properties of cheese in Chapter 2; cheese flavour development and sensory characteristics in Chapter 3; cheese microbial ecology and safety in Chapter 4; cheese with protected land- and tradition-related labels, traceability and authentication in Chapter 5; an overview of the cheesemaking process in Chapter 6 and traditional wooden equipment used for cheesemaking and their effect on quality in Chapter 7.

In Part II, the cheesemaking processes and the quality and sensory characteristics of 100 cheeses are described. Most of the cheeses presented are traditional products (50 of them with the PDO-Protected Designation of Origin designation). Experts on cheese science and technology gave a comprehensive description of cheese varieties that are important for their country. The cheeses are divided into 13 categories, and each is presented in a separate chapter. Relevant research on each cheese and extensive references to facilitate further studies and stimulate further research on specific aspects of cheesemaking are included.

We wish to express our sincere gratitude to all 43 contributors; for their high professionalism and cooperation.

Photis Papademas and Thomas Bintsis

Part I

1

The History of Cheese

Paul S. Kindstedt

Department of Nutrition and Food Sciences, University of Vermont, US

1.1 Introduction

The International Dairy Federation estimated that global cheese production in 2015 totalled approximately 23 million tonnes (IDE, 2016). This production was spread across six continents and included cheese made mainly from cow (20.7 million tonnes) milk. The remainder is composed of cheese from other species (buffalo, goat and sheep) as well as home-made and farmstead cheeses which do not appear in national statistics. How did this come about? More specifically, where, when and why did cheesemaking begin, how did it spread and evolve, and how did cheese attain such diversity, widespread distribution and prominence in our time? Although our understanding of the history of cheese remains very incomplete, various pieces of this vast puzzle can be fitted together to form a narrative that provides context for global cheesemaking in the twenty-first century.

1.2 Origins of Cheese

Until recently, the origins of cheese have remained mostly shrouded in the impenetrable fog of ancient prehistory. During the past two decades, however, groundbreaking advances in widely ranging fields of research and scholarship have yielded new insights into humanity's earliest experiences with cheese. Indeed, the convergence of multiple trains of research has pushed the likely beginnings of cheesemaking back to the Neolithic, perhaps nearly all the way back to the very origins of livestock domestication and dairying, which provided the context for the emergence of cheese.

Sheep and goats were first domesticated in the upper Euphrates and Tigris River valleys of Southwest Asia, as inferred from the study of archaeological skeletal remains. Advances in techniques to recover, evaluate and statistically analyse skeletal and dental remains for vital diagnostic characteristics such as size, sex and age of the animal at death, along with advances in interpretive frameworks based on ethnographic modelling of management strategies used by semi-nomadic shepherds in Southwest Asia today, have led to breakthroughs in the ability to detect the emergence, and track the spread, of livestock domestication (Vigne, 2011; Vigne & Helmer, 2007). Archaeozoological data clearly demonstrate the occurrence of drastic changes in the slaughtering profiles of sheep and goats, considered indicative of the onset of domestication, around the middle of the 9th millennium BC (Helmer, Gourichon & Vila, 2007; Vigne, 2011; Vigne et al., 2011). Similarly, cattle were also domesticated in the Middle Euphrates basin

slightly later, again based on archaeozoological analyses (Vigne, 2011). Furthermore, mitochondrial genetic studies of modern sheep, goats and cattle, along with analyses of mitochondrial DNA extracted from Neolithic skeletal remains, also support the conclusion that the earliest domestication of these livestock occurred in the Fertile Crescent region of Southwest Asia (Bollongino et al., 2012; Bonfiglio et al., 2012; Conolly et al., 2012; Edwards et al., 2007; Hiendleder et al., 2002; Meadows et al., 2007; Naderi et al., 2008). Thus, a considerable body of evidence indicates that goat, sheep and cattle domestication occurred for the first time in the same general region of the upper Fertile Crescent, aptly dubbed the 'cradle of agriculture', where the initial domestication of key founder grain crops such as wheat, barley, lentil, pea and chickpea also took place several centuries earlier (Weiss & Zohary, 2011).

It has been widely (though not universally) presumed that domesticated livestock in Southwest Asia were initially raised for their meat, hides and other products resulting from the animals' slaughter, and that the milking of goats, sheep and cattle did not commence until much later, for example, around the 4th millennium BC during the so-called 'secondary products revolution' (Sherratt, 1981, 1983). However, current archaeozoological and archaeochemical findings reveal that dairying was practised much earlier. For example, analyses of dental remains testify to the occurrence of sheep and goat slaughtering profiles, as early as the late 9th millennium BC, that are consistent with milk production (Helmer, Gourichon & Vila, 2007). Dairying practices appear to have then spread rapidly beyond their initial areas of origin, such that by the 8th millennium BC, Neolithic migrants from the northern Levantine mainland had transported domestic sheep and goats to Cyprus, where the animals were raised partly for milk production, as inferred from the early culling profiles observed there (Vigne, 2008; Vigne et al., 2011). Around the same period, archaeozoological remains of domestic cattle in the Northern Levant show similar evidence of culling strategies indicative of milking (Vigne & Helmer, 2007), which eventually spread to central and western Anatolia by the 7th millennium BC (Çakırlar, 2012; Evershed et al., 2008). Thus, ample indirect archaeozoological evidence points to dairying being practised almost from the beginning of the Neolithic when livestock were first domesticated. Indeed, it is not unreasonable to postulate that the harvesting of milk for human consumption may have been among the original reasons that inspired Neolithic farmers to domesticate ruminant livestock in the first place (Vigne, 2008; Vigne & Helmer, 2007).

The first direct evidence for dairying in the archaeological record, however, had to wait until the dawn of pottery making, during the 7th millennium BC. Recent advances in analytical techniques to recover lipid residues preserved within the fabric of ancient unglazed pottery sherds, and to identify the lipid sources based on stable carbon isotope (C^{12} and C^{13}) content, have enabled archaeochemists to reconstruct the contents of many ancient Neolithic pots at the time of their use (Dudd & Evershed, 1998; Mottram et al., 1999). Using this approach, Evershed et al. (2008) demonstrated definitively, and Thissen et al. (2010) corroborated, that milk production occurred as early as the 7th millennium BC in western Anatolia.

