

The Comprehensive
Guide to Brewing

From Raw Material to Packaging

G. Basařová, J. Šavel, P. Basař, T. Lejsek



FACHVERLAG

HANS CARL

The Comprehensive
Guide to Brewing
From Raw Material to Packaging

The Comprehensive
Guide to Brewing
From Raw Material to Packaging

Gabriela Basařová, Jan Šavel, Petr Basař,
Tomáš Lejsek, Pavlína Basařová



Disclaimer

All information in this book was compiled by the authors to the best of their knowledge and reviewed together with the publisher with the utmost care. However, in terms of product liability law, content errors cannot be completely ruled out. Therefore, the authors and the publisher are neither under any obligation nor provide any guarantee and also do not assume liability for any errors in content, for personal injury, property damage or financial loss.

Bibliographic Information in the Deutsche Nationalbibliothek (German National Library)

The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie (German National Bibliographic Records); detailed bibliographic information is available on the Internet at <http://dnb.ddb.de>.

© 2017 Fachverlag Hans Carl GmbH, Nuremberg, Germany

All rights reserved

This document and all of its parts are protected by copyright law. Any use without the explicit consent of the publisher outside the narrow limits of the copyright law is illegal and punishable by law. This applies in particular to the reproduction and translation as well as storage on microfilm or on electronic media of any portion of this book.

Cover: Christina Schönberger

Translation: McGreger Translations and Consulting, Freising, Germany

Cover design: Susanne Dornes, Stuttgart, Germany

Layout and typesetting: Redaktionsbüro Niethammer, Ludwigsburg, Germany

ISBN 978-3-418-00924-7

FOREWORD

The sixteen chapters of this book cover the entire process of the brewing of beer. The beginning focuses on raw materials used in beer production (malt, adjuncts, hop, hop products, water, and auxiliary materials). Subsequent chapters discuss brewers' yeast, microbial contamination, and nomenclature of enzymes important to beer manufacturing. The heart of the book is devoted to fundamental production process stages: hopped wort preparation, primary and secondary fermentation, filtration and membrane technology, pasteurization, and beer packaging. An overview of the properties of different styles of beer is also included. The physico-chemical and sensory stabilities of beer, beer ageing, and assessment of beer quality are discussed. An entire chapter is devoted to the sanitation of process equipment. Yet another chapter focuses on energy, water, and waste management. Finally, the health aspects of beer drinking are briefly touched upon.

The book utilizes valid chemical nomenclature and classification of chemical compounds important to the brewing of beer (particularly polyphenolic compounds). Each chapter begins with a short overview of historical developments. This is followed by the theoretical foundations of processes described in the given chapter, an overview and assessment of current process technology and equipment (including modern trends), a description of process and laboratory controls, and specialized techniques and instrumentation (in some chapters). Each chapter is supplemented with a comprehensive list of literature references drawn mainly from the last ten years.

The scope and implementation of this book make it well suited to bachelor, master, and doctoral students in the field, as well as employees in breweries and associated institutions. Individual parts of chapters can be selected for study depending on the depth of required knowledge.

Gabriela Basařová, Jan Šavel, Petr Basař, Tomáš Lejsek, Pavlína Basařová

FOREWORD

Writing this preamble to *The Comprehensive Guide to Brewing* is a pleasant task, especially since the book has been authored by Professor Dr. Gabriela Basařová and her colleagues, Dr. Jan Šavel, Petr Basař (M.Sc.), Dr. Tomáš Lejsek and Dr. Pavlína Basařová.

There are various aspects of this book which are quite unique: Dr. Gabriela Basařová has been involved in research as a scientist for 50 years in the Czech Republic, one of the world's most renowned brewing nations. For 35 of those years, she held a position as a university professor. Dr. Šavel is likewise very well known in his own right, and Mr. Basař, a generation on, followed in his mother's footsteps to become a member of the industry as well.

This book reveals the great amount of work Czech scientists have accomplished in exploring a diverse range of topics in brewing. The long list of references in a variety of languages at the end of each chapter demonstrates the meticulous nature and the breadth of the authors' research.

The 16 chapters cover the full range of brewing – from raw materials to packaging – but also include topics such as energy usage, water and wastewater. The biochemical foundations of the ingredients used to brew beer (complete with structural formulas) as well as the individual processes employed in its production are examined in detail. Likewise, the authors competently elucidate the pertinent aspects of process engineering, accompanied by the corresponding formulas and equations. The methods and technology utilized in brewing are communicated clearly and in considerable depth, among them common mashing methods, lautering and sparging equipment, wort boiling systems and, above all, the processes of fermentation and maturation. Additionally, a generous chapter is dedicated to microbiological procedures, including methods for monitoring sources of contamination and how to avoid the proliferation of microbes in practice. The attributes of beer discussed in subsequent chapters encompass both colloidal and flavor stability as well as the complex issue of beer and health. Information on the broad spectrum of modern beer styles and analytical methods required for efficiently monitoring brewery operations round out the book. An abundance of images (diagrams, sketches, photos, electron micrographs, etc.) facilitates comprehension of the material presented in each chapter.

This book will, therefore, serve as an essential reference for those working in brewery operations, as a textbook for students and as a guide for future research. In this spirit, I hope that this book finds its well-deserved place in the library of anyone with an interest in brewing!

Prof. Dr. Ludwig Narziß

PUBLICATION AUTHORS



Prof. Gabriela Basařová, DrSc, MSc, was born on January 17, 1934 in Pilsen to a family of teachers. She graduated from secondary school in Pilsen and the University of Chemistry and Technology (UCT) in Prague (VŠCHT Praha) where she studied malting and beer brewing at the Department of Fermentation Chemistry and Technology (Katedra kvasné chemie a technologie), known today as the Department of Biotechnology (Ústav Biotechnologie). After graduating in 1957, she joined Plzeňské pivovary, where she headed the quality control and research laboratories. In 1967, she transferred to the Research Institute of Brewing and Malting (Výzkumný ústav pivovarský a sladařský) in Prague. Here she founded the biochemistry department and later became the institute director. Between 1981 and 1998, she was the head of the Department of Fermentation Chemistry and Bioengineering (Katedra kvasné chemie a bioinženýrství) at VŠCHT Praha. She taught the following subjects: Malting, Beer Brewing, Winemaking, Modern Biotechnology and Bioecology. The results of her scientific and professional activities have been published in more than 500 articles and six books. She remains an external professor for VŠCHT Praha through this day. She was the first nominee elected into the Hall of Fame of Czech Beer Brewing (Síň slávy českého pivovarství), established in 2002. At VŠCHT Praha, she was awarded the Prof. K. N. J. Balling and Prof. E. Votočka medals. In 2012, the Czech president, Mr. Václav Klaus, conferred the Award of Merit upon Prof. Basařová for her outstanding achievements in science and teaching.



