Copyrighted Material

Woodhead Publishing in Food Science and Technology

Cereals processing technology

Edited by Gavin Owens

WOODHEAD PUBLISHING LIMITED

Cereals processing technology

Edited by
Gavin Owens

CRC Press
Boca Raton Boston New York Washington, DC

WOODHEAD PUBLISHING LIMITED
Cambridge England

Published by Woodhead Publishing Limited
Abington Hall, Abington
Cambridge CB1 6AH
England
www.woodhead-publishing.com

Published in North and South America by CRC Press LLC
2000 Corporate Blvd, NW
Boca Raton FL 33431
USA

First published 2001, Woodhead Publishing Limited and CRC Press LLC
© 2001, Woodhead Publishing Limited
The authors have asserted their moral rights.

This book contains information obtained from authentic and highly regarded sources. Reprinted material is quoted with permission, and sources are indicated. Reasonable efforts have been made to publish reliable data and information, but the authors and the publishers cannot assume responsibility for the validity of all materials. Neither the authors nor the publishers, nor anyone else associated with this publication, shall be liable for any loss, damage or liability directly or indirectly caused or alleged to be caused by this book.

Neither this book nor any part may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, microfilming and recording, or by any information storage or retrieval system, without permission in writing from the publishers.

The consent of Woodhead Publishing Limited and CRC Press LLC does not extend to copying for general distribution, for promotion, for creating new works, or for resale. Specific permission must be obtained in writing from Woodhead Publishing Limited or CRC Press LLC for such copying.

Trademark notice: Product or corporate names may be trademarks or registered trademarks, and are used only for identification and explanation, without intent to infringe.

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library.

Library of Congress Cataloging-in-Publication Data
A catalog record for this book is available from the Library of Congress.

Woodhead Publishing Limited ISBN 1 85573 561 X
CRC Press ISBN 0-8493-1219-1
CRC Press order number: WP1219

Cover design by The ColourStudio
Project managed by Macfarlane Production Services, Markyate, Hertfordshire (macfarl@aol.com)
Typeset by MHL Typesetting Limited, Coventry, Warwickshire
Printed by TJ International, Padstow, Cornwall, England

Related titles from Woodhead's food science, technology and nutrition list:

Extrusion: Technologies and applications (ISBN: 1 85573 559 8)

Edited by Robin Guy

Extrusion is a major technology for a wide range of food products. The first part of this book introduces this technology, examining extruders and their use in thermal transitions of raw materials into functional forms for the manufacture of particular foodstuffs. The second part of the book looks at the application of extrusion in specific product groups. It will be invaluable reference for improving efficiency and product quality in this area of the food industry.

Baking problems solved (ISBN: 1 85573 564 4)

Stan Cauvain and Linda Young

This book will provide immediate answers to the most frequently encountered problems in the baking industry, offering practical solutions as well as invaluable guidance on improving production and optimising product quality. This will be a welcome addition to any bakery.

Cereal biotechnology (ISBN: 1 85573 498 2)

Edited by Peter Morris and James Bryce

Genetic modification is one of the most important and controversial issues facing the food industry, nowhere more so than in cereal production and processing. This major new work explains the techniques involved and their enormous potential for food producers and consumers. Much has been written on this significant issue but until now there has been no single guide for both academia and industry. This book bridges the gap between these groups, giving each a greater awareness of the other's role.

Details of these books and a complete list of Woodhead's food science, technology and nutrition titles can be obtained by:

- visiting our web site at *www.woodhead-publishing.com*
- contacting Customer Services (e-mail: *sales@woodhead-publishing.com*; fax: +44 (0) 1223 893694; tel.: +44 (0) 1223 891358 ext.30; address: Woodhead Publishing Ltd, Abington Hall, Abington, Cambridge CB1 6AH, England)

If you would like to receive information on forthcoming titles in this area, please send your address details to: Francis Dodds (address, tel. and fax as above; e-mail: *francisd@woodhead-publishing.com*). Please confirm which subject areas you are interested in.

Contents

List of contributors ix

1 Introduction 1
W. G. Owens, Satake Centre for Grain Process Engineering, University of Manchester Institute of Science and Technology

Part I Cereal and flour production 5

2 Cereal production methods 7
E. J. Evans, University of Newcastle
2.1 Introduction 7
2.2 Varietal selection 17
2.3 Crop establishment 18
2.4 Crop nutrition 19
2.5 Weed control 22
2.6 Disease control 23
2.7 Pest control 24
2.8 Harvesting and grain storage 25
2.9 References and further reading 26

3 Wheat, corn and coarse grains milling 27
W. G. Owens, Satake Centre for Grain Process Engineering, University of Manchester Institute of Science and Technology
3.1 Introduction 27
3.2 The evolution of modern flour milling 28
3.3 The flour milling process 30

3.4 Recent developments in flour milling 33
3.5 On-line process measurement 36
3.6 Automation and its role within the milling industry 37
3.7 Milling research 42
3.8 Optimisation of processes 44
3.9 The future 48
3.10 References 49

4 Biotechnology, cereal and cereal products quality 53
R. J. Henry, Southern Cross University, Lismore
4.1 Introduction: productivity, product quality and safety 53
4.2 Herbicide resistance 54
4.3 Disease resistance 55
4.4 Improved nutritional properties 57
4.5 Improved processing qualities 58
4.6 Improved cereal quality control 65
4.7 Examples of transformed wheat and barley 65
4.8 Examples of transformed rice and maize 68
4.9 Future trends 71
4.10 Sources of further information and advice 71
4.11 References 72

Part II Cereal products 77

5 Rice production 79
B. S. Luh, University of California, Davis
5.1 Introduction 79
5.2 Rice grain quality indicators 80
5.3 Rice cultivation, including genetic modification 90
5.4 Processing issues 96
5.5 Rice snack foods 96
5.6 Rice noodles, parboiled and quick-cooking rice 98
5.7 Canned and frozen rice 100
5.8 Extruded rice 101
5.9 Shredded rice 102
5.10 Baby foods 103
5.11 Puffed rice cake 104
5.12 Rice Krispies® 105
5.13 Future trends 105
5.14 Sources of further information 106
5.15 Acknowledgements 106
5.16 References 107

6 Pasta production 109
B. A. Marchylo and J. E. Dexter, Canadian Grain Commission, Winnipeg
6.1 Introduction 109
6.2 History of pasta processing 110
6.3 Pasta-making process 112
6.4 Advances in drying technology 117
6.5 Raw material selection 121
6.6 The future 126
6.7 References and further information 127

7 Asian noodle processing 131
D. W. Hatcher, Canadian Grain Commission, Winnipeg
7.1 Introduction 131
7.2 Noodle diversity 132
7.3 White salted noodles 136
7.4 Alkaline noodles 143
7.5 Instant noodles 148
7.6 Buckwheat noodles 150
7.7 Future of the industry 151
7.8 Summary 153
7.9 General sources of information 154
7.10 References 154

8 Breakfast cereals 158
R. B. Fast, Consultant, Robert B. Fast Associates Inc., Poultney
8.1 Introduction 158
8.2 The industry and its structure 159
8.3 Recent trends and technology developments 163
8.4 The future of the industry 170
8.5 Sources of further information 171
8.6 References 172

9 Malting 173
G. Gibson, Consultant, Cowan & Linn, Glasgow
9.1 Introduction 173
9.2 The UK malting industry 173
9.3 Basic malting process 175
9.4 Barley intake, wet bin storage, and drying 181
9.5 Dry barley storage 183
9.6 Malting plant 189
9.7 Malt storage 200
9.8 Automation 201
9.9 The future of the malting industry 202
9.10 Further reading 203

9.11 References 203

10 Breadmaking 204

S. P. Cauvain, Campden and Chorleywood Food Research Association, Chipping Campden

10.1 Introduction 204
10.2 Bread dough development 205
10.3 Breadmaking processes 206
10.4 The character of bread 209
10.5 Bread flavour 211
10.6 Bread types 212
10.7 What determines bread quality? 213
10.8 Current mixing and processing technologies 217
10.9 Future trends in breadmaking 226
10.10 Conclusions 228
10.11 References 228

Index 231

Contributors

Chapters 1 and 3

Dr Gavin Owens
Woodview
Ballycullane
Athy
Co. Kildare
Ireland

Tel/fax: +353 507 31623
E-mail: gavo@iol.ie

Chapter 2

Dr Eric J. Evans
Department of Agriculture
University of Newcastle
Newcastle upon Tyne NE1 7RU
England

Tel: +44 (0)191 222 6925
Fax: +44 (0)191 2227811
E-mail: E.J.Evans@ncl.ac.uk

Chapter 4

Professor Robert J. Henry
Centre for Plant Conservation Genetics
Southern Cross University
PO Box 157
Lismore
NSW
Australia

Tel: +61 (0)2 6620 3010
Fax: +61 (0)2 6622 2080
E-mail: rhenry@scu.edu.au

Chapter 5

Emeritus Professor B. S. Luh
Department of Food Science and Technology
University of California
Davis
CA 95616-8598
USA

Fax: +1 530 752 4759
E-mail: bsluh@ucdavis.edu

Chapter 6

Dr Jim Dexter and Dr B. A. Marchylo
Canadian Grain Commission
Grain Research Laboratory
1404-303 Main Street
Winnipeg
Manitoba
Cananda R3C 3G8

Tel: +1 204 983 3320
Fax: +1 204 983 0724
E-mail: bmarchylo@cgc.ca
jdexter@cgc.ca

Chapter 7

Dr Dave Hatcher
Grain Research Laboratory
Canadian Grain Commission
1404-303 Main Street
Winnipeg
Manitoba
Canada R3C 3G8

Tel: +1 204 983 5362
Fax: +1 204 983 0724
E-mail: dhatcher@cgc.ca

Chapter 8

Mr Robert B. Fast
1545 Hillside Road
Poultney
VT 05764
USA

Fax: +1 802 287 9516

Chapter 9

Mr George Gibson
3 Braehead Road
Thorntonhall
Glasgow G74 5AQ
Scotland

Tel: +44 (0)141 644 3230
Fax: +44 (0)141 644 5398
E-mail:
geo123@highbarn1.freeserve.co.uk

Chapter 10

Dr Stan Cauvain
Campden and Chorleywood Food RA
Chipping Campden
Glos GL55 6LD
England

Tel: +44 (0)1386 842000
Fax: +44 (0)1386 842100
E-mail: spc@baketran.demon.co.uk

1

Introduction

W. G. Owens, Satake Centre for Grain Process Engineering, University of Manchester Institute of Science and Technology

The cereal processing industry may be described as any industry that takes a cereal or a cereal product as its raw material. Most cereal processes produce foodstuffs but a few produce items such as starch for industrial or other uses. Because of the importance of cereals in the human food chain, cereals processing has evolved dramatically from humble beginnings as one of the world's oldest industries to the sophisticated one we know today. It took many incremental advances to achieve today's state of the art. This book aims to highlight some of the more recent contributions to this continual evolution.

Why are cereals so dominant in the food sector? The answer is simple. Cereals are a versatile and reliable source of food. They are easy to store and may be used to produce a myriad of food products. Cereals processing thus forms a large and important part of the food production chain. It also plays a lesser, but no less important role in the non-food sector. It is for these reasons that ways of improving cereal processing technology and practice need to be addressed on a continual basis. There are many texts available, such as 'Kent's Technology of Cereals' that address the basic issues of cereals processing, but there are few texts available that review the most recent developments in each processing sector. This collection seeks to address this gap.

The world is becoming a more competitive place, with trade barriers being removed and transportation becoming more efficient. This coupled with the benefits of scale and efficiency that technological improvements have made possible means that processing facilities are becoming larger and fewer in number. Moreover, these plants are expected to operate with greater levels of reliability over longer operating cycles. Within mainstream processes like flour milling or bread baking, for example, the emphasis is still heavily towards process efficiency and increased scale of operation to curtail processing cost.

The main driving force in making these developments possible has been the advent of sophisticated information based process monitoring and maintenance programmes. With the rapid acceptance of the PC at every level of society, this type of development is set to become more widespread.

Changes in eating habits are also driving development. Northern Europeans, for example, now want to eat more rice, pasta and noodles. Thus the food producers in these regions have had to develop the skills required to produce these foods in their own environment. This is no mean feat. The development of part baked goods in the bakery sector is a direct result of consumer demand for convenient, fresh foods. The cereals processing industry today is as diverse as the range of products it produces. Practically every meal produced today contains cereals in some form, while the range of non-food applications is increasing daily. Enormous processing challenges arise with this diversification in products. Manufacturers need to learn new skills and develop more flexible technologies. Consumers' demand for choice and convenience is forcing the development of more consumer ready products. This produces a technical challenge, but there is a major profit motivation associated with the development of such products, since it is a well-established fact that consumers are prepared to pay handsomely for convenience.

Although, in recent years many advances in cereals processing have been in relation to the application of information technologies, there is now a notable resurgence in the development of improved mechanical and process design. There are also other developments such as applied biotechnology. The current debate over the ethical issues surrounding genetically modified organisms means that this area is receiving more than its fair share of publicity and debate, but, on a global level, such developments are clearly here to stay. Unfortunately, the processor rarely benefits from all the technological developments that are available because of the way many industry suppliers offer turnkey services. Individual supply companies rarely have a monopoly on new developments and so, unless manufacturers are aware of all the developments that are present in the marketplace, they are unlikely to be able to maximise any benefits that technological development can accrue. This text aims to deliver an insight into current and emerging technologies and equipment. It seeks to assess these developments independently and provide a basis for decisions on the suitability of application of each development to an existing or new process. There is a mix of contributors from both academic and industrial backgrounds. Their differing styles of contribution demonstrate the usefulness and necessity for us all to support both sectors of the research divide in order to maintain a healthy industry!

The text has been written with the following classes of reader in mind:

- Raw material producers, since they must be aware of the demands and limitations of the equipment and processes employed by downstream processors. Taken to its extreme, such information could spur the raw material producer into entering downstream processing in order to improve

his ultimate margin. Examples of this are to found all over the world, for example, farmer co-operatives investing in flour milling plants in the USA.

- Professionals involved in primary processing, namely flour millers, maize millers, breakfast cereal manufacturers, maltsters, etc. These people are interested in keeping abreast of technological developments in their own and other sectors. This should help the primary processor to assess his facilities and design process improvements. The text may even help in the selection of new plant.
- Secondary processors, namely bakers, industrial processors, brewers, etc., who have a significant interest in knowing of developments in their own and upstream sectors. This is especially relevant in the light of consolidation between primary and secondary processors.
- Educational and government establishments, who are looking for a text that covers this brief to a significant level of detail.

It is hoped that this text will lead to a greater understanding of technological developments both within particular sectors and across cereals processing as a whole, encouraging the transfer of technology between sectors. Developments of this nature will ultimately benefit the processor and consumer through better products and more efficient processing.

Finally, I would like to thank the contributors to this work. It is a long and difficult path from the point at which an invitation to contribute is accepted and seeing the completed work in print. I am indebted to the contributors for their sterling work.

Part I

Cereal and flour production

2

Cereal production methods

E. J. Evans, University of Newcastle

2.1 Introduction

The dominant cereals of the United Kingdom are wheat and barley; oats, once the most widely grown grain crop, has declined to a minor cereal during the last sixty years. Rye, whilst a major cereal in mainland Europe, is relatively unimportant in UK agriculture. Similarly small areas of triticale, a hybrid of wheat and rye, and mixed corn are grown for livestock feeding. The importance of cereals has long been recognised in both world and UK agriculture. Advances in plant breeding and the adoption of highly efficient production systems have combined to bring about almost a fourfold increase in grain yield during the second half of the twentieth century. This initially secured the profitability of arable farming in lowland Britain, but with continued high levels of production across western Europe grain surpluses have become a major burden on EU finances. Measures adopted within the CAP have resulted in a sharp decline in the overall profitability of cereal production during the latter half of the 1990s.

2.1.1 Trends in cereal production

The total area of land used for the cultivation of cereals in Britain has increased from under three million hectares to over seven million hectares during the twentieth century. Furthermore, during this period there was a significant change in the relative importance of wheat, barley and oats (Fig. 2.1).

The dominant cereal during the period 1898 to 1938 was the oat crop, grown predominantly to satisfy the dietary needs of the farm horse as the principal source of power on the arable farm. At this time barley was largely confined to

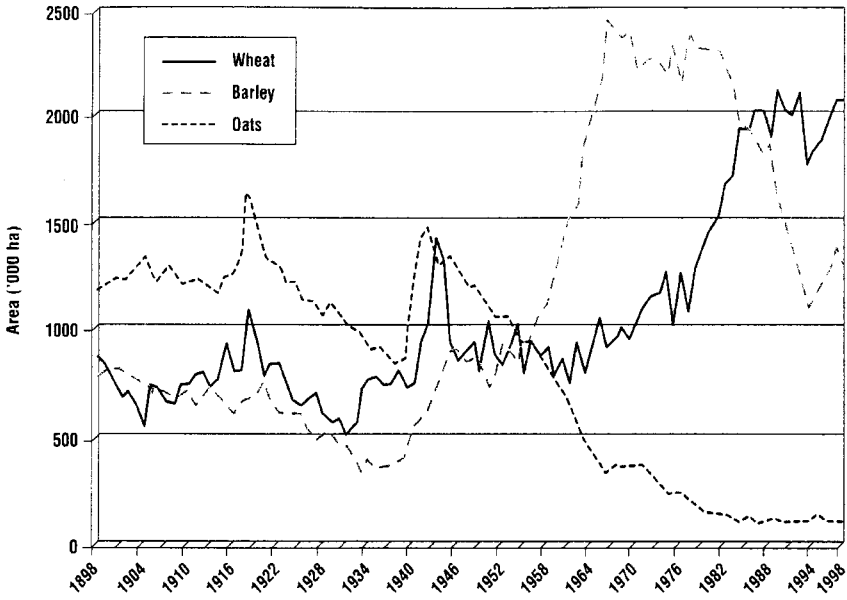


Fig. 2.1 Area of cereals in Great Britain, 1898–1998. (Source: Ministry of Agriculture, Fisheries and Food.)

the production of beer and spirits, whilst a greater reliance was placed on imported rather than home produced wheat for human consumption.

With the outbreak of the Second World War the need to reduce reliance on imported North American wheat resulted in a major Government initiative to promote cereal production in Britain. This 'ploughing out' campaign was successful in increasing the cultivation of wheat and oats on land which hitherto had been considered only marginal for cereal production. Following the end of hostilities the area of wheat and barley remained above those of the pre-war period, due in part to the introduction of a guaranteed price support mechanism for cereals, and the introduction of appropriate machinery to assist cultivation and crop establishment. As the tractor replaced the farm horse the demand for feed oats declined, a trend which has continued to the present time.

During the 1950s barley became the most important cereal crop after it was demonstrated that the grain could be satisfactorily fed to farm animals under more intensive systems of production. In parts of southern England continuous spring barley growing was practised with the adoption of increased mechanisation on large fields made possible through the removal of hedges and ditches. This trend continued until the mid 1960s when the profitability of continuous barley began to decline as production costs began to escalate and the agronomic limitations of continuous cereal production became more apparent.

Between 1945 and 1970 the area of wheat remained fairly static, year to year variation being largely accounted for by the climate during the autumn. Unlike barley most wheat crops at that time were autumn sown; consequently in a wet

autumn the area sown to wheat would be lower than in a dry autumn, although other factors, such as the need to control weeds and soil-borne diseases, also had an impact.

With Britain's entry into the EEC the profitability of wheat increased significantly compared to that of barley with the result that the area of barley began to decline and that of wheat increase. In the early 1980s wheat became the dominant UK cereal. Higher wheat prices, although important, was only one of several factors responsible for the increasing popularity of wheat. The introduction of high yielding winter varieties, the adoption of effective fungicide and herbicide programmes, and the availability of plant growth regulators all combined to achieve high yields and satisfactory financial returns. Improved grain quality and a better appreciation of market requirements also made a significant contribution.

2.1.2 Cereal yields

Cereal yields changed very little during the first half of the twentieth century, but have more than trebled since. There are a number of factors which have contributed to this trend. The rediscovery of Mendel's work provided the scientific basis on which cereal breeding could develop, first within the public sector and more recently by private companies which have now combined into multinational conglomerates. Legislation at national and European levels enabled plant breeding companies to recover their costs in the form of royalties which enabled further advances to be made in developing high yielding cereal varieties with improved quality characteristics. Future developments in cereal breeding will become increasingly dependent on advances in biotechnology and the willingness of the public to accept genetic modification into the food chain.

Austin (1978) calculated the potential yield of winter wheat to be in the region of 13 t/ha. Some high yielding crops have achieved this level of performance, but of more significance has been the constant upward trend in the national average yield (Fig. 2.2).

Although all cereals have benefited greatly from these advances in plant breeding, winter wheat yields have improved to a greater extent than those of oats and barley. During the period 1947 to 1978, Silvey (1981) estimated that the improvement in the national average yields of wheat, barley and oats was of the order of 105%, 76% and 87% respectively. The contribution made by the adoption of new varieties was considered to account for approximately 50% of this improvement.

New varieties undergo extensive field trials to ascertain their field performance and quality characteristics prior to their wide scale commercial adoption. Cereal producers must purchase certified seed or use seed that has been saved from the previous year's crop from their own farm as 'home saved seed'. This ensures high seed quality with good germination capacity, absence of impurities and free from seed borne diseases. Thus advances in plant breeding are rapidly transmitted into farming practice.

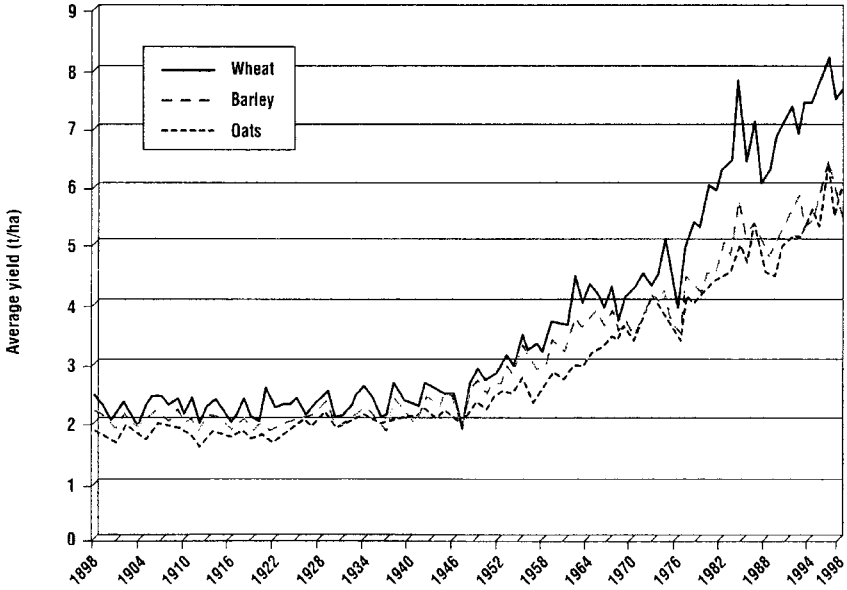


Fig. 2.2 Average yield of cereals in Great Britain, 1898–1998. (Source: Ministry of Agriculture, Fisheries and Food.)

2.1.3 UK regional distribution of the major cereals

Figures 2.3 and 2.4 show the UK distribution of wheat and barley respectively. Traditionally wheat was associated with the heavy soils of eastern England and the East Midlands, but has increasingly been cultivated throughout the eastern side of the country, frequently on lighter textured soils. Winter wheat requires a combination of adequate sunshine, especially during the grain filling stage through to final harvest, coupled with an adequate supply of soil moisture. These requirements become even more important for the production of high quality grain for human consumption.

Barley is less demanding than wheat both in terms of its soil and climatic requirements. The crop is frequently associated with light land, chalk and limestone soils in the south and east of England. In western and northern regions of the UK the crop is mainly grown as a livestock feed, although the highest quality malting barley is frequently produced on the light textured soils in eastern England and Scotland.

Oats are currently cultivated in relatively few areas of the UK. The crop remains popular in Scotland, the south west, Wales and the Welsh border counties, although the best quality grain for human consumption is produced in eastern England.

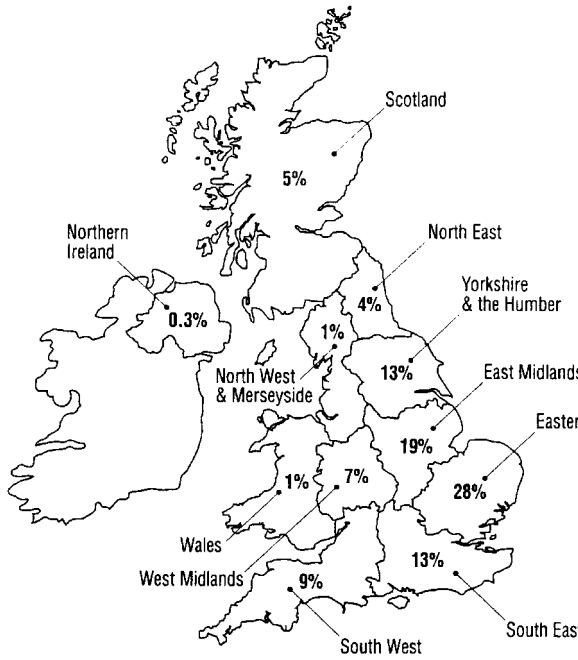


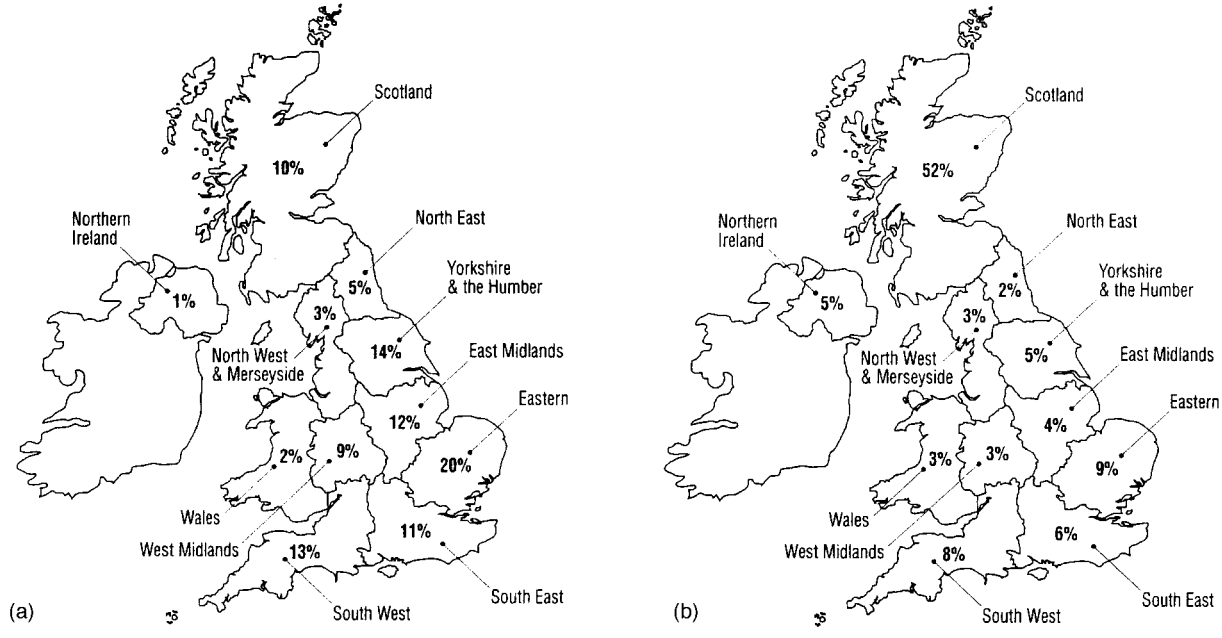
Fig. 2.3 Regional distribution of wheat in the UK, 1998. (Source: Ministry of Agriculture, Fisheries and Food.)

2.1.4 Grain quality and market outlets

There are two main outlets for grain, animal feed, and human consumption, while a small amount is required annually for seed; grain is also exported from the UK, mainly to Europe (Table 2.1). The requirements of these different markets vary considerably, but are essentially defined by a number of 'quality' attributes, which determine the suitability of a sample of grain for a particular end use. The definition of quality therefore depends on the requirements of the specific market.

Grain attributes which determine its suitability for a specific market include its chemical, physical and biological properties. All sectors of the market have a basic requirement for sound grain free from impurities, insect damage and moulds. Other standards are more market specific and will vary in importance according to species and end product. For wheat these may include protein quality and quantity, endosperm texture, flour yield and colour, water adsorption capacity, α-amylase activity and specific weight. For barley appearance, varietal purity, seed vigour and germination, specific weight and moisture content are generally more important, whilst for oats sound well developed grain with a high kernel content is an important determinant of quality.

A number of these attributes are genetically controlled, others are dependent on crop management during both the growing and storage periods, whilst



Total UK area = 792,000 ha

Total UK area = 470,000 ha

Fig. 2.4 Regional distribution of (a) winter barley and (b) spring barley in the UK, 1998. (Source: Ministry of Agriculture, Fisheries and Food.)

Table 2.1 Annual UK cereal supply and demand estimates, 1998/9 ('000 tonnes)

	Wheat	Barley	Oats
Opening stocks	1,358	2,013	33
Production	15,104	6,632	587
Imports	1,124	162	8
Total availability	17,946	8,807	628
Human and industrial use	6,372	1,950	270
Home grown	(5,390)	(1,842)	(262)
Animal feed	6,336	3,185	255
Seed	337	200	18
Other	77	33	3
Total consumption	13,122	5,368	546
Exports and intervention	3,348	2,590	0

Source: Home Grown Cereals Authority, Market Information (mi), 20 December 1999.

climatic conditions during grain filling and harvesting can often determine overall quality standard. Hence year to year variation in grain quality will have a major influence on the balance between supply and demand, which in turn will influence the premium paid to growers over and above that paid for feed grain.

Currently some six million tonnes of wheat and three million tonnes of barley are used as animal feed in the UK each year. During the pre-war period oats was the dominant feed grain, used largely to feed the farm horse, the primary source of power on the arable farm. In the 1960s barley became the dominant feed grain, but more recently wheat with its lower fibre and higher energy and protein content has been used increasingly by the compound feed manufacturing industry. Quality criteria for feed grain have not been well established; consequently very low priority is given to breeding programmes to improve feeding characteristics, although low specific weight grain is considered to be of lower nutritional value.

The major human and industrial uses of wheat in the UK are for breadmaking, biscuit manufacture and distilling. Each year approximately five million tonnes of wheat is milled into flour; two thirds of this is used for breadmaking, the remainder is used in the manufacture of biscuits and other food products. The introduction of the Chorleywood Breadmaking Process has allowed the use of lower protein flour which has enabled a much higher inclusion of home-grown wheat in the manufacture of the standard white loaf. Although most biscuit flour is made from home-grown wheat, some products such as wafers and crackers may require specific varieties or the addition of gluten modifying additives to achieve the desired eating qualities.

Specific weight, a measure of the bulk density of grain, is widely used as a wheat quality indicator. High specific weight grain results in better flour extraction within a specific variety, but is not always consistent across different varieties. It is a crude measure of grain fill and can vary from 40 kg hl to over

80 kg hl for plump, well filled grain. Breadmaking samples are normally over 76 kg hl. Seasonal variation in specific weights of individual varieties is quite marked, largely on account of differences in radiation and rainfall during the grain filling period. However, management practices are also important in ensuring that the plant remains free of pests and disease and is supplied with adequate nutrients and water.

Hard wheat is required for inclusion in breadmaking and a soft texture is required for biscuit making. When hard wheat is milled the endosperm cells separate along the cell wall margins into easily sifted particles, and the bran is easily separated from the endosperm to give a high extraction of white flour, capable of high water adsorption during dough production. Soft wheat has a much lower extraction rate and the flour consists of a mass of fine cell debris with poor flow characteristics and a lower water adsorption capacity. Endosperm texture is under genetic control with varieties either classed as hard or soft. This character is simply inherited and easily managed within breeding programmes, whilst agronomic practices have no influence on this quality component.

Wheat flour is used for breadmaking as a result of the viscoelastic properties of the dough when water is added. The dough may be classed as either strong or weak, depending on the quantity and quality of the grain proteins, which in turn influences gluten strength. For breadmaking, gluten must be strong enough to retain the carbon dioxide generated during fermentation, allowing the bread to rise. The protein content of wheat grain varies widely, but for breadmaking a value of at least 11% is required. In practice high grain protein levels are achieved through the application of nitrogen fertiliser above the optimum for yield. This is especially beneficial when applied late in the season. Foliar applications of urea applied during the milk development stage have been found to be particularly beneficial. Recent work has also demonstrated the importance of supplying the crop with an adequate supply of sulphur at a time when atmospheric depositions have declined significantly as a result of reduced pollution. Applications of around 20 kg S ha in spring have been shown to improve the breadmaking characteristics of wheat grown in sulphur-deficient areas of the UK.

Protein quality is strongly influenced by genotype, although husbandry and environmental factors can also play an important role. Low grain sulphur will result in low concentrations of the sulphur-containing amino acids, cystine and methionine, and may result in poor loaf volume. Protein quality has also been shown to fall as a result of late fungicide sprays that prolong the grain filling period.

During seed germination endosperm starch is converted into soluble glucose and maltose to support the developing embryo. This is brought about by enzymatic activity, especially the enzyme α-amylase, present within the grain and activated during the germination process. Some α-amylase activity is needed to release sugars and aid fermentation during the breadmaking process. Excessive α-amylase levels result in the formation of a darkened loaf crust as a result of sugar caramelization and a sticky crumb structure which can cause

problems during slicing. Genetic variation exists in the amount of α-amylase activity both during pre-maturity and enzyme formation during post dormancy sprouting. These two components are inherited independently giving rise to a situation where varieties differ in their α-amylase content where there is no visible sprouting. Varieties with low α-amylase activity combined with good resistance to sprouting are favoured for breadmaking.

Grain α-amylase levels reach their lowest levels during ripening, thereafter increasing significantly. This suggests an optimum date for harvesting, but one which is difficult to predict and achieve in practice. Nevertheless, it is good practice to harvest crops destined for the breadmaking market early to avoid the effects of wet weather.