This same analytical approach has also made it possible to track the ancient practice of milk production through time and space by analysing pottery remains left behind by migrating Neolithic farmers. For example, a growing body of evidence in the field of archaeoclimatology strongly suggests that a substantial rise in sea level, followed by a major episode of climatic cooling, occurred during the late 7th millennium BC, which in turn precipitated social collapse among Neolithic farmers in Southwest Asia and triggered large-scale migrations out of Southwest Asia into Europe and elsewhere (Clare et al., 2008; Pross et al., 2009; Turney & Brown, 2007; Weninger et al., 2006). Among the evidence for Neolithic migration from Anatolia to Europe around this time are the analyses of potsherds recovered from the Balkan Peninsula that chronicle the spread of dairying as migrating Neolithic farmers transported their pottery-making technology and dairy subsistence strategy with them (Evershed et al., 2008). From

there, Neolithic farmers continued their migration into Central, Eastern and Southern Europe by the 6th millennium BC (Craig et al., 2005; Salque et al., 2012; Spangenberg, Jacomet, & Schibler, 2006), the British Isles by the 5th millennium BC (Copley et al., 2003; Copley et al., 2005a,b), and the Western Baltic region, Scandinavia and Finland by the 5th/4th millennium BC (Craig et al., 2011; Cramp et al., 2014; Isaksson & Hallgren, 2012), leaving behind a trail of potsherds containing milk fat residues. Similar analyses have also confirmed the occurrence of dairying as early as the 5th millennium BC in Northern Africa (Dunne et al., 2012), and the 2nd millennium BC in the steppe zone of Central Asia (Outram et al., 2012). Thus, it appears that Neolithic farmers meticulously conserved dairying as a component of their subsistence strategy, even as they migrated vast distances, sometimes under conditions of great environmental stress.

The presence of milk fat residues in ancient potsherds does not necessarily indicate the occurrence of cheesemaking, only that the original pot contained milk in some form at the time of use. However, results from model studies of unglazed potsherds that were exposed to milk products and then buried to simulate conditions of archaeological pottery strongly suggest that the presence of milk fat residues in ancient potsherds constitutes telltale signs of concentrated dairy products such as butter and cheese. For example, unglazed potsherds that were deliberately exposed to liquid full fat milk only absorbed minute levels of milk fat within the pottery fabric, which rapidly degraded to undetectable levels upon burial of the sherds, probably due to microbial breakdown (Copley et al., 2005a; Dudd & Evershed, 1998). Therefore, it seems unlikely that ancient pots that contained only liquid raw milk at the time of use would have retained permanent measurable milk fat residues embedded within the pottery fabric. In contrast, model potsherds that were deliberately dosed with butter and then buried absorbed milk fat into the pottery fabric at 70 times the level observed for liquid milk, and the embedded milk fat underwent much less degradation during burial for up to one year, resulting in the abundant persistence of measurable milk fat residues (Copley et al., 2005a). It is evident, therefore, that concentrated dairy products such as butter and cheese, which contain high levels of milk fat and low levels of water and lactose, are much more likely than liquid milk to transfer abundant milk fat into the fabric of unglazed pottery in a stable form that may persist for immense periods of time under the right conditions; hence, the rationale for the use of milk fat residues as an indicator of concentrated dairy products such as butter or cheese.

Given this context, it is not surprising then, that milk fat residues have also been identified in sherds from Neolithic ceramic sieves recovered from Northeastern and Northwestern Europe, which have been dated to the 6th millennium BC (Salque et al., 2012, 2013). Remnants of Neolithic ceramic sieves have been observed widely in the archaeological material record throughout Central Europe, and similar ceramic sieves from the Bronze Age have been found in Central Italy, the Balkans, and the Indus River region of Pakistan (Barker, 1981; Bogucki, 1984; Gouin, 1997). It has long been suspected that these ancient pottery sieves were used to separate curds from whey during cheesemaking, on the basis of modern peasant ethnography that has documented the widespread use of similar sieves Central Italy, Central Europe, the Balkans and the Middle East (Barker et al., 1991; Gouin, 1997). The findings of Salque et al. (2012, 2013) confirm that Neolithic farmers used such sieves in cheesemaking some 7000 years ago in much the same way as is still practised today in some traditional societies.

In summary, the occurrence of milk fat residues in Neolithic potsherds and sherds, from ceramic sieves in particular, confirms with near certainty that cheesemaking was well under way in Southwest Asia and parts of Europe by the late Neolithic. However, a much earlier origin of cheesemaking, closer to the beginnings of dairying, is also possible. Genetic modelling based on modern human DNA sampling, combined with analyses of DNA recovered from Neolithic human skeletal remains, indicates that humans were universally adult lactose intolerant at the

onset of dairying around the 9th millennium BC, due to the ubiquitous downregulation of the lactase enzyme (beta-galactosidase) that occurs after weaning in all mammals (Leonardi et al., 2012). Lacking the lactase production needed to break down lactose in the gut, early Neolithic adults were lactose intolerant, and it took several thousand years from the start of dairying before adult lactase persistence/lactose tolerance became widely established in the human population for the first time in Central Europe, sometime after the 6th millennium BC (Burger et al., 2007; Curry, 2013; Itan et al., 2009; Leonardi et al., 2012). This implies that the earliest harvesting of milk was intended exclusively for young children who were still suckling, to supplement the mothers' milk supply.

However, there is an additional possibility. The processing of milk into lactose-reduced products such as butter, and especially cheese, would have rendered a substantial fraction of the total nutrient portfolio of milk accessible to the Neolithic adult population. Dairying must have provided Neolithic farmers with very strong nutritional advantages for them to conserve milking practices over the many millennia and vast distances of migration that eventually enabled the successful genetic selection for the capacity to express lactase into adulthood. It is not unreasonable to postulate that cheesemaking may have commenced soon after the beginnings of dairying in the early Neolithic, which furnished the new farmers with a powerful nutritional incentive to culturally conserve their dairying practices through the long millennia that ebbed and flowed until adults, too, gained the capacity to benefit directly from consuming milk.

Unfortunately, there is no way to know for certain what Neolithic cheeses were like. Probably they were similar to the simplest cheeses still produced traditionally by semi-nomadic shepherds in Southwest Asia today: fresh, soft, acid coagulated and acid-heat coagulated types, which can be dried in the sun and preserved for later use (Gouin, 1997; Kindstedt, 2012). Alternatively, such types, when heavily salted, lend themselves to packing and preserving in sealed animal skins or clay pots, as is still practised today in Southwest Asia (Kamber, 2008), and which may account for some of the milk fat residues recovered from Neolithic potsherds discussed previously. Whether Neolithic cheesemakers perfected rennet-coagulated cheese is a matter for speculation. The culling of very young male livestock, practised from the beginning of dairying, afforded Neolithic farmers with ample opportunity to observe the milk clotting capacity of animal stomachs. It was only a matter of time before the connection between the clotted contents in the stomachs of the suckling lambs, kids and calves that were routinely culled, and the capacity of the stomach, and its curdled contents, to transform harvested liquid milk into a clotted state, inspired the birth of rennet-coagulated cheese.

From that point on, the basic technologies of acid, acid-heat and especially rennet-coagulated cheesemaking evolved in many different directions as cheesemakers in different places and at different times were confronted with new environmental, ecological, social and economic circumstances that caused them to adapt their practices and equipment to the world in which they found themselves. Great milestones in the circuitous evolution of cheesemaking were marked by the foundational technological advances that we take for granted today, such as the development of techniques and devices for cutting the coagulated mass of milk, for heating the cut mass of curd and whey and for separating whey from curds and applying pressure to the drained mass of curd, all of which facilitated the expulsion of whey from curds; the mastering of salt application levels and techniques; and the commandeering of local natural microenvironments for cheese storage and ripening. Taken collectively, these simple yet profound technical advances elegantly enabled cheesemakers to select for chemical characteristics and microbial populations in their cheeses that rendered positive outcomes that would otherwise be impossible (Kindstedt, 2014). The end result over the course of millennia has been the evolution of the major cheese families, each made up of seemingly endless variations on the family theme.