Associate Prof. Jan Šavel, PhD, MSc, was born on July 6, 1944 in České Budějovice. He graduated from secondary school in České Budějovice and University of Chemistry and Technology (UCT) in Prague (VŠCHT Praha), where he studied malting and beer brewing at the Department of Fermentation Chemistry and Technology (Katedra kvasné chemie a technologie). After finishing his studies in 1967, he joined Jihočeské pivovary n. p., where he worked as a microbiologist and headed the quality control department and laboratory. In 1996, he habilitated at VŠCHT Praha in the field of malting and beer brewing. He was an external lecturer at VŠCHT Praha and at the Faculty of Agriculture at the University of South Bohemia (Zemědělská fakulta Jihočeské univerzity) in České Budějovice. He was head of the Research and Development Center (Výzkumné a vývojové pracoviště) at Budějovický Budvar n. p., where he is currently employed. In 2004, he was inducted into the Hall of Fame of Czech Beer Brewing (Síň slávy českého pivovarství). He is the author of the book "Mikrobiologická kontrola v pivovarech" (Microbiological Control in Breweries) (Prague: SNTL, 1980).



Petr Basař, MSc, MBA, was born on September 23, 1964 in Pilsen. He completed secondary school in Prague and went on to study at the University of Chemistry and Technology (UCT) in Prague (VŠCHT Praha). He studied special fermentation production at the Department of Fermentation Chemistry and Bioengineering (Katedra kvasné chemie a bioinženýrství). In 2005-2006, he completed an MBA program at the Prague International Business School (PIBS), part of the University of Economics. After graduating from VŠCHT in 1988, he joined Prague Breweries (Pražské Pivovary). There he went through technical training in all production sectors, and from 1990 to 1991 he worked as assistant to the CEO. Since 1991, he has been at the company Diversey, since they first became established in Czechoslovakia. He has held numerous managerial positions in local and regional offices. At the present time, he is working as the Head of Sector Specialists Beverage & Dairy. He is an external lecturer at the Department of Biotechnology (Ústav Biotechnologie), where he teaches hygiene and sanitation.



Tomáš Lejsek, PhD, MSc, was born on June 24, 1937 in Písek. After graduating from Industrial School in Canning (Průmyslová škola konzervářská) in Bzenec, he went on to study at the Czech Technical University in Prague (ČVUT Praha), Faculty of Mechanical Engineering (Fakulta strojní), where he specialized in machinery for the chemical and food industries. For many years, he worked in research and development at the Research Institute of Brewing and Malting (Výzkumný ústav pivovarský a sladařský - VÚPS) in Prague and headed the Department of Technical Development at the Central Office of the Trust Breweries and Malt Plants Prague (GŘ Pivovary a sladovny Praha). In 1991, he was appointed director of VÚPS Praha, o. z., and in 1995 he became CEO of the brewery Pivovar Velké Popovice, a. s. Since 2001, he has been an executive of the brewery Žatecký pivovar in Žatec. He has been teaching Brewing Engineering at VŠCHT Praha for more than ten years.



Pavlína Basařová, PhD, MSc, was born on September 19, 1965 in Prague. She graduated from the University of Chemistry and Technology (UCT) in Prague (VŠCHT Praha) where she studied technical physical chemistry, and was later awarded the degree of PhD in this specialization. Since 1996, she has been working for the Department of Chemical Engineering at UCT Prague where she teaches Unit Operations for the chemical and food industries. In addition, she specializes in thermodynamics and multiphase systems. Pavlína has authored or made contributions to more than 70 technical publications.

CONTENTS

1.	RAW MATERIALS FOR BEER PRODUCTION (G. Basařová)	1
1.1	BREWER'S MALT	1
1.1.1	Historical development	1
1.1.2	Specific types of malt	2
1.1.2.1	Pilsner malt	4
1.1.2.2	Munich malt	5
1.1.2.4	Specialty malt	5
1.1.3	The effect of storage on the quality of malt	8
1.1.4	The attributes of malt affecting quality	9
1.1.5	The mechanical and physical attributes of malt	9
1.1.5.1	Hectoliter (volumetric) weight and thousand kernel weight	9
1.1.5.2	Floating test	10
1.1.5.3	Mealiness and glassiness	10
1.1.5.4	Determining the friability of malt	10
1.1.5.5	Viscosity and filterability of the Congress wort	12
1.1.5.6	Acidity or pH	12
1.1.6	The chemical composition of malt	12
1.1.6.1	Moisture content	12
1.1.6.2	Extract	13
1.1.6.3	Starch	13
1.1.6.4	Nitrogen compounds in malt	17
1.1.6.5	Non-starch polysaccharides	19
1.1.6.6	Lipids	23
1.1.6.7	Polyphenolic compounds	23
1.1.6.8	Other compounds in malt	25
1.2	ADJUNCTS	28
1.2.1	Starch adjuncts	29
1.2.1.1	Unmalted cereals	29
1.2.1.2	Starch hydrolysates, syrups, and concentrates	32
1.2.1.3	Special adjuncts	32
1.2.1.4	New methods in the production of adjuncts	32
1.2.2	Sugar adjuncts	33
1.2.3	Malt extracts	34
1.3	HOPS	35
1.3.1	History	36
1.3.2	The classification of hops in systematic botany	37
1.3.3	Hop morphology	38
1.3.3.1	Main parts of the hop plant	38
1.3.4	Hop cultivation and agriculture	39
1.3.5	Hop diseases and disorders	40
1.3.6	Drying hops, their post-harvest treatment, and packaging	41
1.3.6.1	Drying hops	41
1.3.6.2	Sulfur treatment of hops	42
1.3.6.3	Packaging and storage of hops	42
1.3.7	Hop varieties	42
1.3.7.1	Grouping hop varieties into marketing categories	43
1.3.8	Chemical composition of hops	45

1.3.8.1	Moisture content _____	47
1.3.8.2	Hop resins _____	47
1.3.8.3	α -Acids, their analogs, and products of isomerization, hydrolysis, and oxidation _____	47
1.3.8.4	β -Acids, their analogs, and products of isomerization, oxidation, and hydrolysis _____	53
1.3.8.5	Hard resins _____	54
1.3.8.6	Hop essential oils _____	54
1.3.8.7	Polyphenolic compounds in hops _____	62
1.3.8.8	Carbohydrates in hops _____	68
1.3.8.9	Nitrogenous compounds in hops _____	68
1.3.8.10	Hop lipids _____	68
1.3.8.11	Minerals in hops _____	68
1.3.8.12	Prenylated flavonoids in hops _____	69
1.3.8.13	Other hop compounds _____	70
1.3.9	Medicinal and antiseptic properties of hops _____	70
1.3.10	Undesirable compounds in hops _____	72
1.3.11	Changes in the composition of hops due to aging _____	73
1.4	HOP PRODUCTS _____	73
1.4.1	Hop products prepared by a mechanical treatment of hops _____	74
1.4.1.1	Hop powders and pellets _____	74
1.4.2	Hop products prepared by extraction _____	76
1.4.2.1	Ethanol hop extract _____	76
1.4.2.2	Carbon dioxide hop extract _____	76
1.4.3	Products from hop essential oils _____	78
1.4.4	Hop products prepared by chemical means _____	78
1.4.4.1	Isomerized hop extracts _____	78
1.4.4.2	Reduced and hydrogenated iso- α -acids _____	79
1.4.4.3	Isomerized hop pellets _____	80
1.4.4.4	Extracts containing hulupones _____	80
1.4.5	Synthetic bitter compounds _____	80
1.4.6	Overview of hop products used in beer production _____	80
1.5	WATER _____	82
1.5.1	History _____	82
1.5.2	Sources of natural water for the brewing industry _____	82
1.5.3	Hardness _____	83
1.5.4	Total, neutralized, and residual alkalinity _____	84
1.5.5	Types of brewing liquor _____	85
1.5.6	The effect of salts on the pH of brewing liquor _____	86
1.5.6.1	Reactions of ions in brewing liquor that decrease acidity _____	86
1.5.6.2	Reactions of ions in the brewing liquor that increase acidity _____	87
1.5.7	A summary of the importance of ions and other constituents _____	88
1.5.8	Gases dissolved in water _____	90
1.5.9	Organic compounds present in water sources _____	90
1.5.10	Water treatment procedures _____	90
1.5.10.1	Water treatments used in breweries _____	91
1.5.10.2	Water sterilization _____	95
1.5.10.3	Water recycling _____	97
1.6	AUXILIARY MATERIALS _____	97
1.6.1	Enzyme preparations _____	97
1.6.2.1	Beer caramel _____	98