Post-harvest management is an essential part in achieving high quality grain to meet specific market requirements. Food hygiene regulations apply to stored grain which must be protected from moulds, bacteria, rodent, bird and insect damage, whilst pesticide residues must not exceed UK statutory levels. These standards form the basis of recently introduced quality assurance schemes, combining all facets of grain production from field to store and on to the mill. Breadmaking grain harvested at moisture contents in excess of 15% must be dried carefully at air temperatures below 60ºC to avoid denaturing the proteins, thereby destroying the elasticity of the gluten.

For biscuit production, flour is produced from soft milling varieties with high extensibility to ensure that the different biscuit shapes cut from the dough retain their outline after cutting. Wheat with a protein level below 10% is preferred to reduce gluten elasticity. The low water absorption characteristics of soft endosperm wheat are desirable to limit the need for drying the final product to a standard moisture content and also to reduce cracking during cooling and subsequent packaging and storage. The α-amylase content of the flour is also less critical than it is for breadmaking.

For distilling, soft endosperm texture is required and whilst there is no protein specification a high protein content can lead to problems with low starch and spirit yields. Distillers often prefer to select specific soft wheat varieties that have consistently produced high yields of spirit.

Grain quality has an extremely important influence on the suitability of a sample of barley grain for malting. Maltsters require grain from a recognised malting barley variety which is of uniform size with low husk and nitrogen content with a high germination capacity. These malting characteristics can only be accurately measured with a micro malting test which is both slow and expensive, although the physical condition of the grain and its nitrogen content are generally considered to be a good guide to its malting potential.

Traditionally spring varieties have commanded the highest malting premiums, but with the increased popularity of winter compared to spring barley in the UK, plant breeders have produced a number of good winter malting barley varieties. All new varieties are evaluated for their malting characteristics from micro malting tests to assess their hot water extract and are graded accordingly. However, not all high graded varieties are approved by the Institute

of Brewing until they have been subjected to commercial scale malting. Two-row barley varieties are preferred to six-row varieties because of the evenness of the grain, whilst varietal admixtures are not acceptable for malting.

The characteristics of a good malting variety are that it readily takes up water on steeping, germinates readily and evenly and produces high levels of hydrolytic enzymes for the conversion of the starch to soluble sugars. The malting process is effectively a process of controlled germination and every effort must therefore be made to retain a high germination capacity. Poor germination can result from careless threshing damaging the embryo, from drying at too high a temperature, or from heating caused by storage at too high a moisture content. Furthermore, uniform, complete germination can only be achieved by avoiding crop lodging and harvesting the grain when it is fully ripe. The physical appearance of the grain is also important; maltsters prefer samples where the grain is uniformly plump. This is usually measured by passing the grain through a sieve and determining the percentage grain retained on the sieve. Screening standards vary slightly between England and Scotland. Samples should also have a low husk and high endosperm content, free from broken grains and damaged husk.

There is a very good correlation between grain nitrogen and the amount of malt extract achieved, low grain nitrogen giving more fermentable extract. During the past decade the swing from traditional cask conditioned draught ale towards light lager beers has reduced the demand for very low nitrogen grain. For the former a nitrogen content of 1.5 to 1.65% is required whereas for lager beer a grain nitrogen content of 1.8% is acceptable. Traditionally the lowest grain nitrogen samples have been obtained from crops grown on light sandy soils along the eastern coast of Britain. These soils have low residual levels of organic nitrogen which allows better control of plant nitrogen supply from annual fertiliser nitrogen applications. The amount of nitrogen applied to a malting barley crop will be less than that applied to a crop destined for the feed market, thereby sacrificing some yield potential for low nitrogen grain. Applications of spring nitrogen to both the winter and spring sown crops should also be completed at an early stage of crop development.

About a half of the UK oat crop is used for human consumption, whilst the remainder is used for animal feeding. Food products containing oats include oatmeal for porridge, oatcake, muesli and other breakfast cereal products. In many of these products it is necessary to remove the fibrous husk surrounding the kernel mechanically, although in recent years the introduction of naked or huskless oats has been a major breeding achievement. Husk content has also been found to differ between varieties and consequently some varieties are more likely to attract a premium.

Traditionally oats were regarded as a low input crop; however, if a high quality product is required for human consumption then more careful management of inputs is required. Foremost amongst these is the need to avoid the crop lodging with careful attention to the time and rate of nitrogen application, coupled with the use of plant growth regulators. Maintaining the

crop free from weeds and diseases, especially mildew, is important in achieving a high yield of quality grain.

2.2 Varietal selection

The contribution of new cereal varieties to the profitability of grain production is well recognised. The prime objective of plant breeders from the outset has been to develop high yielding varieties, with good disease resistance against the major cereal pathogens. This continues to be a major aim of current breeding programmes, although increased attention is now being directed towards improving grain quality to meet specific market requirements.

In wheat, and to a lesser extent barley, improved grain yields have been achieved through selection of short strawed varieties. Old and new varieties of cereals differ very little in the amount of total dry matter accumulated during the growing season, but selection for a higher Harvest Index (HI) has resulted in a greater proportion of this biomass being accumulated in the grain. The HI of varieties in cultivation during the period 1930–40 was around 30%, compared to between 50 and 55% for present day varieties (Austin *et al*. 1980). Further agronomic advances have been achieved with selection for improved standing power, whilst increased resistance to grain shedding and sprouting have contributed significantly to advances in wheat breeding.

Breeding new varieties with improved resistance to the major cereal diseases has always been a key objective for plant breeders. Before the introduction of broad spectrum systemic fungicides in the late 1970s, genetic resistance was often the only defence mechanism available to growers and was often the most important factor to be considered when choosing a variety. Good varietal resistance remains an important consideration, even within current husbandry systems in which routine applications of two or three fungicides is commonplace during the growing season. Poor genetic resistance can lead to a rapid epidemic build up of disease, which may prove difficult and expensive to control leading to a detrimental effect on yield and quality.

The suitability of wheat or barley for different end uses is partly under genetic control, although varietal differences can be modified by husbandry and weather conditions. Characteristics such as the endosperm texture of wheat and the malting potential of barley is entirely under genetic control, while quality parameters such as specific weight are influenced to a greater extent by husbandry and climate. Considerable advances have been made in developing varieties with improved quality attributes through a better understanding of their molecular basis. At the same time market needs have become more clearly defined which is likely to lead to better targeting of new varieties for specific markets in the future.

New varieties must demonstrate that they are distinct in their genetic make-up, uniform and stable in their characteristics and have value for cultivation and use before they are added to the UK National List. Further evaluation with and

without fungicides in trials throughout the country provides further information on their yield and quality characteristics. Recommendation depends on their average performance exceeding the mean performance of varieties already recommended.

2.3 Crop establishment

Traditionally the UK wheat crop has been predominantly winter sown, while barley was largely spring sown until the mid 1970s when the winter crop increased in popularity through the introduction of high yielding feed varieties. Spring barley varieties remain the dominant malting types. In England and Wales winter oats are preferred, whereas in Scotland spring oats dominate.

The optimum sowing time for both winter wheat and barley is from mid September to early October, although with the increase in farm size and the reduction in full-time farm labour both wheat and barley are now sown earlier in the autumn. Early sowing is beneficial in promoting good root and shoot systems before the onset of winter, which in turn enables the crop to intercept a greater proportion of available radiation during spring and summer, thereby establishing a higher yield potential. To achieve this potential growers frequently incur additional production costs, especially through increased use of herbicides and fungicides.

Spring cereals are normally sown as soon as soil conditions allow from February onwards, although spring varieties of wheat may be sown during the period from the middle of November until January after harvesting sugar beet and potatoes on light land. The yield potential of late sown spring wheat and barley is generally inferior to crops sown before the end of March.

Soil conditions during seedbed preparation have a significant effect on crop performance. Seedbeds have normally been produced by ploughing, followed by a series of secondary cultivations to produce a satisfactory tilth. Whilst effective, this method of crop establishment is both time consuming and expensive. Direct drilling of winter cereals became popular in the 1970s as a cost effective system of establishment, but the introduction of the straw burning ban in England and Wales, coupled with an increase in grass weeds has made it less effective in recent times. Minimum cultivation systems have become a popular method of crop establishment on suitable soils in the absence of major grass weed problems. Recent advances in machine design, combining cultivation and drilling machinery behind a single power unit, have significantly increased the ability of growers to sow large areas quickly and effectively. Reducing establishment costs is now regarded as a major factor in containing fixed costs.

An important feature of all cereal plants is their ability to produce a large number of shoots or tillers, although by harvest many of the tillers will have died, leaving a main stem and one to three ear bearing tillers. The number of tillers produced is often negatively correlated with plant density, while tiller survival is strongly influenced by environmental and agronomic factors which,

in turn, influence assimilate supply. The rate and timing of nitrogen can have an important role in both the production and survival of tillers; indeed it is one of the main tools that the grower has at his disposal to influence ear population at final harvest. The practical significance of this is that satisfactory yields can be achieved from a wide range of sowing rates, especially for winter wheat and barley.

The target population of established plants is between 200 and 300 plants/m^2. To achieve this between 100 and 200 kg/ha of seed is sown, depending on seed size. The higher the individual seed weight, the higher the seed rate required to achieve the target plant population. Allowance must also be made for seedling mortality and the loss of established plants to pest and disease attack. The use of fungicide seed dressings is common practice to control soil and seed borne pathogens. Seedling losses can be higher in winter compared to spring sown cereals.

Cereals are relatively insensitive to variations in row width and inter-row spacing. Similarly sowing depth is less critical than in many of the smaller seeded arable crops, such as oilseed rape. Sowing at the target depth of 2 to 3 cm is easily achieved with conventional drills.

2.4 Crop nutrition

The yield and quality of all cereal crops is strongly dependent on the availability of an adequate supply of soil mineral nutrients throughout the growing season. The higher the yield potential the higher the nutrient demand, while the grain nitrogen content is a major quality determinant in wheat and barley.

The nutrient status of most arable soils in the UK is too low to achieve satisfactory yields in the absence of applied nutrients. Crop demand is normally met through the application of inorganic fertilisers, although in organic cereal systems additional nutrients can only be supplied from manures and other organic sources. The results of numerous field trials over the last fifty years have provided a sound basis on which to base the nutrient requirements of cereals. Compared to many arable crops, cereals have a relatively low demand for phosphate and potassium. As a rule of thumb phosphate and potassium are applied at the rate of 10 kg/tonne of expected grain yield to replace the P and K removed and maintain soil reserves. The amount applied may be reduced slightly in soils with high P and K reserves. In recent years with the decline in atmospheric SO_2 deposition and the trend away from sulphur-containing fertilisers some cereal crops grown on light land may benefit from sulphur application. Recent research has also identified the importance of sulphur to the breadmaking qualities of wheat.

Cereals do not have a high demand for trace elements, although copper and manganese deficiencies have been recorded in wheat and barley. Copper deficiency is frequently associated with high organic matter soils; symptoms of deficiency are most common when the ears emerge as white heads, producing

shrivelled grain with low specific weight. Manganese deficiency is most frequently observed on light sandy, or chalk soils with high pH values. Low availability of manganese results in grey-white lesions on the leaves. Deficiencies of other trace elements are less common, although it is desirable to monitor the trace element content of crops from time to time through plant analysis. Maintaining the soil pH at an appropriate level will also be beneficial.

Nitrogen is by far the most important nutrient, influencing both grain yield and quality. With the exception of the high organic peat soils the levels of available soil nitrogen in most arable soils is well below that which is required for satisfactory growth and high yields of grain. Total soil nitrogen, on the other hand, is often present well in excess of crop requirements but is present in the organic matter fraction and is therefore dependent on microbial activity to release the nitrogen into a mineral form, suitable for crop uptake. This process of mineralisation is very dependent on soil environmental conditions, particularly an adequate level of soil moisture, high temperature and aerobic soil conditions. The release of nitrogen from this organic fraction will progress at a faster rate in spring and autumn than at other times of the year. Nevertheless, it is difficult to predict accurately rates of mineralisation throughout the growing season in such a way that it would be possible to adjust fertiliser inputs accurately to meet the precise nitrogen demand of crops. A significant proportion of the mineral nitrogen fraction not used by the crop is leached into water courses, presenting a potential environmental hazard.

The role of nitrogen in promoting grain yield has often been evaluated in terms of its effect on single plant components such as leaf area, tiller production and survival, grain weight and number. More recently, research efforts have been directed at evaluating the effects of nitrogen on the whole green crop canopy, in particular its role in manipulating the canopy size to enable maximum radiation interception over as long a time interval as possible. This approach, which has become known as canopy management, is currently being evaluated in commercial wheat crops throughout the UK (Sylvester-Bradley *et al*. 2000).

The amount of inorganic nitrogen fertiliser applied to cereals in the UK has increased appreciably over the last thirty years. There have been a number of agronomic reasons for this trend, but without question the driving force has been the realisation by cereal producers that high nitrogen rates are associated with high yields and hence higher financial returns. This has been made possible through the introduction of high yielding varieties with improved lodging and disease resistance, coupled with the adoption of highly effective fungicide programmes to control foliar diseases and plant growth regulators to improve further the crop's standing ability.

The nitrogen requirements of winter cereals are significantly higher than those of spring sown cereals on account of their longer growing season and higher demand for biomass production. Additionally, the timing of N application will vary according to their very different growth patterns. The results of

numerous field trials have clearly demonstrated that there is very little benefit from the application of autumn nitrogen to winter wheat or barley. Indeed there may be an excess of nitrogen in seedbeds prepared by traditional ploughing arising from the breakdown of organic matter. Applications of inorganic nitrogen at this time only serves to increase the likelihood of nitrate leaching. Winter cereals established by direct drilling have been shown to benefit from a moderate application of nitrogen in the autumn.

The amount of spring and summer nitrogen required for optimum yields is lower in winter barley than winter wheat, largely due to the former being more prone to lodging than wheat. The rates of application can vary from as little as 50 kg/ha to over 250 kg/ha, depending on a range of agronomic and environmental factors; the most important being the previous cropping, soil type, expected grain yield and overwinter rainfall, while other variables such as the variety's standing ability, disease resistance and crop density must also be taken into account.

The effectiveness of applied nitrogen in promoting crop growth and ultimately grain yield is greatly improved by ensuring that adequate nitrogen is made available according to the demands of the crop. If this objective is achieved then the loss of soil nitrates through leaching will also be minimised. Normal practice is to apply the spring nitrogen in two dressings, the first in late February to early March and the second some time during the period late March to late April. The first of these dressings, of approximately 40 kg/ha, will be applied according to ground conditions and the likely demand for nitrogen by the crop. The second or main application is generally considered to have the greater effect on grain yield and is applied to coincide with the start of stem extension. The window of application will therefore vary according to sowing date, variety and spring temperatures. The timing of the main spring nitrogen to winter sown malting barley is critical in achieving low grain nitrogen concentrations and should be completed in March, irrespective of the crop's stage of growth.

Winter wheat grown for breadmaking requires an additional application of late nitrogen to promote grain protein content. This can either be applied as a solid fertiliser a few weeks after the main application, or as an urea-based solution sprayed onto the crop during grain filling.

The demand for nitrogen by spring cereals is considerably lower than for winter cereals due to the short growing season leading to reduced biomass production. The risk of nitrate leaching is also greatly reduced and therefore the benefits of splitting the application is considerably less than for winter cereals, although with high rates of nitrogen in excess of 125 kg/ha, there may be some practical benefits in splitting the application. To produce low grain nitrogen spring barley it is desirable to apply all the nitrogen before the two leaf stage. In contrast spring wheat for breadmaking would benefit from a late season application of nitrogen to promote grain protein levels.

2.5 Weed control

The presence of weeds will reduce the yield of all cereal crops due to their ability to compete with the crop for water and nutrients from the soil and intercept radiation that would otherwise be utilised by the crop canopy. The combined effects of weed competition on crop yield is greater during the early stages of growth; therefore adequate weed control measures are essential during crop establishment. Some weed species can also have an indirect effect on grain yield by increasing the likelihood of lodging and encouraging the development of pests and diseases. The presence of weeds during the later stages of grain growth is likely to have a detrimental effect on grain quality and often interfere with the harvesting operations.

Intensive cereal growing systems rely heavily on the use of chemical weed control programmes based on the use of one or more products applied either pre- or post-emergence of the cereal crop. At the other end of the spectrum organic cereal production systems are based on non-chemical control measures. Here the options are limited to the use of mechanical weeders and the manipulation of crop growth to allow it to become dominant and to out-compete the weeds. In future it is likely that attention will be given to a more integrated approach to weed control with strategic use of herbicides in combination with cultivation practices. The preparation of a stale seed bed through shallow cultivations to encourage germination of weeds which are then destroyed before the crop is sown is one such technique which may be reintroduced in an attempt to reduce the cost of chemical weed control. Further attention will also be directed to considering the weed spectrum across the whole rotation rather than in a piecemeal, crop by crop basis.

Herbicides represent between 35% and 40% of crop protection costs for winter sown cereals in the UK. Expenditure on weed control will often vary from field to field depending on the weed spectrum present. For example, the cost of controlling grass weeds will be a good deal more expensive than the cost of controlling broad-leaved weeds such as poppy or shepherd's purse. Selection of the appropriate herbicide programme is dependent in the first instance on being able to identify the weed flora present, recognising the dominant weed species within this spectrum and having an appreciation of the likely size of the population. A number of attempts have been made to identify weed thresholds, below which treatment may be deemed unnecessary, but these have been difficult to apply in practice due to the different competitive characteristics of different weed species and their effects on crop growth.

An effective weed control strategy is also dependent on understanding the mode of action of the active ingredient, its interaction with other chemicals with which it may be mixed and its effect on the target weed species. In general herbicides are more effective against weeds during their early stages of growth. Rates of application are determined by the manufacturers, based on many seasons of field and glasshouse evaluation trials, although in an attempt to implement more cost effective weed control strategies growers often adopt reduced dose rates according to prevailing crop and weather conditions.

It is now well recognised that in many areas of southern and eastern England populations of blackgrass (*Alopecurus myosuroides*) have developed that are resistant to the most commonly used herbicides for grass weed control. Resistance has been mainly associated with continuous, or near continuous winter cereal cropping, often established by non-ploughing techniques and regular use of a narrow range of herbicides to control grass weeds. In general grass weeds are more expensive and more difficult to control than broad-leaved weeds.

2.6 Disease control

Cereals are prone to a range of diseases caused by micro-organisms, predominantly fungi, which can attack the roots, stems, foliage and/or the ear, causing substantial losses of yield and frequently having a detrimental effect on grain quality. The presence of disease in an otherwise healthy crop is first recognised in the field by the appearance of well defined symptoms resulting from earlier activity on the part of the pathogen. If the disease is allowed to progress then the pathogen itself becomes more obvious, but often more difficult to control at this stage of its development.

Disease control has traditionally been based on cultural practices aimed at improving the ability of the crop to resist infection or attempting to interfere with the life cycle of the pathogen. Exploiting genetic resistance through careful selection of varieties remains an important disease control strategy but over the last thirty years fungicides have become an integral part of cereal production systems in the UK.

Conditions have been identified from numerous field trials that promote the establishment and development of pathogens on cereal crops. For winter sown cereals, early sowing and a high soil nitrogen status in the autumn promote lush soft tissue which can become very prone to a number of the leaf infecting diseases such as mildew (*Erysiphe graminis*) and brown and yellow rust (*Puccinia* spp.) with mild autumn weather. The frequency with which cereal crops are grown in the rotation can also be a major determinant of crop susceptibility to a range of pathogens. The most important disease in this respect is undoubtedly take-all (*Gaeumannomyces graminis*) which is particularly serious in winter wheat in second and successive crops. Until the recent introduction of seed-based fungicides, the inclusion of a break crop of a different species was the only practical way of keeping this disease under control.

Considerable genetic resistance to the major cereal diseases is to be found in wheat and barley, with the exception of take-all. Selection of resistant varieties is often the simplest and cheapest way of controlling diseases. Unfortunately other criteria may have an overriding influence on the selection process, for example, quality requirements or yield of grain. The emergence of new races of pathogens may also result in an established variety losing its ability to provide an accepted level of resistance against specific pathogens.

Despite the advances made in plant breeding and the adoption of appropriate husbandry strategies, control of the main cereal pathogens by non-chemical means are unlikely to provide total disease control. However, over reliance on chemical control measures is equally unacceptable as it can lead to the overuse of fungicides to the detriment of the environment and over time reduce the fungicidal properties of the chemical itself. For example, populations of *Erysiphe graminis* have developed resistance to some of the older mildewicides which has resulted in these products losing their effectiveness in controlling barley powdery mildew. The development of this kind of resistance has promoted the development of more integrated disease control strategies, where chemical control measures are combined with other measures to combat the pathogen.

2.7 Pest control

Cereals are susceptible to a wide range of pests. Some such as rabbits, birds and slugs attack a wide range of crop plants, whilst others such as wheat bulb fly, frit fly and cereal cyst nematode are specific to cereals. Plants at the seedling stage of growth are particularly vulnerable to pest damage when the green area of the crop is small. The established plant during the phase of active tillering is better able to compensate for moderate pest attacks, but crop damage can again be very significant after ear emergence. For the majority of crops, pest attacks are less threatening than disease outbreaks; therefore effective control strategies are based on early identification of the pest, an assessment of the population relative to the growth stage of the crop and the application of an appropriate pesticide. The aim must be to forestall epidemics at an early stage when a worthwhile cost benefit can be obtained from the control measure adopted.

Pest incidence in cereals varies according to crop species, soil type, farming practice and the weather pattern. Unlike diseases, variety resistance to pests is unlikely to be an important factor in the control strategy. An exception can be found in winter oats where certain varieties show resistance to stem eelworm (*Dtylenchus dipsaci*), whilst others are susceptible. Cereal cyst nematodes (*Heterodera avenae*) are frequently found to attack spring sown cereals sown on light, well drained soils often in areas where high quality malting barley is grown.

Intensive cereal production systems have often resulted in an increase in the incidence of pests, whilst the introduction of crops such as oilseed rape into the rotation may increase the incidence of slugs in the following cereal crops. There is some evidence that set-aside can provide a convenient green bridge which can aid the survival of some pest species between non-consecutive crops. Wheat bulb fly (*Delia coarctata*) may be more prevalent after set-aside if adults are able to lay their eggs on bare soil in the summer.

Weather patterns are known to influence the scale of future pest problems, for example high autumn rainfall preceding a mild winter is known to favour high

populations of leatherjackets (*Tipula paludosa*) in spring. The incidence of barley yellow dwarf virus increases, especially in early drilled crops, if the autumn is warm, due to the increased activity of aphids.

Increasing emphasis is currently being placed on the production of high quality grain whilst minimising pesticide use. To achieve this objective more information is needed to identify situations where the use of pesticides cannot be avoided without serious financial loss. Forecasting pest activity by modelling their behaviour is one way in which more effective control strategies can be developed in the future. Threshold levels for individual pests, below which it is cost effective to apply a pesticide, are already helping to reduce pesticide usage. There is further scope to encourage beneficial organisms to counteract cereal pests in the field under the common aim of developing 'integrated pest management systems'. This approach places greater reliance on promoting vigorous crop growth through appropriate cultivations, rotations, and other agronomic inputs and the encouragement of beneficial organisms. In such a system selective pesticides could be used precisely timed to have the greatest impact on the pest, but to leave the 'beneficials' to prosper.

2.8 Harvesting and grain storage

Grain quality is largely determined during the growing season. Once the grain has been harvested it is difficult to improve its quality, although quality can easily be destroyed by conditions during harvest and subsequent drying and storage. Indeed grain quality can start to deteriorate in the field prior to harvest. Rainfall prior and during the harvest period can encourage ear diseases and premature sprouting, whilst high grain moisture levels will necessitate increased drying costs. For example, delaying the wheat harvest can result in grain with high α-amylase content, lower specific weight and protein contents, factors that will seriously reduce the quality of the grain for breadmaking.

Almost all UK grain will be harvested by large self propelled combine harvesters which are highly efficient, causing minimal physical damage to the grain when they are properly set and operated. The condition of the crop at harvest has a significant influence on combine performance; severely lodged crops not only produce inferior quality grain, but also reduce combine speed and efficiency. The presence of weeds also interferes with the harvesting process and often leads to higher grain moisture levels and contamination with weed seeds which increase the costs of cleaning. Unless the straw is required for animal feeding or bedding the combine harvester is extremely effective in chopping and spreading straw evenly over the soil. This is of considerable help in preparing the seedbed for the subsequent crop.

In Britain grain is often harvested at moisture contents of around 16 to 20%, whilst in exceptionally late seasons in northern regions grain may be harvested at around 25%. At these moisture levels stored grain is extremely susceptible to fungal contamination and deterioration. For safe storage the grain has to be dried

to within the range 13 to 15% moisture, although malting barley may be dried to around 12%. Storage temperatures and grain moisture content have a strong influence on grain dormancy in barley, a condition which is highly important to the maltster.

Drying systems either rely on near ambient air temperatures, or high temperature driers. The former is a relatively slow process whereby the grain is stored in bins or on the floor and is dried by forcing ambient, or slightly warmer air through the grain. Batch and continuous flow high temperature driers rely on air temperatures of between 40 and 120ºC with a necessity to cool the grain before storage. Drying temperatures of grain destined for milling, malting or for seed are more critical than for other uses.

2.9 References and further reading

AUSTIN R B (1978) 'Actual and potential yields of wheat and barley in the United Kingdom'. *ADAS Quarterly Review*, **29**, 76–87.

AUSTIN R B, BINGHAM J, BLACKWELL R D, EVANS L T, FORD M A, MORGAN C L and TAYLOR M (1980) 'Genetic improvement in winter wheat yields since 1900 and associated physiological changes'. *J. Agric Sci. Camb.*, **94**, 675–89.

GAIR R, JENKINS J E E and LESTER E (1987) *Cereal Pests and Diseases*. Farming Press, Ipswich.

GOODING M J and DAVIES W P (1997) *Wheat Production and Utilization, Systems, Quality and the Environment*. CAB International, Oxford.

HOME GROWN CEREAL AUTHORITY. *Weekly Market Information Bulletins*.

KENT N L (1982) *Technology of Cereals*. Pergamon Press, Oxford.

LUPTON F G H (ed.) (1987) *Wheat Breeding: its Scientific Basis*. Chapman and Hall, London.

NIAB (1999) *Cereal Variety Handbook*. NIAB, Cambridge.

NIX J (1999) *Farm Management Pocketbook*. Wye College, University of London, London.

PARRY D (1990) *Plant Pathology in Agriculture*. Cambridge University Press, Cambridge.

SILVEY V (1981) 'The contribution of new wheat, barley and oat varieties to increasing yield in England and Wales 1947–78'. *Journal of the NIAB*, **15**, 399–412.

SYLVESTER-BRADLEY R, SPINK J, FOULKES M J, BRYSON R J, SCOTT R K, STOKES D T, KING J A, PARISH D, PAVELEY N D and CLARE R W (2000) 'Sector challenge project – canopy management in practice' in *Proceedings of the HGCA Crop Management into the Millennium Conference*, Homerton College, Cambridge, January 2000.

WIBBERLEY E J (1989) *Cereal Husbandry*. Farming Press, Ipswich.

3

Wheat, corn and coarse grains milling

W. G. Owens, Satake Centre for Grain Process Engineering, University of Manchester Institute of Science and Technology

3.1 Introduction

The term ‘coarse grains milling’ is a very broad one that refers to the comminution of the berries of the wheat, barley and other coarse grain crops. This is the definition of milling as interpreted by an engineer or process manager. However, a cereal chemist or quality assurance manager might interpret the term milling as the transformation of raw material into a primary product for secondary processing. This definition encompasses every aspect of the transformation, from raw material purchasing to quality assurance and product testing. However, this definition is too broad to discuss in the context of a chapter such as this. Moreover, many of these subjects are discussed exhaustively in related and other texts. Instead this chapter will focus on the engineering perspective of the development of the milling industry.

In many cases milling is a very simple process, involving the use of a simple grinder to create a specific particle size distribution from the bulk raw material. The opposite end of the spectrum is the complex process employed to produce white flour for the baking industry. In between these two extremes lies the whole spectrum of milling processes. These include milling for the brewing industry and milling for the breakfast cereal industry among others.

The wet milling process employed by some starch manufacturers is a considerable departure from most other processes encountered, because of the introduction of large quantities of water to the process, with the result that the product of the process is a liquid and not a powder. This process is a very specific one and will not be discussed in this chapter. However significant detail is entered into in the book *Corn, Chemistry and Technology*, published by the American Association of Cereal Chemists (Watson and Ramsted 1984). The

author recommends referral to this book if the wet milling of corn or wheat is of interest.

Because the actual milling process in many industries is relatively simple, technological progress has been limited to increases in efficiency and the adoption of computer control to the process to improve efficiency and quality while minimising labour requirements. In contrast, intermediate processes, such as those milling corn for breakfast cereal manufacture have advanced considerably as a result of advances in the most complex of the milling processes, flour milling, because many of the same machines are employed. For example roller mill capacities have increased dramatically over the last 20 years and new process philosophies have been adopted, such as double grinding without intermediate sieving.

It is because the flour milling industry is the most complex and predominant of the milling industries that most technological development has occurred here and so the following text focuses initially on the flour milling industry with notes in regard to the other milling industries where appropriate. The chapter then discusses a number of other significant developments and then moves on to discuss research with regard to milling and its current focus. The chapter concludes by speculating where the industry might progress technologically in the future.

In discussing technological developments within flour milling it is first worth considering the historical development of the flour milling process.

3.2 The evolution of modern flour milling

The process of flour milling dates back to Egyptian and earlier times. There are illustrations from ancient inscriptions showing grain being crushed using a mortar and pestle, with the resulting material being sieved to produce material of greater purity. The development that followed this was the use of millstones, first hand operated, then driven by animals and finally driven by waterpower. The latter power source allowed the development of the first automatic mills, where all operations between wheat delivery and flour collection were performed automatically.

Millstones dominated the process used to produce flour until the 1870s when roller mills began to supplement them on a large scale, because of the superior flour that could be produced using them. The method used to produce flour today was developed during this period of fundamental change in the type of equipment employed (Simon 1997). This method has its origins in what is now known as the ‘French process’ (see Fig. 3.1). This process began to emerge in the sixteenth century and advocated the use of a number of grinding stages with intermediate sieving of the products to produce final products of intermediate grades. The other notable feature was the fact that the millstones used were set in such a way as to perform a gentle grinding action and thus maintain the purity of the endosperm being separated.

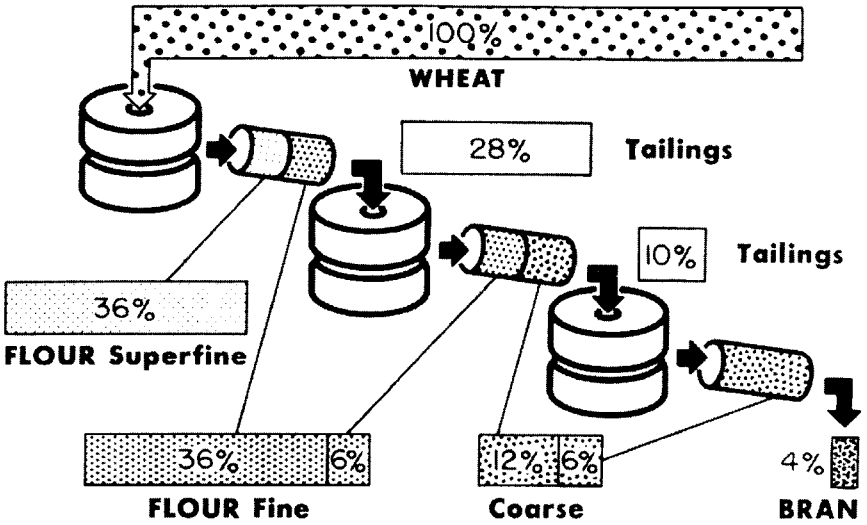


Fig. 3.1 French process flour mill flow sheet (Storck and Teague 1952).

Henry Simon, the Manchester-based milling engineer, perfected the gradual reduction system in the 1870s. The main features of this milling technique were the use of a large number of process stages in an extension of the French process and the exclusive use of roller mills for grinding. The principles of gentle grinding and intermediate sieving were developed upon to give the break, purification and reduction systems that are used exclusively today.

Before the development of the long process using roller mills, stone mills and shorter processes were normal. The advantage of the newer, more elaborate process was that higher yields of quality flour could be produced. The older processes employed can only be described as crude and produced typically only 10% high quality flour from the wheat berry compared to more than 70% in roller milling plants. The remaining flour was of very poor quality and heavily contaminated with the bran and germ constituents of the wheat berry.

Many variations in the detail of the process flow sheet emerged in the years after the perfection of the gradual reduction system. This was due to the varying requirements of customers and even political directives. For example, in wartime, the British government ordered millers to produce high extraction flour in order to extend supplies and to supplement people's diet with the essential vitamins and minerals found in the outer layers of the wheat berry (Smith 1938).

Development of flour milling technology since the introduction of roller mills and the gradual reduction system include flow sheet alterations to accommodate newer machine technologies and increased machine capacities as well as the adoption of information-based technologies.

3.3 The flour milling process

There are a number of aspects of the overall process of flour milling that are particular to it and are not to be found in other industries. Thus a group of terms are used which would be unfamiliar to individuals not acquainted with the process. This section aims to provide a brief introduction to the process and the terms employed to describe aspects of it. Posner and Hibbs (1997) describe the process in greater depth and the reader is urged to consult this book for further insight into the process.

Flour milling is the continuous process that is used to transform the raw wheat berry into a form which is of use to the baking and other industries and the domestic consumer. A small portion of production is geared towards the production of whole-wheat flours, employing a simplified process flow sheet, but most demand and effort is directed towards the production of white flour.

White flour is the ultimate product of flour milling. The aim of white flour milling is to extract a maximum amount of endosperm from the wheat berry in as pure a form as possible. The outer bran layers become the co-product of the process called wheat feed. Many operations also separate the embryonic part of the berry, known as the germ. This is a high value co-product when a market exists. Where a market for germ does not exist, it is sold for animal feed with the wheat feed produced. These co-products contribute significantly to the financial viability of milling operations.

One of the keys to the success of a flour milling operation is the efficient, economical separation of starchy endosperm from the rest of the berry. The process has developed along very specific lines towards achieving this goal. There is just one accepted manner in which flour is produced globally. This is known as the gradual reduction system.