1.3 Cheese in Antiquity

It was not until several thousand years after start of cheesemaking, however, that descriptive information about cheeses and their manufacture began to be written down as humanity's first civilizations dawned. The earliest known examples of proto-writing, dating from the late 4th millennium BC, come from Uruk, the first great city-state of the Sumerian civilization of Southern Mesopotamia. These proto-cuneiform clay tablets represent the antecedents of humanity's first written language, and among the tablets recovered at Uruk are numerous administrative records that tabulate annual production figures for dairy products, primarily cheese and butteroil (ghee), produced from the milk of state-controlled herds of cattle and flocks of goats and sheep (Englund, 1991, 1995a; Green, 1980). The administrative complexity reflected in these clay records is astonishing and indicates that dairying and dairy processing had become very sophisticated. At the centre of Uruk's economic and political system stood two soaring temples dedicated to Inanna and An, the patron deities of Uruk whose cultic practices demanded a constant supply of agricultural products, including cheese and butter. These cultic practices not only underpinned the religious ideology of Uruk but also formed the basis of its centrally administered redistributive economy (Kindstedt, 2012).

The Inanna mythology of Uruk, and the Inanna-Demuzi cult that it inspired, institutionalised the routine cultic sacrifices of cheese and butter, which were subsequently replicated in various other Sumerian city-states during the 3rd millennium BC. Indeed, more than a thousand years after the initial rise of Uruk, sophisticated administrative oversight of cheese and butteroil production continued to be practised in Sumer, as is evident from abundant cuneiform records recovered from the massive city-state of Ur around the end of the 3rd millennium BC (Englund, 1995b; Gomi 1980). Other written accounts from Ur record the details of daily sacrifices of cheese and butter to Inanna and Ningal (Inanna's mythological mother), always in equal amounts ranging from about 29 to 54 litres of cheese and butteroil per day (Figulla, 1953). This strong linkage between cheese and religious expression is repeatedly observed in the Hittite, Greek and Roman civilizations that followed Sumer, the consequence of powerful currents of cultural influence that flowed northwards and westwards out of Mesopotamia from the Bronze Age forward (Kindstedt, 2012; McCormick, 2012).

Mesopotamia, however, was evidently not the only region where cheese was used as an element of religious expression during the 3rd millennium BC. Craig et al. (2015) uncovered striking evidence of the use of processed dairy products, most likely probably cheese, in religious practices in the vicinity of the Stonehenge megalithic complex in England, dating to around 2500 BC. Their findings, which were based on the identification of milk fat residues embedded in pottery sherds recovered at the site, raise intriguing questions as to whether these religious practices at Stonehenge originated independently of similar concurrent practices in Southern Mesopotamia (approximately 5000 km to the southeast of England), or whether they derived from a common pre-existing religious system that Neolithic migrants from the Levant and Anatolia brought with them to England and Southern Mesopotamia following the great migrations of the 7th millennium BC. Although direct evidence of the use of cheese in religious observances extending back to the 7th millennium BC is lacking, it is interesting to note that ceramic barrel-shaped vessels, believed to be butter churns, have been recovered from a 7th millennium BC Neolithic site in southwest Anatolia that seems to have been a cultic shrine; the churns may have been used for cultic ceremonies (Morris, 2014). Thus, a link between dairy products and religious practices in the early Neolithic seems possible. Unfortunately, detailed analyses of lipid residues in pottery sherds recovered from Neolithic Near East religious sites, which may help to elucidate this mystery, have yet to be reported. Returning to Southern Mesopotamia, a particularly noteworthy feature of Sumerian cuneiform literature from the standpoint of cheese history are modifiers that appear along with the term for cheese, which

provide the first descriptive information about cheese in antiquity, and which indicate that cheeses were beginning to diversify. Modifiers that have been translated with reasonable certainty include terms for small and large cheese, herb-flavoured cheese, cheese with cereal grains added, milled or grated cheese, rich cheese, fresh cheese, sharp cheese, white cheese, stinking cheese, and dung cheese (Bottéro, 1985; Stol, 1993). None of these terms provide definitive insight into whether rennet-coagulated cheesemaking was practised in Sumer; however, a few terms have been noted among Sumerian cuneiform texts that could possibly be translated as animal rennet and plant rennet (Stol, 1993).

The first definitive evidence for rennet and rennet-coagulated cheesemaking does not appear in the archaeological record until the rise of the Hittite civilization in Anatolia during the late Bronze Age. Anatolia and Southern Mesopotamia maintained extensive trade networks and cultural exchanges during the Bronze Age; thus, the Hittites were profoundly influenced by Sumerian civilization. For example, they adapted the technique of cuneiform writing to the Hittite language and assimilated many Sumerian cultural features such as architectural forms and religious practices, including the use of cheese in various sacrificial rites (Kindstedt, 2012). Cuneiform texts from the mid-2nd millennia BC reveal that the Hittites performed sacrificial rites involving not only cheese but also rennet, suggesting that rennet had attained a revered status (Güterbock, 1968; Hoffner, 1995, 1998). Other Hittite texts clearly indicate that rennet-coagulated cheesemaking was firmly established in Hittite Anatolia by this time (Wainwright, 1959). Hittite modifiers for cheese that have been translated include terms for small cheese, large cheese, crumbled or grated cheese, scoured or finished cheese, and aged soldier cheese (Carter, 1985; Hoffner, 1966). The latter term suggests that the Hittites used cheese as a military ration, a practice that future armies and navies of Western civilization would often repeat, down to the present.

The Hittite Civilization collapsed around 1200 BC during a period of catastrophic upheaval throughout the Eastern Mediterranean that also triggered an abrupt end to the Greek Mycenaean Civilization, whom Homer referred to as the Achaeans. The cultural legacies of the Mycenaean, Hittite and Sumerian civilizations lived on, however, and helped shape the rise of classical Greek civilization a few hundred years later. The Greek world would come to embrace cheese in daily life and elevate its status to new heights in trade and gastronomic appreciation.

Cheese that the Greeks called 'fresh cheese' was a regular feature of the *opson*, or relish that accompanied the *sitos*, or main course of the Greek meal, which consisted of bread and cereal porridge (Neils, 2008; Wycherley, 1956). Fresh cheese mixed with honey also served as the filling for the beloved flaky cheesecake pastries known as *plakous* or *plakounta*. Fresh cheese probably was a simple rennet-coagulated, uncooked, unpressed or lightly pressed, surface-salted or brine-salted, rennet-coagulated type produced from sheep or goats milk, or blends of the two, much like the fresh white cheeses still produced throughout the Aegean and Eastern Mediterranean regions (Kamber, 2008). The term 'fresh cheese' in Greek literature also refers to the district of the Athens marketplace where cheese was bought and sold, and since every Greek polis (city-state) had a marketplace in the city-centre (agora), each also probably had its own fresh cheese district.