1.6.3	Products affecting beer foam	98
1.6.3.1	Products designed to increase head retention	98
1.6.3.2	Products for reducing foam formation in the brewing process	98
	Literature references	99
2.	THE PREPARATION OF HOPPED WORT (G. Basařová)	108
2.1	HISTORY	108
2.2	MALT MILLING	114
2.2.1	The theory of milling	114
2.2.2	The malt milling process	118
2.2.3	Malt milling equipment	118
2.2.3.1	Dry milling of malt	118
2.2.3.2	Malt milling with conditioning	121
2.2.3.3	Wet milling of malt	122
2.2.3.4	Preparation of very fine grist	122
2.2.3.5	Malt milling under low-oxygen conditions	123
2.2.4	Control of the grinding process	125
2.2.4.1	Process control	125
2.2.4.2	Laboratory controls	125
2.3	MASHING IN AND ACHIEVING TARGET MASH TEMPERATURE	127
2.3.1	Theory	127
2.3.2	Practice	128
2.3.2.1	Techniques for mashing in and raising mash temperature	128
2.3.2.2	The duration of the mashing in process	129
2.3.2.3	The size of the grain bill	129
2.3.2.4	Strike water calculation	130
2.3.3	Monitoring the process of mashing in	130
2.3.4	High gravity brewing	131
2.3.5	Grist hydration equipment	131
2.4	MASHING	133
2.4.1	Theory	133
2.4.1.1	The degradation of starch by amylolytic enzymes ²	133
2.4.1.2	Degradation of nitrogenous compounds by proteolytic enzymes	136
2.4.1.3	Enzymatic cleavage of non-starch polysaccharides	137
2.4.1.4	Changes in lipids during mashing	141
2.4.1.5	Changes in polyphenols during mashing	143
2.4.1.6	Changes in acidity (pH) during mashing	143
2.4.1.7	Oxidation reactions during mashing	144
2.4.1.8	Enzymes catalyzing oxidation-reduction reactions in the malt during mashing ³	144
2.4.1.9	Non-enzymatic oxidation during mashing	145
2.4.1.10	Changes in inorganic compounds during mashing	145
2.4.2	Practice	146
2.4.2.1	Important mashing temperatures	146
2.4.2.2	Decoction mashing	147
2.4.2.3	Infusion mashing	149
2.4.2.4	Special mashing procedures	150
2.4.3	Control of the mashing process	150
2.4.3.1	Process control	150
2.4.3.2	Laboratory controls	150

2.4.4	Processing adjuncts _____	151
2.4.5	Biological acidification of mash and sweet wort _____	151
2.4.6	Mashing equipment _____	154
2.5	SWEET WORT SEPARATION AND sparging of the GRAIN bed _____	156
2.5.1	Theory of wort separation _____	156
2.5.1.1	A mathematical model of wort separation _____	156
2.5.1.2	Factors affecting the wort separation process _____	157
2.5.2	Processes and equipment for wort separation and sparging of the grain bed _____	159
2.5.2.1	Wort separation with a traditional lauter tun _____	159
2.5.2.2	Drawing sweet wort "from the top" _____	167
2.5.2.3	Accelerated wort separation _____	167
2.5.2.4	Intensified wort separation for conditioned and wet-milled grist _____	167
2.5.2.5	Sweet wort separation and sparging in modern lauter tuns _____	167
2.5.2.6	Sweet wort separation and sparging using a conventional mash filter _____	168
2.5.2.7	Sweet wort separation and sparging using modern mash filters _____	171
2.5.2.8	Wort separation using a Strainmaster _____	172
2.5.2.9	Other methods and equipment used for wort separation _____	172
2.5.3	Spent grain _____	173
2.5.4	Monitoring the wort separation and sparging processes _____	174
2.5.4.1	Process control for wort separation _____	174
2.5.4.2	Laboratory monitoring of wort separation _____	174
2.6	BOILING THE SWEET WORT WITH HOPS _____	174
2.6.1	Theory _____	175
2.6.1.1	Heating the wort kettle _____	175
2.6.1.2	Evaporation of excess water and changes to volatile substances during wort boiling _____	176
2.6.1.3	Enzyme inactivation _____	178
2.6.1.4	Sterilization of the wort _____	178
2.6.1.5	Protein coagulation and hot break formation _____	178
2.6.1.6	Hot and cold break precipitation _____	179
2.6.1.7	Isomerization and solubilization of hop bitter compounds _____	180
2.6.1.8	Factors affecting the utilization of hop bitter compounds _____	181
2.6.1.9	Changes in polyphenols during wort boiling _____	182
2.6.1.10	Changes in other extractable compounds derived from hops _____	183
2.6.1.11	Maillard products _____	183
2.6.1.12	Formation of reductones and creation of wort redox potential _____	185
2.6.1.13	Oxidation of compounds extracted from wort during wort boiling _____	186
2.6.1.14	Increase in acidity during wort boiling _____	186
2.6.1.15	Changes in color _____	186
2.6.2	The equipment employed in the wort boiling process _____	186
2.6.2.1	Kettle material and heating methods _____	187
2.6.2.2	Hopping _____	188
2.6.2.3	Determining additions of hops and hop products _____	188
2.6.2.4	Hops and hop product dosing _____	188
2.6.2.5	Boiling hopped wort at atmospheric pressure _____	189
2.6.2.6	High and low pressure wort boiling _____	192
2.6.2.7	Two-phase wort boiling _____	193
2.6.2.8	Hopped wort boiling under an inert gas atmosphere _____	198
2.6.3	Spent hops _____	199
2.6.4	Monitoring the wort boiling process _____	200