The gradual reduction system of flour milling is the process of taking the whole wheat berry and, via a series of grinding and sieving stages, producing white flour of the desired quality and yield. The gradual reduction system has enabled the production of flours of low ash content and high yield. Specialist, high quality flours, are produced by extracting high purity sub-products from within the process.

The flour milling process can be represented by a simple block diagram (Fig. 3.2). There are three principal divisions within the process. These are known as the breaking system, the purification system and the reduction system. The purification system is not favoured by many millers and may be absent from processes. It is often replaced by what is known as the Sizing system. However, the other two blocks are present in all gradual reduction flour mills in operation today.

The breaking block or break system is the area of the process where most endosperm separation is achieved. This work is performed principally on roller mills whose surfaces have a saw tooth profile. The rollers run at different speeds towards each other. The combination of these two attributes in operation mean that, in the first contact with the wheat berry, the grain is split open and a

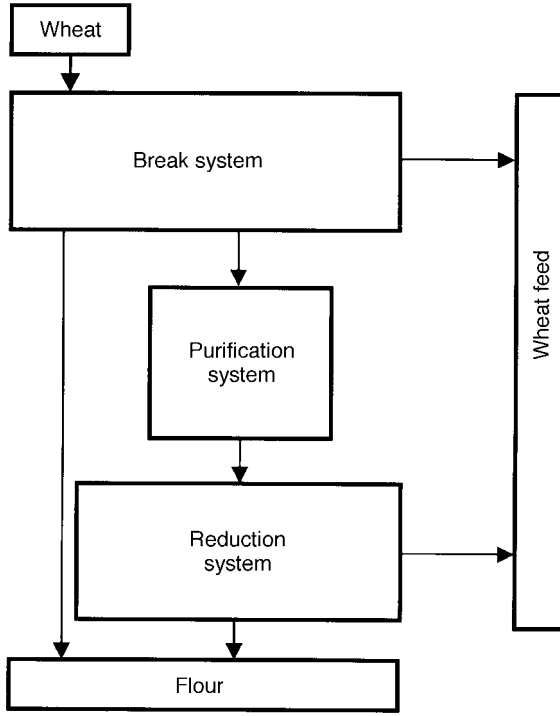


Fig. 3.2 Block diagram of milling process.

significant amount of material is released into the purification and reduction blocks by the subsequent sieving operation. A small amount of flour is also produced at this stage and is removed before further processing occurs. The material that remains in the break system after first contact is presented to a second set of rollers for further grinding. Again, material is released into the purification and reduction blocks and some flour is released. This procedure is repeated four or five times. When the desired amount of material is released from the wheat berry, the remaining material is discharged to the wheat feed stream, the co-product of flour milling.

The purification block contains three machine types: purifiers, roller mills and sifters. Purifiers are machines that separate particles on the basis of differences in size, air resistance, and particle specific gravity, simultaneously. The streams feeding the purification system come from the break system discussed above. The streams are classed on a size basis before entry to the purification system and contain a mixture of pure endosperm and intermediate purity particles. Particles that are pure enough are separated immediately, exit the purification system and are passed to the reduction system for further processing. The remaining particles are processed on roller mills whose surfaces have a fine saw tooth profile. Further bran and endosperm separation is possible as a result of this grind. Ultimately most of the material that enters the

purification system is passed on to the reduction system. The remaining material is sent to the break system. Because the aim of this block is the purification of milling streams, almost no flour is produced in the purification system.

The reduction block is the main flour producing block. It is also the area where the other desirable property in flour is manipulated, that is mechanical starch damage.[1] The reduction block consists of a series of roller mills and sifters in sequence. Material is transferred from the break and purification blocks to these roller mills principally for size reduction, although the sieving apparatus removes some remaining impurities. The roller mills used in the reduction system differ from the roller mills used in the other blocks in that smooth surfaced rollers are usually used and lower differential speeds are employed (Scanlon and Dexter 1986). Material that is not sufficiently reduced in size in a particular grinding pass is sieved out and ground again in a subsequent grinding stage. This process is repeated up to eleven times in what are termed long surface mills.

The starch damage mentioned earlier is achieved through the application of shear and pressure to the starch granules that constitute the endosperm. The shear stresses are applied by virtue of the differential speeds employed by the grinding rolls. The mechanical linkage that supports the grinding rolls applies the pressure to the particles.

The result of the above iterative grinding and sieving process in the three processing blocks is the cumulative release of endosperm from the wheat berry, followed by the cumulative release of flour from this material. The actual quantities released at each stage vary widely between particular examples of mills. The operational settings depend on factors as diverse as wheat type, plant operator, customer demands, equipment supplier, geographical location, and even tradition. Typical releases[2] for a flour mill in the British Isles are (NABIM 1990):

Cumulative release from the break system:	88%
Rejection from the purification and reduction systems:	10%
Cumulative flour release:	78%

While no two milling plants are the same, the differences between them occur in the intensity with which the processes described above are applied and particular machine configurations. This same process has been applied for more than one hundred years with only minimal changes to processing strategy.

[1] Mechanical starch damage is induced in order to increase the water absorbing capacity of flours, which in turn improves bread yield for bakers.

[2] Release is a term widely used in flour milling. It is used in association with the break system to describe the amount of material passed out of the break system to the reduction and purification systems.

3.4 Recent developments in flour milling

The following discussion highlights the fact that many of the latest developments are old ideas that have been revisited in recent times because of advances in manufacturing technology. A prime example is the application of double grinding without intermediate sieving.[3]

There are two principal reasons for the current pace of technological progress. The first is the small operating margins present in the flour milling business. These do not allow large quantities of capital to be channelled into research. The other reason is that flour millers generally consider themselves as technology 'consumers' rather than developers. Thus, they rely almost exclusively on a small number of 'milling engineers' to supply them with state of the art equipment and process designs. Again, because of their small numbers and low margins, technological progress by milling engineers is a difficult and slow process. Despite these limitations, there have been a number of advances in the application of conventional technologies, which have improved processing efficiency in flour mills. The following overview details these advances. There are three main categories where advances have been made. These are in machine capacities, machine construction and new machine technologies.

3.4.1 Machine capacities

The principal emphasis in this area has been on improving the effectiveness of existing machines rather than on new types of machine. The so-called 'short surface mill' is now the norm. This refers to the amount of grinding equipment required to process a specific throughput of wheat. The indicative figure is known as the available roll surface and is expressed as millimetres of roll surface per hundred kilograms of wheat processed per twenty-four hours. This figure has more than halved in the last thirty years (NABIM 1990) from a typical figure of 18 mm/100 kg/24 h to examples of 6 mm/100 kg/24 h.

The efficiency of plansifters[4] has also been increased significantly. This has been achieved by making them larger, more space efficient and by increasing sieving rates. The incorporation of rotary sieving machines into the process flow before plansifter sections has reduced the amount of sieving surface required in break sections. This is because these sieving machines are more efficient at performing coarse separations of large volumes of bulky material.

[3] The conventional wisdom in flour milling is that after every grinding step the ground material should be sieved and the undersize material removed before regrinding. Double grinding technology successfully counters this philosophy and yields significant process economies.

[4] Plansifters are the industrial-scale sieving machines employed in flour milling. These are gyratory-type sieving machines, which have several compartments capable of handling different materials simultaneously.

3.4.2 Machine construction

Significant changes have occurred in the way machines are built. Steel has replaced timber as the material of choice for the construction of plansifters. Roller mills were constructed from cast iron and wood until recently but many roller mill manufacturers now use prefabricated steel sheets for the main frame of the roller mill, with the grinding forces being contained in what are known as 'roll packs'.[5] This has made the roller mill much lighter than its cast iron predecessors and this has had implications for machine cost and building design. The advent of the roll pack has also dramatically reduced roll replacement times. This has become increasingly important where flour mills are expected to run for extended periods without shutting down.

Developments in roller mill technology are not just limited to the method of fabrication and the way the roll chills[6] are fitted. Significant strides have been made in minimising the amount of noise generated by roller mills in operation. This includes the replacement of chain and gear drives with timing belt drives on the differential mechanism. Application of exhaust air to the grinding zone of rolls has minimised fluidisation and roll 'bounce'[7] is less of a problem. Sophisticated electronic control systems provide reliable roll engagement and disengagement and instances of rolls running without feeds have been eliminated. This is a considerable advance in terms of increasing roll life expectancy and safety. This is because rolls running in contact with each other wear rapidly and pose a significant fire risk.

3.4.3 New machines

The most notable process developments in flour milling have been the double grinding of intermediate streams before sieving and the debranning of wheat before main processing. New machines have been developed to exploit these techniques. These machines and their application are well documented in trade literature and are the subject of numerous patent applications (Forder 1996, Posner and Hibbs 1997). The function of these new machines in the flow sheet has been to reduce the number of machines used.

The double-grinding roller mill has been employed successfully in flour mills only in the last decade, even though it was first examined during the original development of the gradual reduction system (Storck and Teague 1952). A variation, the six-roller mill, has been in use in the malting industry for many years (Buhler 1981). The configuration of the double-grinding roller mill enables mill stocks to be ground twice without intermediate sifting or grinding.

[5] This refers to the self-contained bearing housings that support the roller mill grinding forces.

[6] Roll chill is the term used to describe the cast metal rollers that form the working components of roller mills. The phrase is derived from the method of production of the steel used in their manufacture, namely chilled steel.

[7] Roll bounce is the phenomena experienced in grinding using roller mills when fluidisation of the material being ground occurs at the point of contact between the rolls. The rolls literally bounce as they encounter inconsistent feeds to the grinding zone.

This development reduces sifting and conveying requirements within the process significantly. Considerable capital savings can be made in terms of equipment purchase requirements and the size of building required to contain the process.

The most radical of recent developments has been the advent of debranning as a unit operation in flour milling (Posner and Hibbs 1997). This is the process of removing the outer bran layers from the wheat berry before the milling process proper. A rationalised process flow is possible with debranning installed. The conventional break system is rendered obsolete with only one or two fluted rolls[8] being required. Because of the purity of the semolina[9] produced in such a grinding system, the requirement for a purification system is significantly reduced. Both these features of debranning enable a streamlined process with corresponding savings in building size and running costs.

Pin mills[10] have also been adapted for use throughout the process. They have been among the key factors in reducing the amount of grinding equipment required in flour mills. The pin mills used are standard machines but the innovation is in the process locations where they have been applied. Pin mills are favoured where starch damage of the bulk flour will not be adversely affected or where flour production rates are relatively low. Pin mills are widely used in plants where starch damage production is not an issue or where it is undesirable.

There are two features that these newer developments have in common. These are that they typically do not enhance product quality and cannot be applied universally. However, significant capital and operational savings are possible through even limited application and so they are always worth applying as extensively as possible. The application of double grinding at 1st/2nd break and A/B[11] reduction rolls is one example of this approach. The application of debranning in durum or bobtail mills[12] is another.

3.4.4 Conclusion

The stimulus for development in the flour milling process is the flour miller's requirement to produce the highest quality products at minimum cost. This has been achieved in the past through investment in new technologies, which are

[8] Fluted rolls refer to the rolls employed in the break system that are finished with a saw tooth profile.
[9] Semolina is the term used to describe the coarse endosperm material produced at all stages during the milling process. It is too coarse to be considered as flour and must be further reduced in size.
[10] Pin mills are a type of comminution device which consist of a revolving rotor with a series of pins attached. The material to be comminuted enters the mill at the centre of the rotor and is thrown towards the periphery by centrifugal forces. The particles impact the pins along this route and are comminuted as a consequence of these impacts.
[11] These are the terms used to describe the sequential stages in the milling process. The British convention is to use 1st, 2nd, etc., for the rolls in the break system, and A, B, etc., for rolls in the reduction system.
[12] A bobtail mill is the term used for a flour milling unit that utilises surplus machine capacity from an adjacent processing plant in order to minimise equipment requirements.

supplied by a small number of equipment manufacturers. However, most recent development work has been centred on the optimisation of machine design and capacity and then the application of these machines to existing processing strategies. The result has been the development of more compact flour mills in recent years.

3.5 On-line process measurement

The importance of accurate and reliable data for control, optimisation and information systems cannot be over-emphasised. These data are the first step in the loop that makes process optimisation possible. Mill processes use many tools to measure performance, but many of the methods are unsuitable for on-line application. The Farrand[13] method for starch damage measurement is an example. To be suitable for on-line application, measurement methods need to be accurate and capable of producing results that can be interpreted by personal computer-based systems. Verification of sensor data is an essential and realistic demand of these systems. However, problems with measurements are one of the main reasons for the failure of process control. The problems include incorrect readings, unreliable readings and even the complete absence of readings.

Most complex instruments depend on statistical data analysis and a lot of work has to be performed in the area of assembling enough test data to develop and maintain calibrations (Fearn and Maris 1990, Graf 1994). This work has to be performed in every application of instrumentation.

McFarlane (1992) documented the large number of sensors employed in the food manufacturing industry. However, Near Infra Red (NIR) analysis currently forms the backbone of on-line process analysis in flour mills and is likely to remain so for some years to come. Psotka (1999) mentioned the emergence of X-ray fluorescence as a technology that may supplant NIR in some applications in the future. This technology appears to be superior to NIR for ash and starch damage measurement and is currently being evaluated in the USA.

The NIR equipment employed by Fearn and Maris (1990) is typical of the equipment in use throughout the milling industry today. The reasons for its popularity are: the instrumentation is rugged and simple, there are few manipulations (no weighing, titration, calculation) required and the devices deliver rapid results. A small increase in error over classical methods can be tolerated for most quality control applications because this error is counter-balanced by the analysis of larger numbers of samples. The NIR determination of protein and moisture is now comparable with that of classical methods (Osbourne 1980), while ash determination is readily available in laboratory and on-line instruments. In addition plant breeders and other specialised users have developed their own calibrations for NIR (Davies and Grant 1987).

[13] AACC method 76-30A.

Technology exists today that can measure most process control properties on-line and in real time. This technology centres on the use of NIR techniques, but X-ray fluorescence and gravimetric methods are also emerging. However, confidence levels in these technologies are not yet sufficient to allow an increase in plant operators' dependence on on-line control for functions other than protein addition and open loop control of other parameters. The main difficulty is the concept of establishing sufficient calibrations that are verified regularly. However, the work documented by Graf (1994), Fearn and Maris (1991)[14] and others are examples of the developments that are beginning to bring process plants closer to the goal of producing a mill that can be controlled intelligently.

3.6 Automation and its role within the milling industry

Liveslay and Maris (1992) performed a survey on the use of Computer Integrated Manufacturing (CIM) and Programmable Automation (PA) in the milling and baking industries. The conclusions were that:

- the milling and baking industries have a small number of examples of mature CIM developments, namely automation and manning reduction
- the number of such developments is likely to increase, although slowly
- much of the industry remains unconvinced about the benefits of CIM and PA
- it is possible to demonstrate some specific benefits that CIM and PA will bring to the industry.

The benefits of CIM include quality improvement and enhanced production control. Many CIM processes also have features that enhance hygiene aspects of the process. In addition, data collection and analysis as well as product traceability are built-in features of CIM that are readily exploited by processors to ensure optimum quality for customers and as tools to enhance profitability.

Improving control saves energy and improves product consistency by ensuring key process variables are more stable, thus allowing comfort margins to be reduced. Processes may also be operated closer to optimum values or constraints (Hart *et al*. 1996). In many cases a simple control system will achieve the desired effect but others require a more sophisticated approach.

Advanced techniques are required in a number of situations. Highly integrated processes, with many interacting elements, for example, mill processes, cannot be controlled satisfactorily by basic control systems. In addition simple controllers find it difficult to cope with significant time delays between controller actions and system responses and non-linear responses from the process. Finally, advanced controllers are required where the process is expected to be flexible; for example the process plant may produce different products, requiring operation at different throughputs.

[14] The applications examined were the automatic control of gluten addition to flour and a miniature gravimetric sensor designed to measure the release of material from a milling passage.

Process control equipment/methods may be divided into two principal sub-categories, namely conventional controls and advanced controls. The details of these two types and their differences are as follows.

3.6.1 Conventional controls

Conventional controls are generally Single-Input Single-Output (SISO) Proportional Integral Differential (PID) controllers. These have been in use for many years and are especially effective when process dynamics are reasonably constant, where there is minimal lag in the process and where the objective is to adhere to some measurable set point. Other control systems have been developed subsequently to handle complex process dynamics. These include:

- Feed forward control, which compensates for up stream disturbances before the controlled variable is influenced.
- Ratio control, which is able to hold one process variable at a fixed ratio to another.
- Cascade control, which is the application of one controller to adjust the set point of a second controller.
- Constraint control, which is used to move a process variable towards one or more constraint values.

Dead-time or lagging compensated controllers are ones that have algorithms that allow for delays in a process or slow sensor responses, an example being discrete sampling, on-line analysers.

In addition to these major groups, controllers incorporating specialist features are also available. Robust control techniques add functionality to controllers that are designed to work under all operating conditions. These are applied especially in safety critical applications. Overrides are functions employed to ensure a control system does not violate the limits of the process and gain scheduling is used to adjust automatically the tuning parameters of a controller to take account of different operating regions.

The type of controller employed in mills today fits into one or more of the above categories. They are used for operations such as water-addition to wheat and micro-ingredient addition to flour.

It may be seen from the list above that many different types of conventional controller exist to cope with most simple process requirements. However, whole process control does not fit into this category of control requirement and so advanced control techniques must be investigated in the future in order to increase process efficiency.

3.6.2 Advanced control techniques

As stated, advanced control techniques are considered when conventional approaches cannot develop adequate performance. The types employed are as follows:

- Model-based predictive control
- Rule-based control
- Fuzzy control
- Adaptive control.

Model-based predictive control

Model-based predictive control (MBPC) is an advanced control technique that is applied where time delay compensation is required, complex process dynamics, and/or multivariable interactions exist. A prerequisite is that suitable process models are available. There are a number of software packages available that encompass model and control strategy development, and system implementation.

A common application of MBPC is in feed forward control of processes. An example in the flour milling context is the feed forward moisture addition system that the Buhler™ company of Switzerland market. This controller uses MBPC to predict the post-addition moisture content of the grain being treated, based on the pre-addition moisture content.

The technique requires the construction of a dynamic model that is capable of predicting future process behaviour. The employment of this model within a predictive control strategy involves calculating optimal settings for the plant to ensure the controlled variables are kept at their set points. This may not always be possible since the optimum value for the process may change in a dynamic fashion because of varying raw material properties or some other variables.

The model of the process is developed from historical data by applying statistical techniques. The least squares method is the favoured method, although other modelling methods may be used where least squares cannot satisfactorily manipulate the data. Preferably a continuous model is used in MBPC, but the higher powered microcomputers now available can deal with discontinuous functions.

MBPC has a number of useful features where the control of processes is considered. Process response is predictable and so operation at optimum levels is straightforward. The basic nature of the control strategy also means that the computing demand of a controller based on MBPC is quite low. Other advantages include rapid controller response to changing process conditions and the ease with which process dead times can be handled.

On the negative side, MBPC must have models available that consider all process variables. If any variable is not considered, the result can be significant errors in the control system's response. The models employed are usually not adaptable, except through human intervention, thus in the situation where the process model changes with variable values or even lapsed time the controller error becomes large.

Mill processes experience this kind of model evolution. For example, as the fluting wears off the rolls used in flour mills, the particle size distribution produced by the roller mills changes for a given roll setting. Thus a rigid

predictive model is not suitable for the application and could not be considered for real time process control.

Rule-based and fuzzy control

Rule-based control is used in situations where other control techniques are inappropriate, for example where sufficient theoretical knowledge is not available or historical data is not complete enough to enable the creation of accurate models of process behaviour. Rules used in control systems can take the form of language-based equalities or number-based equalities; for example, 'if temperature exceeds 100 degrees then turn off steam supply'. The nature of the rules is discrete in rule-based control in that the equality being monitored either has a true or false value, with a definite action as a consequence of the value of the rule evaluation changing.

Rule-based control is highly suitable where concise rules regarding the operation of the process can be drawn up. There are many processes where this is the case and where rule-based control can be successfully applied. For example, the filling of containers to a minimum weight could employ a concise rule for the rejection of underweight packages. The rule might take the form: 'if the package weight is less than minimum allowable weight, then reject the package to rework'. Rule-based control does have a place in the operation of controllers in mills where quality control or operational parameters require control. For example, the rule might pertain to a limiting ash content or maximum allowable moisture content in the flour being produced.

Rule-based control schemes are implemented using expert systems or knowledge-based systems[15] approaches. A number of rule-based packages are currently available which can be integrated seamlessly with modern Distributed Control Systems (DCS) or Supervisory Control And Data Acquisition systems (SCADA). Alternatively rules can be applied using a high-level programming language.

Fuzzy control is an extension of rule-based control, where the rules are expressed in a less precise manner. This approach is generally suited to control problems where smooth changes in the control action are more desirable than step changes or where it is not possible to define clear boundaries between process conditions. A typical fuzzy rule might be 'if the water is hot, and the house is cold, then the water pump is not running'. It is difficult to see an application for fuzzy logic in mill direct process control, but the operation of many of the quality control procedures could potentially benefit from the application of fuzzy logic. For example 'hard' and 'soft' wheat, 'strong' and 'weak' flour are terms in flour mill quality control that are used widely, but

[15] An expert or knowledge-based system is a computer program that can capture human expertise, which can subsequently be applied in a consistent fashion at high speed. The two terms may be used interchangeably. The object of an expert system in a process scenario would be to monitor process parameters, give an alarm when a fluctuation occurs and suggest causes and remedies. Taken to its ultimate and practical limits, such an expert system could actively control plant and tackle process variations automatically.

which cannot be defined in precise terms as yet. The development of automatic assessment of these parameters would open up the possibility of automated responses to unexpected changes in these parameters. This could potentially have a significant impact on the manner in which mills are operated and on the consistency of the products produced.

A fuzzy controller typically consists of four elements:

- An automatic rule generation module, which creates rules automatically for the fuzzy controller based on input process models.
- A database management module, which synthesises the rules generated by the automatic rule generation module.
- A fuzzy inference engine which performs fuzzification, inferencing and defuzzification of design variables based on the rules generated by the automatic rule generation module.
- An evaluation module to decide when to stop program execution.

Vishnupad and Shin (1998) cited the advantages of using a fuzzy controller over conventional controllers. Fuzzy control leads to a higher degree of automation for complex problems. This is especially true if the knowledge available about the process can be expressed as language-based rules. It can be expressed in the form of if–then rules, which can be incorporated easily into a fuzzy controller. In addition fuzzy controllers are more robust than conventional controllers.

Considering the non-linear and multi-modal nature of many processes, fuzzy control offers a significant advantage over traditional numerical optimisation methods. This is because most decision-making logic is developed automatically by the fuzzy controller and requires little input from the operator. This is in contrast to traditional methods where models have to be developed and verified for each aspect of the process to be controlled. Because the fuzzy logic controller develops rules on the basis of cause and effect, many process variables are programmed for, that could not be considered using conventional numerical techniques. The result is fuzzy controllers offer a more robust and versatile form of control than conventional numerical techniques.

A fuzzy expert system may also be developed with analytical and heuristic models in mind. These features of fuzzy controllers have led to their widespread adoption for poorly understood and difficult to model processes. Linko *et al.* (1992) give an example in the form of fuzzy logic applied to extrusion control.

Adaptive control

Adaptive control is where the control algorithm or parameters are altered on-line in real time to cope with changes in process dynamics. Adaptive control is relevant to both conventional and advanced control strategies in that each can be programmed to operate in an adaptive environment.

The technique is useful where a rigid control strategy fails to provide satisfactory performance because process dynamics alter, as in the flour milling process. Process dynamics may change because of non-linearity, drifts in plant

performance or changes in operating conditions. A classic example is a change in production rates or plant wear.

Distributed Control Systems (DCS) and Supervisory Control And Data Acquisition (SCADA)

These systems are now the accepted standard for process control and monitoring. SCADA systems are often used in conjunction with Programmable Logic Controllers (PLCs). SCADA systems are usually mounted on personal computer hosts that communicate with PLCs.

SCADA/PLC and DCS systems offer extensive control and monitoring capabilities that are easily manipulated. The data collected can be stored in an efficient manner and presented in a usable form within the package or via a standard presentation package. The information gathered may also be relayed to other computing systems, for example, management and accounting systems. They are also an essential element with which the application of advanced computer and control techniques may be considered.

It is impractical to consider advanced control techniques without having some form of DCS or SCADA/PLC system in place. These are used to enact the decisions reached by the advanced control system in terms of the optimal solution to the current set of process conditions and requirements.

3.7 Milling research

Milling research can be divided into two categories, namely commercial research and academic research. Commercial research tends to be confidential in nature, but the results of this work can be seen in the new products and processes marketed by manufacturers in the field. These developments have been discussed above. In contrast, academic research is well documented and may be discussed extensively. The following review discusses some of the work carried out in the milling field.

The engineering work that has been reported tends to be purely experimental in nature with little emphasis placed on understanding the basic principles employed (Speight 1969, Wanzenreid 1970, Moss *et al*. 1980, Hook *et al*. 1984, Wingfield and Ferrer 1984, Szauter 1985, Scanlon and Dexter 1986, Curran *et al*. 1994, Mason 1994, and Murata *et al*. 1994). There are notable exceptions to this rule: Nuret and Thielin (1949), Nuret and Jeannot (1951), Pratique (1952a, 1952b, 1952c, 1952d, 1953, 1954a, 1954b) and Ruffet (1994) have performed considerable amounts of work in the areas of plansifter and roller mill mechanical performance. Owens (2000) worked in the area of overall process modelling and optimisation.

3.7.1 Modelling of mill processes

> Oxford dictionary definition of simulation: '*an imitation of the conditions of a situation*'.

The optimisation of processes requires understanding the operations that make up the process. In the context of the milling process this means understanding the behaviour of materials and machine operations and being able to assign mathematical models to this behaviour.

The two principal operations in milling are grinding and sieving. Thus this section documents the work carried out in modelling grinding and sieving processes, in addition to the work performed on the basic principles of the fracture of granular materials.

3.7.2 Fracture modelling

The subject has been the focus of work by numerous authors including Hook *et al*. (1984), Thuy (1994) and Moss *et al.* (1994). Most research concentrates on the impact of the process on the quality characteristics of the resultant flours, rather than on the mechanical efficiency of the process.

Thuy's (1994) model used Bingham's plastic theory to develop a model of grain deformation whose parameters can be determined experimentally. Parameters such as expected energy requirement and thrust force generated could be predicted for a grain sample. Hook *et al*. (1984) determined the relationship between air humidity and temperature, and flour milling and quality characteristics. Moss *et al*. (1994) examined the microstructure of grains and were able to predict the various milling characteristics such as cleavage pattern and relative sieving performance from micrographs. Thus a tool for predicting milling performance was developed which could be used in wheat breeding programmes.

Scanlon and Lamb's (1993, 1995) papers take the process of fracture mechanics to a much more detailed level and use matrix mathematics as well as physical material properties to understand the mechanisms of particle fracture. This material is of fundamental importance in understanding the macro process of milling.

3.7.3 Roller mill models in milling

There are many mill types in use in mills, but roller mills dominate the flour milling process. Consequently roller mills dominate the literature on the subject.

The mechanics of roller mills

The complex machine that is a roller mill may be represented for analytical purposes by a simple two component schematic. The essential elements of the scheme are two cylindrical rollers almost touching each other along their full length. Because the rollers are perfect cylinders and contact is made along the

roller's entire length, a simple two-dimensional analysis can describe the system. Other features are that the rollers are rotating towards each other and their rotational speeds are different. This differential is governed by the ratio of the drive apparatus that powers the rolls.

Ruffet (1994) performed a theoretical review of the principal parameters governing the operation of a roller mill using this two-dimensional description. The parameters examined were power, specific power, the thrust on machine components and the friction forces exerted on rolls.[16] The theoretical work was tested for validity in a series of tests that were carried out at an industrial plant on the first break rolls. In these experiments grinding performance, specific power requirement, thrust forces, friction forces and differential forces were all measured.

Brabend (1962) found that the use of large diameter rolls in some instances avoided the difficulty of excessive thrust forces. Wanzenreid (1970) in his experiments determined that a roll differential of 1.25 and a roll diameter of 250 mm were optimum for smooth roll grinding of semolina in flour mills. Scanlon and Dexter (1986) performed similar experiments and in addition measured flour colour, ash content and starch damage. In addition to finding that an optimum existed for energy efficiency, it was found that as differential was increased, starch damage and ash content increased.

3.8 Optimisation of processes

Optimisation refers to the achievement of optimal conditions within processes in terms of process and economic performance. Optimisation represents a major opportunity to reduce energy costs and improve quality. Optimisation algorithms can identify the most economic operating conditions, select the best combinations and loadings for plant and even determine the best production schedules to meet requirements and minimise costs. Optimisation techniques are generally applied in conjunction with the advanced control systems described earlier.

In order to accomplish optimisation, a variety of steady state and dynamic models have to be developed for individual unit operations and overall plant performance. Mathematical techniques are then employed to find inputs to the models that satisfy operational objectives while meeting quality and other constraints. In turn these models have to be incorporated into computer packages, which are user friendly enough to be useful to the process engineers.

Optimisation techniques include (Brinksmeier *et al*. 1998):

- Linear and quadratic programming.
- Gradient-based methods.

[16] A similar treatment of the forces at work in a roller mill is given in the pamphlet on roller mills produced by Birch (1930).

- Evolutionary approaches including genetic algorithms and simulated annealing.[17]

3.8.1 Which optimisation technique for milling?

Linear and quadratic programming techniques may only be used where models of that nature apply to the process. However, this excludes a large body of processes, including non-linear, discontinuous processes, processes that are not well understood, and many other classes. Milling operations have been optimised using these techniques by numerous researchers (Tillman *et al*. 1969, Niernberger and Phillips 1972, Flores 1989, Flores *et al*. 1991, Liu *et al*. 1992), but this work did not examine the process itself. The models examine aspects such as the economic performance of the operation, or the least cost formulation of the raw material blends used. Milling processes themselves are highly non-linear and so this type of optimisation technique may not be used.

Gradient-based search techniques such as the back-propagation method, Brent's method, conjugate gradient methods or variable metric methods are the most widely used optimisation techniques for training adaptive control systems. The methodology of these techniques is explained in considerable detail with programming examples in Press *et al*. (1988). However, it has been shown that these techniques are limited in their ability to find global solutions where the problem model is represented by multi-modal and non-smooth functions (Press *et al*. 1988). The flour milling process is an example where discrete data may be all that is available and many near similar solutions may exist to the optimisation problem.

Global search techniques have been identified as a potential solution to these problems (Chen *et al*. 1998, Sexton *et al*. 1999). Simulated Annealing and Genetic Algorithms are two such techniques. The main advantage of these algorithms, in comparison with exact algorithms, is that they do not suffer from an exponential explosion in computational requirement with increase in problem size.

The Simulated Annealing algorithm is a stochastic optimisation technique, ideally suited to the solution of combinatorial optimisation problems. Its application in solving problems in the global wiring of integrated circuits and the famous 'travelling salesman problem' are well documented (Maier and Whiting 1998, Reyes and Steidley 1998, Treadgold and Gedeon 1998).

3.8.2 Off-line or on-line optimisation?

Optimisers can be off- or on-line. On-line refers to systems that collect data automatically. This is the modern approach. Optimisers may also be open loop or closed loop. Open loop optimisation refers to systems that do not take actions automatically. Instead they are used to advise operators how to run plant and

[17] Genetic algorithms and simulated annealing are computational optimisation techniques.

determine optimum control strategies and set points that can be implemented within existing control systems. They do not, however, take action on the basis of the optimum solution determined.

On-line Near Infra Red (NIR) apparatus is being used in an open loop system to control flour ash in flour mills. In this example the measurement device simply presents real time results of flour ash to the process operator. The operator closes the control loop by assessing the measured data and acting appropriately to maximise product yield and minimise product fluctuation. I am not aware of closed loop control being in place in any operational facilities. Indeed, the similarities between the closed loop control of flour protein[18] and the potential for closed loop control of flour ash or starch damage has not been recognised by many in the flour milling industry. There are mills in operation today that have the on-line measurement capability and automated roll gap measurement available, but the link between the two using adaptive control has not been made.

3.8.3 Application of optimisation techniques

Successful application of optimisation techniques involves a systematic approach to using any models developed. The first step of the methodology is concerned with steady state optimisation. This process delivers predictions of potential benefits and savings. However, plants never actually operate at steady state, but rather are in a perpetual transient state due to a variety of disturbances. Nevertheless, the benefits predicted by steady state simulations may be achieved on average, thereby improving process performance.

Dynamic optimisation must be performed to compensate for process disturbances and involves reacting to these disturbances in such a manner that plant productivity is maximised at every instant in time. Dynamic models in the form of simulations can be used for off-line control strategy development and on-line dynamic models can be used to help make well-informed responses to each disturbance.

Reyman (1992) gives an example of the application of an integrated control system in the design of a new process. The importance of a methodical approach and especially proper choice of a process model is shown. In summary, the steps towards integrated control development from beginning to end should consist of the following:

1. Determination of control performance requirements and collecting process data.
2. Analysis of process instrumentation.
3. Analysis of process input/output responses.
4. Improvement of the primary control strategy.

[18] The protein content of flour is a strictly controlled parameter in flour mills. Most modern mills employ closed loop control systems to maintain flour protein at predetermined levels.

5. Dynamic modelling of the process.
6. Development of a supervisory control strategy specific for a given process.
7. Testing and tuning of the developed control strategy/controller by simulation.
8. Implementation of a pre-tuned controller.

The utilisation of high performance computer systems for automation allows the application of advanced control techniques to overcome existing dynamic limitations in processes, particularly if older mechanical equipment is utilised. Case studies have demonstrated that steady state optimisation provides the basis to increase plant throughput up to 15 per cent (Keintzel *et al*. 1998). Subsequent dynamic optimisation minimises the effort required for control system design through off-line evaluations and potentially provide a further 10 per cent gain.

3.8.4 Flour mill optimisation to date

Niernberger and Phillips' (1972) work is typical of the application of computer techniques to the milling industry. In this case linear programming methods are employed to optimise wheat grist formulation. The paper by Liu *et al*. (1992) demonstrates a similar approach twenty years later but encompassing a broader range of parameters. Their work produced a model of the milling process, but made no attempt to optimise the process.