Beyond being common elements of the basic daily Greek meal, cheese and cheesecakes were enjoyed by the aristocracy during the symposium, or drinking party, which was the premier form of entertainment among the upper aristocratic classes (Grandjouan, Markson & Rotroff, 1989; Noussia, 2001). Exceptional local cheeses sometimes became items of maritime commerce, and some cheeses that acquired stellar reputations became identified by their place of origin, such as those from the islands of Cythnos and Chios in the Aegean Sea (Berlin, 1997; Casson, 1954; Migeotte, 2009). Many of the imported cheeses in Athens were probably variants of basic fresh cheese that, when stored and ripened in ceramic jars containing brine, were

transformed into the flavourful Feta-type white brined cheeses that became ubiquitous throughout the Aegean and Balkan regions and have remained so to this day (Anifantakis & Moatsou, 2006; Kamber, 2008). Other imported cheeses that were highly esteemed in Athens came from the heavily Greek colonised island of Sicily, where hard, dry cheeses were crafted that were long-lasting yet flavourful enough to serve as condiments in cooking when grated. Sicilian grating cheeses probably consisted of small rennet-coagulated, uncooked, unpressed or lightly pressed, surface-salted sheep and goats milk cheeses similar to those produced in Sardinia and the Southern Italian peninsula today (Kindstedt, 2012). The use of such cheeses in cooking became so popular throughout the Greeks world that Archestratos, a renowned fourth-century BC chef and cookbook writer from Sicily, complained about the overuse of cheese sauces in cooked dishes of the time (Rapp, 1955). Thus, besides serving as a staple of peasant subsistence, cheese in the Greek world became a gourmet luxury food and a flavourful ingredient that added coveted gastronomic variety to an increasingly sophisticated food culture.

The Romans greatly admired Greek culture, and the Greek love of hard, dry pecorino grating cheeses captivated the Romans from the beginning. Indeed, the process began with Etruscans, forerunners of the Romans, whose aristocratic warriors left behind cheese graters, an essential feature of a Homeric feasting ritual that the Etruscans assimilated from the Greeks, in their seventh-century BC tombs (Ridgway, 1997; Sherratt, 2004). By the time of the Roman Empire, the bronze or iron cheese grater had become a standard utensil in the Roman kitchen. The Romans officially recognised two classes of cheese for tax purposes: *caseus mollis*, or soft cheese, and *caseus aridus*, or dry cheese. According to the first-century AD Roman agricultural writer Columella, both cheeses were made from sheep and/or goats milk by a common rennet-coagulated, uncooked, lightly pressed, surfaced-salted make procedure, but to produce the dry version, the salting and pressing steps were repeated, and the pressing pressure was increased (Forster & Heffner, 1954).

Conspicuously absent from Columella's instructional manual on cheesemaking, however, is any mention of one of the most ancient and beloved of cheeses of the Central Italian peninsula, the acid-heat-coagulated (Ricotta) types. The making of whole milk Ricotta seems to have dominated cheese production on the Italian peninsula during the 2nd millennium BC, as inferred from the abundant occurrence of ceramic devices referred to as 'milk boilers' in the archaeological record. Milk boilers, which were produced according to two different designs, were used throughout much of the Italian peninsula during the 2nd millennium BC to prevent heated milk from frothing and boiling over (Potter, 1979; Trump, 1965). Similar devices are still used today by shepherds in the Italian Apennines for the making of traditional Ricotta cheese (Barker, 1981; Barker et al., 1991). Milk boilers disappeared from the Italian archaeological record during the first millennium BC, however, which coincided with the rise of hard pecorino grating cheeses, suggesting that a shift from the making of whole milk Ricotta to whey Ricotta (which is less prone to frothing and boiling over, obviating the need for milk boilers) may have taken place in conjunction with the rise in hard pecorino grating cheese production (Kindstedt, 2012).

The Roman love affair with hard pecorino grating cheeses had not only culinary implications but also military implications as well. The vastness of the Roman Empire, with some 16,000 km of frontier to protect against the 'barbarians' beyond, presented daunting logistical challenges for Roman military planners that had to feed, clothe and otherwise provision a permanent force of nearly half a million soldiers to guard the Empire. To address these needs, Roman forts were endowed with agricultural lands that were used to produce wheat and to raise sheep and pigs for the provisioning of the legions (Bezaczkzy, 1996; Davies, 1971). Cheese was a basic ration of the Roman military, and the frequent occurrence of perforated heavy-duty ceramic press moulds in the archaeological material records from Roman forts throughout Europe

indicate that the making of hard pecorino grating cheese often took place on site, perhaps by the soldiers themselves during times of peace (Davies, 1971; Niblett, Manning & Saunders, 2006). The widespread introduction of Roman cheesemaking technology to Europe north of the Alps left its mark on the future of European cheesemaking, particularly that of the conquering Anglo-Saxons in England, as discussed later.

The Romans were not the first to introduce cheesemaking to Europe north of the Alps, however. On the contrary, they frequently encountered vibrant cheesemaking activities among the Celtic peoples that they conquered, and many cheeses from the provinces to the north came to be imported to Rome, where they attained stellar reputations. Particularly noteworthy were the alpine cheeses that were made all along the arc of the Alps, and the cheeses from the Massif Central of France (Kindstedt, 2012). Thus, the Neolithic migration of dairy farmers from Southwest Asia to Central Europe that occurred thousands of years earlier ultimately gave rise to a very sophisticated and widely dispersed cheesemaking culture in Central Europe by the time of the Roman invasions.

1.4 Cheese in the Middle Ages and Renaissance

Virtually all aspects of medieval life in Europe were profoundly shaped by the two ubiquitous institutions that collectively formed the scaffolding for much of the economic, social, intellectual and spiritual infrastructure of medieval society: the manor and the Benedictine monastery. Cheesemaking in the Middle Ages was no exception. The manor and the monastery were fertile centres of cheesemaking activity, and the great proliferation of new varieties of cheese that came of age during this period is a testimony to the powerful influence that these institutions exercised over cheesemakers.

Because the continent of Europe encompasses extremely diverse physical environments (e.g. with respect to climate, topography, indigenous flora), manorial and monastic cheesemakers were confronted with a wide range of microenvironments, each with its own set of opportunities and constraints, depending on where they were situated. Furthermore, the social and economic structures of manorial and monastic communities differed at different times and in different regions across Europe, which imposed additional formative conditions and constraints on cheesemaking. All of this created incentives for European cheesemakers to develop novel practices and equipment to accommodate their diverse needs. On the other hand, in other regions, cheesemaking technology changed little from the basic methods used throughout the Mediterranean in antiquity. However, the radically different environmental, social and economic conditions of medieval Europe north of the Alps produced very different outcomes even though the same basic Mediterranean technology continued to be employed.