2.6.4.1	Process controls	200
2.6.4.2	Laboratory controls	200
2.6.5	Brewhouse yield	200
2.7	WORT CHILLING AND HOT/COLD BREAK REMOVAL	201
2.7.1	Theory	201
2.7.1.1	Chemical and physical binding of oxygen	202
2.7.1.2	Formation and precipitation of hot and cold break in hopped wort	202
2.7.1.3	Changes in wort composition during chilling and hot/cold break precipitation	205
2.7.2	Processes and equipment for hot/cold break removal and wort chilling	206
2.7.2.1	Hot break separation	206
2.7.2.2	Processing of unclarified wort	211
2.7.2.3	Procedures for cold break separation	212
2.7.2.4	Methods for chilling wort to pitching temperature	214
2.7.3	Monitoring the wort chilling process	218
	Literature references	219
3.	BREWER'S YEAST (J. Šavel)	229
3.1	HISTORY	229
3.2	BREWER'S YEAST STRAINS	233
3.2.1	Top- and bottom-fermenting brewer's yeast	233
3.2.1.1	Differences between top- and bottom-fermenting brewer's yeast	234
3.2.2	Yeast strain subtyping - sorting into strain collections	236
3.2.3	Genetic basis for brewer's yeast traits	238
3.3	THE YEAST CELL (morphology, cytology)	239
3.3.1	Shape and size of a yeast cell	239
3.3.2	Specific functional and structural parts of a yeast cell	239
3.3.2.1	Cell composition	239
3.3.3	Chemical composition of brewer's yeast	242
3.4	YEAST REPRODUCTION	243
3.5	CELL CYCLE AND AGING OF YEAST CELLS	245
3.5.1	Phases of the cell cycle	245
3.5.2	Yeast aging factors	246
3.6	YEAST GROWTH KINETICS	246
3.6.1	Batch and continuous fermentation	246
3.6.2	Growth curve	248
3.6.3	Primary fermentation modeling	250
3.7	YEAST NUTRITION AND METABOLISM	251
3.7.1	Anabolism and catabolism	251
3.7.1.1	Nutrient uptake	251
3.7.2	Carbon sources	251
3.7.3	Nitrogen sources	252
3.7.4	Oxygen	253
3.7.5	Inorganic salts	255
3.7.6	Vitamins and enzymes	256
3.8	METABOLITE FORMATION DURING FERMENTATION	256
3.8.1	Harnessing energy from carbohydrate oxidation (glycolysis)	256
3.8.2	The formation of alcohol and carbon dioxide	256
3.8.3	Formation of higher alcohols	258
3.8.4	Formation of esters	260

3.8.5	Formation and reduction of aldehydes and ketones _____	260
3.8.6	Formation of sulfur metabolites _____	262
3.8.7	Formation of organic acids _____	265
3.8.8	Changes in acidity during fermentation _____	265
3.8.9	Yeast proteolytic enzymes _____	265
3.9	FLOCCULATION AND SEDIMENTATION OF BREWER'S YEAST _____	266
3.9.1	Description of flocculation _____	266
3.9.2	Flocculation mechanism _____	266
3.10	METHODS FOR MONITORING AND STUDYING BREWER'S YEAST _____	268
3.10.1	Metabolic tests _____	268
3.10.2	Microscopy in the visible spectrum _____	269
3.10.2.1	Cell staining for viewing in the visible spectrum _____	269
3.10.3	Fluorescence methods _____	269
3.10.3.1	Fluorescent dyes _____	269
3.10.3.2	Fluorescence microscopes _____	269
3.10.3.3	Spectrofluorimeters _____	270
3.10.3.4	Fluorescence scanners (scanning cytometers) _____	270
3.10.3.5	Flow cytometers _____	270
3.11	MEASURING THE CONCENTRATION OF BREWER'S YEAST _____	271
3.11.1	Yeast concentration and activity _____	271
3.11.1.1	Determination of the volume of wet biomass _____	272
3.11.1.2	Dry matter determination _____	272
3.11.1.3	The direct counting of yeast cells _____	272
3.11.1.4	Spectrophotometry in the visible and infrared range _____	272
3.11.1.5	Other methods _____	272
3.12	MEASURING THE ACTIVITY OF BREWER'S YEAST _____	273
3.12.1	Requirements for brewer's yeast activity _____	273
3.12.2	Determining the reproductive ability (viability) and vitality of brewer's yeast _____	275
3.12.3	Measuring the physiological process activity of brewer's yeast _____	275
3.12.4	Combination method for assessing the activity of brewer's yeast _____	276
3.12.5	Yeast technological activity _____	276
3.13	STRESS FACTORS AFFECTING BREWER'S YEAST _____	276
3.13.1	Negative influences on yeast _____	276
3.13.1.1	Temperature stress _____	277
3.13.1.2	Ethanol stress _____	277
3.13.1.3	Osmotic stress _____	277
3.13.1.4	Pressure and carbon dioxide stress _____	278
3.13.1.5	The pH value as a stress factor _____	278
3.13.1.6	Oxidative stress _____	278
3.13.1.7	Ionic stress _____	279
3.13.1.8	Nitrite stress _____	279
3.13.1.9	Effect of break material or trub _____	279
3.13.1.10	Effect of pesticides _____	279
3.13.2	Effect of contaminating microorganisms _____	279
3.14	PREPARATION, STORAGE, AND THE SCALE-UP OF PURE CULTURES _____	279
3.14.1	Yeast propagation _____	279
3.14.1.1	Strain storage _____	280
3.14.1.2	Non-aerated batch propagation _____	280
3.14.1.3	Aerated batch propagation _____	280

3.14.1.4	Fed-batch and continuous yeast propagation	280
3.14.2	Propagation station equipment	281
3.14.2.1	Examples of traditional and continuous propagation stations	284
3.15	IMMOBILIZED YEAST	285
	Literature references	289
4.	MICROBIOLOGY OF BREWING (J. Šavel)	300
4.1	HISTORY	301
4.2	MOLDS	302
4.3	WILD YEASTS	304
4.4	BACTERIA	308
4.4.1	Bacteria in beer brewing	308
4.4.1.1	Wort bacteria	311
4.4.1.2	Acetic acid bacteria	313
4.4.1.3	Lactic acid bacteria	313
4.4.1.4	Micrococci	316
4.4.1.5	Zymomonas mobilis	317
4.4.1.6	Pectinatus cerevisiiphilus	317
4.4.1.7	Megasphaera cerevisiae	317
4.4.1.8	Bacillus and Clostridium	317
4.4.1.9	Selenomonas and Zymophilus	318
4.5	MICROBIOLOGY OF BEER PRODUCTION	318
4.5.1	Microorganism occurrence and harmfulness	318
4.5.2	Free cells and biofilms	319
4.5.3	Growth of microorganisms in beer	321
4.6	DETECTION OF MICROORGANISMS	323
4.6.1	Traditional methods	323
4.6.2	Rapid methods	327
	Literature references	331
5.	PRIMARY AND SECONDARY BEER FERMENTATION (G. Basařová, P. Basař)	337
5.1	HISTORY	337
5.2	PRIMARY FERMENTATION	339
5.2.1	The theory of primary fermentation - Balling's attenuation laws	339
5.2.1.1	Heat generation during the fermentation process	341
5.2.2	Factors affecting the course of primary fermentation	343
5.2.2.1	Wort composition	343
5.2.2.2	Fermentation temperature and pressure	344
5.2.2.3	Yeast strain and dosage	345
5.2.2.4	Oxygen in the pitched wort	345
5.2.3	Changes in wort during primary fermentation	345
5.2.3.1	The decline in extract content of the wort	346
5.2.3.2	Carbohydrate fermentation	346
5.2.3.3	The formation of ethanol and carbon dioxide	346
5.2.3.4	Changes in acidity	346
5.2.3.5	Changes in color	346
5.2.3.6	Changes in redox capacity	347
5.2.3.7	Reduction in the concentration of nitrogenous compounds	347
5.2.3.8	Changes in hop bitter compounds	347