Willm (1985) demonstrated the manner in which mill optimisation is performed currently. This is an effective method of optimisation but it is totally empirical. The analysis discusses the practice of visiting the production site, visually assessing materials and acting on the observations based on experience. This practice is effective where the individual is experienced but once this person leaves the site the experience leaves with him and performance can only deteriorate from that point.

Takahashi *et al*. (1990) developed a knowledge-based system whose function was to store in a hierarchical fashion all parameters associated with a particular process flow. A user interface was developed which enabled unskilled operators to retrieve and store relevant information. Such a system could be developed further to incorporate models of the process. This application was merely a database that stored all mill technical parameters in a structured manner for intuitive data recovery. No analysis or manipulation of the data was performed.

Moss *et al*. (1991) provide an example of how training and staff development within the flour milling industry is practised. The objective of all training programmes is vocationally oriented and so the finer points of optimising processes are lost on trainees.

Odhuba (1999) developed models of the breakage of wheat at first break and used the General Algebraic and Modelling System (GAMS)[19] to optimise the non-linear models obtained. This is the first piece of work in this field that aims

[19] GAMS is a proprietary computer-based optimisation package.

to examine scientifically the phenomena at work in roller mills and to optimise this operation subsequently.

Campbell and Webb (2000) have taken the breakage matrix approach to modelling comminution operations and applied it to the roller milling of wheat in the flour milling process. This work demonstrates conclusively that flour milling operations can be modelled using discrete mathematical methods.

Owens (2000) built on the work mentioned above in an effort to develop an integrated optimisation technique for flour mill processes.

3.8.5 Conclusion

Process optimisation is a large and complex area, with many possible options from which to choose the best solution to a particular problem. The findings of this review are as follows:

- Optimisation of milling operations to date has been simplistic and focused on macro models of the process. No attempt has been made to optimise the process in a calculated fashion.
- The basic framework for optimisation already exists in many mills, namely DCS and/or SCADA systems.
- There are many advantages to be gained from the successful application of process optimisation, all of which are profitability enhancing.
- PID feedback control is the accepted control method in milling at present, but this form of control is not suitable for whole process optimisation.
- Simulated Annealing, Genetic Algorithms and Rule-based control would appear to be the systems of choice for an advanced control system in mills. This is because the former two are combinatorial optimisation methods that can operate with many different data set types and even discontinuous functions. The latter system could be employed to incorporate the considerable experience base present in operating mills.
- Reyman's (1992) summary lists the steps that need to be taken to enact an advanced control system. There are currently some gaps in the milling knowledge base that need filling. These gaps include the lack of a global performance strategy for mills, the almost complete absence of process models and dynamic modelling simulations and very little formal understanding of the behaviour of the process. Reyman (1992) also stated the importance of process instrumentation for reliable operation of advanced control systems.

3.9 The future

The aspects of milling discussed highlight the way in which this sector of the cereals processing industry has developed to date and may develop in the future. Developments in machine capacity have been dramatic, but progress in this area

is sure to slow down due to limits in material properties being reached. However, maximising utilisation of that capacity has moved to the forefront of both commercial and academic research. Some of that effort has resulted in commercial applications, namely the adoption of computer control to facilitate longer operational runs in plants as well as minimising downtime. However, sophisticated control strategies have yet to make an impact in the sector. There is considerable work being undertaken in this area and many other industries have already employed these techniques commercially. It is therefore simply a matter of time before advanced control systems and optimisation algorithms become an important aspect of commercial milling operations.

In addition to these internal developments within the process, external influences will have a significant impact on the manner in which mill processes are operated. For example, new products and product specifications will demand different things from mill processes and necessitate change.

It is also certain that technologies that are in early stages of application today, for example double grinding and debranning, will become normal features of mill processes and gain greater acceptance among the milling community at large.

To conclude, the future of development in the milling industry is likely to take the form of incremental development of those technologies mentioned above and the introduction of the new technologies discussed in some form.

3.10 References

BIRCH B (1930) *The Roller Mill*, National Joint Industrial Council for the Flour Milling Industry, Pamphlet No. 16.

BRABEND P (1962) 'Theory for a High Speed Roller Mill', *Getreide Mehl. Brot*, **34**, 439–40.

BRINKSMEIER E, TOENSHOFF H K, CZENKUSCH C and HEINZEL C (1998) 'Modelling and optimization of grinding processes', *Journal of Intelligent Manufacturing*, **9**, 4, 303–14.

BUHLER (1981) Malt Mill, Diagram, Buhler Ltd, CH9240, Uzwil, Switzerland, Dec, 78, pp. 7, 8.

CAMPBELL G M and WEBB C (2001) On predicting roller milling performance, part I: the breakage equation, *Powder Technology*, In press.

CHEN S, ISTEPANIAN R H, WHIDBORNE J F and WU J (1998) 'Adaptive simulated annealing for designing finite-precision PID controller structures', *IEE Colloquium (Digest)*, 521, 3/1–3/3.

CURRAN S, EUSTACE W and GWIRTZ J (1994) 'The effect of cloth tension on sifting performance', *Association of Operative Millers*, May, 6379–81.

DAVIES A M C and GRANT A (1987) 'Review: near infra red analysis of food', *International Journal of Food Science and Technology*, **22**, 191–207.

FEARN T and MARIS P I (1991) 'An application of Box Jenkins methodology to the control of gluten addition in a flour mill', *Applied Statistics*, **40**, 3, 477–84.

FLORES R (1989) Computer Simulation Model for Wheat Flour Milling Systems, PhD Thesis, Kansas State University, Manhattan, Kansas, USA.

FLORES R A, POSNER E S, MILLIKIN G A and DEYOE C W (1991) 'Modelling the milling of hard red winter wheat: estimation of cumulative ash and protein recovery', *Transactions of the ASAE*, **34**, 5, 2117–22.

FORDER D E (1996) Flour Milling Process for the 21st Century, Conference Presentation, Cereals: Novel Uses and Processes, UMIST, PO Box 88, Sackville St, Manchester M60 1QD, England, 4–6 June 1996.

GRAF D O (1994) 'Verbesserung zum Vermahlen von Kornerfruchten', *Die Muhle + Mischfuttertechnik*, **131**, 14, April, 172–3.

HART D, CHENG P, JOHNSTON J, GOODALL A and OGDEN-SWIFT A (1996) Reducing energy costs in industry with advanced computing and control, Energy Efficiency Enquiries Bureau, ETSU, Harwell, Didcot, Oxfordshire, OX11 0RA, England.

HOOK S, BONE G and FEARNE T (1984) 'Influence of air temperature and relative humidity on milling performance and flour properties', *Journal of Science in Food and Agriculture*, **35**, 597–600.

KEINTZEL G, SCHOISSWOHL M, VORSTANDLECHNER P, AISTLEITNER K and SCHNEEWEIS R (1998) 'Advanced control methods in rolling applications', *Proceedings of the 1998 IEEE Industry Applications Conference*, **3**, 2263–9.

LINKO P, UEMURA K and EERIKAINEN T (1992) 'Neural networks in fuzzy extrusion control', *Institution of Chemical Engineers Symposium Series*, No. 126, 401–20.

LIU M C, FLORES R A, DEYOE C W and POSNER E S (1992) 'Assessment of a computer simulation model for the flour milling industry', *Cereals Food World*, **37**, 8, 649–54.

LIVESLAY W A and MARIS P I (1992) 'Computer integration and programmable automation in the UK milling and baking industries', *Institution of Chemical Engineers Symposium Series*, No. 126, 499–505.

MAIER R W and WHITING W B (1998) 'Variation of parameter settings and their effects on performance for the simulated annealing algorithm', *Computers & Chemical Engineering*, **23**, 1, 47–62.

MASON W (1994) 'Stressing the point', *International Milling*, Aug., **188**, 16–18.

MCFARLANE I (1992) 'Use of in-line sensors and closed-loop control for food manufacturing processes', *Institution of Chemical Engineers Symposium Series*, No. 126, 133–64.

MOSS R, MCCORQUODALE J, BYRNES T, EGAN J, LEE A, REID A and STEPHENSON J (1994) 'The effect of mill variables on starch damage and other aspects of flour quality', *Association of Operative Millers*, November, 6459–62.

MOSS R, REID A and STEPHENSON J (1991) 'An overview of the Australian milling industry and research carried out on the bread research institute pilot mill', *Association of Operative Millers Bulletin*, Aug., 5923–29.

MOSS R, STENVERT N, KINGSWOOD K and POINTING G (1980) 'The relationship between wheat microstructure and flour milling', *Scanning Electron Microscopy*, **III**, 613–20.

MURATA S, SOROUR H, IMADA D and AMARATUNGA K (1994) 'Vacuum effect on milling wheat', *Journal of the Faculty of Agriculture Kyushu University*, **39**, 12, 59–66.

NABIM (1990) Mill Processes (I), Flour Milling Industry Correspondence Course, 1st Edn, NABIM, 21 Arlington St, London SW1A 1RN, p. 37.

NIERNBERGER F F and PHILLIPS D P (1972) 'Computerisation of wheat mixes', *Cereal Science Today*, **17**, 7, 194–7.

NURET H and JEANNOT J (1951) 'La détermination du blutage dans un moulin', *Bulletin de L'ENSMIC*, No. 123.

NURET H and THIELIN P (1949) 'Étude quantitative et qualitative d'un diagramme-type de 300–350 quintaux par 24 heures', *Bulletin de L'ENSMIC*, No. 113.

ODHUBA E (1999) Optimisation of wheat breakage in flour milling, PhD Thesis, SCGPE, UMIST, PO Box 88, Sackville St, Manchester, M60 1QD, England.

OSBOURNE B G (1980) 'Current and future applications of NIR analysis, Paper presented at the technical session of the FMBRA Annual General Meeting, 2 April.

OWENS W (2000) Engineering the flour milling process, PhD Thesis, University of Manchester Institute of Science and Technology, PO Box 88, Sackville St., Manchester M60 1QD, England.

POSNER E S and HIBBS A N (1997) *Wheat Flour Milling*, AACC, 91–187.

PRATIQUE J (1952a) 'Le debit des appareils à cylindres, *Bulletin de L'ENSMIC*, No. 131, 175–82.

PRATIQUE J (1952b) 'Le mouvement des produits sur le tamis de plansichters', *Bulletin ENSMIC*, No. 130, 154–9.

PRATIQUE J (1952c) 'Le mouvement des produits sur le tamis de plansichters', *Bulletin ENSMIC*, No. 127, 3–8.

PRATIQUE J (1952d) 'Le mouvement des produits sur le tamis de plansichters', *Bulletin ENSMIC*, No. 132, 218–23.

PRATIQUE J (1953) 'Le mouvement des produits sur le tamis de plansichters', *Bulletin ENSMIC*, No. 137, 207–14.

PRATIQUE J (1954a) 'Le mouvement des produits sur le tamis de plansichters', *Bulletin ENSMIC*, No. 140, 62–7.

PRATIQUE J (1954b) 'Le mouvement des produits sur le tamis de plansichters', *Bulletin ENSMIC*, No. 141, 106–7.

PRESS W H, FLANNERY B P, TEUKOLSKY S A and VETTERLING W T (1988) *Numerical Recipes, The Art of Scientific Computing*, Cambridge University Press, Cambridge, New York, Chapter 10, pp. 274–334.

PSOTKA J (1999) Personal Communication, American Institute of Baking, Manhattan, Kansas, USA.

REYES E N and STEIDLEY C (1998) 'Optimization using simulated annealing, Northcon – Conference Record, pp. 120–6.

REYMAN G (1992) 'Integrated control development for food industry', *Institution of Chemical Engineers Symposium Series*, No. 126, 165–78.

RUFFET M, 'Break Roller Mill Performances' (1994) *Primary Cereal Processing*, VCH Publishers, pp. 189–210.

SCANLON M and DEXTER J (1986) 'Effect of smooth roll grinding conditions on reduction of hard red spring wheat farina', *Cereal Chemistry*, **63**, 5, 431–5.

SCANLON MG and LAMB J (1993) 'Particle size formation during food comminution operations', *Powder Technology*, **74**, 279–86.

SCANLON MG and LAMB J (1995) 'Analysis of size reduction of foods by breakage and selection functions', Poster given at IX World Congress in Food Science, Budapest.

SEXTON RS, DORSEY RE and JOHNSON JD (1999) 'Optimization of neural networks: a comparative analysis of the genetic algorithm and simulated annealing', *European Journal of Operational Research*, **114**, 3, 589–601.

SIMON B (1997) *Henry Simon of Manchester*, Perdue Press, Chapter 4, pp. 47–58.

SMITH L (1938) *Flour Milling Technology* (2nd edition), Thomas Robinson & Son Ltd, Rochdale, England.

SPEIGHT J (1969) 'The plansifter sieve', *Milling*, Apr, 412–14.

STORCK J and TEAGUE WD (1952) *Flour for Man's Bread, A History of Milling*, University of Minnesota Press, Minneapolis.

SZAUTER R (1985) 'Increasing the capacity and efficiency of plansifters', *Getreide Mehl. Brot.*, **38**, 6–9.

TAKAHASHI K, HOSOKOSCHI J, YIMING C, HUANG YW and FAN LT (1990) 'Hierarchically-structured knowledge representation scheme for a flour milling system', *Association of Operative Millers Bulletin*, Dec., 5793–800.

THUY LTN (1994) 'Deformation and fracture behaviour of grains during milling in the roll gap', *Tec. Molit*, **45**, 625–32, 637.

TILLMAN FA, WARD A and JANZEN E (1969) 'Linear programming in grain processing; let's take a trip', *Bulletin of the Association of Operative Millers*, 3075–9.

TREADGOLD NK and GEDEON TD (1998) 'Simulated annealing and weight decay in adaptive learning: the SARPROP algorithm', *IEEE Transactions on Neural Networks*, **9**, 4, 662–8.

VISHNUPAD P and SHIN YC (1998) 'Intelligent optimization of grinding processes using fuzzy logic', *Proc Instn. Mech. Engrs*, **212**, Part B.

WANZENREID H (1970) 'Grinding with smooth rolls', *Milling*, Nov., 18–21.

WATSON A and RAMSTED P (1994) *Corn, Chemistry and Technology*, American Association of Cereal Chemists, St. Paul, Minnesota, USA.

WILLM C (1985) 'Étude de diagramme', *Industries des Céréales*, **37**, 11–15.

WINGFIELD J and FERRER A (1984) 'Multiple sieve sifter performance using various combinations of feed rates circles and speeds', *Journal of Food Process Engineering*, **7**, 91–110.

4

Biotechnology, cereal and cereal products quality

R. J. Henry, Southern Cross University, Lismore

4.1 Introduction: productivity, product quality and safety

The value of cereal crops can be improved in two main ways. Firstly, the quantity of crop produced can be increased and secondly, the quality of the harvested grain can be enhanced. Linked to the question of quality is also the improvement of safety (Henry and Kettlewell 1996). These two approaches are not entirely independent. Improvements in the productivity of cereal varieties can be associated with improved quality of the grain.

Removing constraints imposed by biotic stress (the impact of pests and diseases) is an attractive option for improving the productivity of cereal crops. The introduction of genes conferring resistance to major pests and diseases provides an opportunity to improve productivity by removing the losses associated with the specific disease targeted. The introduction of herbicide resistance into cereal crops allows a reduction of losses associated with competition from weeds. Both these approaches may lead to associated improvements in grain quality. Freedom from weeds can reduce or eliminate the problem of weed seed contamination in cereal grain. Removal of disease constraints may result in improved grain quality avoiding the losses in quality associated with the presence of disease organisms in the crop. Diseases often result in reduced grain size and associated quality deterioration.

The quality of cereal grain may be improved either in a nutritional sense or by improving the processing properties of the grain. Most conventional plant breeding has addressed the need for appropriate processing qualities in new cereal varieties. Biotechnology may allow more emphasis to be placed on novel alterations of nutritional quality.

Molecular markers can be used to improve the efficiency of cereal breeding programs aiming to improve the value of cereal crops. Molecular analysis may also be applied in fingerprinting or identification of cereal genotypes with more immediate potential for improvement of cereals. For example, molecular analysis of genotypes can be used to monitor seed purity and identity prior to planting and to characterise grain lots in trading and processing (Henry *et al.* 1997). The composition of cereal-based foods or products can be monitored to ensure authenticity of labelling. These applications of biotechnology can have an almost immediate impact on the quality and value of cereal production.

Genetic engineering offers the possibility of going beyond these short-term outcomes of biotechnology applications to the generation of more novel cereals with increased value in the longer term (Henry 1995). In the sections that follow, the main benefits of genetic engineering are summarised under the following headings:

- productivity
- product quality
- safety.

4.2 Herbicide resistance

The control of weeds in cereal crops may have a major influence on grain yields but usually has a much lesser impact on grain quality (Kettlewell 1996). This is because the major effect is in early crop growth impacting more on grain number than size. Late weeds are an exception. Generally, contamination of seed crops with weed seeds is likely to be the major quality defect.

4.2.1 Classes of herbicides and available resistance genes

Resistance genes are available for many different classes of herbicide. The major groups of herbicides and the genes available for conferring resistance to these herbicides are listed in Table 4.1.

The most attractive herbicide resistance genes for introduction into cereals are those that confer resistance to herbicides that are considered safe in the environment. Herbicides with low mammalian toxicity and little or no other environmental problem may be attractive alternatives to the more specific herbicides currently in use. The development of transgenic cereals with resistance to appropriate herbicides may facilitate the reduction in use of less desirable herbicides in agriculture and food production.

4.2.2 Problems of escape of herbicide genes to weeds

A major risk associated with the production of transgenic cereals with herbicide resistance is the possibility that new weeds may result either from escape of the

Table 4.1 Herbicide resistance genes (Henry 1997)

Herbicide	Mode of action
Glyphosate	Inhibits 5-enolpyruvyl shikimate-3-phosphate (EPSP)[1]
Sulphonylureas	Inhibits acetolactate synthesis (ALS)[2]
Imidazolinones	Inhibits acetolactate synthesis
Triazalopyrimidines	Inhibits acetolactate synthesis
2-dichlorophenoxyacetic acid	Auxin action
Phosphinothricin	Inhibits glutamine synthesis
Atrazine	Inhibits electron transport in photosystem II

[1] Prevents the synthesis of aromatic amino acids.
[2] Prevents the synthesis of leucine, isoleucine and valine.

gene into other plants or by the transgenic cereals themselves becoming weeds. The production of transgenic plants with resistance to herbicides that have unique modes of action is highly desirable. Multiple herbicide resistance may arise if genes target biochemical pathways that are associated with the action of several classes of herbicide. The problem of escape of herbicide resistance genes from cereals is likely to be a more serious issue for species that are out-crossing rather than for those that are predominantly or exclusively self-pollinating. In some species such as rice, weedy varieties have developed as a result of current agricultural practices. The introduction of herbicide-resistant rices could lead to the development of a further class of weedy rices based upon their herbicide resistance if appropriate agricultural practices are not adopted in association with the new varieties. This could require production to be limited to specific regions and to include the rotation of herbicides or varieties. Despite these limitations, herbicide-resistant cereals should provide enormous advantages in the enhancement of cereal productivity.

4.3 Disease resistance

4.3.1 Disease resistance

Diseases may seriously reduce grain quality. Fungal diseases may have a large impact on grain quality (especially grain size) because they may be active on the leaves during grain filling or directly infect the head. Insect pests may reduce yield and grain quality. Post-harvest damage from insects can be a major problem (Mills 1996). Mycotoxins resulting from fungal growth on the grain are a serious safety issue for grain from some environments.

Development of pest- and disease-resistant cereals provides a major opportunity for enhancing cereal productivity. In many environments single diseases may be associated with very serious losses in grain yield. Breeding resistant varieties has been a major strategy used in increasing cereal yields. Transgenic cereals with high levels of disease resistance may extend the options available from conventional plant improvement. Resistance to a wide range of

biotic factors may be engineered using appropriate genes. Resistance to viruses, bacteria, fungi, nematodes and insects has been reported.

4.3.2 Manipulation of expression of native genes for disease resistance

Classical cereal breeding has involved the combination of disease-resistant genes from different sources to produce commercial varieties with effective disease resistance (Hammondkosack and Jones 1997). Molecular markers or direct analysis for the presence of the required gene are now used to improve the efficiency of selection of disease-resistant lines in breeding.

One option for the engineering of cereals with disease resistance is to manipulate or enhance the levels of expression of genes already present in the genome. Specific options include the expression of defence genes using constitutive promoters such that the defence gene product was always produced by the plant regardless of the presence of a specific pathogen. Promoters induced by the disease are also an important option. This approach allows defence gene products to be produced by the plant only in response to attack by the pest.

4.3.3 Novel genes for disease resistance

Novel genes from other plants or non-plant sources (Bowles 1990) may provide durable resistant genes for use in cereals (Table 4.2). Examples have been described for bacteria, fungi, nematodes and insects (Shewry and Lucas 1997). The use of virus-derived sequences for breeding virus-resistant plants has been a notable success in many species (Buck 1991, Malik 1999).

4.3.4 Environmental impact of disease resistance

Transgenic plants with resistance to pests and diseases may have a significant impact on the environment (Dale and Irwin 1998). The risks should be similar to

Table 4.2 Some novel pest- and disease-resistant genes of potential value in cereals (Malik 1999)

Type of protection	Gene	Source
Virus	Coat protection	Barley yellow dwarf
	Coat protection	Maize chlorotic mottle Maize chlorotic dwarf Maize chlorotic mosaic
Bacterial and fungi	Chitinase Glucanase	Various Various
Insects	Bt toxin	*Bacillus thuringiensis*

those of traditional resistance breeding. However, if the transgenic strategies prove dramatically more effective they could seriously deplete populations of plant pathogens and even lead to the extinction of highly specific pest organisms. Evaluation of these risks is important in successful applications of transgenic technology (Bergelson *et al*. 1999).

4.4 Improved nutritional properties

4.4.1 Cereals and human nutrition

Cereals are a very important part of human diets. The three major species, wheat, maize and rice, account for a large proportion of the calories and protein in human diets. The importance of cereals in the food chain is also attributable to the extensive use of cereals in the diets of animals. The major constituents of cereals are the carbohydrates and proteins. Other grain components such as lipids and vitamins may be of great significance in human nutrition because of the large contribution of cereals to the diet. Biotechnology provides new options for manipulation of the nutritional properties of cereal grains. The carbohydrates of cereals include the simple sugars, the more complex oligosaccharides such as fructans, storage polysaccharides of the grain (starch) and the cell wall polysaccharides, all of which are of nutritional value. All of these carbohydrate components are potential targets for manipulation in improvement of cereal quality. (For example, sugar beet has been transformed to produce fructans (Sevenier *et al*. 1998).) Benefits that may result include reduced cariogenic bacteria (dental health), lower energy value and stimulation of beneficial bacteria in the colon. The sugar content may also influence the quality of the grain for various products. Fructans may be considered to be important to human nutrition because of their possible role as soluble fibre (Ninees 1999). Starch, as the major component by weight of the grain, may have a great impact on nutritional quality. Resistant starches (not digested in the gut) may be considered critical in influencing the incidence of certain human diseases, such as heart disease. The cell wall polysaccharides may also be important as either soluble or insoluble fibre, depending on the composition of the polysaccharides in the cereal product. Soluble fibres may reduce the risk of heart disease while insoluble fibres contribute to reduced risk of colonic cancers.

Cereal proteins are not well balanced in amino acids required in a nutritionally balanced diet, and genetic engineering may provide opportunities to improve the balance of essential amino acids in cereal-based diets. The lipids in cereals are generally of limited importance in human nutrition but may be important in animal diets. The manipulation of iron levels in cereals through the introduction of haemoglobin illustrates the potential application of biotechnology to enhancing the nutritional value of cereals.

4.4.2 Cereals and animal nutrition

The major requirements of animals differ depending on whether they are monogastric or ruminant animals and the potential of biotechnology to improve the nutritional values for these two classes of animals differs. Ruminants have a much greater capacity to digest cereal fibre effectively. Soluble fibre components may also be important. For example, the β-glucans of barley limits the use of this cereal in the diet of chickens because of its adverse impact on nutrient utilisation.

4.4.3 Cereals in aquaculture

The increasing shortage of seafoods (declining fish stocks in the oceans and increasing human population) indicates great potential for enhanced use of cereals in aquaculture diets used in fish farming (Sarac and Henry 1998). Cereals provide a very cheap option and if biotechnology can be used to enhance the nutritional value of cereals as a component of aquaculture diets we can expect wide-scale use of cereals for the production of aquaculture products. Cereals may have an important role as a binder in aquaculture feeds. Improvement of protein and lipid composition by genetic engineering may produce more useful cereal aquaculture feeds.

4.5 Improved processing qualities

The quality requirement of cereal processors may be complex as indicated for barley in Table 4.3. This table lists a few of the characteristics defined as requirements of a barley for use in malting and brewing. Establishing opportunities for quality improvement requires a knowledge of the processes used to convert cereals into end products.

Table 4.3 Barley quality characteristics required for brewing (Henry 1990)

Character	Requirement
Grain colour	Bright, white aleurone
Grain size	Plump grains, 90% above 2.5 mm, as little as possible below 2.2 mm
Protein content	Optimum 10.5%–11.5% (dry basis)
β-glucan content	Low – maximum and minimum not defined
Husk	Minimum required for brewing
Dormancy	As little as possible (but no pre-harvest sprouting)
Rate of modification	As fast as possible (steeping and germination maximum 110h)
Malt extract	As high as possible (only too high if protein on husk becomes limiting)
Malt enzymes	As high as possible (minimum requirements for diastatic power and β-glucanase)

4.5.1 Cereal quality and process requirements: the potential role of biotechnology

The processing of cereals involves a wide range of techniques with very differing raw material requirements. Several of the major processes of cereal processing will be described here in an attempt to identify the major opportunities for biotechnology to be applied to improving cereal processing quality.

Milling

The milling of cereals (Fig. 4.1) involves processes that are dependent substantially on the anatomical structure of the grain. The potential for single genes to be manipulated in ways that enhance milling quality may be limited because of the large number of grain characteristics contributing to milling performance. The shape of the grain and adherence of the various outer layers are of great importance. Hardness is also a key attribute in milling. Grain colour is a key quality attribute that is influenced by the milling process. The levels of pigments and the size of particles generated in milling both influence colour. The contamination of endosperm fractions with more highly coloured outer layers such as bran are key determinants of colour (Ziegler and Greer 1971).

Baking

Many components of cereals such as wheat are important in baking quality and are obvious candidates for the application of biotechnology. The requirements of modern high-speed plant bakeries are for a very consistent quality. Characteristics such as dough stickiness associated with some alien (non-wheat) sources of disease resistance in wheat are serious problems in these high-capacity facilities.

The major components of wheat all contribute to baking quality and are thus targets for genetic improvement of baking quality. Proteins are essential for the visco-elastic properties of wheat doughs. Starch and cell wall polysaccharides (e.g., pentosans) also influence baking quality. The breakdown of starch by amylases is a key process in baking. The pentosans of the cell wall also have a significant influence on loaf quality (Pomeranz 1971).

Malting

Malting is the first step of processing grain for use in brewing and distillation. The malting of cereals, most specifically barley, is a process of germination. The rate of germination and the changes in the composition of the barley during malting are potentially important targets for biotechnology. The breeding of malting barley varieties focuses on several major quality characteristics associated with the malting process.

Enzymes are involved in the breakdown of cell walls during malting. The β-glucanases expressed during germination are essential to ensure that the levels of β-glucan in the malt are low. High malt β-glucan levels contribute to high

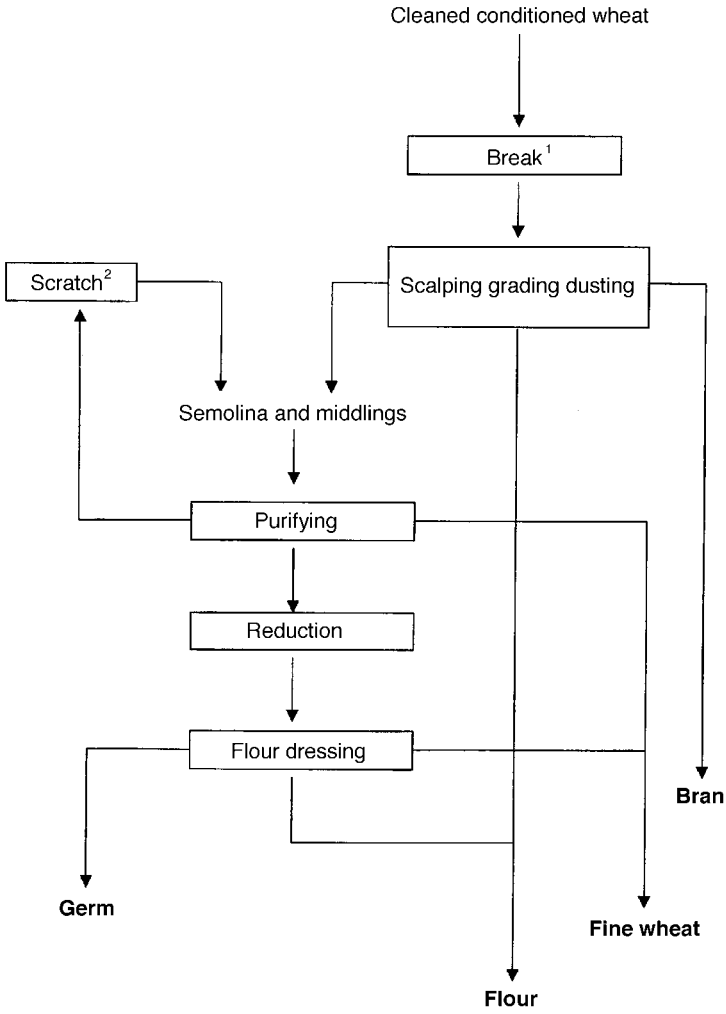


Fig. 4.1 Schematic of flour milling (based on Kent and Evers 1994).

wort viscosity, poor wort and beer filtration and potential hazes in finished beer.

Brewing

The brewing of beer from malt requires specific malt specifications that are potentially able to be manipulated using biotechnology. Diversification of beer styles and markets are imposing divergent raw material requirements for the different beer styles.

Sufficient levels of starch degrading enzymes in the malt are necessary to ensure breakdown of starch to fermentable sugars during brewing. The amount

of starch (adjunct) added in the form of rice or maize is a key determinant of the level of starch degrading enzyme required in the malt. The relative levels of different starch degrading enzymes are important in determining the nature of the substrate for fermentation and the sugar, alcohol and oligosaccharide content of the beer. The alcohol and residual sugar content (sweetness) are influenced by the levels of fermentable sugars and the non-fermentable oligosaccharides contribute to the taste (mouthfeel).

Distilling
Distillation is a process where the product quality may be less dependent on the raw materials than many other processes and may be a less important target for biotechnology application in relation to the cereal raw material. However, the quantity of starch available for fermentation might be enhanced.

Extrusion
Extrusion (production using high temperatures and pressures) of cereal products is an increasingly important process in the production of a wide range of products including snack foods, breakfast cereals and pet foods. The processing properties required are complex but may be enhanced by the application of biotechnology.

4.5.2 Cereal quality: the case of wheat

Wheat is used for a wide range of products with differing quality requirements (Fig. 4.2). The importance of different wheat grain components and characteristics depends on the ultimate end use product (Morris and Rose 1996). The protein quality is much more important for products such as breads than for cakes and biscuits. Enhanced levels of desirable high molecular weight glutenins may be desirable in wheat for use in breadmaking. Manipulation of starch synthesis and starch properties may be more important in products such as noodles. Colour may be controlled by a small number of genes and has differing importance. For example, the yellow pigments in durum wheat are considered highly desirable while some noodle products require very white flour. The improvement of specific attributes using biotechnology needs to target characters specific for particular end uses. Wheat is used to produce the types of food products listed in Table 4.4 (Morris and Rose 1996).

Improvement of the value of wheat for this wide diversity of uses requires the matching of wheat characteristics to specific end product requirements. For example, wheat with different combinations of protein and hardness are better suited to particular end uses (Fig. 4.2). However, some combinations of characteristics will not be optimal for any major end use.

Genetic improvement of wheat quality needs to address targets relevant to the end use characteristics of wheat from a particular environment or region. For example, selection for specific starch metabolism mutants or engineering of

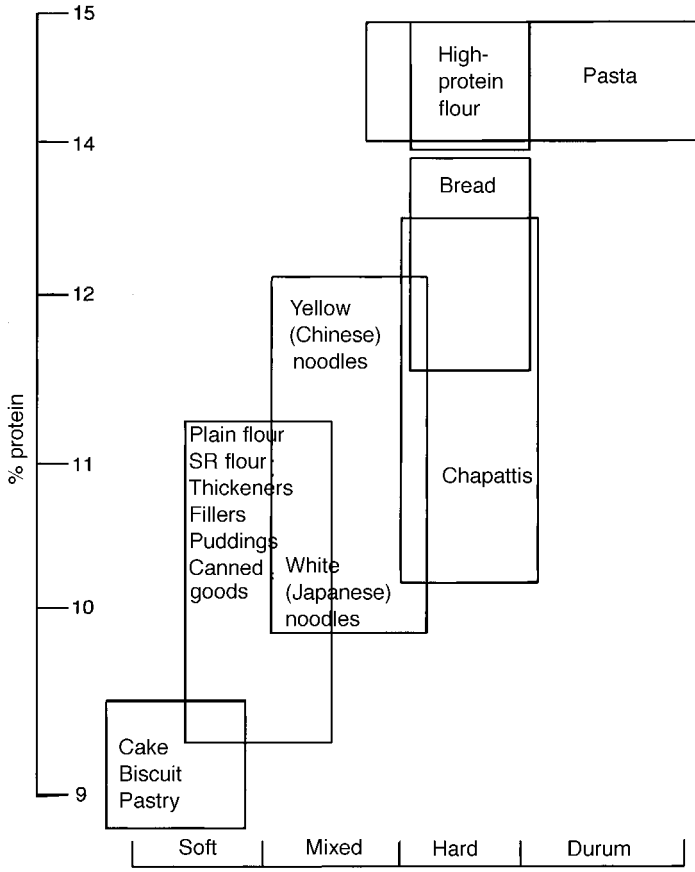


Fig. 4.2 The broad range of wheat types required for different uses (Moss 1978).

improved starch qualities (such as starch-pasting properties) may be important in regions producing noodle wheats while storage protein modification may be more appropriate in regions producing bread wheats (Anderson 1996).