For example, manorial peasant families who made up the labour force of the large manors of Northwest Europe were typically allowed to raise a cow or two on common pastures, which furnished small but vital quantities of milk for the family needs. Peasant wives there employed a basic rennet-coagulated, uncooked, unpressed, surface-salted make procedure, using cow's milk, that was similar to that used by Greek shepherds to produce the ubiquitous 'fresh cheese', and that was used by Italian shepherds to produce the Roman *caseus mollis*, or soft cheese, which Columella described as 'cheese which is to be eaten within a few days while still fresh...' (Forster & Heffner, 1954). Manorial peasant wives probably often had to combine multiple milkings when making cheese because of the small quantity of milk available, which favoured high populations of lactic acid bacteria (and other bacterial species) in the cheesemilk. The end result was the production of small, high-moisture, low-pH (ca. pH 4.6) cheeses. In the warm climate of the Mediterranean, such cheeses spoil or dry out and become inedible within a few days. In the damp temperate climate of Northwest Europe, however, the environmental

conditions present in damp cool cellars, or sometimes natural caves, that were used to store the cheeses selected for the prolific growth of surface yeasts and moulds, especially the greyish-white mould *Penicillium camemberti*, which produced desirable transformations during storage instead of spoilage/rotting. The origins of the plethora of surface mould-ripened (e.g. bloomy rind) cheeses so beloved in Northwest Europe almost certainly had their earliest roots in the peasant manorial communities and, later, the peasant villages that emerged out of the breakup of the manors (Kindstedt, 2012).

In the same regions of Northwest Europe, Benedictine monastic cheesemakers practised the same basic rennet-coagulated, uncooked, unpressed, surface-salted make procedure as their manorial peasant neighbours but arrived at a very different outcome: the evolution of the bacterial smear-ripened cheeses, sometimes referred to as monastery cheeses. Monastic cheesemakers had the advantage of abundant fresh cow's milk from the monastic herd; there was no need to combine multiple milkings for cheesemaking. Warm fresh milk, used immediately after harvesting, ensured low populations of lactic acid bacteria, which resulted in high-moisture cheeses that were higher in initial pH than those of their manorial peasant neighbours. The high moisture, relatively high pH chemistry of the curd, combined with salting techniques that included surface smearing with brine and ready access to cool damp monastic cellars for storage provided the right combination of conditions for prolific yeast and coryneform bacterial growth on the cheese surface that pre-empted spoilage/rotting by transforming the cheese in new desirable ways during storage (Kindstedt, 2014).

In the Southern Massif Central of France, this same basic rennet-coagulated, uncooked, unpressed, surface-salted make procedure gave birth to another radically different cheese, Roquefort, which has become emblematic of the family of blue-veined cheeses. Although cheesemaking in the Roquefort region predated the Romans, it seems that important fine-tuning of the make procedure did not take place until around the eleventh century AD, when manorial sheep ranges and cheesemaking operations on the Larzac Plateau of the Southern Massif Central, and the ageing of cheeses in the famous Caves of Cambalou just below the Plateau, came under monastic control (Whittaker & Goody, 2001). The combination of high-moisture, low-pH sheep milk curd, along with intensive surface salting of the cheese (made possible courtesy of the Romans, who developed salt works along the Mediterranean coast of France and a system of roads ascending from the coast to Massif Central to transport the salt), and access to the Caves of Cambalou for ageing in a well-ventilated, near constant temperature (6–10°C) and humidity (95–98% relative humidity) environment, provided the right combination of conditions for prolific growth of *Penicillium roqueforti* mould growth that produced desirable transformations during storage in place of destructive spoilage/rotting (Kindstedt, 2012). In summary, the simple rennet-coagulated, uncooked, unpressed, surface-salted cheesemaking technology that became deeply embedded in the Mediterranean region in antiquity evolved into radically new families of cheese such as soft surface-ripened types (white mould-ripened and bacterial smear-ripened cheeses) and blue-veined types when practised in diverse European microenvironments.

In England, the conquering Anglo-Saxon aristocracies inherited Roman agricultural infrastructure along with the Roman technology for making small rennet-coagulated, uncooked, lightly pressed surface-salted dry pecorino cheeses of the type described by Columella. Evidently, the Anglo-Saxons continued to produce these small, hard pecorino cheeses on their demesnes for some 500 years until the Normans wrested control of England during the eleventh century AD. With the Normans came the blossoming of trade across the English Channel, including trade in cheeses, which coincided with noteworthy increases in the size of English demesne cheeses, as noted in monastic records of manorial holdings at the time. A change in cheese geometry almost certainly also occurred at this time, as the small cylindrical cheeses of the Anglo-Saxon period evolved into larger wheel-shaped cheeses by the end of the Middle

Ages (Kindstedt, 2012). In other words, English cheesemakers began to modify their practices in response to market opportunities/pressures brought on by trade. Indeed, as the Renaissance dawned and lucrative trade routes re-emerged across Europe after centuries of isolation that followed the collapse of the Roman Empire, cheesemakers in various regions responded to the new world of expanding trade networks with innovative new practices.

For example, cheesemakers in the highlands of Gruyère Switzerland began to produce increasingly larger cheeses during the Renaissance as the reputation of Gruyère cheese grew, and demand in lucrative distant markets soared (Birmingham, 2000). The production of large durable cheeses, which were tailored in size to be transported on foot (in head yokes) over steep mountain passes to Lake Geneva and then packed tightly in barrels for passage down the Rhone River to the Mediterranean, presented immense challenges for the alpine cheesemakers. Moisture control was particularly troublesome because large cheeses possess less surface area relative to their volume than do small cheeses, which slows down evaporative moisture loss outwards from the cheese centre to the surface, and diffusion of salt inwards from the surface to the centre, thereby elevating the risk of spoilage in the high-moisture, low-salt interior during ageing. To combat this, alpine cheesemakers went to great technical lengths to maximise whey expulsion during cheesemaking by cutting the curd into tiny rice-sized particles, cooking the curds to exceptionally high temperatures, and pressing the drained curds into thin wheel-shaped cheeses of immense diameters that maximised the surface area to volume ratio in the finished cheeses. By the end of the Middle Ages, new methods of cooking, pressing and salting developed in various regions of Europe had given birth to a new generation of larger cheeses, ranging from the more diminutive Gouda (ca. 7 kg) in Holland to the massive Parmesan (ca. 40 kg) in the Po River Valley of northern Italy and Cantal (ca. 40 kg) in the northern Massif Central of south-central France (Kindstedt, 2012).

1.5 Cheese in the Modern Era

The seventeenth century arguably marked a turning point in the history of cheese, which ushered in the modern era. The explosive growth of urban populations in rapidly expanding cities such as London, the establishment of truly global trade networks by major European powers as they competed to colonise east and west, and the onset of the Enlightenment, which gave rise to profound scientific advances that soon stimulated the scientific and industrial revolutions, collectively began to change the market forces that confronted modern cheesemakers, as well as the capacity of cheesemakers to respond to market forces with technical innovations. It is true, of course, that market forces affected cheese practices and inspired technical advances long before the seventeenth century, as in the aforementioned example of Gruyère cheese. However, the growing intensity of market forces, which increasingly emphasised efficiency and cost, began to affect cheesemakers in new ways that ultimately paved the way for the cheese factory and industrial cheesemaking.