5.2.3.9	Changes in polyphenols _____	347
5.2.3.10	The formation of fermentation by-products _____	348
5.2.4	Primary fermentation: equipment and processes _____	350
5.2.4.1	Bottom primary fermentation as a batch process _____	350
5.2.4.2	Top fermentation _____	356
5.2.4.3	Accelerated primary fermentation methods _____	357
5.2.4.4	Abnormalities during primary fermentation _____	358
5.2.5	Yeast harvesting, processing, treatment, and storage _____	360
5.2.5.1	Harvesting the sedimented yeast _____	361
5.2.5.2	Processing the harvested yeast _____	361
5.2.5.3	Treatment of yeast for future pitching _____	363
5.2.5.4	Yeast storage _____	364
5.2.6	Control of the traditional fermentation process _____	365
5.2.6.1	Process control _____	365
5.2.6.2	Supplemental laboratory analyses _____	366
5.2.6.3	The yield and loss of beer during fermentation _____	366
5.3	SECONDARY FERMENTATION AND MATURATION (LAGERING) OF BEER _____	366
5.3.1	Theory _____	367
5.3.1.1	Lowering the temperature and fermentation of the residual extract _____	367
5.3.1.2	Beer carbonation and carbon dioxide fixation _____	367
5.3.1.4	Maturation of beer flavor and aroma _____	369
5.3.2	The processes and equipment for secondary fermentation and beer maturation as a batch process _____	370
5.3.2.1	The space and equipment required for secondary fermentation and beer maturation _____	370
5.3.2.2	The processes and equipment for secondary fermentation and maturation of bottom-fermented beers _____	373
5.3.2.4	The secondary fermentation of top-fermented beers _____	374
5.3.3	Monitoring secondary fermentation and beer maturation _____	374
5.3.3.1	Process control during secondary fermentation and beer maturation _____	374
5.3.3.2	Routine and expanded laboratory analysis _____	374
5.3.3.3	Losses in the lager cellar _____	374
5.4	PRIMARY AND SECONDARY BEER FERMENTATION ON A LARGE SCALE _____	374
5.4.1	Benefits of fermentation on a large scale _____	374
5.4.2	The design and geometry of large-scale vessels _____	375
5.4.3	Primary and secondary fermentation of beer in cylindroconical vessels (CCVs) _____	377
5.4.3.1	Design, material, and geometry of CCVs _____	377
5.4.3.2	CCV cooling _____	379
5.4.3.3	Automated process control for CCVs _____	382
5.4.3.4	CCV insulation _____	382
5.4.3.5	Sensors for the control and regulation of fermentation processes in CCVs _____	382
5.4.3.6	Connectors and other fittings on CCVs _____	383
5.4.4	Processes in cylindroconical vessels (CCVs) _____	383
5.4.4.1	Factors affecting the fermentation process in CCVs _____	383
5.4.4.2	Methods for pitching yeast into CCVs _____	385
5.4.4.4	Single-phase fermentation processes _____	387
5.4.4.5	Two-phase processes _____	388
5.4.5	The regulation of fermentation processes in CCVs _____	388
5.4.5.1	Process control _____	388
5.4.5.2	Devices for monitoring the fermentation process in CCVs _____	389

5.5	CONTINUOUS PRIMARY AND SECONDARY BEER FERMENTATION	389
5.5.1	Continuous fermentation according to Couatts	389
5.5.2	The ABM continuous fermentation process	390
5.5.3	The cascade system of continuous fermentation	390
5.5.4	Continuous fermentation in an APV tower fermentor	390
5.5.5	Immobilized yeast fermentation	391
5.6	CARBON DIOXIDE RECOVERY	393
	Literature references	395
6.	ADDENDUM: ENZYMES IN BEER BREWING (J. Šavel)	402
6.1	THE PROPERTIES OF ENZYMES AND THEIR REACTIONS	402
6.2	ENZYME NOMENCLATURE	406
6.3	ENZYMES IN BEER BREWING	407
	Literature references	413
7.	FILTRATION, CENTRIFUGATION, AND MEMBRANE TECHNOLOGY (G. Basařová, J. Šavel, T. Lejsek, P. Basařová)	414
7.1	HISTORY	415
7.2	FILTRATION	416
7.2.1	Theory of filtration	416
7.2.1.1	Permeability of and flux through the filter bed	416
7.2.1.2	Factors affecting the filtration process	419
7.2.1.3	Filter bed fouling	421
7.2.1.4	Predicting beer filterability	421
7.2.2	Filter aids	423
7.2.2.1	Pulp	423
7.2.2.2	Diatomaceous earth	423
7.2.2.3	Perlite	428
7.2.2.4	Activated charcoal	428
7.2.2.5	Regenerable filter aids	429
7.2.2.6	Composite filter aids	429
7.2.2.7	Pre-coat filter sheets (pads)	429
7.2.2.8	Sheets for secondary beer filtration	429
7.2.2.9	Modular filtration units	429
7.2.2.10	Filtration membranes	430
7.2.3	Instruments for assessing filterability, permeability, and the flow rate of filter aids	430
7.2.4	Beer filtration: process and equipment	434
7.2.4.1	Filter septa	434
7.2.4.2	Pulp filtration with a bowl filter	435
7.2.4.3	Pre-coat powder filtration using diatomaceous earth	436
7.2.4.4	Secondary beer filtration with plate and frame filters	442
7.2.4.5	Modular filters for sterile filtration	443
7.2.4.6	Ceramic and plastic candle filter modules for secondary and sterile filtration	444
7.2.4.7	Auxiliary filtration equipment	444
7.2.5	Filtered beer cellar (bright beer tank cellar)	445
7.2.6	Monitoring filtration	446
7.3	CENTRIFUGATION	446
7.3.1	Theory	446
7.3.2	Centrifuge types	447