4.5.3 Process requirements: the case of beer production

The production of a specific product such as beer can be the basis for analysis of opportunities for application of biotechnology. The traditional process from barley to beer is depicted in Fig. 4.3. Some key attributes for malting and brewing have been described above. The efficiency of this process may be influenced by the composition of raw materials (especially the cereals) used and the type of beer to be produced.

Changing composition of barley by genetic engineering might alter performance in any of the many steps in the process of beer production (Henry 1996, McElroy and Jacobsen 1995). The production of proanthocyanidin-free

Table 4.4 Food products produced from wheat

Fermented (leavened) breads	white pan breads	white pan loaves, sandwich (hamburger buns), raisin breads, variety breads
	hearth breads	baguettes, Vienna breads, sourdough breads
	sweet goods	Doughnuts, cinnamon rolls, coffee cakes, danish, puff pastries, French brioche
	steambreads	Chinese northern style steambread, Chinese southern style steambread, *Pan de sol* (Philippines), *Saka-manju* (Japan), *Mushi-manju* (Japan)
Flat breads and crackers	flatbreads	chapatti, rotti, naan, paratha, poori, balady, pia, banabri
	tortillas	
	pizza crust	
	muffins	
	crumpets	
	bagels	
	pretzels	
	crackers	soda crackers, cream crackers, water biscuits, graham crackers, sprayed crackers, savoury crackers
Cookies and cakes	pie crusts	
	cookies (biscuits)	
	scones	
	moon cake	
	batters (ice cream cones, pancake and waffles)	
	cakes	
	tempura	
	soup thickeners	
Noodles	alkaline noodles	
	white salted (Udon)	
	soba	
	buckwheat	
	egg	
	noodles may be fresh, dried, frozen or instant.	
Breakfast foods		
Starch/gluten		
Pasta and durum products	pasta	spaghetti, macaroni, lasagne, fettuccine
	couscous	
	bulgur	
	durum bread	

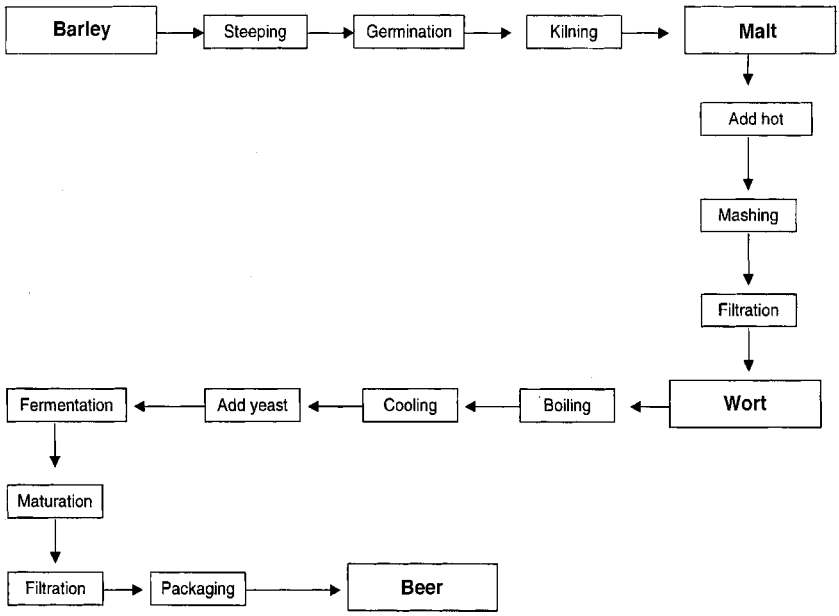


Fig. 4.3 Traditional beer brewing (Henry 1996).

barley to reduce haze and improve the shelf life of beer in cold storage has been achieved using mutants and may be more precisely controlled using genetic transformation to block specific steps in the pathways leading to proanthocyanidin formation. One complication of this change may be that the absence of proanthocyanidins in the wort may result in reduced protein precipitation during boiling. The overall result can be a decline in product stability due to increased levels of protein in the beer. This illustrates the need to understand all the interactions during processing before implementing changes to novel cereal raw grains.

Molecular markers have been developed for many malting quality attributes and these may accelerate the development of new malting quality barley varieties for use in beer production (Han *et al.* 1997).

Genetic engineering of barley to improve cell wall breakdown during malting and brewing (Fincher 1994) and lipids contributing to beer flavour (Hoekstra *et al.* 1994) have been the subject of active research. Modifications of starch properties and metabolism and protein composition may also be important (Edney 1996). A fundamental limitation is that extract levels are limited by the need to preserve a minimum amount of husk to act as a filter bed in many traditional brewing processes. Grains with extremely high proportions of endosperm necessary for extreme extract levels will have insufficient husk. New filtration technologies could overcome this limitation allowing the development of very high extract barleys. Reliance on enzymes in the malt for starch breakdown during mashing and the issue of yeast nutrition also requires that a

minimal protein level be maintained. Genetic engineering could allow a higher proportion of proteins in the malt either to contribute useful enzyme activity or support yeast nitrogen nutrition.

4.6 Improved cereal quality control

The value of cereals can be improved by better specification of the identity and composition of cereals in marketing. The major contributions to achieving this type of value addition are quality assurance programs and enhanced tools for analysis of products for chemical and microbial contamination and for genetic identity and purity.

4.6.1 Chemical and microbial purity

The strict application of quality assurance principles can ensure cereal safety and value. New technologies allow the use of ELISA tests to establish the level of pesticide residues and DNA-based analysis of microbial contaminants.

4.6.2 Genetic purity

The identity of a cereal genotype defines many of the quality characteristics such as protein content and grain size. This can define the processing value and optimal end use of a parcel of cereal grain. Protein content can currently be measured rapidly in the field using near infra-red reflectance (NIR). The development of rapid genotyping methods would find wide application in the cereal industry and allow a relatively complete objective description of samples for commercial valuation.

Distinction of high-value noodle wheats from visually similar wheats of low noodle quality, and distinction of malting and food barleys with similar appearance, are good examples of the areas of potential application of this technology. Genetic purity and level of admixture are also important attributes to assess in commercial trading because of the financial incentive to add low-value grain to parcels of very high value but visually similar genotypes. Rapid DNA extraction from grain is a key technical requirement for successful application of these methods.

4.7 Examples of transformed wheat and barley

4.7.1 Desease resistance

The first experiments to engineer resistance in barley focused on barley yellow dwarf virus. Wan and Lemaux (1994) transformed barley with a construct containing the coat protein of the virus under control of the constituent 35S promoter. This approach was based on the results of virus protection

experiments with dicots. The experiments with dicots showed that over-expression of the viral coat protein could result in viral protection. The mechanism of this protection is not completely understood though it is thought to act via silencing of the activity of the viral genome. Several of the transgenic barley lines were resistant to the barley yellow dwarf virus. However, no field trials have been conducted yet.

4.7.2 Improved nutritional properties

Barley grains have low contents of lysine and threonine and have therefore poor nutritional value for animals. The biochemistry of the biosynthetic pathways for threonine and lysine are well understood and it appears that there are two major regulatory enzymes: aspartate kinase (AK) and dihydrodipicolinate synthase (DHPS). Both enzymes in barley are subject to feedback inhibition by the end products, lysine and threonine. Mutant barley varieties have been identified in which AK lacks feedback inhibition but these barley mutants have not found any application for commercialisation. Brinch-Pedersen *et al.* (1996) have taken a transgenic approach and have expressed feedback-insensitive AK and DHPS from *E.coli* in barley. Both *E.coli* genes were under control of the constitutive 35S promoter. Analysis of the transgenic plants showed that the leaves of the transgenic barley lines contained a fourteenfold increase in free lysine and eightfold increase in free methionine. Moreover, there was a twofold increase in lysine, arginine and asparagine in the mature seeds while free proline was reduced by 50%. No differences were observed in the composition of total free amino acids in the seeds. These results suggest that this transgenic barley would be of higher nutritional value than the non-transformed. The next step would be to introduce these genes into a current malting variety and to determine what effect the transgenes have on malting quality. If there is no effect on the malting quality then this barley would be of no particular interest to farmers. It quite often occurs that the malting barley variety in the field is not really up to malting quality. This barley will be used for feeding animals and the farmers might get a better price for high-lysine/threonine barley.

4.7.3 Improved malting quality

Since barley is used for malting purposes to serve the brewing and distilling industry, a lot of effort has gone into transforming barley with malting-related genes. Barley has been transformed with a heat-stable 1,3-1,4-β-glucanase hybrid from *Bacillus* (Jensen *et al.* 1996), a heat-stable β-glucanase from the fungus *Trichoderma reesei* (Mannonen *et al.* 1997) and with mutagenised barley β-amylase (Kihara *et al.* 1997) with higher heat stability. The corresponding endogenous barley enzymes are heat labile and their activities are destroyed either during kilning or mashing. In the case of 1,3-1,4-β-glucanase this might result in an extract with a high glucan content which is prone to give a beer with a haze.

The nucleotide sequence of the hybrid *Bacillus* β-glucanase was extensively modified, without altering the amino acid sequence, so that the codon usage was more like the endogenous β-glucanase. This was necessary since some codons are very rarely used in barley aleurone and would therefore limit expression levels. One of the α-amylase promoters was used to drive the expression of the heat-stable β-glucanase. The result was that the transformant indeed produced a heat-stable β-glucanase during germination that was absent in the control plants. The effect of the heat-stable β-glucanase on malting, however, has to be determined.

The fungal β-glucanase was used in unmodified form and driven by the α-amylase promoter as well. The protein was expressed and functional during germination through molecular weight and iso-electric points were different from the protein isolated from the fungus. The enzyme was thermotolerant which was revealed by β-glucanase assays at 65ºC. The transgenic barley has not been used in malting studies yet but the enzyme has been exogenously applied during mashing and has proven to keep soluble glucans low and to improve filterability of the wort.

The mutagenised barley β-amylase with higher heat stability was driven by the endogenous β-amylase promoter. Several transformants were obtained that expressed a heat-stable β-amylase which was absent in the untransformed plants. The effects on malting and how the heat-stable β-amylase would alter the sugar spectra of worts remains to be investigated.

4.7.4 Improved baking quality

Considerable amounts of fundamental research into the function of glutenins in relation to dough properties have accumulated. The processing characteristics of wheat dough are thought to be closely related to the number of active high-molecular-weight glutenin genes. High gluten doughs are in general more elastic and more suitable for making bread. The function and formation of the glutenin polymer and how these could be targeted by genetic engineering are reviewed by Vasil and Anderson (1997). Several groups have now taken transformation approaches to introduce extra glutenins into wheat. Blechl and Anderson (1996) and Altpeter *et al*. (1996) introduced various constructs containing high-molecular-weight glutenin subunits (HMW-GS) into the wheat variety Bobwhite. The expression of the HMW-GS under control of a glutenin promoter was clearly demonstrated but no data on the elasticity of the dough were presented. More recently, Barro *et al*. (1997) showed that indeed dough elasticity increased with an increase in copies of HMW-GS. They transformed a wheat line containing less endogenous HMW-GS copies and the challenge now is to transform current cultivars which are already selected for bread-making quality to see whether the dough elasticity in these cultivars can also be improved.

4.8 Examples of transformed rice and maize

4.8.1 Herbicide resistance

Understanding the expression of simple reporter and selectable marker genes in transgenic plants is important in predicting the behaviour of agronomically useful genes introduced into crops. Consequently, it is imperative to assess gene expression in large seed populations. In this respect, Zhong *et al*. (1996) studied expression of the *bar*, potato proteinase inhibitor II and *uidA* (*gus*) genes, confirming their co-integration, co-inheritance and co-expression in 286 first generation (T1) plants and in 11,000 second seed generation (T2) maize plants. Similar, Brettschneider *et al*. (1997) followed the inheritance and expression of transgenes to the fourth seed generation in several inbred lines and sexual hybrids of maize. In field studies, Oard *et al*. (1996) assessed expression of the *bar* gene, giving resistance to the herbicide glufosinate, in the commercial rice cultivars Gulfmont, IR72 and Koshihikari. They confirmed that the *bar* gene was effective in conferring field-level resistance to the herbicide in rice, although, importantly, variation amongst transgenic lines required traditional breeding selection procedures to identify plants with high levels of herbicide resistance. These workers also emphasised the need to generate several independent transgenic lines of each cultivar for transgene assessments.

4.8.2 Insect resistance

Recent studies have reported the development of transgenic plants containing agronomically useful genes, in addition to those for herbicide resistance. Since insects cause substantial crop losses world-wide, it follows that engineering plants for insect resistance has, and will continue, to receive high priority. Stem-boring insects are common pests in maize and rice, and resistance against these insects has been achieved, primarily, by the introduction and expression of modified or synthetic versions of the *Bt* δ-endotoxin, a natural insecticidal toxin from *Bacillus thuringiensis*. For example, Wunn *et al*. (1996) and Cheng *et al*. (1998) introduced the *cryIA*(*b*) gene into rice cultivars, including the indica cultivar IR58, to confer resistance to yellow stem borer (*Scirpophaga incertulas*) and striped stem borer (Chilo suppressalis), while Alam *et al*. (1998) were the first to engineer a lowland deep water rice for stem borer resistance using the same gene. In addition to giving resistance to stem-boring insects, expression of the *cryIA*(*b*) gene also inhibited feeding of the leaf-folding insects *Cnaphalo crocis* and *Marasmia patnalis* on transgenic rice (Wunn *et al*. 1996). Comparisons have been made of the expression of the *Bt cryIA*(*b*) gene driven by different promoters, including the constitutive 35S and Actin-1 promoters, with tissue-specific promoters from pith tissue and the pep-carboxylase (PEPC) promoter from chlorophyllous tissue of maize. The latter promoter gave high levels of transgene expression in leaves and stems of rice (Datta *et al*. 1998).

Modified versions of the *cryIA*(*b*) gene have been used in rice transformation to give plants which induced 100% mortality in feeding yellow stem borers (Wu

et al. 1997). Synthetic truncated genes based on the *cryIA*(*b*) gene, have also been introduced into rice (Ghareyazre *et al*. 1997). The latter authors targeted low tillering aromatic rices which are particularly difficult to improve by conventional breeding because of loss of quality characteristics upon sexual hybridisation. The *cryIA*(*c*) gene has also been assessed in rice transformation for stem borer resistance (Cheng *et al*. 1998, Nayak *et al*. 1997); the *cry2A Bt* gene also conferred resistance to yellow stem borer and rice leaf folder insects in the indica rices Basmati 370 and M7 (Maqbool *et al*. 1998). A recent example of the transformation of maize for insect resistance is that of Fearing *et al*. (1997) who introduced the *cryIA*(*b*) gene into six commercial cultivars and four back-cross generations. They reported the highest concentration of insecticidal protein to be at anthesis in transformed plants. Other genes conferring insect resistance which have been evaluated in rice, including the Cowpea trypsin inhibitor (*CpTi*) gene, which increased resistance of transgenic rice to striped stem borer and the pink stem borer (Xu *et al*. 1996), and the snowdrop lectin (GNA) gene. The latter was directed against sap-sucking insects, such as the brown plant hopper, through the use of a rice sucrose synthase promoter to drive GNA expression in the phloem of transgenic plants (Sudhakar *et al*. 1998).

Nematodes cause severe crop losses in some areas, including rice cultivated in Africa. In attempts to reduce nematode damage, a cysteine proteinase inhibitor (oryzacystatin-I Delta D86) gene was introduced into four elite African rice cultivars (ITA212, IDSA6, LAC23, WAB56-104), resulting in a 55% reduction in egg production by the nematode *Meloidogyne incognita* in the roots of transgenic plants (Vain *et al*. 1998).

4.8.3 Disease resistance and environmental stress

Viral and fungal diseases reduce crop productivity. The insertion of viral coat protein genes into transgenic plants is a well-established procedure for conferring viral resistance, this approach being exploited in rice for resistance to rice dwarf virus (Zheng *et al*. 1997). Rice has also been engineered for resistance to sheath blight incited by the fungus *Rhizoctonia solani*. Thus, introduction of a 1.1 kb fragment of a rice chitinase gene linked to the CaMV35S promoter resulted in transgenic plants in which resistance to the fungus correlated directly with chitinase activity (Lin *et al*. 1995). It will be interesting to determine whether chitinase gene expression confers cross-protection to other fungal pathogens. More recently, the introduction of the stilbene synthase gene, which is thought to be involved in the sythesis of a phytoalexin, provided protection in rice to infection by the fungus *Pyricularia oryzae* (Stark-Lorenzen *et al*. 1997).

One of the challenges facing biotechnologists is to modify plants so as to increase net carbon gain (Ku *et al*. 1999). C_4 plants, such as maize and several weed species, have evolved a biochemical mechanism to overcome oxygen inhibition of photosynthesis. In an initial assessment of the feasibility of improving photosynthesis in C_3 plants, the intact gene of phospho*enol*pyruvate

carboxylase (PEPC), which catalyses the initial fixation of atmospheric carbon dioxide in maize, was introduced into japonica cultivars of rice, a C_3 plant (Ku *et al*. 1999). Transgenic plants exhibited reduced oxygen inhibition of photosynthesis and photosynthetic rates comparable to those of non-transformed plants. Such an approach for modifying one of the major physiological processes in plants holds promise for the transformation of cultivars of the other sub-groups (indica, javanica) of rice and, indeed, for the transformation of other C_3 crops. Other experiments have been reported which attempt to increase the resistance of crop plants to environmental stresses such as ozone, high light, drought, cold and heat. A common feature in stressed plants is the production of free oxygen radicals which damage DNA, lipids and proteins. In this respect, transformation procedures have been presented to increase the levels of superoxide dismutase, ascorbate peroxidase and catalase in cells in order to improve the tolerance of maize and rice to oxidative stress (Van Breusegem *et al*. 1998).

4.8.4 Nutritional properties

Experiments have been directed towards modifying the nutritional quality of rice grain. For example, introduction of a fatty acid desaturase gene from tobacco into rice resulted in modification of the proportions of linoleic acid and linolenic acid in fatty acids, with the former decreasing and the latter increasing, respectively (Wakita *et al*. 1998). A significant recent advance has been the transformation of rice to produce beta-carotene, a precursor of vitamin A. Thus, the introduction of genes for phytoene synthase, phoetene desaturase, carotene desaturase and lycopene cyclase from *Narcissus*, or a double-desaturase from the fungus *Erwinia uredovora* resulted in transgenic plants with grain producing yellow endosperm (Burkhardt *et al*. 1997). Some lines produced enough beta-carotene to supply the daily human requirements from 300 grams of cooked rice. Since vitamin A deficiency affects affects about 7% of the world population (mostly children), mainly in developing countries, this work represents a significant advance in attempts to alleviate the problems of vitamin A deficiency.

In the future, it may may be essential to engineer complex biochemical pathways by the introduction of several transgenes into target species. In order to provide a foundation for this technology, embryogenic tissues of rice have been bombarded with a mixture of 14 different genes on pUC-based plasmids (Chen *et al*. 1998). Eighty per cent of the regenerated plants contained more than two and 17% more than nine of the transgenes. Importantly, plants with transgenes were phenotypically normal and 63% set viable seed. Detailed information collected over several seed generations from such plants will clarify the interaction and expression of multiple transgenes in genetically engineered plants, such as cereals.

4.9 Future trends

Biotechnology is likely to have a major impact on the value of cereal production both by increasing productivity and by improvements in product quality. The improved productivity is likely to result initially from the removal of biotic stress constraints associated with major pests and diseases. Herbicide resistance is an option that is likely to be able to achieve early adoption and success. Improvements in grain quality are likely to be generally more difficult to achieve. The major attraction of biotechnology is the possibility of introducing totally new or novel characteristics into cereals that will result in products with characteristics outside the range of those currently available. A major limitation to the introduction of such characteristics is the requirement of cereals to be compatible with existing processes of cereal food production. Market resistance to products requiring new processing techniques will come from the large investment that may be required to develop new processing facilities. Improved methods of quality control and analysis of product identity and purity will enhance the value of cereal products. Adverse consumer attitudes are also a significant risk if transgenic products are not well designed and marketed.

4.10 Sources of further information and advice

Key books

The following books are sources of further information:

Cereal grain quality. R J Henry and P S Kettlewell (eds) Chapman and Hall, London 1996.

Principles of cereal science and technology. Carl Hoseney. American Association of Cereal Chemists, St Paul, Minnesota 1994 (2nd edn).

Practical applications of plant molecular biology. R J Henry. Chapman and Hall, London 1997.

Kent's Technology of Cereals (4th edn) N L Kent and A D Evers. Woodhead, Cambridge 1994.

Improvement of cereal quality by genetic engineering. R J Henry and J A Ronalds (eds) Plenum, New York 1994.

Agri-Food Quality. An interdisciplinary approach. G R Fenwick, C Headly, R L Richards and S Khokhar (eds) The Royal Society of Chemistry, Cambridge 1996.

Applied Plant Biotechnology. V L Chopra, V S Malik and S R Bhat (eds) Science Publishers, USA 1999.

Alternative End Uses of Barley. D H B Sparrow, R C M Lance and R J Henry (eds) Royal Australian Chemical Institute, Melbourne 1988.

Major trade/professional bodies

American Association of Cereal Chemists. St Paul, Minnesota.

International Association for Cereal Science and Technology (ICC). Vienna.

Royal Australian Chemical Institute Cereal Chemistry Division. Melbourne.
The Institute of Brewing. London.
International Society for Plant Molecular Biology. Athens, Georgia.
Association of Applied Biologists. Wellesbourne, UK.
Plant and Animal Genome conferences – San Diego, California.

4.11 References

ALAM M F, DATTA K, ABRIGO E, VASQUEZ A, SENADHIRA D and DATTA S K, Production of transgenic deepwater indica rice plants expressing a synthetic *Bacillus thuringiensis cryIA(b)* gene with enhanced resistance to yellow stem borer, *Plant Sci* (1998) **135** 25–30.

ALTPETER F, VASIL V, SRIVASTAVA V and VASIL I K, Integration and expression of the high-molecular-weight glutenin subunit 1Ax1 gene into wheat. *Nature Biotechnology* (1996) **14**(9) 1155–9.

ANDERSON O, Molecular approaches to cereal quality improvement in *Cereal Grain Quality*, Chapman and Hall, London (1996) pp 371–404.

BARRO F, ROOKE L, BÉKÉS F, GRAS P, TATHAM A S, FIDO R, LAZZERI P A, SHEWRY P R and BARCELO P, Transformation of wheat with high molecular weight subunit genes results in improved functional properties. *Nature Biotechnology* (1997) **15**(11) 1295–9.

BERGELSON J, WINTENER J and PURRINGTON C B, Ecological impacts of transgenic crops in *Applied Plant Biotechnology* Chopra V C, Malik V S and Bhat S R (eds). Science Publishers Inc, USA (1999) pp 325–43.

BLECHL A E and ANDERSON O D, Expression of a novel high-molecular-weight glutenin subunit in transgenic wheat. *Nature Biotechnology* (1996) **14**(7) 875–9.

BOWLES D J, Defence-related proteins in higher plants. *Ann. Rev. Biochem* (1990) **59** 873–907.

BRETTSCHNEIDER R, BECKER D and LÖRZ H, Efficient transformation of scutellar tissue of immature maize embryos, *Theor Appl Genet* (1997) **94** 737–48.

BRINCH-PEDERSEN H, GALILI G, KNUDSEN S and HOLM P B, Engineering of the aspartate family biosenthetic pathway in barley (*Hordeum vulgare* L.) by transformation with heterologous genes encoding feedback-sensitive aspartate kinase and dihydrodipicolinate synthase. *Plant Molecular Biology* (1996) **32**(4) 611–20.

BUCK K W, Virus resistant plants in *Plant Genetic Engineering* Grierson D (ed.) Blackie, USA (1991) pp 131–78.

BURKHARDT P K, BEYER P, WÜNN J, KLÖTI A, ARMSTRONG G A, SCHLEDZ M, LINTIG J V and POTRYKUS I, Transgenic rice (*Oryza sativa*) endosperm expressing daffodil (*Narcissus pseudonarcissus*) phytoene synthase accumulates phytoene, a key intermediate of provitamin A biosynthesis, *Plant J* (1997) **11** 1071–8.

CHEN L, MARMEY P, TAYLOR N J, BRIZARD J-P, ESPINOSA C, D'CRUZ P, HUET H,

ZHANG S, DE KOCHKO A, BEACHY R N and FAUQUET C M, Expression and inheritance of multiple transgenes in rice plants, *Nature Biotechnol* (1998) **16** 1060–4.

CHENG X, SARDANA R, KAPLAN H and ALTOSAAR I, *Agrobacterium*-transformed rice plants expressing synthetic *cryIA(b)* and *cryIA(c)* genes are highly toxic to striped stem borer and yellow stem borer, *Proc Natl Acad Sci USA* (1998) **95** 2767–72.

DALE P J and IRWIN J A, Environmental impact of transgenic plants in *Transgenic Plant Research* Harwood Academic Publishers, Amsterdam (1998) pp 227–85.

DATTA K, VASQUEZ A, TU J, TORRIZO L, ALAM M F, OLIVA N, ABRIGO E, KHUSH G S and DATTA S K, Constitutive and tissue-specific differential expression of the *cryIA(b)* gene in transgenic rice plants conferring resistance to rice insect pest, *Theor Appl Genet* (1998) **97** 20–30.

EDNEY M, Barley in *Cereal Grain Quality* Henry R J and Kettlewell P S (eds) Chapman and Hall, London (1996) pp 113–51.

FEARING P L, BROWN D, VLACHOS D, MEGHJI M and PRIVALLE L, Quantitative analysis of *CryIA(b)* expression in Bt maize plants, tissues, and silage and stability of expression over successive generations, *Mol Breed* (1997) **3** 169–76.

FINCHER G B, Potential for the improvement of malting quality of barley by genetic engineering in *Improvement of Cereal Quality by Genetic Engineering* Henry R J and Ronalds J A (eds) Plenum Press, New York (1994) pp 135–8.

GHAREYAZIE B, ALINIA F, CORAZON A, MENGUITO C A, RUBIA L G, DE PALMA J M, LIWANAG E A, COHEN M B, KHUSH G S and BENNETT J, Enhanced resistance to two stem borers in an aromatic rice containing a synthetic *cryIA(b)* gene, *Mol Breed* (1997) **3** 401–14.

HAMMONDKOSACK K E and JONES J D G, Plant disease resistance genes. *Ann. Rev. of Plant Physiology and Plant Molecular Biology* (1997) **48** 575–607.

HAN F, ROMAGOSA I, ULLRICH S E, JONES B L, HAYES P M and WESENBERG D M, Molecular marker-assisted selection formulating quality traits in barley. *Molecular Breeding* (1997) **3** 427–57.

HENRY R J, Barley quality: an Australian perspective. *Aspects of Applied Biology* (1990) **25** 5–14.

HENRY R J, Biotechnology applications in the cereal industry: Procedures and prospects. *Cereal Foods World* (1995) **40** 370–3.

HENRY R J, Improvement of the quality of barley for beer production in *Agri-food Quality – an interdisciplinary approach* Fenwick G R, Hedley C, Richard R L and Khokhar S (eds). The Royal Society of Chemistry, London (1996) pp 15–18.

HENRY R J, *Practical applications of plant molecular biology.* Chapman and Hall, London (1997).

HENRY R J and KETTLEWELL P S (eds), *Cereal Grain Quality*. Chapman and Hall, London (1996).

HENRY R J, KO H L and WEINING S, Identification of cereals using DNA-based

technology. *Cereal Foods World* (1997) **42** 26–9.

HOEKSTRA S, VAN ZIJDERVELD M, VAN BERGEN S, VANDER MARK E and HEIDEKAMP F, Genetic modification of barley for end use quality of barley by genetic engineering in *Improvement of Cereal Quality by Genetic Engineering* Henry R J and Ronalds J A (eds). Plenum Press, New York (1994) pp 139–44.

JENSEN L G, OLSEN O, KOPS O, WOLF N, THOMSEN K K and VON WETSTEIN D, Transgenic barley expressing a protein-engineered, thermostable (1,3-1,4)-β-glucanase during germination. *Proc. Natl. Acad. Sci. USA* (1996) **93**(4) 3487–91.

KENT N L and EVERS A D, *Technology of cereals*, 4th edn Woodhead Publishing, Cambridge (1994).

KETTLEWELL P S, Agronomy and cereal quality in *Cereal Grain Quality* Henry R J and Kettlewell P S (eds). Chapman and Hall, London (1996) pp 407–37.

KIHARA M, OKADA Y, KURODA H,SAEKI K, YOSHIGI N and ITO K, Generation of fertile transgenic barley synthesizing thermostable βamylase. *26th European Brewing Convention Convention Congress*, Maastricht Netherlands, Oxford University Press, Oxford (1997).

KU M S B, AGARIE S, NOMURA M, FUKAYAMA H, TSUCHIDA H, ONO K, HIROSE S, TOKI S, MIYAO M and MATSUOKA M, High-level expression of maize phospho*enol*pyruvate carboxylase in transgenic rice plants, *Nature Biotechnol* (1999) **17** 76–80.

LIN W, ANURATHA C S, DATTA K, POTRYKUS I, MUTHUKRISHNAN S and DATTA S K, Genetic-engineering of rice for resistance to sheath blight, *Bio/Technol* (1995) **13** 686–91.

McELROY D and JACOBSEN T, What's brewing in barley biotechnology? *Bio/Technology* (1995) **13** 245–9.

MALIK V K, Biotechnology: Multi-billion dollar industry in *Applied Plant Biotechnology* Chopra V L, Malik V S and Bhat S R (eds). Science Publishers, USA (1999) pp 1–69.

MANNONEN L, RITALA A, NUUTILA A, KURTÉN U,ASPERGREN K, TEERI T H, AIKSALO R, TAMMISOLA J and KAUPPINEN V, Thermotolerant fungal glucanase in malting barley. *26th European Brewing Convention Congree*, Maastricht, Netherlands, Oxford University Press, Oxford (1997).

MAQBOOL S B, HUSNAIN T, RIAZUDDIN S, MASSON L and CHRISTOU P, Effective control of yellow stem borer and rice leaf folder in transgenic rice indica varieties Basmati 370 and M7 using the novel delta-endotoxin *cry2A Bacillus thuringiensis* gene, *Mol Breed* (1998) **4** 501–7.

MILLS J T, (1996) Quality of stored cereals in *Cereal Grain Quality* Henry R J and Kettlewell P S (eds). Chapman and Hall, London (1996) pp 441–78.

MORRIS C F and ROSE S P, Wheat in *Cereal Grain Quality* Henry R J and Kettlewell P S (eds), Chapman and Hall, London (1996) pp 1–54.

MOSS H J, Factors determining the optimum hardness of wheat. *Aust J Agric Res*. (1978) **29** 1117–26.

NAYAK P, BASU D, DAS S, BASU A, GHOSH D, RAMAKRISHNAN N A, GHOSH M and SEN

SK, Transgenic elite indica rice plants expressing *CryIAc* delta-endotoxin of *Bacillus thuringiensis* are resistant against yellow stem borer (*Scirpophaga incertulas*), *Proc Natl Acad Sci USA* (1997) **94** 2111–16.

NINEES K, Breakfast foods and the health benefits of inulin and oligofructose. *Cereal Foods World* (1999) **44** 79–81.

OARD J H, LINSCOMBE S D, BRAVERMAN M P, JODARI F, BLOUIN D C, LEECH M, KOHLI A, VAIN P, COOLEY J C and CHRISTOU P, Development, field evaluation, and agronomic performance of transgenic herbicide resistant rice, *Mol Breed*, (1996) **2** 359–68.

POMERANZ Y, Composition and Functionality of Wheat flour components in *Wheat Chemistry and Technology Volume III* Pomeranz Y (ed.) AACC St. Paul (1971) pp 585–674.

SARAC H Z and HENRY R J, Use of cereals in aquaculture production systems in *Pacific People and Their Food*, American Association of Cereal Chemists (1998) pp 193–217.

SEVENIER R, HALL R D, VAN DERMEE I M, HAKKERT H J C, VAN TUNEN A J and KOOPS A J, High level fructan accumulation in a transgenic sugar beet *Biotechnology* (1998) **16** 843–6.

SHEWRY P R and LUCAS J A, Plant proteins that confer resistance to pests and diseases, *Advances in Botanical Research 26* Academic Press (1997) pp 135–92.

STARK-LORENZEN P, NELKE B, HÄNSSLER G, MÜHLBACH H P and TOMZIK J E, Transfer of a grapevine stilbene synthase gene to rice (*Oryza sativa* L.), *Plant Cell Rep* (1997) **16** 668–73.

SUDHAKAR D, FU X D, STOGER E, WILLIAMS S, SPENCE J, BROWN D P, BHARATH M, GATEHOUSE J A and CHRISTOU P, Expression and immunolocalisation of the snowdrop lectin, GNA, in transgenic rice plants, *Transgenic Res* (1998) **7** 371–8.

VAIN P, WORLAND B, CLARKE M C, RICHARD G, BEAVIS M, LIU H, KOHLI A, LEECH M, SNAPE J, CHRISTOU P and ATKINSON H, Expression of an engineered cysteine proteinase inhibitor (Oryzacystatin-I Delta D86) for nematode resistance in transgenic rice plants, *Theor Appl Genet* (1998) **96** 266–71.

VAN BREUSEGEM F, VAN MONTAGU M and INZE D, Engineering stress tolerance in maize, *Outlook on Agric* (1998) **27** 115–24.

VASIL I K and ANDERSON O D, Genetic engineering of wheat gluten. *Trends in Plant Science* (1997) **2**(8) 292–7.

WAKITA Y, OTANI M, IBA I C and SHIMADA T, Co-segregation of an unlinked selectable marker gene and NtFAD3 gene in transgenic rice plants produced by particle bombardment, *Genes and Genet Systems* (1998) **73** 219–26.

WAN Y and LEMAUX P G, Generation of large numbers of independently transformed fertile barley plants. *Plant Physiology* (1994) **104** 37–48.