The beginnings of the modern era are perhaps best illustrated by the transformation that took place in English cheesemaking during the seventeenth and eighteenth centuries, when London became England's foremost population centre. The sprawling metropolis of London created a mega-market that reshaped much of English agriculture, including English cheesemaking. Access to the cheese and butter markets of London was controlled by the London cheesemongers, a cartel of buyers and distributors, who began to apply intense pressure on their suppliers in East Anglia during the early seventeenth century to produce more butter along with their cheese or risk losing their contracts, butter being more profitable to sell in London than cheese. As the demand for butter grew, cheesemakers were forced to skim more cream from their milk before cheesemaking, resulting in cheese with progressively lower fat

content. East Anglian cheesemakers lacked the technical expertise to develop high-quality reduced-fat cheeses (a challenge that cheesemakers still wrestle with today), and consequently their product quality deteriorated. The situation reached crisis proportions when the cheesemongers then began to source full fat cheese from Cheshire, effectively forcing East Anglia out of the London cheese market and relegating dairy farmers there to the production of butter. Thus, by the early eighteenth century, East Anglia, which had been London's premier cheese supplier for more than a century, essentially stopped producing cheese, and the Cheshire region became London's foremost supplier (Stern, 1973).

Cheesemakers in Cheshire then quickly came under pressure from the cheesemongers to produce ever-larger cheeses, which were more efficient to transport and distribute, and more profitable because they experienced less moisture loss (and therefore less yield loss) during storage than small cheeses due to their lower surface area relative to volume. However, the move to larger cheeses necessitated innovations in cheesemaking practices and equipment to produce cheese with lower moisture and higher salt contents in the centre that would withstand internal rotting during storage. Cheesemakers in Cheshire responded by phasing in a high-pressure pressing step, using newly developed heavy-duty presses and perforated press moulds, along with a new salting technique that replaced surface salting of the pressed cheese with dry salting of milled curd particles before pressing into cheese (Cheke, 1959; Fussell, 1966). Cheshire cheesemakers then had to develop an alternative protective coating and vapour barrier at the cheese surface to replace the dense rind produced by surface salting, which had previously served as a natural packaging that protected the surface from physical harm and prevented surface cracking. This was accomplished, imperfectly, by smearing inexpensive whey butter on the cheese surface (Kindstedt, 2012).

Despite the impressive, rapid-fire technical innovations developed by the cheesemakers of Cheshire, the region lost its pre-eminence in the London market by the mid-nineteenth century, displaced by cheese produced in the West Country to the south. Cheesemakers there combined a mild cooking or scalding step with the salting of milled curd before high-pressure pressing to render a new cheese variety that eventually came to be called Cheddar. Soon after, English Cheddar cheesemakers found themselves in a technological race for survival as lower-cost Cheddar-style cheese from America, and later Canada, New Zealand and Australia, flooded the London market. Ultimately, the English dairy industry was forced to reorient away from cheesemaking in favour of fresh liquid milk production for the burgeoning urban population of London and other major cities (Blundel & Tregear, 2006). By this time, the modern era of cheesemaking had reached a tipping point, with global market forces and technological innovations firmly in control of the fate of much that would come during the twentieth century and beyond.

Cheesemakers in America, who produced mostly English style cheeses during the seventeenth and eighteenth centuries and who closely emulated the technical innovations coming out of England, rendered this tipping point irreversible during the mid-nineteenth century with the introduction of factory cheesemaking. The factory system, supported by rapid advancements in the field of dairy science and a plethora of new mass-produced labour-saving equipment and utensils, enabled cheese to be made on ever-larger scales with ever-greater efficiency and consistency. By the end of the nineteenth century, the cheese factory had virtually eliminated traditional on-farm artisanal cheesemaking in America while generating astonishing increases in annual US cheese production (Kindstedt, 2012). Highly efficient, large-scale, technology-intense industrial cheesemaking eventually became the norm for many of the world's cheesemaking regions during the twentieth century, including the United States, western Canada, Australia, New Zealand, Ireland, Holland, Denmark and many other regions to varying degrees.

However, a sharp dichotomy also characterised the modern era of cheese from the beginning because many other cheesemaking regions tenaciously continued to produce hand-crafted

artisanal cheeses on small scales using traditional practices, even as the factory gained ground elsewhere. Traditional artisanal cheesemaking often persisted in geographically isolated regions of Europe and Southwest Asia, and in regions with marginal lands that are poorly suited for agricultural purposes other than sheep and goat herding. Traditional cheesemaking also persisted in more accessible and fertile regions of Europe and beyond, where strong cultural conservatism prevailed and where traditional cheesemaking formed an integral component of the working landscape, such as in many parts of France and in Quebec, Canada.

As the twentieth century progressed, however, increasingly intense competition from lower-cost industrial cheeses, spurred on by global trade, posed grave challenges to the economic survival of these bastions of traditional cheesemaking. Artisanal cheeses by nature are very labour intensive to produce and not amenable to the cost savings that accompany economies of scale, rendering them much more expensive to the consumer than industrial cheeses (Bouma, Durham & Meunier-Goddik, 2014; Nicholson & Stephenson, 2007). Traditional cheeses also often utilise practices and equipment that conflict with the rapidly evolving global standards for hygiene and safety, posing further threats to their continued existence (Licitra, 2010). Thus, in the twentieth-first century, the long-term sustainability of traditional artisanal cheeses seems unlikely unless (1) modern safety regulations and traditional cheesemaking practices can be reconciled in ways that preserve the essence of traditional cheeses while satisfying the appropriate level of public health protection, and (2) the public can be convinced to pay much more for traditional cheeses than industrial cheeses, either in the form of higher prices or through public subsidies of some sort.

One encouraging model for how this might be accomplished emerged during the past few decades in the United States and several other developed countries, where a new public appreciation for traditional artisanal cheeses has arisen (Kindstedt, 2005). Traditional cheeses collectively offer a rich diversity of intrinsic physical and sensory characteristics that, arguably, are unmatched in industrial cheeses (Licitra, 2010). This diversity, contrasted with the perception of a growing segment of the public that industrial cheeses are bland and uninspiring, has helped to stimulate consumer interest in, and willingness to pay for, a new generation of artisanal cheeses, produced in traditional ways on small scales, but which often employ advanced practices and technologies that satisfy public health regulations while preserving traditional cheese character. Furthermore, the public's willingness to pay more for artisanal cheeses is also being encouraged by extrinsic attributes related to values that consumers hold, such as sustainability and stewardship of the environment, animal welfare, closeness to nature, and so on, which they associate with traditional cheesemaking (Wang et al., 2015). Consequently, small-scale artisanal cheesemakers have at their disposal powerful intrinsic and extrinsic drivers of the public's willingness to pay, which has enabled the new generation of traditional cheesemakers to experience remarkable growth during the last two decades. Effective management of these drivers of consumer willingness to pay, coupled with targeted adoption of technologies to satisfy public health regulations, will undoubtedly be among the keys to future sustainability of traditional cheesemaking worldwide.