7.3.2.1	Vertical disc centrifuges _____	447
7.3.2.2	Horizontal scroll-type centrifuges _____	449
7.4	MEMBRANE TECHNOLOGY _____	449
7.4.1	Theory _____	451
7.4.2	Membrane material and design _____	452
7.4.2.1	Membrane material _____	454
7.4.2.2	Membrane design _____	454
7.4.3	Industrial application of membrane technology _____	456
	Literature references _____	462
8.	BEER PASTEURIZATION (J. Šavel) _____	466
8.1	HISTORY _____	466
8.2	THEORY _____	467
8.2.1	Thermal resistance of microorganisms _____	467
8.2.2	Measuring the temperature resistance of microorganisms _____	469
8.2.3	Factors affecting the heat-induced kill rate of microorganisms _____	471
8.2.4	Chemical and sensory changes in beer during pasteurization _____	472
8.2.4.1	The effect of oxygen _____	472
8.2.4.2	Changes in color _____	472
8.2.4.3	Formation of carbonyl compounds and a decrease in amino acid content _____	473
8.2.4.4	Other changes in beer composition _____	473
8.2.5	The effect of pasteurization on the organoleptic properties of beer _____	473
8.3	TECHNOLOGICAL OPTIONS AND EQUIPMENT FOR PASTEURIZATION _____	473
8.3.1	Tunnel pasteurization _____	473
8.3.1.2	Tunnel pasteurization equipment _____	476
8.3.2	Flash pasteurization _____	478
8.3.2.1	Flash pasteurization equipment _____	478
8.3.3	Comparison of tunnel and flash pasteurization _____	480
8.4	CONTROL OF PASTEURIZATION _____	481
8.4.1	Microprocessor instruments _____	481
8.4.2	Microbiological analysis _____	483
8.4.3	Chemical proof of pasteurization _____	483
8.4.4	Measuring the reliability of flash pasteurization _____	483
	Literature references _____	486
9.	BEER PACKAGING AND SHIPMENT (T. Lejsek) _____	488
9.1	HISTORY _____	488
9.2	CURRENT TRENDS IN BEER PACKAGING _____	488
9.3	BEER PACKAGING FACILITIES _____	489
9.4	PACKAGING AND PACKAGING MATERIALS _____	492
9.4.1	Draft beer packaging _____	492
9.4.1.1	Casks and kegs for transport _____	492
9.4.1.2	Draft beer bulk tanks _____	495
9.4.1.3	Party kegs _____	496
9.4.2	Small-pack consumer packaging _____	497
9.4.2.1	Glass bottles _____	497
9.4.2.2	Plastic bottles _____	499
9.4.2.3	Bottle caps _____	501
9.4.2.4	Cans _____	502

9.5	HANDLING EQUIPMENT	503
9.5.1	Conveyors	503
9.5.2	Palletization	506
9.5.3	Bottle crating and de-crating	508
9.6	CRATE WASHING	510
9.7	SMALL CONTAINER WASHING	511
9.8	FILLING AND CAPPING	514
9.9	PASTEURIZATION	519
9.9.1	Flash pasteurizers	519
9.9.2	Tunnel pasteurizers	519
9.10	LABELING	520
9.10.1	Labels	521
9.10.2	Labelers	522
9.11	CONTROL EQUIPMENT FOR BOTTLING LINES	524
9.12	WASHING AND FILLING of CASKS AND KEGS	527
9.12.1	Conventional cask washing and filling	527
9.12.2	Keg washing and filling	527
9.13	WAREHOUSES FOR BEER PACKAGING FACILITIES	530
	Literature references	532
10.	BEER STYLES (J. Šavel, G. Basařová)	535
10.1	HISTORY	535
10.2	CZECH AND INTERNATIONAL BEERS	536
10.2.1	Beer styles	536
10.2.2	Czech-style beer	543
10.2.3	Homebrewing and microbreweries	546
10.3	PRODUCTION OF LOW-ALCOHOL AND NON-ALCOHOLIC BEERS	547
10.3.1	Legislation of low-alcohol and non-alcoholic beers	548
10.3.2	Production methods for low-alcohol and non-alcoholic beers	548
10.3.2.1	Procedures using adapted processes	548
10.3.2.2	Procedures using special brewer's yeast or other microorganisms	549
10.3.2.3	Ethanol removal from beer using specialized equipment	550
10.4	BEER WITH A REDUCED CARBOHYDRATE CONTENT - DIETETIC BEER	555
10.4.1	Production conditions	555
10.5	PREPARATION OF WORT AND BEER CONCENTRATES	557
10.6	The CHEMICAL COMPOSITION OF BEER	557
10.6.1	Determining extract and alcohol content	557
10.6.2	Other important analyses	563
10.6.3	Sensory evaluation of beer	575
10.6.4	How to influence the basic characteristics of beer	579
	Literature references	580
11.	THE PHYSICO-CHEMICAL STABILITY OF BEER (G. Basařová)	584
11.1	HISTORY	584
11.2	THEORY	585
11.2.1	Haze particles and colloids in beer	585
11.2.2	Types of colloidal haze	585
11.2.2.1	Chill haze or reversible haze	586
11.2.2.2	Permanent or irreversible haze	586

11.2.2.3	Polysaccharide haze _____	586
11.2.2.4	Metal haze _____	586
11.2.2.5	Silicate and oxalate haze _____	586
11.2.2.6	Other types of haze _____	586
11.2.3	Chemical composition of colloidal haze _____	587
11.2.3.1	Polyphenolic compounds _____	587
11.2.3.2	Polypeptides _____	588
11.2.3.3	Carbohydrates _____	588
11.2.3.4	Metal ions _____	588
11.2.4	Mechanism of colloidal haze formation _____	588
11.2.5	Natural colloidal stability of beer _____	590
11.2.5.1	Effect of brewing liquor _____	590
11.2.5.2	Effect of malt quality _____	591
11.2.5.3	Effect of hops and hop product quality _____	591
11.2.5.4	Effect of beer preparation methods _____	591
11.2.5.5	Yeast strain properties _____	592
11.3	STABILIZING AGENTS, PROCEDURES, AND THEIR TECHNOLOGICAL APPLICATIONS _____	592
11.3.1	Stabilizing precipitants _____	593
11.3.1.1	Tannic acid _____	593
11.3.1.2	Formaldehyde _____	594
11.3.2	Enzyme stabilizers _____	594
11.3.2.1	Requirements for enzyme stabilizers _____	595
11.3.2.2	Agents with proteolytic enzymatic activity _____	595
11.3.2.3	Immobilized proteolytic enzymes _____	595
11.3.2.4	Enzymes from genetically modified yeast strains _____	596
11.3.2.5	Enzymes able to cleave non-starch polysaccharides _____	596
11.3.3	Adsorbents _____	596
11.3.3.1	Requirements for adsorbents _____	596
11.3.3.2	Nitrogenous compound adsorbents _____	596
11.3.3.3	Polyphenolic compound adsorbents _____	599
11.3.4	Combined sorption of haze-forming compounds in beer _____	605
11.3.4.1	Combined use of adsorbents of polyphenols and polypeptides _____	605
11.3.4.2	Combined sorption of beer polyphenols and polypeptides with the aid of ion exchangers _____	606
11.3.5	Barley varieties with reduced anthocyanogen content _____	606
11.3.6	Antioxidant stabilizers _____	607
11.3.6.1	Ascorbic acid _____	607
11.3.6.2	Sulfur dioxide _____	607
11.3.6.3	Enzymatic antioxidants _____	608
11.4	ASSESSING THE EFFECTIVENESS OF STABILIZATION PROCESSES _____	608
11.4.1	Precipitation tests _____	608
11.4.2	Concentration of haze-forming polyphenols in beer _____	609
11.4.3	Determination of the beer redox potential _____	609
11.4.4	Prediction of beer colloidal stability using forcing tests _____	610
11.4.5	Specialized methods for determining the properties of haze-forming compounds _____	610
	Literature references _____	611
12.	BEER STALING (J. Šavel) _____	618
12.1	HISTORY _____	618