WUNN J, KLOTI A, BURKHARDT P K, GHOSH-BISWAS G C, LAUNIS K, IGLESIAS V A and POTRYKUS I, Transgenic indica rice breeding line IR58 expressing a synthetic *cryIA(b)* gene from *Bacillus thuringiensis* provides effective insect control, *Bio/Technol*, (1996) **14** 171–6.

XU D, XUE Q, McELROY D, MAWAL Y, HILDER V A and WU R, Constitutive expression of a cowpea trypsin inhibitor gene, *CpTi*, in transgenic rice plants confers resistance to two major rice insect pests, *Mol Breed* (1996) **2** 167–73.

ZHENG H H, LI Y, YU Z H, LI W, CHEN M Y, MING X T, CASPER R and CHEN Z L, Recovery of transgenic rice plants expressing the rice dwarf virus outer coat protein (S8), *Theor Appl Genet* (1997) **94** 522–7.

ZHONG H, SUN B L, WARKENTIN D, ZHANG S B, WU R, WU T Y and STICKLEN M B The competence of maize shoot meristems for integrative transformation and inherited expression of transgenes, *Plant Physiol* (1996) **110** 1097–107.

ZIEGLER E and GREER E N, Principles of milling in *Wheat Chemistry and Technology Volume III* Pomeranz Y (ed.) AACC St. Paul (1971) pp 115–99.

Part II

Cereal products

5

Rice production

B. S. Luh, University of California, Davis

5.1 Introduction

Rice is a semi-aquatic, annual grass which can be grown under a broad range of climatic conditions. Cultivated rice is designated as either *Oryza sativa L.* or *Oryza glabberrima*.[3] *O. sativa* is the predominant species. *O. glaberrima* is grown only in Africa on a limited scale.

The rapid rise in rice production in the years following World War II, mainly in Asia, stemmed from expanded irrigation areas, the increased use of fertilizers, effective control of pests, double rice cropping, and the widespread adoption of improved genetic materials. The combined use of nitrogen fertilizers and use of high-yielding varieties has made possible the expression of high yield in irrigated areas. Varieties of short growth duration which are insensitive to the photoperiod have allowed year-round planting and multiple cropping.

The adoption of semi-dwarf high-yield varieties triggered the beginning of the 'Green Revolution' among rice growers in tropical Asia beginning in 1967. Chinese farmers also turned to the utilization of the semi-dwarf varieties. The development of hybrid rice in China since the 1970s has set off a second Green Revolution in that area.

New genetic information and genetic diversity provide the foundation for more efficient breeding programs for rice production. It remained for the simply inherited recessive gene (sd_1) in the Chinese semi-dwarf rice to provide rice breeders with the impetus to achieve further progress in rice breeding. The cytoplasmic male sterility found in a Chinese wild rice plant fueled further yield increases.[5]

Information on genetics and breeding of rice grain has been published by Adair *et al*.[1] and Chang and Li.[4,5] Houston[11] edited a 1972 book entitled *Rice:*

Chemistry and Technology. Other books on rice have been edited by Hoseney,[10] Juliano,[13] Luh,[18,19] and Marshall and Wadsworth.[21] This chapter presents recent developments in rice production, including rice grain quality, rice cultivation, genetic modification, processing issues and future trends.

5.2 Rice grain quality indicators

The most important factors that plant breeders consider in developing new rice varieties are grain quality and yield. The term 'grain quality' has many meanings and is perceived differently depending on end use, field of interest, specialization and ethnic background. In marketing, appearance is of foremost importance as a quality characteristic; rice millers emphasize milling quality; food manufacturers emphasize processing quality; and consumers demand a widely divergent array of cooking and eating qualities.

Quality in rice may be categorized into four broad areas: (a) milling quality; (b) cooking and processing quality; (c) nutritive quality; and (d) specific standards for cleanliness, soundness, and purity.[32] All four categories are important in judging the suitability of rice for a specific use. The quality characteristics desired vary considerably, being ultimately related to final consumer acceptance of each rice product. Boiled rice prepared in homes and institutions constitutes by far the greatest consumption pattern. Other important uses include: rice flours, parboiled rice, quick cooking rice, canned rice, frozen rice, breakfast rice cereals, baby foods, fermented rice products, rice snack foods, wine and vinegar, and many others.[19]

Characteristics that influence rice quality include those under genetic control and those independent of genetic control, such as purity and cleanliness. These latter characteristics are primarily a function of handling and storage, and as such, are described thoroughly in *United States Standards for Rice*[30] and in the *Rice Inspection Handbook*.[31]

Modern rice breeding programs continually refine and improve genetic characteristics influencing quality to obtain the most desirable product. Breeding and selecting for desirable milling, eating and processing qualities in hybrid selections, breeding lines, and new varieties are essential components of responsible varietal improvement programs conducted by the US Department of Agriculture, and state agricultural stations in Arkansas, California, Louisiana, Mississippi and Texas. New varieties developed in these programs meet required industry standards for milling, cooking, eating, and processing quality before release for commercial production.[1,32,33]

A major factor influencing rice quality is the environment in which the plants are grown. Once a new variety is released for commercial production, it spreads to wherever it can be produced advantageously compared to currently grown varieties. Consequently, before release, new varieties are tested agronomically and for quality over their likely production area. Tests are carried out in rice performance nurseries in each rice-producing state. These trials permit

evaluating quality characteristics of new varieties over wide ranges of environmental influences such as soil, climate and cultural practices.

Characteristics influencing qualities in rice include: (a) hull and pericarp color; (b) grain shape, size, weight, uniformity, and general appearance; (c) milling outturn; (d) kernel chalkiness, translucency and color; and (e) cooking, eating and processing characteristics.

5.2.1 Interrelationships of variety, grain type and quality

Traditionally, rice varieties in the United States are classed as long-, medium-, and short-grain types. More than 99% of the US crop is produced from varieties developed by public rice research centers and experiment stations located at Stuttgart Arkansas, Briggs California, Crowley Louisiana, Stoneville Mississippi and Beaumont Texas. These centers are operated and supported by the five state agricultural experiment stations, the USDA-ARS, and local producer organizations. Through planned breeding, varieties of each grain type are associated with specific cooking, eating, and processing qualities. High-quality conventional US long-grain varieties cook dry and fluffy, with cooked grains tending to remain separate, whereas cooked kernels of conventional medium- and short-grain varieties are moist and chewy, with grains tending to cling together. All three grain types, with their characteristic cooked textural qualities, are needed for both domestic and foreign trade. In the US, the long-grain types account for over 60% of the total production, medium-grain types less than 30%, and short-grain types the remainder.[7]

In many rice products, qualities and grain types of conventional long-grain varieties are preferred; in others, short- and medium-grains, with their characteristic textural properties, are required. It is essential that new varieties of each grain type have the same or improved milling and cooking qualities as the varieties they replace. Although thousands of rice varieties exist worldwide, only a few (usually less than a dozen) varieties are grown commercially in the United States in any one crop year. Generally, these consist of four or five long-grain, four or five medium-grain, and one or two short-grain varieties, which are continually replaced by new, improved varieties developed in public breeding programs.

Scented (aromatic) long-grain rice is produced in small acreages as specialty products. This rice gives off an aroma similar to that of roasted nuts and has a flavorful nutty taste. A major constituent responsible for the unique flavor of this type of rice is 2-acetyl-1-pyrroline, present in the volatile oil fraction. Two aromatic rices are in limited production: (a) Della types, characterized as intermediate-amylose/intermediate-gelatinization-temperature types that cook dry, fluffy, and separate like conventional US long-grains; and (b) Jasmine types, which are low-amylose/low-gelatinization-temperature types and cook soft, moist, and clingy like imported fragrant rices from Thailand. A third type is the so-called Toro-type rice. This rice has the grain size and shape of US long-grains but possesses the cooking and eating behaviors of US short- and medium-grain types.

Recently, long-grain rices with superior processibility, referred to as 'Newrex/Rexmont'-type quality, were developed for a drier and fluffier table rice with improved processibility for manufacturing into canned soups, quick-cooking, and frozen rice products. Newrex/Rexmont-type quality represents the first major improvement in US long-grain quality and is the forerunner in superior processibility.

5.2.2 Components of rice quality

Hull and bran (pericarp) color

Rice produced in the United States is classed as either light (straw)- or dark (gold)-hulled. Although hull color is not a major concern in producing regular white milled rice, it is important in processing parboiled rice. Varieties with light-colored hulls are preferred by parboilers than dark-hulled varieties parboiled under similar conditions. Genetic selection for light-hulled varieties is an important consideration in developing new varieties suitable for parboiling. Selection for hull and bran color is accomplished by close examination or by colorimetric methods.

Grain size, weight and uniformity

Rice is marketed according to three grain size and shape classes (long, medium and short). Kernel dimensions are primary quality factors in most phases of processing, drying, handling equipment, breeding and grading. Grain size and shape are among the first quality characteristics considered in developing new varieties. Intensive genetic selection is practiced to eliminate heritable abnormalities such as: deep creases, which tend to leave bran streaks on milling; irregularly shaped kernels; sharp-pointed extremities, which break easily in milling; and oversized germs, which detract from milling quality and grain appearance.

The various grain types are classified according to length, width, thickness and grain weight (Table 5.1). Methods for measuring rice grains include use of photographic enlargers to magnify kernels or simply measuring with a ruler the length, width, and thickness of several grains placed in adjacent positions for particular measurements.[31] Uniformity of grain size, shape and weight is determined by calculating the coefficient of variation for measurement on randomly selected grains of representative samples. Grain weight (size) is expressed in g/1000 grains or mg/grain.

Test weight

Test weight is a comparative indicator of total milled rice yield. It also provides relative measures of dockage and/or foreign material present and of proportions of unfilled, shriveled, and immature kernels. Test weight of rice is the weight of a known volume. Test weight is expressed in pounds per Winchester bushel. To convert to kilograms per hectoliter, multiply by a factor of 1.287. Average test weight of US rough rice is 58 kg/hl (45 lb/bu),

Table 5.1 Range of average grain size and shape measurements among conventional US long-, medium-, and short-grain rice[a]

Grain type	Grain form	Length (mm)	Width (mm)	Length/ width ratio	Thickness (mm)	Grain weight (mg)
Long		6.5–7.5	1.9–2.2	3.0:1–3.7:1	1.5–1.8	15–21
Medium	Milled[b]	5.4–6.0	2.3–2.7	2.1:1–2.6:1	1.7–1.9	17–21
Short		5.0–5.2	2.5–2.9	0.7:1–2.0:1	1.8–2.0	18–22
Long		6.8–8.0	2.0–2.3	3.0:1–3.8:1	1.6–1.9	16–20
Medium	Brown[c]	5.8–6.3	2.4–2.8	2.2:1–2.7:1	1.8–2.1	18–22
Short		5.2–5.4	2.6–3.0	1.8:1–2.0:1	1.9–2.1	20–23
Long		8.7–9.9	2.3–2.5	3.4:1–4.0:1	1.8–2.0	21–24
Medium	Rough[d]	7.8–8.4	2.9–3.2	2.5:1–2.8:1	1.9–2.2	23–25
Short	(Paddy)	7.2–7.3	2.9–3.4	2.1:1–2.4:1	2.0–2.3	24–29

[a]Based on measurements of clean, mature grains of conventional varieties from Uniform Performance Trials, TX, LA, AR, and MS.
[b]Whole milled kernels with hull, bran, and germ removed.
[c]Grain with hull removed.
[d]Unhulled grain.[31]

but it varies with factors such as pubescence, amount of dockage, unfilled and immature kernels, and grain type.

General appearance

Many factors constitute general appearance in rice. Some, including grain size, shape, and uniformity, vitreousness, translucency, chalkiness, color, and damaged and imperfect kernels, are equally important contributors to general appearance.

Translucency

Translucent kernels are demanded by practically all segments of the rice industry. Typical nonwaxy US varieties are required to possess these traits to a high degree. Consequently, rice breeders practice intensive genetic selection for bright, clear, translucent kernels in new varieties at all stages of varietal development.

Chalkiness

Chalkiness detracts from general appearance and usually results in lower milling yields since chalky kernels tend to break more during milling. Excessive chalkiness is undesirable for many processed products because of nonuniformity produced by overprocessing chalky kernels under usual processing conditions. Chalkiness occurs when rice is harvested at too high a moisture level or in varieties of nonuniform maturity in which excessive numbers of immature kernels exist. Both type and amount of chalk are, in many instances, highly heritable, and intensive selection is carried out to develop varieties as free of

chalk as genetic and environmental conditions allow. Kernels inherently free of chalkiness are one of the first quality characteristics breeders select for in new US varieties. Chalkiness in rice is often referred to as 'white belly,' or 'immature,' depending on its location on or within the endosperm. Close visual examination is used most for determining type and amount of chalkiness. Translucency instruments offer promise as objective measures of transparency, including chalkiness, in rice.

Milling quality and yield

No rice variety can be commercially successful unless it possesses high whole-kernel (head) and total milled rice yield. Whole-kernel (head) yield is the quantity of intact whole kernels (including broken kernels three-quarters or more in length) of well-milled rice obtainable from given quantities of rough (paddy) rice. Total milled rice yield includes whole kernel (head) and all other sizes of broken kernels obtainable from specified amounts of rough rice. The objective of rice milling is removal of hulls, bran, and germ, with minimum breakage of endosperms. Milling quality in rice is based on yield of whole-kernel (head) rice because it is the milled product of greatest economic value. Yield of total milled rice is important, and is influenced by proportion of hulls and amounts of fine endosperm particles.

Several laboratory instruments are available for determining milling yield in rice. Two commonly used methods are: (a) the official grading method for determining milling quality of rough rice by *United States Standards for Rice* (USDA 1982 with changes 1982–1990),[30] which requires 1000-g rough rice (McGill #3 Mill), and (b) a modification of the official method requiring only 125-g rough rice for analysis. The modified method is used in rice-breeding programs, rice mills, and processing plants.

Milling quality is usually reported as a percentage of whole-kernel (head) rice and total milled rice obtained from a unit of rough rice. Average milling yields of whole kernel rice was 55–63% from long-grain rice, and 57–66% from medium- and short-grain types.

Cooking and processing quality indexes

Cooking and processing quality, with milling quality, are fundamental components of quality that determine and establish economic values of rice.

Conventional cooking and processing US rice

Average values for some comparative chemical and physical (quality) characteristics of typical cooking and processing long-, medium-, and short-grain US rice types are given in Table 5.2. The values shown are representative of each grain type although environmental factors influence these characteristics to some extent.[32,33]

Chemical and physical characteristics associated with traditional cooking and processing of southern US long-grain types are: an intermediate to relatively high amylose content, a slight to moderate reaction of whole-kernel milled rice

Table 5.2 Physicochemical (quality) characteristics of conventional cooking and processing long-, medium-, and short-grain rice types

Milled rice characteristics	Conventional cooking and processing type		
	Long	Medium	Short
Apparent amylose content, %	21–23	15–20	15–20
Alkali spreading value, average	3–5	5.5–7	5.5–7
Gelatinization temperature,[a] ºC	69–72	64–48	64–68
Gelatinization temperature type	Intermediate	Low	Low
Protein (N × 5.95), %	6–8	6–8	6–8
Amylographic paste viscosity, BU[b]			
Peak	650–850	700–900	700–900
Hot	350–400	350–400	350–400
Cool	650–850	650–800	650–800
Breakdown	300–400	350–450	350–450
Setback	−150–+250	−250–−50	−250–−50

[a]Amylographic gelatinization temperature.
[b]Bu = Brabender units.

in contact with dilute alkali (indicative of intermediate-gelatinization-temperature types), and intermediate gelatinization temperatures (69–73ºC). Amylographic pasting characteristics of typical long-grain varieties usually show intermediate peak viscosities and relatively high paste viscosities on cooling to 50ºC.

In the United States, specific chemical and physical criteria are used to describe cooking and processing qualities desired in new varieties of each grain type. These criteria, based on a series of physicochemical tests, collectively, serve as indices of rice cooking and processing behavior. New varieties under development are systematically tested for apparent amylose content, the alkali spreading reaction of whole-kernel milled rice in contact with dilute alkali, an indirect measure of gelatinization temperature, amylographic gelatinization and pasting characteristics. Average and range of test values for these characteristics are established for commercially acceptable varieties.[32,33]

Chemical and physical characteristics of new varieties are always compared with those of comparably grown leading commercial varieties of appropriate grain type. If, after a number of years at several locations, properties of new varieties are similar or superior to those of standard varieties, they are judged to have satisfactory or superior cooking and processing quality; if not, they are considered undesirable or of unknown quality.

Typical medium- and short-grain varieties for cooking and processing are characterized by relatively low amylose content, extensive reaction of whole-kernel rice in contact with dilute alkali, and relatively low gelatinization temperatures (69–73ºC). Amylograms of typical medium- and short-grain varieties usually show relatively low cooked paste viscosities on cooling to 50ºC.

Specialty US rices

Newrex/Rexmont-type rice represents the first major improvement in the inherent cooking, eating, and processing quality of southern long-grain varieties. The types were developed to satisfy industry's need for drier, fluffier table rice combined with improved canning stability. The Newrex/Rexmont type is the forerunner of these improved types. The Della types (Table 5.3) are scented (aromatic) long-grain produced in limited amounts as specialty rice. They give off an aroma on cooking like that of roasted nuts and have flavorful nutty tastes. Jasmine aromatic (scented) rices are recently introduced types similar in taste and aroma to Della, but they are softer and more clingy in texture. Jasmine types are characterized by low amylose and low gelatinization temperature like the Toro and conventional short- and medium-grain types.

Toro types are specialty rice produced in limited amounts for specific markets. They have the grain size and shape of other US long-grains but possess cooking and eating behaviors of US short- and medium-grain types. Toro-quality rice is used by segments of the population who prefer the clingy cooked texture of short- and medium-grains in long-grain types. Toro is characterized as a low-gelatinizing, low-amylose type like those of conventional US short- and medium-grain varieties.

Specialty waxy Mochi Gome-type short-grain rice varieties are produced in limited quantities in California. They are characterized by opaque endosperms of virtually all amylopectin starch, low gelatinization temperatures, and relatively low amylographic peak, hot paste and cool paste viscosities. Waxy rice is produced primarily for specialty products, and numerous commercial product formulations, including rice cakes, crackers, sauces, gravies, salad dressing, desserts, and batter dips for fried foods.

5.2.3 US rice standards and grades

United States Standards for Rice (USDA 1989)[31] and *Rice Inspection Handbook* (USDA 1982 with changes 1982–1990)[30] provide a means for the orderly marketing of rough rice, brown rice for processing, and milled rice by grades. Although grades are useful tools, they do not provide a sufficiently refined classification of rice to satisfy all quality requirements of the rice industry. Factors involved in establishing rice grades include moisture content, color, degree of milling, dockage (impurities), damaged kernels, odors, red rice, and seeds or kernels of any plant other than rice.

Moisture content

Rough-rice moisture contents of 13% must be harvested at recommended moisture contents (about 23%), dried carefully to safe storage moisture levels, and stored and milled under moisture conditions suitable for maximum milling yield. Methods for measuring moisture content vary widely. Air-oven, or vacuum-oven, procedures are basic methods for determining moisture in rice.

Table 5.3 Physicochemical (quality) characteristics of US aromatic, waxy, toro, and L202 type rices

Milled rice characteristics	Cooking and processing type				
	Aromatic (scented)				
	Della	US jasmine	Waxy	Toro	L202
Grain type	Long	Long	Short	Long	Long
Apparent amylose content, %	21–23	15–18	<1	15–18	25–28
Alkali spreading value, average	3–4	6–7	6–7	5.5–7	4–7
Gelatinization temperature type	Int[b]	Low	Low	Low	Low/Int
Gelatinization temperature,[a] ºC	69–72	–	59–63	64–68	–
Protein (N × 5.95), %	6–8	6–8	6–8	6–8	6–8
Parboil-canning stability, solids loss, %	20–23	>30	>30	>30	20–23
Amylographic paste viscosity, BU[c]					
Peak	650–850	700–900	250–450	700–900	300–400
Hot	350–400	350–400	100–200	350–400	250–300
Cool	650–850	650–800	250–350	650–800	600–800
Breakdown	300–400	350–450	100–150	250–450	100–150
Setback	−50– +150	−200– –50	−100– –50	−300– –50	+250– +400

[a]Amylographic temperature.
[b]Intermediate.
[c]BU = Brabender units.[31,32]

When rapid results are needed, properly calibrated electronic moisture meters are sufficiently accurate for most control work.

Color and milling requirements
For milled rice, *United States Standards for Rice* (Table 5.4) specifies:

> US No. 1 grade shall be white or creamy, and shall be well milled. US No. 2 may be slightly gray, and shall be well milled. US No. 3 may be light gray, and shall be at least reasonably well milled. US No. 4 may be gray or slightly rosy, and shall be at least reasonably well milled. US No. 5 and No. 6 may be dark gray or rosy and shall be at least slightly milled.

Degree of milling
Extent of bran layer and germ removal from the endosperm is referred to as degree of milling. *United States Standards for Rice* (Table 5.4) specifies three degrees of milling: well milled, reasonably well milled, and lightly milled.

Dockage
According to *United States Standards for Rice* (USDA, USDA 1982 with changes 1982–1990):[30,31]

> dockage shall be any matter other than rice which can be readily removed from rough rice by use of appropriate sieves and cleaning devices, and underdeveloped, shriveled, and small pieces of kernels of rough rice removed in properly separating dockage and which cannot be recovered by properly rescreening and recleaning.

Other impurities difficult to remove because of size, shape, and density similar to rice are classed as objectionable materials, including glass fragments and certain weed seeds.

Damaged kernels
United States Standards for Rice[31] defines damaged kernels as whole or broken kernels of rice which are distinctly discolored or damaged by water, insects, heat, or any other means, and whole or large broken kernels of parboiled rice in nonparboiled rice.' 'Heat-damaged' kernels are defined as whole or large broken kernels of rice which are materially discolored and damaged as a result of heating, and whole or large broken kernels of parboiled rice in nonparboiled rice which are as dark as, or darker in color than, the interpretive line for heat-damaged kernels.[30,31] Visual inspection by trained inspectors is the only reliable method available for determining amounts of damaged kernels in rice.

Odors
Off-odors in rice severely affect grade.[31] Rice that is musty or sour, or that has any commercial objectionable foreign odor, shall be graded US sample grade. According to the *Rice Inspection Handbook* (USDA 1982 with changes 1982–

Table 5.4 Milled rice grades and requirements for US long-, medium-, and short-grain types

	Maximum limits												
	Seeds, heat damaged, and paddy kernels (singly or combined)			Chalky kernels			Broken kernels			Other types[a]			
Grade	Total number in 500	Heat damaged kernels and objectionable seeds number in 500	Red rice and damaged kernels (singly combined), %	In long-grain rice, %	In medium- or short-grain rice, %	Total, %	Removed by a 5 plate, %	Removed by a 6 plate, %	Through a 6 sieve, %	Whole kernels, %	Whole and broken kernels, %	Color requirements	Minimum milling requirements
US No. 1	2	1	0.5	1.0	2.0	4.0	0.04	0.1	0.1	–	1.0	Shall be white or creamy	Well milled
US No. 2	4	2	1.5	2.0	4.0	7.0	0.06	0.2	0.2	–	2.0	May be slightly gray	Well milled
US No. 3	7	5	2.5	4.0	6.0	15.0	0.1	0.8	0.5	–	3.0	May be light gray	Reasonably well milled
US No. 4	20	15	4.0	6.0	8.0	25.0	0.4	2.0	0.7	–	5.0	May be gray or slightly rosy	Reasonably well milled
US No. 5	30	25	6.0	10.0	10.0	35.0	0.7	3.0	1.0	10.0	–	May be dark gray or rosy	Lightly milled
US No. 6	75	75	16.0	15.0	15.0	50.0	1.0	4.0	2.0	10.0	–	May be dark gray or rosy	Lightly milled
US Sample grade	US Sample grade shall be milled rice of any of these classes which: (a) does not meet the requirements for any of the grades from US No. 1 to US No. 6, inclusive; (b) contains more than 15.0% of moisture; (c) is musty, or sour, or heating; (d) has any commercially objectionable foreign odor; (e) contains more than 0.1% of foreign material; (f) contains two or more live or dead weevils or other insects, insect webbing, or insect refuse; or (g) is otherwise of distinctly low quality.												

[a]These limits do not apply to the class Mixed Milled Rice.[31]

1990), musty or sour odors include earthy, moldy ground odors; insect odors; rancid odors; and sharp, acrid odors.[30] Commercially objectional foreign odors include odors of fertilizers, hides, oil products, skunk, smoke, and decaying animal and vegetable matter. Trained inspectors determine subjectively the type and severity of odors in rice.

Chalkiness

United States Standards for Rice[31] defines chalky grains as those that are one-half or more chalky. Chalky grains are important grading factors. Type of chalk, location of chalky areas on or in the endosperm, as well as amount of chalk, is important to processors because certain types of chalk affect quality of processed products more than others.

5.2.4 Seeds and objectionable seeds

Seeds or grains, either whole or broken, of plants other than rice are classed as seeds. Objectionable seeds are those difficult to remove by screening, sieving, or aspiration because of their likeness to rice in size, shape and density.

5.2.5 Special and numerical grades

Parboiled, smutty, weevily, coated, granulated, brewer's, and undermilled rice are listed in *United States Standards for Rice*[31] as special grades for various types and classes of rough, brown, and milled rice. These are additional factors that describe conditions or processing treatments of rice. Coated milled rice is coated, whole or in part, with safe and suitable substances in line with commercially acceptable practice. Granulated brewer's rice is rice that is crushed or granulated to specified sizes. Numerical grades for both regular and special grades are determined by trained inspectors based on size of whole and broken grains, uniformity, cleanliness, damage, general appearance, infestation, and odor.

5.3 Rice cultivation, including genetic modification

Rice is usually grown under shallow flood or 'wet paddy' conditions but is also cultured where flood waters may be several meters deep. It is capable of anaerobic respiration and has aerenchyma tissue in the aerial organs through which oxygen diffuses to the roots. The unique ability of rice plant to grow on all kinds of land and water regimes, combined with its adaptation to a wide variety of climates and agricultural conditions, make rice the world's most important cereal crop. Thousands of rice cultivars are grown throughout the world. More than 90% of the world's rice is produced in Asia. The average yields of rough rice in the years 1985–1987 were 3.3 tons/ha in Asia; 2.3 in Latin America; 1.9 in Africa; 6.2 in the US; and in the world 3.2. The difference was

caused by the various climatic conditions, fertilizer application, soil types, rice cultivars, availability of water, rice species, and cultural practices. Through diversification accelerated by climatic changes, human dispersal and selection over a wide range of latitude and altitude, plus manipulation for cultural adaptation, many different cultivars have been developed. The dispersal of *O. sativa* has led to the development of three ecogeographical races: indica, japonica, and javanica, each grown with cultural practices ranging from upland to lowland and to deepwater cultures.

The main area of rice production is found on the Asian continent and adjacent islands which lie in the tropical and subtropical regions. Much of the Asian rice is produced in the monsoon area where abundant rainfall, plus some supplementary irrigation, provides an edaphic advantage. Rice production is concentrated in areas where water management is convenient on flat lowlands, river basins, and delta areas. Within the Asian area, regional monsoons, winds, typhoons, and tropical depressions create a pattern of distinct wet and dry seasons and add variability to the climatic features from year to year.

5.3.1 Climatic factors affecting rice production

Rice production is controlled primarily by climatic variables that ideally should provide adequate water during the entire growing season, relatively high air and soil temperatures, adequate solar radiation, a moderately long growing season, and relatively rain-free conditions during the ripening period. Important edaphic factors include the need for relatively level land with poor internal drainage and favorable chemical and physical properties in the soil itself.

5.3.2 Precipitation and water

Water, precipitation is the most important factor influencing the distribution of rice in the world, and also its growth and yield potential. Consequently, rice is preferentially grown only in the rainy season except where water storage and irrigation facilities are available. The intensity and distribution of the rainfall, the water retention characteristics of the soil, and water conserving cultural practices all affect water availability. Irrigated lowland rice covers about 50% of the rice-growing area of the world. Irrigation allows more complete control of water application and depth and is becoming the major system of world rice culture.

5.3.3 Temperature

In temperate regions, temperature is a limiting factor in rice culture. In the main rice-growing season of the Asian tropics, temperature is more or less constant and within safe limits. Rice is adaptable to areas with abundant sunshine and average temperatures above 20 to 38ºC. Temperatures below 15ºC retard seedling development, delay transplanting, and consequently reduce grain yields.

5.3.4 Photoperiod

The photoperiod represents the duration of the light period between sunrise and sunset. It is a major factor influencing the development of the rice plant, especially its flowering characteristics. Photoperiod-sensitive cultivars flower when the decreasing day length reaches a critical point. Day length also exerts a large effect on the growth duration of rice cultivars, depending upon their photoperiod sensitivity. The response is seen largely through changes in the basic vegetative growth pattern, especially the duration of the reproductive phase. Photoperiod sensitivity (the critical day length required for flowering) varies greatly, some cultivars being referred to as nonseasonal or neutral, others as weakly photoperiod sensitive, and others as strongly photoperiod-sensitive.

5.3.5 Solar radiation

Solar radiation and sunshine hours are important climatic determinants in rice production. Young seedlings have a comparatively low solar radiation requirement. Light becomes progressively more important through the vegetative and reproductive phases, reaching maximum importance at the heading stage. The need for solar energy is most critical from panicle differentiation to about ten days before maturity. Rice yields are strongly correlated with total solar radiation between thirty and forty-five days before harvest. The amount of sunlight a crop receives depends on solar radiation intensity, day length, cloud cover, and mutual shading by the plants in a population.

5.3.6 Weed pests

Weeds are universal competitors of rice, competing for moisture, light, and plant nutrients. Weeds also create problems in harvesting, drying, and cleaning, and reduce the quality and marketability of the crop. Insects pests such as leafhoppers and stemborers also live on weeds as alternate hosts and directly attack the rice crop. Water management is often impeded when weeds block irrigation systems, slowing drainage.

There are over 30,000 weed species regarded as serious rice pests in the world. Of these, 30 species are very damaging and some 88 species are noxious. Since rice is grown under such a wide range of climatic conditions, soil types, and crop rotations, it is not possible to identify the most damaging species. *Echinochloa crusgalli*, *E. colonum*, *Cyperus rotundus*, *Rottboellia cochinchinensis*, and *Imperata cylindrica* are serious weed pests in most upland rice areas of the world.[8] The most common means of weed control in tropical areas is hand weeding, usually with a short-handled hoe. Without satisfactory weed control, upland rice yields are severely restricted.

5.3.7 Rice culture and production methodology

Based on land and water management practices, ricelands are classified as either lowland (wetland preparation of fields) or upland (dryland preparation of fields).

Based on water regimes, ricelands can be classified as upland (with no standing water), rain-fed lowland (with 5–50 cm of standing water), deepwater (with >51 cm standing water), and floating (with from 101 cm to 5–6 m of standing water). The irrigated areas will continue to dominate production. Irrigated land now comprises about half the total harvested area but contributes more than two-thirds of the total production.

It will be necessary to develop sufficient component technology for crop management, such as tillage method, and control of insects, diseases, weeds, and nematodes. Further, it is necessary to develop varieties with suitable plant type, maturity, and management characteristics, and develop the know-how to manage the crops under a range of conditions of fertility, tillage, water, and labor availability.

5.3.8 Development of new cultivars

The areas under irrigation are increasing for rice production, so efforts to develop cultivars and technology that would produce higher yields than those currently in use are being intensified.

5.3.9 New technology

Fertilization

One area of recent concern is increasing fertilizer use efficiency. Agronomists have demonstrated that deep placement of nitrogen fertilizer increased efficiency, sometimes saving 40% of fertilizer nitrogen with no reduction in grain yield.

Mechanization

The modern technology is referred to as seed-fertilizer technology. However, throughout Asia, the concept of modernization is closely associated not only with biological and chemical technology but also with mechanical technology. The biological and chemical technology is thought of primarily as saving land and the mechanical technology as saving labor.

Weed control is an operation that needs to be mechanized, especially in the rain-fed areas under dry seeding. Threshing is another operation where mechanization would be helpful. At present, losses in threshing are high in most farms in tropical Asia.

5.3.10 Genetic modification

Genetic engineering and biotechnology have brought in the new knowledge to map the genetic structure of plants and animals, and to rearrange genes within a species, as well as transfer genes between species. These techniques have been used to produce genetically modified (GM) seeds, rice, and fiber. Genetically modified organisms (GMOs) are here. Some estimates state that the processed

foods we eat contain some type of GMO. In a 1995 survey of consumer opinions, only 22% of Austrians and 30% of Germans said 'yes' when asked if they would be likely to purchase a food modified by biotechnology to resist insect damage. The penetration of GM foods into the agricultural-input (seed) industry and their adsorption by growers have been quite rapid. Around the world the increase in acreage devoted to GM crops increased from 4.3 million acres in 1996 to 69.5 million acres in 1998.

Seventy-one percent of the transgenic crops have been engineered to tolerate herbicides, and 28% to resist insects. These modifications have benefited farmers by reducing risk and increasing profit. They help reduce the use of chemical insecticides and herbicides. Through newer biotechnological methods, use of GM crops has resulted in higher yields because loss of crops to pests in the field has been reduced, and cleaner, higher-grade end products have been produced for the market.

Genetically-modified (GM) foods are protected on several grounds, and everyone in the food supply chain, from seed manufacturers to retailers, will need to accommodate consumer demands in some fashion. The burden of proof is on the scientific community and on the producers and manufacturers of food products to establish the safety of GMOs. It is a new era of innovation in food production. Molecular genetic studies of rice have accelerated rapidly due to the favorable qualities of rice, including its small genome size and ease of transformation. Redona and Mackill[25] studied molecular mapping of quantitative trait loci in japonica rice. A linkage map of 129 random amplified polymorphic DNA (RAPD) and 18 restriction fragment length polymorphism (RFLP) markers was developed using 118 F_2 plants derived from a cross between two japonica cultivars with high and low seedling vigor, *Italica livarno* (IL) and *Labelle* (LBL), respectively. The map spanned 980.5 cM with markers on all 12 rice chromosomes and an average distance of 76 cM between markers. Codominant (RFLP) and coupling phase linkages (among RAPDs) accounted for 79% of total length and 71% of all intervals. This map contained a greater percentage of markers on chromosome 10, the least marked of the 12 rice chromosomes, than other rice molecular maps, but had relatively fewer markers on chromosomes 1 and 2. The authors used this map to detect quantitative trait loci (QTL) for four seedling vigor related traits on 112 F_3 families in a growth chamber slantboard test at 18ºC. Two coleoptile, five root, and five mesocotyl length QTLs, each accounting for 9–50% of the phenotype variation, were identified by interval analysis. Single-point analysis confirmed interval mapping results and detected additional markers significantly influencing each trait. About two-thirds of alleles positive for the putative QTLs were from the high-vigor parent, IL. One RAPD marker (OPAD 13_{720}) was associated with a IL allele that accounts for 18.5% of the phenotype variation for short length, the most important determinant of seedling vigor in water-seeded rice. Results indicate that RAPDs are useful for map development and QTL mapping in rice populations with narrow genetic base, such as those derived from crosses among japonica cultivars. Other potential uses of the map are discussed.