References

- Anifantakis, E. M. & Moatsou, G. (2006). Feta and other Balkan Cheeses. In Tamime, A. (ed.), *Brined Cheeses*. Blackwell Publishing Ltd, Oxford.
- Barker, G. (1981). *Landscape and Society. Prehistoric Central Italy*. Academic Press, London.
- Barker, G., Grant, A., Beavitt, P., Christie, N., Giorgi, J., Hoare, P., Leggio, T. & Migliavacca, M. (1991). *Ancient and modern pastoralism in Central Italy: An interdisciplinary study in the Cicolano mountains*. Papers of the British School at Rome, 59, 15–88.

- Berlin, A. M. (1997). Archaeological sources for the history of Palestine: Between large forces: Palestine in the Hellenistic Period. *The Biblical Archaeologist*, 60 (1), 2–51.
- Bezeczy, Dr. (1996). Amphora inscriptions – legionary supply? *Britannia*, 27, 329–336.
- Birmingham, D. (2000). *Switzerland: A Village History*. St. Martin's Press, New York.
- Blundel, R. & Tregear, A. (2006). From artisans to “factories”: The interpretation of craft and industry in English cheese-making, 1650–1950. *Enterprise & Society*, 7 (4), 705–739.
- Bogucki, P. (1984). Ceramic sieves of the linear pottery culture and their economic implications. *Oxford Journal of Archaeology*, 3 (1), 15–30.
- Bollongino, R., Burger, J., Powell, A., Mashkour, M., Vigne, J.-D. & Thomas, M. G. (2012). Modern taurine cattle descended from small number of Near-Eastern founders. *Molecular Biology and Evolution*, 29 (9), 2101–2104.
- Bonfiglio, S., Ginja, C., De Gaetano, A., Achilli, A., Olivieri, A., Colli, L., Tesfaye, K., Hassan Agha, S., Gama, L. T., Cattonaro, F., Penedo, M. C. T., Ajmone-Marsan, P., Torroni, A. & Ferretti, L. (2012). Origin and spread of *Bos Taurus*. New clues from mitochondrial genomes belonging to haplogroup T1. *PLoS One*, 7 (6), e38601.
- Bouma, A., Durham, C. A., and Meunier-Goddik, L. (2014). Start-up and operating costs for artisan cheese companies. *Journal of Dairy Science*, 97, 3964–3972.
- Bottéro, J. (1985). The cuisine of ancient Mesopotamia. *Biblical Archaeologist*, 48 (1), 36–47.
- Burger, J., Kirchner, M., Bramanti, B., Haak, W. & Thomas, M. G. (2007). Absence of the lactase-persistence-associated allele in early Neolithic Europeans. *PNAS*, 104 (10), 3736–3741.
- Çakırlar, C. (2012). Neolithic dairy technology at the European-Anatolian frontier: Implications of archaeozoological evidence from Ulucak Höyük, İzmir, Turkey, ca. 7000–5700 cal. BC. *Anthropozoologica*, 47 (2), 78–98.
- Carter, C. (1985). Hittite Hashas. *Journal of Near Eastern Studies*, 44 (2), 139–141.
- Casson, L. (1954). The grain trade of the Hellenistic world. *Transactions and Proceedings of the American Philological Association*, 85, 168–187.
- Cheke, V. (1959). *The Story of Cheese-Making in Britain*. Routledge & Kegan Paul, London.
- Clare, L., Rohling, E. J., Weninger, B. & Hilpert, J. (2008). Warfare in Late Neolithic/Early Chalcolithic Pisidia, Southwest Turkey. Climate induced social unrest in the late 7th millennium cal bc. *Documenta Praehistorica*, 35, 65–92.
- Conolly, J., Manning, K., Colledge, S., Dobney, K. & Shennan, S. (2012). Species distribution modelling of ancient cattle from early Neolithic sites in SW Asia and Europe. *The Holocene*, 22 (9), 997–1010.
- Copley, M. S., Berstan, R., Dudd, S. N., Docherty, G., Mukherjee, A. J., Straker, V., Payne, S. & Evershed, R. P. (2003). Direct chemical evidence for widespread dairying in prehistoric Britain. *PNAS*, 100 (4), 1524–1529.
- Copley, M. S., Berstan, R., Dudd, S. N., Aillaud, S., Mukherjee, A. J., Straker, V., Payne, S. & Evershed, R. P. (2005a). Processing of milk products in pottery vessels through British prehistory. *Antiquity*, 79, 895–908.
- Copley, M. S., Berstan, R., Mukherjee, A. J., Dudd, S. N., Straker, V., Payne, S. & Evershed, R. P. (2005b). Dairying in antiquity. III. Evidence from absorbed lipid residues dating to the British Neolithic. *Journal of Archaeological Science*, 32, 523–546.
- Craig, O. E., Chapman, J., Heron, C., Willis, L. H., Bartosiewicz, L., Taylor, G., Whittle, A. & Collins, M. (2005). Did the first farmers of central and Eastern Europe produce dairy foods? *Antiquity*, 79, 882–894.
- Craig, O. E., Shillito, L.-M., Albarella, U., Viner-Daniels, S., Chan, B., Cleal, R., Ixer, R., Jay, M., Marshall, P., Simmons, E., Wright, E. & Parker Pearson, M. (2015). Feeding Stonehenge: Cuisine and consumption at the Late Neolithic site of Durrington Walls. *Antiquity*, 89, 1096–1109, doi: 10.15184/aqy.2015.110.