12.2	DEFINITION OF BEER STALING	618
12.3	CHEMICAL COMPOSITION OF BEER AND ITS CHANGES	619
12.3.1	Beer color and clarity	619
12.3.2	Beer aroma and flavor	620
12.3.3	Key sensory-active compounds produced during beer staling	620
12.3.3.1	Principles of the study of beer aroma and flavor	620
12.4	MECHANISMS OF SENSORY STALING	622
12.4.1	Main reaction types	622
12.4.2	Strecker degradation of amino acids	623
12.4.3	Maillard reaction	623
12.4.4	Oxidation and photo-oxidation of unsaturated fatty acids and their derivatives	625
12.4.4.1	Oxidation of fatty acids and their esters	625
12.4.4.2	Enzymatic oxidation of fatty acids	626
12.4.4.3	Non-enzymatic oxidation of fatty acids	627
12.4.5	Oxidation of alcohols and acetals	627
12.4.6	Oxidation of bitter compounds and essential oils	629
12.4.7	Oxidation of polyphenols	629
12.4.8	Aldol condensation of carbonyl compounds	629
12.4.9	Secondary auto-oxidation of aldehydes	629
12.5	EFFECT OF PHYSICO-CHEMICAL FACTORS THAT INFLUENCE BEER STALING	630
12.5.1	Storage temperature	630
12.5.2	Light and radiation	630
12.5.3	Anaerobic and aerobic oxidation	631
12.5.4	Oxidation-reduction potential	632
12.5.5	Radical oxidation by reactive oxygen species	633
12.5.5.1	Reactive oxygen species	633
12.5.5.2	Various types of oxygen radicals	634
12.5.5.3	Methods for proving the presence of radicals	635
12.5.6	Acceleration and deceleration of beer staling	635
12.5.7	Compounds with antioxidant properties	635
12.5.7.1	Types of antioxidants	635
12.5.7.2	Polyphenolic compounds	635
12.5.7.3	Sulfur dioxide	636
12.5.7.4	Reductones and melanoidins	637
12.5.8	Acidity (pH)	637
12.5.9	Mechanical factors	637
12.6	COMPREHENSIVE THEORIES OF BEER STALING	637
12.6.1	Formation of volatile aldehydes in the presence of melanoidins	637
12.6.2	Formation of volatile aldehydes in the presence of polyphenols	637
12.7	TECHNIQUES FOR PREDICTING AND IDENTIFYING CHANGES THAT TAKE PLACE DURING BEER STALING	638
12.7.1	Measuring the oxidation-reduction potential	638
12.7.2	Indicators of staling	639
12.7.2.1	Chemical methods	639
12.7.2.2	Physical methods	642
12.8	TECHNOLOGICAL STRATEGIES FOR SLOWING STALING IN PACKAGED BEER	644
12.8.1	Factors affecting staling	644
12.8.2	Raw materials	645
12.8.3	Primary and secondary beer fermentation	647

12.8.4	Filtration, stabilization, pasteurization, packaging, and storage of beer	648
	Literature references	651
13.	QUALITY CONTROL IN BEER PRODUCTION (J. Šavel)	659
13.1	HISTORY	659
13.2	QUALITY AND ITS CONTROL	659
13.2.1	Definition of quality	659
13.2.2	Total quality control and ISO 9000	661
13.2.2	EFQM model	665
13.2.3	Certification	666
13.2.4	International approach to quality	666
13.3	A SYSTEM APPROACH TO CONTROL	667
13.4	QUALITY CONTROL TECHNIQUES AND TOOLS	669
13.4.1	General techniques	669
13.4.2	Critical control point technique (HACCP)	672
13.5	STATISTICAL TOOLS FOR QUALITY CONTROL	674
13.6	METROLOGY AND MEASUREMENT ACCURACY	678
13.6.1	Metrology and measurements	678
13.6.2	Accuracy of analytical methods	680
13.7	COST OF QUALITY CONTROL	683
13.8	MEASURING PROPERTIES IMPORTANT TO CONSUMERS	684
13.8.1	First impression properties	684
13.8.2	Beer color	685
13.8.4	Beer foaming potential	691
13.8.4.1	Factors affecting beer foam	696
13.8.5	Excessive foaming of beer - gushing	697
13.9	MEASURING PROPERTIES IMPORTANT TO CONSUMERS	699
	Literature references	704
14.	HYGIENE AND SANITATION (P. Basař, P. Basařová)	710
14.1	THE HISTORY OF SANITATION IN THE CZECH REPUBLIC	710
14.2	THEORETICAL FOUNDATION OF CLEANING AND DISINFECTION	711
14.3	CHEMISTRY OF CLEANING	712
14.3.1	Material corrosion	712
14.3.2	General classification of soil and techniques for its removal	713
14.4	INDUSTRIAL SANITATION PRODUCTS	714
14.4.1	Modern cleaning products	714
14.4.1.1	Alkaline substances	714
14.4.1.2	Acids	716
14.4.1.3	Sequestrants	716
14.4.1.4	Oxidizers	718
14.4.1.5	Surface-active compounds	719
14.4.1.6	Other additives	721
14.4.2	Disinfectants and their effects	721
14.4.2.1	Chemical disinfectants	722
14.4.2.2	Reduced sensitivity of microorganisms to disinfectants	729
14.5	PRINCIPLES OF SAFE HANDLING OF CHEMICAL AGENTS	729
14.5.1	Storage and distribution of cleaning and disinfecting products within the plant	729
14.5.2	Receiving products supplied in tankers	730