Rice disease resistance gene, Xa21
The rice Xa21 gene, which confers resistance to *Xanthomonas oryzae* pv. *oryzae* race 6, was isolated by positional cloning.[27] Fifty transgenic rice plants carrying the cloned Xa21 gene display high levels of resistance to the pathogen. The sequence of the predicted protein, which carries both a leucine-rich repeat motif and a serine-threonine kinase-like domain, suggests a role in cell surface recognition of a pathogen ligand and subsequent activation of an intracellular defense response. Characterization of Xa21 should facilitate understanding of plant disease resistance and lead to engineered resistance in rice.

Fertile transgenic rice
Shimamoto *et al*.[28] reported on fertile transgenic rice plants regenerated from transformed protoplasts. Redona and Mackell[26] made a quantitative trait locus analysis for rice panicle and grain characteristics. The development of molecular genetic maps has accelerated the identification and mapping of genomic regions controlling quantitative characters referred to as quantitative loci or ATLs.[15]

Submergence tolerance genome mapping on rice chromosome 9
A major locus for submergence tolerance mapped on rice chromosome 9 has been reported by Xu and Mackill.[34] Submergence stress is a widespread problem in rice-growing environments where drainage is impeded. The authors used RAPD (random-amplified polymorphic DNA) and restriction fragment length polymorphism (RFLP) markers to map submergence tolerance in 169 F_2 plants and the resulting F_3 families of a cross between a tolerant indica rice line, IR 40931-26 and a susceptible japonica line, P 1543851. IR 40931-26 inherited strong submergence tolerance from the unimproved cultivar FR 13A. Eight day old F_3 seedlings were submerged for 14–16 days in 55 cm deep tanks, and tolerance was scored after seven days recovery on a scale of 1 (tolerant) to 9 (susceptible). The tolerant and susceptible parents scored 1.5 and 8.4 respectively, and the F_3 means ranged from 1.6–8.9. Two bulks were formed with DNA from F_2 plants corresponding to the nine most tolerant and the nine most susceptible F_3 families. Of 624 RAPD primers used to screen the bulks, five produced bands associated with either tolerance or susceptibility. The markers were mapped to a region of chromosome 9 by linkage to RFLP markers. A submergence tolerance quantitative trait locus (QTL), here designated Sub l. was located ca. 4 cm from the RFLP marker and accounted for 69% of the phenotypic variance for the trait.

Genetic variation for traits related to temperate adaption of rice cultivars
MacKill and Lei[20] reported on genetic variation for traits related to temperate adaption of rice cultivars. Rice (*Oryza sativa L.*) was cultivated in diverse environments including temperate, subtropical, and tropical regions. Temperate rice areas are dominated by the japonica subspecies, while indica cultivars are confined.

5.4 Processing issues

Rice is one of the world's most important cereals for human consumption. In the densely populated countries of Asia, as much as 80–90% of the daily caloric intake of some people is derived from rice. It is also consumed in the form of noodles, puffed rice, breakfast cereals, rice cakes, fermented sweet rice, and snack foods made by extrusion cooking. Rice is also used in making beer, wine, and vinegar.

5.5 Rice snack foods

In most Asiatic countries, rice cereals are consumed as cooked rice and are served simultaneously with prepared vegetable dishes, poultry, beef, seafood, among others. There are many kinds of snack foods, prepared for more attractive taste, texture, and aroma. They are served in some cases for special occasions, for some special tastes, and for convenience.

Some rice snack foods are made from either glutinous rice (sweet or waxy rice) containing largely amylopectin (98% of total starch), but very little amylose (less than 2% of total starch), while others are made from both types. A typical glutinous rice flour contains 11.0–13.5% moisture, 1% ash (max.), 75–80% total starch, 5.5–6.5% protein, and 0.5% total fat. Glutinous rice flour is often used in making snack foods since the sticky characteristics of high amylopectin content are necessary in many specialty rice foods. Another reason for application of glutinous rice in baked and popped snacks is that glutinous rice flour expands readily and produces a more porous texture.

5.5.1 Rice cracker processing

Rice cracker is a Japanese snack food made from rice. *Arare* and *senbei* are the traditional rice crackers in Japan. Rice crackers made from glutinous rice are generally called *arare* or *okaki*. Rice crackers made from nonglutinous rice are called *senbei*. They have a harder and rougher texture than *arare*. In choosing between glutinous or nonglutinous rice, one has to pay attention to uniformity in quality, rate of water absorption, extent of refinement, and absence of objectionable odors and taste. In order to improve the flavor and appeal of snack foods, seaweed, sesame, red peppers, sugar, pigments and spices are added.

A flowchart for processing *arare* rice crackers from glutinous rice is presented in Fig. 5.1. Glutinous rice is washed in a washing machine and soaked for 16 h in water at temperatures below 20ºC. After draining, the rice, which contains about 38% moisture, is crushed by rollers into fine powder, passed through an 80-mesh sieve, and steamed for 20 min. After cooling for 2–3 min, it is kneaded three times in a special machine. The kneaded cake is put in a cake vessel, quick-frozen, and kept at 2–5ºC for 2–3 days for hardening. The cake is cut into various shapes and dried by hot air at 45–75ºC to a final moisture content of 20%. The cake is coated

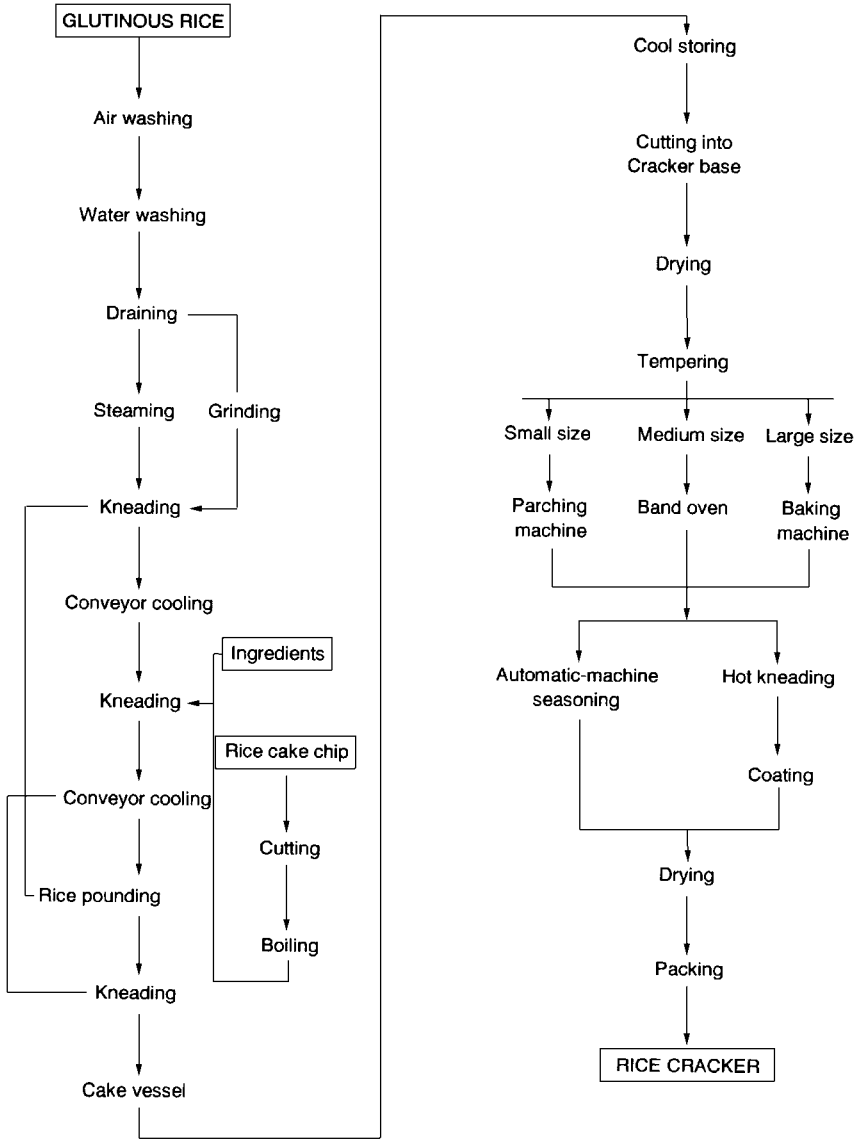


Fig. 5.1 Flow chart for making rice crackers (Arare). Courtesy of TaiAn Food Company, Taiwan

with soy sauce, spices, and other seasoning materials and placed in a continuous baking machine or an oven. After baking, the product is dried in a continuous baking machine at 90ºC for 30 min. After cooling, the product is packaged in plastic pouches or aluminum film-plastic pouches.

5.6 Rice noodles, parboiled and quick-cooking rice

In China, rice noodle is called *mi fen* and in Japan, *harusame*. *Mi fen* is made from rice only; *harusame* may be made from mung bean, starch, or rice or a mixture of these. Rice noodles are consumed in the form of soups. The rice noodle soups are usually prepared from *mi fen*, water, meat or chicken, green vegetables, soy sauce, and Chinese onion for an attractive aroma. The product is highly attractive in sensory quality because of the special texture, aroma, and taste. The conventional processing method is limited to sun drying. There are a few exceptions using hot air drying or infrared drying methods. A short description for the manufacture of *mi fen* follows.

Nonglutinous rice is soaked in water for 3–5 h, ground, and mashed into a rice paste, which is then pressed in a bag to force out the excess water. The product is steamed for 5–80 min. The optimum condition is to reach 80% gelatinization of the rice starch. The product is then kneaded in a machine and shaped into a column from which raw rice noodle is extruded. The raw rice noodle is steamed for 30 min, dipped into a seasoning solution, cut, and put into racks for hot-air drying. The final product is then cooled and packaged. *Mi fen* is a dehydrated product. It can be kept for 1–2 years at room temperature after packaging and sealing in plastic films. To attain the quick reconstitution characteristics, *mi fen* should be dried in a hot air current at 80ºC to prevent reverting the gelatinous (alpha) starch to the beta form. There are fresh *mi fen* in various forms, packaged in plastic films available in the supermarkets.

Parboiling is a hydrothermal procedure in which the crystalline form of starch present in the paddy rice is converted into amorphous form. This is accomplished by soaking the paddy rice in warm water at 65ºC for 4–5 h, followed by steaming under pressure in a continuous apparatus, drying, and milling the dried paddy rice. The parboiling process produces physical and chemical changes of the rice kernel with some economical and nutritional advantages. The process is quite popular in India, Brazil, the United States, Italy, and other countries.

The major objectives of parboiling are to (a) increase the total and head yield of the paddy, (b) reduce the loss of nutrients during milling, (c) salvage the wet and damaged paddy, and (d) prepare the rice according to the requirements of the consumers and rice processors.

The changes occurring in the parboiling process are as follows:

- the starch grains embedded in a proteinaceous matrix are gelatinized and expanded until they fill up the surrounding air spaces,
- the protein substances are separated and sink into the compact mass of gelatinized starch, becoming less liable to extraction
- the water-soluble vitamins and mineral salts are spread throughout the grain.

The riboflavin and thiamin content are four times higher in parboiled rice than in milled rice.

The milling yield of parboiled rice is higher than milled rice because there are fewer broken grains. The milled parboiled rice can be kept longer because germination is no longer possible. The enzymes involved in germination were inactivated during the parboiling process. The nutritive value of parboiled rice is richer because of the higher vitamin and mineral content that has diffused into the endosperm.

Parboiled rice takes a longer time to cook compared with ordinary milled rice but is favored by the food industry in canned chicken rice soup and beef rice soup. Parboiled rice is more resistant to textural changes that can occur during the prolonged heating in the canning process. More detailed information on rice parboiling can be found in *Rice Utilization*.[19]

5.6.1 Quick-cooking rice

Quick-cooking rice is a popular product in the United States, Japan, and several Western countries. Up to the present, quick-cooking rice available on the market can be cooked in 5 min to reach a satisfactory level of culinary acceptability. After cooking, the product should match the characteristic flavor, taste, and texture of conventionally cooked rice. The quick-cooking rice must possess good storage stability of 6–12 months at ambient temperature. The product should be packaged properly in plastic film bags of special design against moisture changes during storage.

To prepare quick-cooking rice, it is necessary to precook the rice and gelatinize the starch to some extent in water, steam, or both. The cooked or partially cooked rice is usually dehydrated in such a manner as to retain the rice grains in a porous and open-structured condition. The finished product should consist of dry, individual kernels, be free of lumps, and have approximately one and a half to three times the bulk volume of the raw rice.

Many quick-cooking rice products are designed specifically for certain consumer markets. Some quick-cooking rice for special applications, such as dry soup mixes, casseroles, or other dry food mixtures that have certain dehydration requirements, were designed to be compatible with the ingredients in the mix.

5.6.2 Types of quick-cooking rice

Difference in precooking times and temperature, dehydration conditions, and processing variables results in various types of quick-cooking rice. These range from relatively undercooked rice, requiring 10–15 min of cooking time, to a good quick-cooking rice requiring 5 min preparation time. Minute Rice®, a commercial rice product, can be rehydrated with hot water in a minute or two, which yields a fairly mushy product when boiled with water. Completely precooked rice should be used in cup and standing form because no further cooking is necessary during preparation. The other types could use either completely or partially cooked rice products. Except for the standing-type commercial product, all others usually contain a seasoning mix. As for quality

consistency, cup and standing types give consistent quality in the finished dish because no real cooking is involved, whereas the others may vary, especially simmering and sauté/simmering types.

5.6.3 Quick-cooking processes

Many quick-cooking rice products and processes have been developed and patented during the past decades. Among the processes and products developed, the following are the commercially useful quick-cooking processes.

- Soak-boil-steam-dry method: Raw milled long-grain white rice is soaked in water to 30% moisture and cooked in boiling water to 50–60% moisture, with or without steam. The product is further boiled or steamed to increase the moisture to 70% and then dehydrated to 8–14% moisture to maintain a porous structure.
- Expanded and pregelatinization method: Rice is soaked, boiled, steamed, or pressure-cooked to gelatinize the grain thoroughly, dried at a low temperature to yield fairly dense glassy grains, and then expanded or puffed at a temperature to produce the desired porous structure in the product.
- Rolling or 'bumping' method: Rice is pregelatinized as described in the previous section, rolled, or 'bumped' to flatten the grains and dried to a relatively hard glassy product.
- Dry heat treatment method: Rice is exposed to a blast of hot air at 65–82ºC for 10–30 min, or at 272ºC for 18 sec, to dextranize, fissure, or expand the grains. No boiling or steaming is applied.
- The freeze-thaw-drying process: Rice is precooked and then frozen, thawed, and dried. The procedure combines the hydration and gelatinization steps, in addition to the critical steps of freezing and thawing before drying.

5.7 Canned and frozen rice

Various methods have been used for making canned rice more acceptable. These fall into two categories: wet pack and dry pack. A product in which there is an excess of liquid, such as in soup media, is termed wet pack. The rice is precooked or blanched sufficiently to promote buoyancy in the product. The washing process removes excess surface starch. The rice is put into cans together with the sauce. The cans are sealed under vacuum and then retorted to sterilize the product. A commercial process has been evaluated for canned white rice packed in 301 $\times$ 411 cans with a fill weight of 340 g rice (55–60% moisture) for each can. The initial temperature is 40ºC, and the come up time 10–15 min. The recommended processing time at 118.3ºC is 55 min. The equivalent sterilization value at 121ºC is 13.3 min.

5.7.1 Frozen rice

Frozen cooked rice is convenient to use since it requires less time to prepare than raw rice. The rice may be frozen plain or in combination with other foods. Rice is an integral part of frozen dinners. A commonly used method for preparing frozen cooked rice is as follows:

- Soak long-grain rice (Indica type) in an abundance of water at 54–60ºC, which contains enough citric acid to reach a pH of 4.0–5.5. Sufficient water should be used to cover the rice after soaking for 2 h.
- Drain off the excess soaking water, and rinse with more of the same pH water to remove fines.
- Drain thoroughly, tapping the screen to shake loose the adhering water. The soaked, drained rice is placed in layers 5 cm deep or less over a screen supported above the water in the pressure cooker. Place a small volume of water at the bottom of the pressure cooker. Close the vessel, and heat with the vent open until steam is emitted to expel air in the retort. Close the vent, raise the steam pressure to 2.09 kg/sq cm, and hold for 12–15 min. Then blow off steam gradually to prevent violent boiling and flashing.
- Place the hot steamed rice in a large amount of water at 93–99ºC without stirring. The rice will imbibe water until the grains are large, tender, and quite free. Stirring will cause the rice to become sticky. The rice should be held in a perforated vessel so that water may circulate freely through it.
- Cook by boiling the rice for 10–15 min. Drain off the hot water, and rinse twice with cold water that has the pH adjustment described above.
- Tap and shake to remove the free water, or suck off the free water over a vacuum filter.
- Convey the cooked rice on a stainless steel mesh belt through an airblast cooler to reduce it to room temperature, and then package in cartons or plastic pouches. Freeze the rice in air-blast freezers. The rice can also be frozen as individually quick-frozen (IQF) products prior to packaging in a fluidized-bed freezer.

Frozen storage at −18.8ºC for up to one year has no deleterious effects on quality.

Prechilling the cooked rice results in removing most of the surface moisture and at the same time permits quick-freezing. Before freezing takes place, the individual grains are separated and kept out of contact with one another during the freezing process. The product is then frozen solid. Excellent results have been obtained by subjecting the rice to a moving air-blast at −34ºC. After the grains are solidly frozen, they can be packed in any desirable manner.

5.8 Extruded rice

Rice breakfast cereals may be divided into two classes: those requiring cooking before serving and those ready to eat directly from the package. Here, we will concentrate on the processing of ready-to-eat breakfast rice cereals.

Ready-to-eat rice breakfast cereals are being made in increasing amounts by extruding super-heated and pressured doughs through an orifice into the atmosphere. The sudden expansion of water vapor in the extrudate as the excess pressure is released results in a volume increase of several times. The process has several advantages such as high and continuous production rates, greater versatility in product shape, and easier control of product density.

The rice flour mix containing a 60–75% expandable starch base is moistened with water or steam and equilibrated to ensure a uniform supply of extrusion material. The resultant mash is compacted by a screw revolving inside a barrel, which may be heated by steam. The thread of the screw has a progressively closer pitch as it approaches discharge. In some extruder designs, the rice premix is fed directly into the extruder. The water and/or steam are injected into the barrel and mixed with the premix. The pressurizing, sharing, and steam heating bring the dough to a temperature of about 150–175°C and a pressure of 5–10 MPa at the die end. Under these conditions, the dough is quite flexible and easily adapts to complex orifice configurations. The dough pieces expand very rapidly as they leave the dice orifice, and the expansion may continue for a few seconds since the dough is hot and still flexible and water continues to boil off. The moisture content of pieces is in the order of 10–15% and is too high for satisfactory crispness. Thus, the pieces are dried on vibrating screens in hot-air ovens to a final moisture content of 3–4%. The product may be coated with sugar syrup and flavoring if desired, dried again, cooled, and packaged.

Fortification of ready-to-eat rice breakfast cereals with vitamins, minerals, and flavor compounds is now a very common practice. The usual approach is to add the minerals and more heat-stable vitamins such as niacin, riboflavin, and pyridoxine to the basic formula mix and then spray the more heat-labile vitamins such as vitamin A and thiamin on the product after processing.

5.9 Shredded rice

Shredded rice is a ready-to-eat breakfast cereal. Whole kernel or broken rice is washed and cooked in a rotary cooker with sugar, salt, and malt syrup under 100–150 kPa steam pressure for a period of 1–2 h or until the rice is uniformly cooked. The cooked particles are then discharged at a moisture content of about 40% and partially dried to a moisture content of 25–30%. The dried kernels are tempered to ensure a uniform moisture distribution and form a hard, glazed surface. This process allows the rice kernels to flow freely through the process.

The shredding rolls are from 15.2 cm to 20.3 cm in diameter and as wide as 60 cm or more. They are much smaller than flaking rolls. On one roll of the pair is a series of about 20 shallow corrugations running around the periphery. In cross section, these corrugations may be square, rectangular, or a combination of these shapes. The other roll of the pair is smooth. Soft and cooked rice is drawn between these rolls as they rotate and issues a continuous strand of dough.

Rice Chex® and Crispix® are made by using two pairs of shredding rolls. Rice Chex® is made with rice as the sole cereal ingredient, while Crispix® is made from rice and corn as the cereal components. The dough sheet formed from the first pair of rolls is placed on a moving belt. The dough sheet from the second pair of rolls is then slid on top of the first sheet on the same moving belt. The layered sheets can be cut by one or two pairs of cutting rolls, which fuse a thin line of the dough sheets into a solid mass at regular intervals to form a continuous matrix of biscuits. The wet biscuits are transferred to a metal belt moving through a gas-fired oven. The shredded rice cereals are toasted, cooled, and broken apart from each other through a vibrator conveyor. Fortification of the shredded rice cereal with vitamins and minerals is a common practice. Packaging of the product is a very important step for protection from moisture and atmospheric light changes.

5.10 Baby foods

Rice in the form of rice flour or as granulated rice is used in the formulation of many strained baby foods. Rice flour, glutinous rice flour, and rice polishings are used in preparing baby foods. The largest use of rice in the baby food industry is in the manufacture of precooked infant rice cereals.

5.10.1 Precooked rice cereal

The process for making precooked baby foods consists of preparing and cooking a cereal slurry. The objective is to precook the rice and to convert the starch from crystalline to amorphous form. The rice slurry is first precooked in water to form a slurry and then treated with amylase enzyme to predigest the starch into dextrin and oligosaccharides. The ingredients used in the formulation of baby foods are rice flour, rice polishings, sugar, dibasic calcium phosphate, gycerol monostearate (emulsifier), rice oil, thiamine, riboflavin, niacin, or niacinmide. The prepared rice slurry is dried with an atmospheric drum drier. The thickness of the film on the drier surface, the spacing between the drums, the temperature of the drum surface, the drum speed, and the flowing properties of the slurry are controlled with the objective of making an easy-to-digest rice product. The solids, drum speed, and the drum temperature are adjusted to obtain a finished product of excellent quality. Packaging of the final product in selected paperboard carton containers is common practice.

Some precooked rice cereals with strawberries or apples appear to be gaining favorable consumer acceptance. Cereal ingredients, fruit, sugar, oil, vitamins, and minerals are cooked, dried on an atmospheric drum drier, flaked, and packaged. Because of the hygroscopicity of the fruit and sugar, fruit cereals require moisture-proof packages. Some diastase enzymes can be used to lower the liquid requirement for reconstitution. The temperature, time of digestion, enzyme activity, and solid content must be controlled closely to obtain a

satisfactory product. Rice cereal may become rancid if packaged in a hermetically-sealed container. The package material most suitable for such product is one that allows transmission of both moisture vapor and gas. Most precooked infant cereals are packaged in paperboard cartons. A bleached manila liner on the interior of the carton is very commonly used. The carton is wrapped with a glue-mounted, printed paper label. The tight wrap offers sifting and insect protection to the package.

5.10.2 Extrusion-cooked baby food

Extrusion cooking is a new method for preparing baby foods. The type of extruders used, the particle size of the rice flour, the moisture content of the rice-water mixture, and the extrusion conditions are some of the important factors influencing the properties of extruded rice baby foods.

5.10.3 Formulated baby foods

Rice cereal products are customarily used in the preparation of formulated baby foods. Not only is rice a food ingredient, but its use in baby foods has a significant role in the consistency of the product. The variety of rice used in these products is important to the physical properties of the final product. Long-grain rice, because of its higher amylose content, causes the product to thicken during storage caused by starch retrogradation and eventually to produce a very rigid gel and water separation. Glutinous-rice flour is a good stabilizer for canned and frozen food products. The stability is achieved as a result of a reduction of amylose/amylopectin rationing the product.

There is a grade of baby food designed for more advanced babies called junior grade. 'Junior' baby foods have a coarser texture. To produce the junior grade baby foods, granulated rice is incorporated into the formulation for many junior vegetable and meat items. In the formulation of junior baby foods, care must be taken to avoid thin consistency after cooking, or particles can settle out to form a mat in the bottom of the jar. To ensure uniform distribution of the junior-sized particles, modified waxy-maize starch is frequently incorporated into the product.

5.11 Puffed rice cake

Puffed rice cakes are gaining popularity. They are a disk-shaped puffed product, low in calories (35–40 kcal per cake). Other minor ingredients, such as sesame seed, millet, and salt, may be used in making the product. The procedures for making puffed rice cake are as follows: Water is added to the medium-grain brown rice to adjust its moisture content to 14–18%. The added water and brown rice are mixed and tempered in a liquid-solids blender and tumbled for a selected time (1–3 h) at room temperature. The moistened rice is then introduced to a rice

cake puffing machine that has been preheated to 200ºC or higher. An example of the rice cake machine is the Lite Energy® rice cake machine (Real Foods Pty., St. Peters, Australia).

The influence of moisture content and tempering temperature and time immediately before puffing on rice cake volume has been investigated by Hsieh *et al.*[12] In general, a lower moisture level (14% vs. 16–20%) in raw rice and a longer tempering time (5 h vs. 1–3 h) resulted in higher specific volumes in the rice cakes. Higher heating temperature at 230ºC versus 200–220ºC and an 8 sec heating time produces rice cakes of higher specific volumes.

5.12 Rice Krispies®

A very popular rice product called Kellogg's Rice Krispies® is consumed in large quantities as a snack food, as well as a rice breakfast cereal. It is a toasted cereal made of rice, sugar, salt, high fructose corn syrup, and malt flavoring. It is free from fat and cholesterol and an average serving would be 1¼ cups (33 g) with 1/2 cup of skim milk. The product is enriched with several vitamins and minerals for improvement of nutritive value.

5.13 Future trends

- Biotechnology and genetic engineering are recognized as the new areas in rice research. The new technology, in its different forms, will contribute to rice improvement.
- Anther culture is a new method that allows regeneration of true breeding lines (double haploids) from anthers of rice. The advantage of this method is to hasten the conventional breeding process, which requires several generations after a cross to have lines reach a true breeding stage (homozygosity) for evaluation and testing.
- RFLP (restriction fragment polymorphism) mapping is used to study rice genome. This technique is of particular interest to rice breeders and geneticists as a tool for identifying important genetic characters in segregating populations.
- Rice plants can be regenerated successfully from protoplasts (single cells), an important step in the application of genetic engineering methods in transferring genetic characters into rice.
- Transgenic rice plants are being produced by a number of research groups in California, Louisiana, Mississippi, and Texas. Such techniques may yield new or improved quality types for future rice cultivars.
- Genetic engineering techniques will allow improvements of rice cultivars by increasing productivity, tolerance to stress, and broader adaptation in material with desirable quality characteristics.

- Research and development of new rice products is continuing by the food industries and various research institutes. Every year, some new processed rice products appear in supermarkets.

5.14 Sources of further information

There are many rice research institutes in the world, including ones in Brazil, China, Germany, India, Italy, Japan, Korea, Pakistan, Philippines (IRRI), Spain, Taiwan, Thailand, and the United States. New results on rice research are being produced every year.

In the United States, public rice-breeding programs are located in the following states:

- Rice Research and Extension Center, Stuttgart, AR
- Rice Experiment Station, Biggs, CA
- Rice Research Station, Crowley, LA
- Texas Agricultural Research and Extension Center, Beaumont, TX
- Delta Branch Experiment Station, Stoneville, MS and
- Everglades Research and Extension Center, Belle Glade, FL.

Public cultivars have accounted for more than 90% of the US acreage. There are several private rice research programs in the United States as follows:

- Busch Agricultural Resources, Inc., Pleasant Grove, CA, and Jonesboro, AR
- N.F. Davis Drier and Elevator, Inc., Firebaugh, CA
- Rice Researchers, Inc., Glenn, CA
- Rice Tech, Alvin, TX

5.15 Acknowledgements

The author thanks Professor Charles F. Shoemaker of the Department of Food Science and Technology, UC Davis; Dr. Te-Tzu Chang, Taipei, Taiwan (formerly IRRI); Dr. S. K. DeDatta (IRRI); Dr. Cheng-Chang Li, President, National Chung Hsing University; Dr. Duane S. Mikkelsen, Agronomy and Range Science, UC Davis; Dr. B. D. Webb, Rice Research Institute, USDA, TX; Dr. James I. Wadsworth, USDA, New Orleans, LA; Dr. James Hill, Agronomy and Range Science, UC Davis; Dr. David Mackill and Mr. Xiamao Lei of USDA, Agronomy and Range Science, UC Davis, for their advice in preparing this chapter. I thank Mrs Clara Robison of the Department of Food Science and Technology, UC Davis, for typing the manuscript of this chapter.

5.16 References

1. ADAIR C R, BOLLICH C N, BOWMAN D H, JODON N E, JOHNSTON T H, WEBB, B D and ADKINS J G, 'Rice breeding and testing methods in the United States', *Rice in the United States: Varieties and Production*, Handbook 289 (rev), Washington DC, US Department of Agriculture, 1973.
2. BOLLICH C N, WEBB B D, MARCHETTI M A and SCOTT J E, 'Registration of Rexmont rice (Reg No CV–81)', *Crop Sci*, 1990 **30** 1160.
3. CHANG T T, 'The origin, evolution, cultivation, and diversification of Asian and African rices', *Euphytica*, 1976 **25** 425–41.
4. CHANG T T and LI C C, 'Genetics and breeding', *Rice: Production and Utilization*, ed LUH B S, Westport CT, Avi Publishing Co, 1980.
5. CHANG T T and LI C C, 'Genetics and breeding', *Rice Production*, Vol. I, ed LUH B S, New York NY, Van Nostrand Reinhold, 1991.
6. CHANG T T and LUH B S, 'Overview and prospects of rice production', *Rice Production*, Vol. I, ed LUH B S, New York NY, Van Nostrand Reinhold, 1991.
7. CHILDS N N, *U.S. Rice Distribution Patterns*, Washington DC, USDA ERS Statistical Bulletin 776, 1989.
8. DE DATTA S K, 'Sustainable rice production: challenges and opportunities', 17th session of the Intl Rice Commission (IRC), Food and Agricultural Organization of UN, Goiania, Goias, Brazil, 1990.
9. FEDERAL GRAIN INSPECTION SERVICE, *Rice Inspection Handbook*, Washington DC, USDA, 1990.
10. HOSENEY R C, *Principles of Cereal Science and Technology*, St Paul, MN, Am Assoc Cereal Chemists, 1986.
11. HOUSTON D F, *Rice: Chemistry and Technology*, Minneapolis, MN, Am Assoc Cereal Chemists, 1972.
12. HSIEH F, HUFF H E, PENG I C and MAREK S W, 'Puffing of rice cakes as influenced by tempering and heating conditions', *J Food Sci*, 1989 **54**(5) 1310–12.
13. JULIANO B O, *Rice Chemistry and Technology*, St Paul, MN, Am Assoc Cereal Chemists, 1985.
14. JULIANO B O, PEREZ C M, KAUSHIK R and KHUSH G S, 'Some grain properties of IR36–based starch mutants', *Starch/Starke*, 1990 **42** 256.
15. KAUSHIK R P and KHUSH G S, 'Genetic analysis of endosperm mutants in rice (Oryza sativa L)', *Theor Appl Genet*, 1991 **83** 146.
16. LEI X and MACKILL D J, 'Studies on sterility of pollen and spikelet in potential rice P/TGMS lines', *US 27th Rice Technical Working Group*, Reno NV, University of California and USDA, 1998.
17. LEI X M, LEE R, THORUP T and MACKILL D J, 'Studies on pollen and spikelet sterility in potential rice P/TGMS lines in California', *US 27th Rice Technical Working Group*, Reno, NV, 1998.
18. LUH B S, *Rice Production*, Vol. I, ed LUH B S, New York NY, Van Nostrand Reinhold, 1991.

19. LUH B S, *Rice*, Vol. I: Production, ed LUH B S, New York NY, Van Nostrand Reinhold, 1991.
20. MACKILL D J and LEI X, 'Genetic variation for traits related to temperate adaptation of rice cultivars', *Crop Sci*, 1997 **37**(4) 1340–46.
21. MARSHALL W E and WADSWORTH J I, *Rice Science and Technology*, New York, Basel, Hong Kong, Marcel Dekker, 1994.
22. MCKENZIE K S, BOLLICH C N, RUTGER J N and MOLDENHAUER K A K, *Rice, Principles of Cultivar Development*, Vol. 2, ed FEHR W R, New York NY, Macmillan Publ Co, 1987.
23. MIKKELSEN D S and DE DATTA S K, 'Rice culture', *Rice production*, Vol I, ed LUH B S, New York NY, Van Nostrand Reinhold, 1991.
24. RAINA S K, 'Tissue culture in rice improvement: status and potential', *Adv Agron*, 1989 **42** 339–98.
25. REDONÃ E D and MACKILL D J, 'Molecular mapping of quantitative trait loci in japonica rice', *Genome*, 1996 **39** 395–403.
26. REDONÃ E D and MACKILL D J, 'Quantitative trait locus analysis for rice panicle and grain characteristics', *Theor Appl Genet*, 1998 **96** 957–963.
27. SONG W Y, WANG G L, CHEN L L, KIM H S, PI L Y, HOLSTEN T, GARDNER J, WANG B, ZHAI W X, ZHEE L H, FAUQUET C and RONALD P, 'A receptor kinase-like protein encoded by the rice disease resistance gene Xa21', *Science*, 1995 **270** 1804–06.
28. SHIMAMOTO K P, TERADA R, IZAWA T and FUJIMOTO H, 'Fertile transgenic rice plants regenerated from transformed protoplasts', *Nature*, 1989 **338** 274–76.
29. TEXAS AGRICULTURAL EXPERIMENT STATION, *Proceedings 27th Rice Technical Working Group*, Reno NV, The Texas A & M University System, 1998.
30. USDA, *Rice Inspection Handbook*, Federal Grain Inspection Service, Washington DC, USDA, 1982 (with changes 1982–1990).
31. USDA, *United States Standards for Rice*, rev ed, Federal Grain Inspection Service, Washington DC, USDA, 1989.
32. WEBB B D, 'Rice quality and grades', *Rice*, Vol. II: Utilization, ed LUH B S, New York NY, Van Nostrand Reinhold, 1991.
33. WEBB B D, BOLLICH C N, CARNAHAN H L, KUENZEL K A and MACKENZIE K S, 'Utilization characteristics and qualities of United States rice', *Symposium on Rice Grain Quality and Marketing*, Los Banos, Philippines, IRRI, 1985.
34. XU K and MACKILL D J, 'A major locus for submergence tolerance mapped on rice chromosome 9', *Molecular Breeding*, 1996 **2** 219–24.