- Craig, O. E., Steele, V. J., Fischer, A., Hartz, S., Andersen, S. H., Donohoe, P., Glykou, A., Saul, H., Jones, D. M., Kock, E. & Heron, C. P. (2011). Ancient lipids reveal continuity in culinary practices across the transition to agriculture in Northern Europe. *PNAS*, 108 (44), 17190–17195.
- Cramp, L. J. E., Evershed, R. P., Lavento, M., Halinen, P., Mannermaa, K., Oinonen, M., Kettunen, J., Perola, M., Onkamo, P. & Heyd, V. (2014). Neolithic dairy farming at the extreme of agriculture in Northern Europe. *Proceedings of the Royal Society B*, 281, 2014.0819.
- Curry, A. (2013). The milk revolution. *Nature*, 500 (7460), 20–22.
- Davies, R. W. (1971). The Roman military diet. *Britannia*, 2, 122–142.
- Dudd, S. & Evershed, R. P. (1998). Direct demonstration of milk as an element of archaeological economies. *Science*, 282 (5393), 1478–1481.
- Dunne, J., Evershed, R. P., Salque, M., Cramp, L., Bruni, S., Ryan, K., Biagetti, S. & di Lernia, S. (2012). First dairying in green Saharan Africa in the fifth millennium BC. *Nature*, 486 (7403), 390–394.
- Edwards, C. J., Bollongino, R., Scheu, A., Chamberlain, A., Tresset, A., Vigne, J.-D., Daird, J. F., Larson, G., Ho, S. Y. W., Heupink, T., Shapiro, B., Freeman, A. R., Thomas, M. G., Arbogast, R.-M., Arndt, B., Bartosiewicz, L., Benecke, N., Budja, M., Chaix, L., Choyke, A. M., Mashkour, M., Özdoğan, M., Schulting, R. J., Stephan, E., Uerpman, H.-P., Vörös, I., Voytek, B., Bradley, D. G. & Burger, J. (2007). Mitochondrial DNA analysis shows a Near Eastern Neolithic origin for domestic cattle and no indication of domestication of European aurochs. *Proceedings of the Royal Society B*, 274, 1377–1385.
- Englund, R. K. (1991). Archaic dairy metrology. *Iraq*, 53, 101–104.
- Englund, R. K. (1995a). Late Uruk period cattle and dairy products: Evidence from proto-cuneiform sources. *Bulletin on Sumerian Agriculture*, 8, 33–50.
- Englund, R. K. (1995b). Regulating dairy productivity in the Ur III period. *Orientalia*, 64, 377–429.
- Evershed, R. P., Payne, S., Sherratt, A. G., Copley, M. S., Coolidge, J., Urem-Kotsu, D., Kotsakis, K., Özdoğan, M., Özdoğan, A. E., Nieuwenhuys, O., Akkermans, P. M. M. G., Bailey, D., Andeescu, R., Campbell, S., Farid, S., Hodder, I., Yalman, N., Özbasaran, M., Bıçakçı, E., Garfinkel, Y., Levy, T. & Burton, M. M. (2008). Earliest date for milk use in the Near East and Southeastern Europe linked to cattle-herding. *Nature*, 455 (7212), 528–531.
- Figulla, H. H. (1953). Accounts concerning allocations of provisions for offerings in the Ningal-Temple at Ur. *Iraq*, 15 (2), 171–192.
- Forster, E. S. & Heffner, E. H. (1954). *Lucius Junius Moderatus Columella on Agriculture*. Harvard University Press, Cambridge.
- Fussell, G. E. (1966). *The English Dairy Farmer*. A.M. Kelley, New York.
- Gomi, T. (1980). On dairy productivity at Ur in the late Ur III period. *Journal of the Economic and Social History of the Orient*, 23 (1/2), 1–42.
- Gouin, P. (1997). Ancient oriental dairy techniques derived from archaeological evidence. *Food and Foodways*, 7 (3), 157–188.
- Grandjean, C., Markson, E. & Rotroff, S. I. (1989). *Hellenistic relief molds from the Athenian agora*. Hesperia Suppl., Vol. 23. American School of Classical Studies at Athens, Princeton.
- Green, M. W. (1980). Animal husbandry at Uruk in the Archaic period. *Journal of Near Eastern Studies*, 39 (1), 1–35.
- Güterbock, H. G. (1968). Oil plants in Hittite Anatolia. *Journal of the American Oriental Society*, 88 (1), 66–71.
- Helmer, D., Gourichon, L. & Vila, E. (2007). The development of the exploitation of products from *Capra* and *Ovis* (meat, milk and fleece) from the PPNB to the early Bronze in the Northern Near East (8700 to 2000 bc cal.). *Anthropozoologica*, 42 (2), 41–69.
- Hiendleder, S., Kaup, B., Wassmuth, R. & Janke, A. (2002). Molecular analysis of wild and domestic sheep questions current nomenclature and provides evidence for domestication from

- two different subspecies. *Proceedings of the Royal Society B: Biological Sciences*, 269 (1494), 893–904.
- International Dairy Federation (2016). Bulletin of the International Dairy Federation 485/2016 – The World Dairy Federation, Brussels, Belgium.
- Isaksson, S. & Hallgren, F. (2012). Lipid residue analyses of Early Neolithic funnel-beaker pottery from Skogsmossen, eastern Central Sweden, and the earliest evidence of dairying in Sweden. *Journal of Archaeological Science*, 39, 3600–3609.
- Hoffner, H. A. (1995). Oil in Hittite texts. *Biblical Archaeologist*, 58 (2), 108–114.
- Hoffner, H. A. (1998). *Hittite Myths*, 2nd edition. Society of Biblical Literature. Scholars Press, Atlanta.
- Hoffner, H. A. (1966). A native cognate to West Semitic *GBN “Cheese”? *Journal of the American Oriental Society*, 86 (1), 27–31.
- Itan, Y., Powell, A., Beaumont, M. A., Burger, J. & Thomas, M. G. (2009). The origins of lactase persistence in Europe. *PLOS Computational Biology*, 5 (8), 1–13, e1000491.
- Kamber, U. (2008). The traditional cheeses of Turkey: Cheeses common to all regions. *Food Reviews International*, 24, 1–38.
- Kindstedt, P. S., with the Vermont Cheese Council. (2005). *American Farmstead Cheese*. Chelsea Green Publ., White River Jct.
- Kindstedt, P. S. (2012). *Cheese and Culture. A History of Cheese and Its Place in Western Civilization*. Chelsea Green Publ., White River Jct.
- Kindstedt, P. S. (2014). The basics of cheesemaking. In Donnelly, C. W. (ed.), *Cheese and Microbes*. ASM Press, Washington, DC.
- Leonardi, M., Gerbault, P., Thomas, M. G. & Burger, J. (2012). *International Dairy Journal*, 22, 88–97.
- Licitra, G. (2010). World wide traditional cheeses: Banned for business? *Dairy Science & Technology*, 90, 357–374.
- Meadows, J. R. S., Cemal, I., Karaca, O., Gootwine, E. & Kijas, J. W. (2007). Five ovine mitochondrial lineages identified from sheep breeds of the Near East. *Genetics*, 175, 1371–1379.
- McCormick, F. (2012). Cows, milk and religion: The use of dairy produce in early societies. *Anthropozoologica*, 47 (2), 99–111.
- Migeotte, L., translated by J. Lloyd. (2009). *The Economy of the Greek cities. From the Archaic Period to the Early Roman Empire*. University of California Press, Berkeley.
- Morris, S. (2014). Dairy Queen. Churns and milk products in the Aegean Bronze-Age. *Opuscula*, 7, 205–222.
- Mottram, H. R., Dudd, S. N., Lawrence, G. J., Stott, A. W. & Evershed, R. P. (1999). New chromatographic, mass spectrometric and stable isotope approaches to the classification of degraded animal fats preserved in archaeological pottery. *Journal of Chromatography A*, 833, 209–221.
- Naderi, S., Rezaei, H.-R., Pompanon, F., Blum, M. G. B., Negrini, R., Naghash, H.-R., Balkiz, Ö., Mashkour, M., Gaggiotti, O. E., Ajmone-Marsan, P., Kence, A., Vigne, J.-D. & Taberlet, P. (2008). The goat domestication process inferred from large-scale mitochondrial DNA analysis of wild and domestic individuals. *PNAS*, 105 (46), 17659–17664.
- Niblett, R., Manning, W. & Saunders, C. (2006). Verulamium: Excavations within the Roman town 1986–88. *Britannia*, 37, 53–188.
- Nicholson, C. & Stephenson, M. W. (2007). *Financial performance value-added dairy operations in New York, Vermont and Wisconsin*. <http://purl.umn.edu/9732>. Accessed Mar. 17, 2014.
- Neils, J. (2008). *The British Museum Concise Introduction to Ancient Greece*. Univ. Michigan Press, Ann Arbor.
- Noussia, M. (2001). Solon’s symposium. *The Classical Quarterly*, New Series, 51 (2), 353–359.