14.5.3	Design of supply tanks for concentrated chemicals _____	731
14.5.4	Product distribution within the plant _____	731
14.6	PRIMARY METHODS FOR THE APPLICATION OF CLEANING AND DISINFECTING PRODUCTS _	732
14.6.1	CIP sanitation _____	732
14.6.1.1	Principles of CIP sanitation _____	732
14.6.1.2	Design of CIP stations _____	733
14.6.1.3	Individual elements of a CIP system _____	738
14.6.1.4	CIP control system _____	743
14.6.1.5	CIP sanitation in individual production areas _____	743
14.6.2	Surface sanitation _____	746
14.6.2.1	Medium pressure foam and gel sanitation _____	747
14.6.2.2	Equipment for surface sanitation _____	749
14.6.3	Track treatment _____	751
14.6.4	Washing of beer containers _____	754
14.6.4.1	Tanker sanitation _____	755
14.6.4.2	Sanitation of non-returnable small containers _____	755
14.6.4.3	Bottle washing _____	756
14.6.4.4	Washing of bottle crates _____	759
14.6.4.5	Sanitation of kegs _____	759
14.6.5	Treatment of tunnel pasteurizers _____	761
14.6.5.1	Corrosion during pasteurization and protection against corrosion _____	761
14.6.5.2	Suppression of excessive biofilm formation _____	762
14.6.5.3	Formation of hard water deposits _____	763
	Literature references _____	764
15.	MANAGING WATER, ENERGY, WASTE AND EMISSIONS IN A BREWERY	
	(G. Basařová, P. Basařová, T. Lejsek _____)	766
15.1	WATER MANAGEMENT _____	767
15.1.1	Water consumption and wastewater generation _____	768
15.1.2	Wastewater pollution _____	770
15.1.2.1	Assessment of wastewater _____	770
15.1.2.2	Wastewater treatment _____	772
15.1.2.3	Mechanical wastewater treatment _____	772
15.1.2.4	Chemical and physico-chemical wastewater treatment _____	772
15.1.2.5	Biological wastewater treatment _____	773
15.1.2.6	The performance of wastewater treatment plants _____	777
15.2	ENERGY USAGE IN BREWING _____	778
15.2.1	Heat energy management _____	779
15.2.1.1	Heat energy consumption in the brewery _____	780
15.2.2	Refrigeration _____	781
15.2.2.1	The energy consumption required for cooling in a brewery _____	782
15.2.3	Electrical equipment _____	782
15.2.3.1	Power consumption _____	782
15.3	OVERVIEW OF WASTE AND EMISSIONS FROM BEER PRODUCTION _____	783
15.3.1	Solid waste from beer production _____	783
15.3.2	Solid and gaseous atmospheric emissions _____	784
15.3.2.1	Toxic emissions _____	784
15.3.2.2	Non-toxic emissions _____	785
	Literature references _____	786

CONTENTS

16.	BEER AND HEALTH (J. Šavel, G. Basařová)	787
16.1	HISTORY	787
16.2	COMPOUNDS WITH HEALTH BENEFITS	788
16.3	COMPOUNDS WITH HARMFUL HEALTH EFFECTS	791
16.4	BEER AND HANGOVERS	793
	Literature references	795
	ABBREVIATIONS	799
	INDEX	805
	TABLE "AVERAGE COMPOSITION OF 12 % LAGER"	846

1. RAW MATERIALS FOR BEER PRODUCTION

Beer is a weak alcoholic beverage that has been produced for centuries from malted grain, water, and hops with the help of microorganisms – principally brewer's yeast but occasionally other yeast and bacteria. Malt is produced by germinating and drying cereal grains under carefully controlled conditions. In many countries, sugars and adjuncts containing starch are employed as alternatives to malt, particularly during periods of economic hardship, such as in wartime and during the period that follows. Adjuncts continue to be used today because they are less expensive to produce than malt.

1.1 BREWER'S MALT

1.1.1 Historical development

In the past, malt was prepared from a variety of cereals. Aside from water, barley (*Hordeum vulgare* L.) is the primary raw material used in beer production, at least in traditional brewing countries. It is also one of the oldest cultivated crops and is thought to have been utilized for malt preparation for the past several thousand years. The first botanical description of barley (*Hordeum sativum*, Poaceae) was made in 1753 by Carl von Linné in his work *Species Plantarum* [Bothmer and Jacobsen 1985]. The botanical classification of barley has not been completely standardized, and according to the *Code of Nomenclature for Cultivated Plants* [Brickell et al., 2009], it is divided into a number of categories, including subspecies (ssp.), convarietas (conv.), varietas (var.) and forma (f.).

In prehistoric times, malt was prepared from both six-rowed and four-rowed barleys (*Hordeum vulgare* L., convar. *vulgare* L., f. *hexastichon* and f. *tetrastichon*). In Europe during the Middle Ages, species of six-rowed and two-rowed (*Hordeum vulgare* L., convar. *distichon* (L.) Alef.) barleys were preferred for malting. Today, two-rowed nodding barley (*Hordeum vulgare* L., convar. *distichon* (L.) Alef., var. *nutans* Alef.) is the most commonly cultivated malting barley across Europe, including in Bohemia, Moravia, and Silesia. It replaced erect-eared barley (*Hordeum vulgare* L., convar. *distichon* (L.) Alef., var. *erectum* (Rode) Alef.) and the less common peacock's barley (*Hordeum vulgare* L., convar. *distichon*, var. *breve* Alef. (*zeocriton* L.) (Figure 1.1). Malting barley varieties grown in what is now the Czech Republic and in other regions of Europe as well as in some countries overseas, can be traced back to the cultivation of this crop in Haná (Moravia) in the 11th century.

Figure 1.1 Six-rowed and two-rowed barley ears (<http://vfu-www.vfu.cz/>)



Wheat (*Triticum aestivum* L.) was the primary grain used for malt production in Europe until the end of the 18th century (including in the region of today's Czech Republic). Top-fermented beers (white beers) were prepared from wheat malts. Beer produced using barley malt was less common, though a few quality beers were brewed with it at that time. They were known as Märzen (March) beers because they were only brewed during the winter months. Even oats (*Avena sativa*, L.) were utilized in the production of specialty beers, but this practice disappeared from our area during the 17th century. Thanks to the Czech brewing revolutionary, František Ondřej Poupě (1753-1805), who coined the phrase "wheat for cakes, oats for horses, barley for beer", malt has been produced in Bohemia almost exclusively from barley since the 18th century, though it can be made using other cereals. The production of wheat malt, and likewise top-fermented beers began to decline, while the production of bottom-fermented beers grew.

Originally, each brewery produced its own malt. Raw barley was the only commodity that was sold and exported. Malt production took a significant step forward in the middle of the 19th century during the Industrial Revolution with the advent of so-called industrial breweries. Separate commercial malthouses were built, and started selling malt to domestic breweries. These malthouses flourished, and not long afterwards, their malt was also exported to breweries around the globe. Malt production thus became a new branch of the brewing industry [Chodounský 1891; Basařová and Hlaváček 1999].

1.1.2 Specific types of malt

Distinctive malt types exhibiting unique characteristics are created by adjusting the processes of steeping and germination during malting. The biosynthesis and activity of malt enzymes is regulated over the course of these processes. Malt enzymes act on specific substances in the kernel and define the degree of degradation of the high molecular weight compounds, as well as the redox potential and acidity of malt. The degree to which the formation of color and aromatic compounds occurs can be regulated by adjusting the malt kilning process. To ensure reproducibility in beer production and the quality of the final product, it is important to use malt lots prepared from only one or at most two genetically similar barley varieties.

Worldwide, pilsner malts and Munich malts are the predominant malt types used for the production of pale and dark beers, respectively. Other types of specialty malt are utilized to highlight certain characteristics of both pale and dark beers and likewise to create a range of distinctive products (Figure 1.2).

Figure 1.2 Kernels of various malts

(Archive of the malthouse Soufflet, a. s., Prostějov, part of The Soufflet Group)



a – Czech pilsner

b – pale caramel

c – caramel pilsen

d – chocolate