6

Pasta production

B. A. Marchylo and J. E. Dexter, Canadian Grain Commission, Winnipeg

6.1 Introduction

The basic forms of pasta products such as spaghetti, lasagna, macaroni, and other types of short goods, have not altered much over the centuries. Similarly, pasta continues to be made using the same ingredients: durum wheat semolina or flour, common wheat farina or flour, or various combinations of these, water and optional ingredients such as egg, spinach, tomato, herbs, etc. Modern processing technology, however, has changed dramatically. The large automated, computer controlled plants that we are familiar with today are very different from the small factories seen in the infancy of the modern pasta processing industry. Large amounts of pasta can now be processed in a day in modern plants that are run by only a few personnel.

Estimates of pasta consumption vary widely by country (Table 6.1). For example, Italy consumes the most at about 28.5 kg/person/year[1] and regionally it may range as high as 48 kg in Sicily (personal communication, Marina Solinas, Agnesi). Italian domestic pasta consumption is flat and a proportion of the production is aimed at the export market. On the other hand, consumption is growing in other countries around the world. For example, in the United States, pasta consumption rose from about 3 kg/person/year in 1965 to an estimated level of 9 kg in 1999. In Canada, consumption is expected to have increased to just over 7 kg/person/year by the year 2000.[2] In South America, Venezuela has the second highest consumption next to Italy. Other South American countries such as Brazil have a much smaller consumption, about 4 kg/person/year, but show large growth potential. There are many reasons for the popularity of pasta but the most important ones are as follows:

Table 6.1 Estimate of pasta consumption of several countries from around the world

Country	kg/person/year	Country	kg/person/year
Italy	28.2	Germany	5.3
Venezuela	12.7	Spain	4.6
Tunisia	11.7	Turkey	4.5
Peru	9.9	The Netherlands	4.4
Switzerland	9.6	Austria/Australia/Israel	4.0
United States	9.0	Costa Rica	3.5
Greece	8.8	Finland	3.2
Chile	8.2	Poland	3.0
France	7.3	United Kingdom	2.5
Argentina	6.8	Mexico	2.3
Portugal	6.5	Denmark/Libya	2.0
Canada	6.3	Japan	1.7
Brazil	6.1	Romania	1.3
Russia/Sweden	6.0	Egypt	1.2
Belgium/Luxembourg	5.4	Ireland	1.0

Source: Survey conducted by the Italian Pasta Association (Unione Industriali Pastai Italiani[1]), 1999.

- Pasta has an excellent nutritional profile. It is a good source of complex carbohydrates and a moderate source of protein and some vitamins. For example, a two-ounce portion of dry pasta contains about 210 calories and is about 75 percent carbohydrate, 13 percent protein, and 1.5 percent fat.[3,4] In North America, dietary guidelines published by the United States Department of Agriculture and by Health Canada show that grain-based products, which include pasta, should be a major part of a healthy diet.
- Pasta represents good consumer value and, as such, it sells well in both good and bad economic times.
- Dry packaged pasta is virtually non-perishable if stored appropriately.
- Pasta is easy to cook, has a wholesome taste, and an extensive variety of dishes can be prepared using the many different pasta shapes and sizes available.

6.2 History of pasta processing

Pasta products are ubiquitous in households, restaurants, and institutional settings around the world, but their origins are only conjecture. Etruscan art found in the tombs of Revieli in Cerveteri (about 30 km northwest of Rome, Italy), suggests that a type of pasta product was consumed in this part of the world as early as 600 BC. In Genoa, there is a record of a will dated 1279 in which a basket-full of macaroni was bequeathed.[5] Obviously, pasta was dear to the hearts of Italians even at that early date, and Italy is generally considered the home of pasta.

Pasta processing in its earliest form was a very simple procedure performed by artisans or 'pastaio'.[6] Flour and water were mixed and kneaded into

dumpling-like form. The process evolved with time and it was discovered that the dough could be sheeted, cut into strips and then dried in the sun. The resulting dried pasta was safe for storage and could be readily transported.[5]

The mechanization of pasta processing gained momentum during the industrial revolution. According to Agnesi[7] wooden extrusion presses were designed in the early 1700s and into the early nineteenthth century. At the turn of the present century, equipment consisting of mixers, kneaders or gramolas, hydraulic extrusion presses, and drying cabinets were built to increase efficiency and throughput. Pasta processing during this era was a batch manufacturing process, which by its nature was laborious and restricted productivity. In addition, the finished pasta was not as consistent as the product we eat today. Numerous pasta plants utilizing this process, however, sprang up between 1900 and the mid 1930s. In the United States, for example, the pasta industry flourished following World War I and throughout the 1930s and the Great Depression.[6]

The processing industry was revolutionized circa 1934 with the development of the continuous press. The Bühler Brothers from Switzerland were the first to incorporate an extrusion worm into a continuous press. Around the same time, Braibanti, an Italian company, introduced a press that used a worm drive in conjunction with pistons. Automatic dryers were then added to the continuous presses with Augusto Fava credited with manufacturing and installing the first continuous pasta dryer.[8] The first continuous, automatic production line, which processed semolina into dried spaghetti or macaroni ready for packaging was designed and built by a Swiss firm in 1946.[9,5] Other developments that have impacted on pasta processing technology include:

- Application of vacuum during mixing and extrusion lessened oxidation of pigments and minimized the loss of pasta color.
- The use of Teflon inserts in bronze dies provided smoother and more uniform products with better appearance.
- The introduction of higher drying temperatures beginning in the 1970s produced products with improved cooking quality and gave better bacterial control in egg products. Shorter drying times enabled equipment manufacturers to build more compact drying lines for a given capacity.
- Computerization of pasta factories further increased production efficiency and capacity, and provided more consistency in product quality.

With the acceptance of high temperature drying and computer control, the pasta industry made significant progress in a relatively short time in terms of production capacities, product diversity, and consistency in product quality. As with many other industries, the pasta industry is now global in nature. With globalization, however, has come fierce competition and it is becoming ever more important for processors to produce pasta products with quality that is consistent over time, within regions in a country, and even from country to country. Consumers generally are becoming more discriminating in their quality requirements, and less accepting of variability in product quality, especially for high-end or premium products.

6.3 Pasta-making process

Pasta manufacturers today produce many varieties of dried products with hundreds of shapes and sizes available. These products may be broadly classified as either short or long goods. Internationally, the most well-known long goods are spaghetti (of various diameters), fettuccini, and linguini. Elbow-shaped-macaroni is probably the most familiar short good, along with penne and the many types of shells. Stamping the forms such as bow ties from an extruded thin sheet of dough produces another familiar group of short goods, Bologna-type pasta.

In addition to dried pasta with or without egg, there are fresh, frozen and microwavable pastas, instant pastas, retortable pasta, etc., available to consumers.[10] Each of these products has its own processing requirements, but this chapter will focus primarily on the fundamental aspects of production of basic short and long dried pasta.

Simple schematic diagrams of long and short pasta production lines are shown, for reference purposes, in Figs 6.1 and 6.2. This chapter is intended to give a general overview of pasta-making equipment and the basic elements of pasta manufacturing. The pasta manufacturing process for both long and short goods has been described in detail in publications by many authors.[9,11–15]

All types of pasta are prepared using a few common elements. In each instance, a semolina or flour is mixed with water to form a stiff dough. The dough is then shaped, usually by extrusion through various shaped dies. For dried pasta the formed product is dried to between 12 percent to 13 percent moisture content.

The main ingredient of premium quality pasta is 100 percent durum wheat semolina. Semolina, which originates from the endosperm of durum wheat, is essentially coarse flour. Good quality pasta can also be made with durum wheat flour or a blend of semolina and durum wheat flour (granular). Pasta can be produced using common (soft or bread) wheat farina or flour, but is generally inferior in appearance (color) and cooking quality to pasta made from durum wheat.

In the first stage of the process, semolina and water are initially combined in a premixer (normal range 25–30 kg of water per 100 kg semolina[15]). The amount of semolina, water and other optional ingredients (such as eggs, enrichment, spinach, herbs, etc.) are measured and dispensed using various types of dosers depending on equipment manufacturer.[14] If fresh eggs are added, the amount of water is adjusted accordingly. This mixture is then combined into a homogeneous mass in a mixing chamber. Water temperature should be controlled and water quality is a consideration. Semolina particles must be hydrated homogeneously during mixing to prevent the inclusion of white specks (unhydrated semolina particles) or streaks in the finished dried pasta. Small particles absorb water more rapidly than coarse particles, so semolina particle size distribution should be as narrow as possible to minimize uneven hydration. A Vortex vertical hydration system, recently marketed by

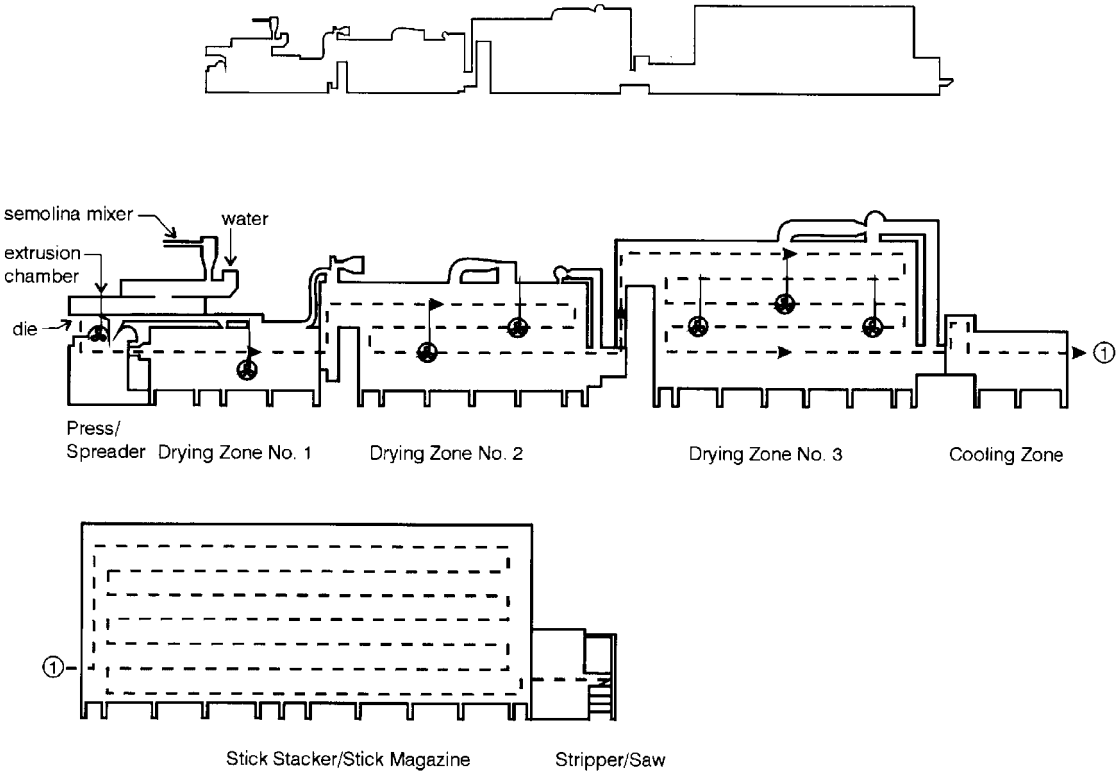


Fig. 6.1 A simple schematic of a long goods pasta line. (Adapted with kind permission from a diagram by Bühler AG, Uzwil, Switzerland.)

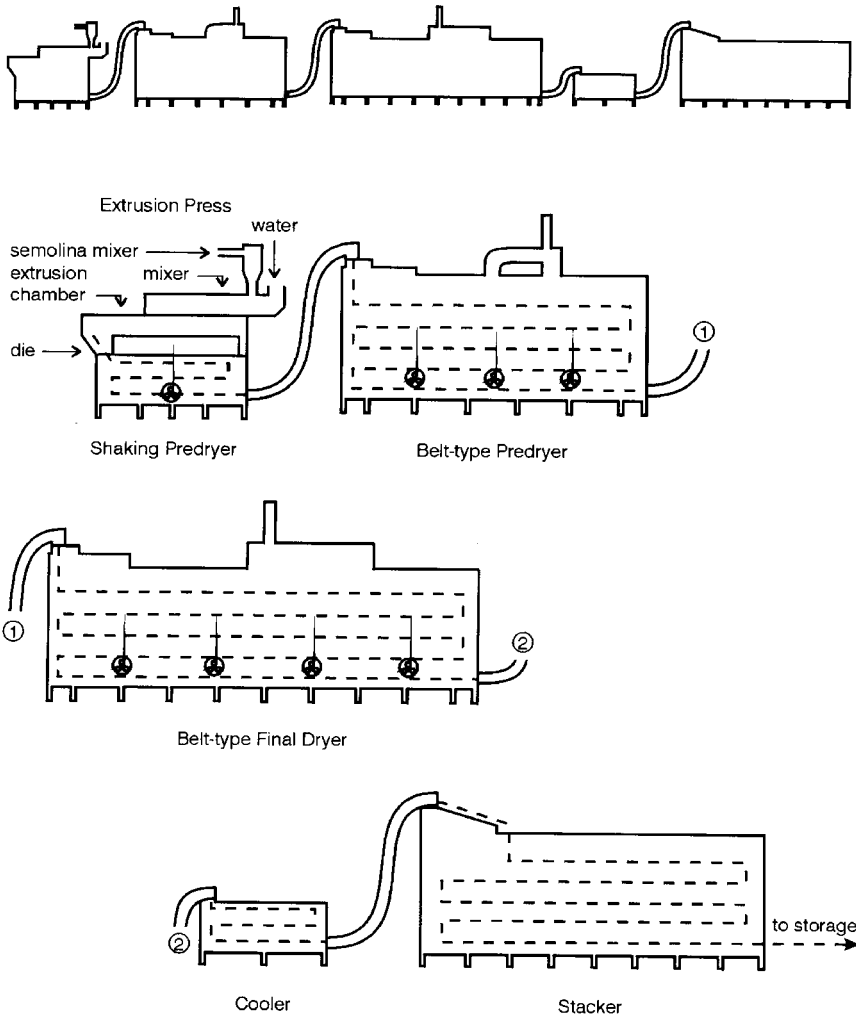


Fig. 6.2 A simple schematic of a short goods pasta line. (Adapted with kind permission from a diagram by Bühler AG, Uzwil, Switzerland.)

Braibanti, reportedly gives homogeneous hydration irrespective of granulation.

The product of a conventional pasta mixer is not a cohesive dough, but rather a mixture of agglomerated lumps of semolina.[16] This mixture, through the action of mixing paddles or kneading blades, passes from the mixing chamber to the extrusion chamber and extrusion worm where the dough is formed and developed under pressures in the range of 80–120 kg/cm^2. Temperature, water absorption, and the rotational speed and geometry of the screw influence the magnitude of the pressure. Presses also have the facility to reintroduce scraps

from the spreader or cutter into the mixing trough. Ground dried waste (regrinds) are also used along with the semolina in short pasta lines. Care must be taken however, to ensure that final product quality is not decreased by the reintroduction of inordinately high levels of regrinds.[14]

Dough temperature during the extrusion process should not increase above about 50ºC to prevent damage to the gluten network, and consequently to final product cooking quality. Heat, generated by the pressure and friction created during the extrusion process, must be dissipated through cooling to prevent inordinately high dough temperatures. To this end water, which is at a temperature of 20–30ºC, is circulated in water jackets around the extrusion cylinder and head. Mixing and extrusion chambers operate under vacuum to minimize oxidation of the carotenoid or xanthophyll pigments. Oxidation of these pigments is known to decrease the yellow color of finished pasta. In addition, the vacuum prevents air bubble formation, which can give rise to defects and an unsightly appearance in the dried product.

In recent years engineering innovations have developed presses with much greater capacity and improved performance. For example, in 1995 Bühler introduced the Polymatik press that mixes and develops the dough in 20 seconds. This extrusion press is based on a twin-screw mixer/kneader system, and according to the manufacturer it provides good dough development with improved product color. In conjunction with a 'Clean in Place' (CIP) system, the manufacturer also reports that the Polymatik furnishes excellent sanitation. From a capacity perspective, presses with an 8000 to 10 000 kg/h capacity have been manufactured recently by different manufacturers.

The dough must now be shaped before it is dried. In the case of long goods, the dough is augered forward by the screws into the diffusor/spreader tube. The apparatus spreads the dough over the long straight die and the long good is then extruded into strands. The strands are spread evenly onto metal sticks, and automatically cut to the appropriate length. The product is immediately subjected to a blast of hot air to minimize strands sticking together before entering the pre-dryer. In the case of short goods the dies are circular and rotary cutters cut the product. The pieces fall onto a shaker/conveyor where they are also exposed to circulating hot air to set their shape and to prevent pieces sticking together. The moisture loss in this, the shaking pre-dryer, is up to about 5 percent.

The product must now be dried down to a moisture of around 12.5 percent to ensure that it is strong and will have a long storage life. The drying process itself must be managed carefully to attain a uniform rate of water removal. Otherwise, the outside surface of the product may dry too quickly and harden too much before the inside has dried. Formation of such a barrier will hinder natural moisture diffusion and set up undesirable stresses within the product. These result in 'checking', or fracture lines in the product, which may give rise to breakage of the product during packaging and handling. Such a result will impact negatively on consumer acceptance because of a poor appearance and inferior cooking quality. Thus, proper drying is perhaps the most critical stage in

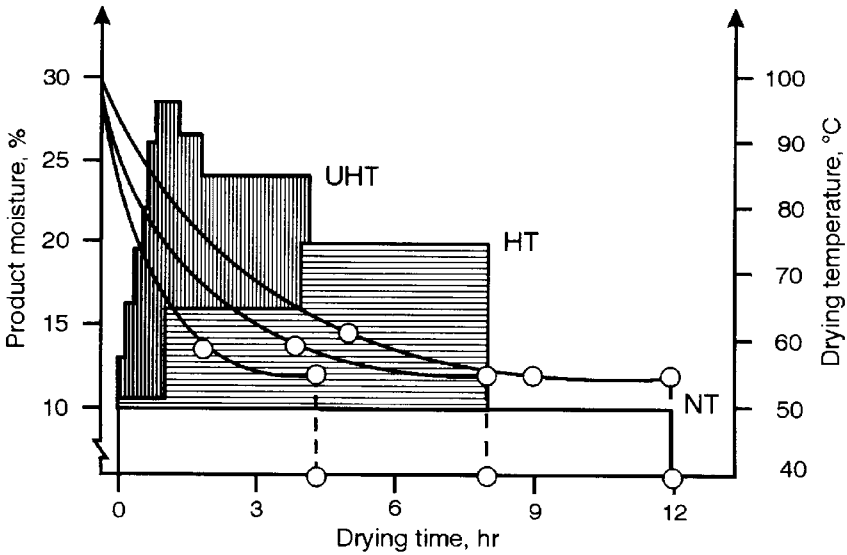


Fig. 6.3 Drying diagrams at ultra-high temperature (UHT), high temperature (HT) and normal temperature (NT) for the drying of long goods. (Adapted with kind permission from a diagram (*c*. mid-1990s) by Bühler AG, Uzwil, Switzerland.)

the production of high-quality pasta products that are acceptable to the demands of increasingly quality conscious consumers around the world.

As will be discussed in more detail later, there have been many innovations in drying technology in the latter part of the twentieth century. In general, moving the pasta through a number of drying zones maintained at precise temperature and relative humidity completes drying. Different equipment manufacturers have developed their own approach to the drying process, but in each case the general process is much the same. Drying of long goods (Fig. 6.3) is more delicate than that of short goods (Fig. 6.4). As a result greater care and longer drying time must be taken to reduce the moisture content of long goods.

For long goods, the first stage of drying is carried out in the pre-dryer where the moisture content is decreased from about 30 percent down to around 17 to 19 percent. In the case of short goods, the moisture content has already been lowered and decreases from about 25–27 percent down to between 17 to 19 percent. The pasta, long or short, then moves into the final drying phase where the moisture content is further reduced to about 12.5 percent. The product is then stabilized so that the moisture remaining within the product can redistribute itself evenly so that there are no stressful moisture gradients from the center to the outside of the product. If the product is not provided with appropriate stabilization, stress fractures or checking may develop. In the case of long goods a dampening step may follow stabilization to slightly increase moisture content and further stabilize the product and thus protect it from cracking.[17] The product must then be cooled to a temperature (28–32ºC) close to that of the surrounding

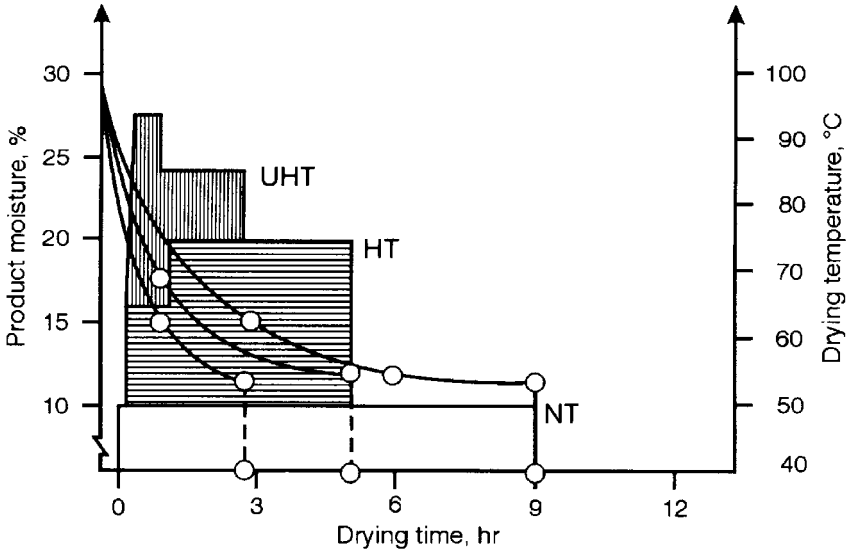


Fig. 6.4 Drying diagrams at ultra-high temperature (UHT), high temperature (HT) and notmal temperature (NT) for the drying of short goods. (Adapted with kind permission from a diagram (*c*. mid-1990s) by Bühler AG, Uzwil, Switzerland.)

environment with a final moisture close to 12.5 percent. As noted above, long pasta moves through the drier zones draped over metal sticks. Short goods are generally conveyed through the dryers on belts. Dryers may contain multiple levels of belts or sticks.

Cooled short goods are conveyed into bins in preparation for packaging. In the case of long goods, following cooling the product passes through the stick stacker where the product is removed from the sticks, and onto the stripper-saw that then cuts the pasta with high-speed saws. This operation removes the bends (the portion of the strand which curves over the stick) and trims the product to the appropriate length for packaging.

Packaging is a most important process since it protects the product from breakage or contamination before delivery and sale. In the case of product destined for sale on the store shelf, it must also present the product in an attractive manner to appeal to the consumer. More recently, with the advent of stringent labeling laws in many countries, the package itself is a necessary means of providing among other things important nutritional information to the consumer.

6.4 Advances in drying technology

The drying of pasta, as described above, has seen numerous innovations over the past 25 years or so. Undoubtedly, the most important advances in pasta

processing have taken place in drying technologies.[8,12] Drying diagrams typical of LT/HT/UHT for short and long pasta are illustrated in Figs 6.3 and 6.4.

Before the 1970s drying was performed at relatively low temperatures (LT) up to a maximum of 60ºC, and drying times for long goods were 18 h or more. Low temperature drying processes are now considered the traditional means of drying.[18] High temperature (HT) drying at temperatures of 60–85ºC was introduced to the industry in the 1970s and early 1980s.[19,20] The initial driving force behind the development of HT drying was improved bacterial control for egg products. Another immediately recognized benefit was much shorter drying cycles (≈8 h) that permitted more compact drying lines for a given capacity concomitant with a reduction in the high capital costs associated with plant space. As HT drying cycles became operational, it was discovered that an additional benefit was improved cooking quality and better color.[20–22] Once the benefits of HT drying to product quality became generally recognized, HT quickly became the process of choice for most pasta manufacturers worldwide.

In the past few years, the application of ultra-high temperature (UHT) drying (85–110ºC) has become common, with drying times as short as ≈4–5 h for long goods and ≈2–3 h for short goods. UHT drying reportedly produces pasta products with cooking quality and color equal to or better than that obtained with HT drying.

The impact of drying temperature on pasta cooking quality is readily apparent from a recent study by Schlichting *et al.*[23] (unpublished results). As seen in Table 6.2, when six Canadian durum wheat varieties of comparable protein content were processed into spaghetti at four drying temperatures, they all exhibited a similar response. As drying temperature increased, cooked spaghetti peak firmness increased.

In essence, the introduction of HT and UHT drying technology has enabled the pasta industry to produce pasta products with acceptable or even superior cooking quality, using lower-grade raw material. This technology has also led to improvements in cooking quality of pasta made from common wheat farina or mixtures of durum semolina and farina.[14,22] When HT drying is used the

Table 6.2 Cooked spaghetti firmness of Canadian durum wheat varieties dried at four drying temperatures[23]

	Cooked Spaghetti Peak Force (g)[a]			
Drying temperature (ºC)	40	70	90	95
Variety				
Kyle	878 a	869 b	965 b	1027 c
AC Avonlea	976 a	1033 a	1073 a	1219 a
AC Morse	875 a	928 ab	1009 ab	1121 bc
AC Melita	903 a	955 ab	1015 ab	1125 ab
AC Pathfinder	935 a	974 ab	1029 a	1117 bc
AC Navigator	964 a	972 ab	1061 a	1147 ab

[a] Means in a column followed by the same letter are not significantly different ($P = 0.05$).

cooking quality, particularly surface stickiness of pasta made from 100 percent common wheat farina, or mixtures of durum semolina and farina, improve dramatically.[24]

The improvement in color attributable to HT and UHT drying is a more intense yellow. For example, as shown by Schlichting *et al*.[23] (unpublished results) as drying temperature increased, Canadian durum wheat cultivars exhibited an increasing Minolta b*, indicative of greater yellowness, for most but not all varieties (Table 6.3). The improvement in pasta yellowness with increasing drying temperature has been attributed to inactivation of lipoxygenase, a bleaching enzyme linked to the loss of yellow pigment during pasta processing.[25]

Of some concern with higher temperature drying, particularly UHT drying, is the potential for development of a brown or reddish color due to excessive non-enzymatic browning, i.e. the Maillard reaction, or the 'burning' of the pasta. A brown or red hue in pasta is detrimental to consumer acceptance in many countries where a bright amber color is preferred. The interaction between drying temperature and a brown or reddish hue is a complex one. As shown by Schlichting *et al*.[23] (unpublished results), Canadian durum wheat varieties exhibit variable tendencies to redness (Minolta a*) as drying temperature increased (Table 6.3). Also, the response to temperature is not linear, and becomes increasingly apparent as the temperature increases above 70ºC. Factors associated with pasta color, including the interrelationships between varieties, growing environment, drying procedure and semolina extraction rate, are not well understood.[26]

In addition to imparting a detrimental effect on pasta appearance non-enzymatic browning by the Maillard reaction, which involves the condensation of sugars with amino acids, particularly with the essential amino acid lysine, can have a negative impact on protein nutritional quality. Research has shown that under some HT and UHT drying conditions there is a loss of lysine, vitamins, and the formation of furosine.[27] The maximum temperature, duration of HT or UHT, and the moisture content of the product when HT or UHT is applied affect the extent of nutritional loss. Pasta equipment manufacturers in the development of commercial drying cycles have taken the nutritional implications of HT and UHT drying into consideration, but some nutritional loss is unavoidable. However, according to Pollini[28] the loss of nutritional value due to HT and UHT should not be considered a serious defect because generally pasta products are not consumed as a source of essential amino acids or B vitamins.

Regardless, HT and UHT drying have revolutionized the pasta processing industry. The reduction in plant space for a given capacity paved the way for the development of pasta lines with far greater capacity than would ever be possible with LT drying. Improvements in pasta color and pasta cooking quality have made the quality of premium pasta products available to the most demanding consumers better than ever before. The technology has allowed pasta manufacturers targeting less demanding consumers to use less costly raw material, thereby giving access to good quality pasta at an affordable price.

Table 6.3 Impact of four drying temperatures on color of spaghetti from Canadian durum wheat cultivars[23]

Drying temperature (°C)	a* (redness)[a]				b* (yellowness)[a]			
	40	70	90	95	40	70	90	95
Variety								
Kyle	62.8 c	65.8 c	68.1 bc	67.9 bc	−0.10 b	0.21 b	3.37 b	5.00 b
AC Avonlea	64.2 bc	67.1 bc	68.2 bc	68.5 b	−0.57 c	−0.26 b	2.48 bc	4.09 c
AC Morse	60.6 cd	63.0 d	65.7 cd	65.0 cd	−0.13 b	−0.28 b	2.87 bc	4.19 bc
AC Melita	66.4 b	68.4 b	70.2 b	69.6 b	−0.64 c	−0.33 b	2.86 bc	3.09 d
AC Pathfinder	59.1 d	61.8 d	64.7 d	64.7 d	−0.73 c	−0.26 b	2.20c	2.90 d
AC Navigator	74.0 a	72.4 a	74.0 a	73.8 a	1.04 a	1.26 a	4.45 a	5.90 a

[a] Means in a column followed by the same letter are not significantly different ($P = 0.05$).

6.5 Raw material selection

Globalization and increased competition within the pasta industry are pushing pasta processors to produce products that have consistent quality over time, among regions in a country, and even from country to country. Consumers are becoming more discriminating in their quality requirements and less accepting of variability in product quality. To achieve a quality final product processors must begin by using raw materials that have the desired quality characteristics. Another essential part of the raw material quality package, which includes both the durum wheat and its milled product, semolina, is uniformity and consistency.

The production of good quality pasta begins with the milling of good quality durum wheat. Many pasta manufacturing plants are integrated milling and pasta processing units. Durum wheat is purchased on the basis of specifications that ensure that the semolina will achieve the expected pasta quality. Independent durum wheat millers must also establish durum wheat quality specifications in response to customer specifications for semolina.

For durum wheat milling, the primary quality selection criteria that must be considered are related to the physical condition of the wheat. These characteristics are largely influenced by environmental conditions during the growing season and during harvest.[29,30] The yield of semolina declines as kernels become thinner because the proportion of endosperm concomitantly decreases. The plumpness of kernels is related to weight per unit volume, or test weight. Therefore, minimum test weight is a widely used specification to ensure good milling performance.

Physical defects associated with surface discoloration of kernels are important because bright speck-free semolina is required to give the aesthetic appearance required for successful marketing of premium pasta products. The most common surface discolorations, black point (discoloration of the germ), smudge (more progressed infection extending into the crease) and mildew, are caused by fungi. Another fungal infection, Fusarium, reduces semolina yield due to kernel shriveling, and imparts inferior color to pasta. Fusarium is also a food safety concern because of associated mycotoxins such as deoxynivalenol (vomitoxin).

Weather damage can also impart serious physical defects. Frost prior to kernels reaching physiological maturity causes shriveled kernels, which impact on semolina yield. Immaturity associated with frost damage causes greenness, which in turn impacts negatively on pasta color. Pre-harvest sprouting due to damp harvest conditions results in high levels of the starch degrading enzyme α-amylase. The most accepted test to estimate α-amylase activity is Falling Number (FN), which estimates the thickness of a hot wheat-water slurry by measuring the time in seconds for a plunger to free-fall through the paste. Many manufacturers of premium pasta specify very high FN because they believe that starch degradation due to α-amylase will cause greater loss of solids during cooking, increased surface stickiness and softer cooked pasta texture. However, there is no firm scientific evidence that α-amylase has an adverse effect on pasta cooking quality unless sprout damage is very severe.[31]

A minimum hard vitreous kernel (HVK) content is an important trading specification because of its relationship to milling quality and protein content. Kernels, which are not vitreous (commonly referred to as starchy or mealy kernels, or yellow berry because of their opaque yellow appearance), are softer than vitreous kernels, and, in general, as HVK declines the yield of coarse semolina declines, negatively affecting milling quality. This aspect of HVK may become less important in the future as high-speed mixing technologies and improved extrusion press technologies come into more general use. Pasta equipment manufacturers are recommending finer semolina particle size for manufacturers using these technologies, making the greater production of flour and fine semolina during milling associated with lower HVK of less concern.

The next group of quality selection criteria to consider are related to various components found in the wheat and semolina. Of these, protein content is the most important of all durum wheat and semolina quality characteristics since it has a major influence on cooking quality.[32–34] HVK specifications have traditionally been used to guarantee sufficient protein content to achieve the desired pasta texture. With the development of rapid instrumental protein testing (near infrared technology) protein content guarantees are becoming an accepted part of durum wheat sales agreements, which makes the use of an HVK specification as a protein guarantee redundant.

High protein durum wheat of good physical condition is highly desirable because it will generally yield a semolina of uniform particle size with a minimum number of starchy semolina particles, and thus will hydrate evenly during mixing and will produce a pasta product which is physically strong and elastic. Such a pasta product will swell adequately during cooking, will not leave much residue in the cooking water, and will remain firm when kept in warm water after cooking and before it is served. Generally, as protein content increases, the cooked pasta becomes firmer and less sticky, which are desirable characteristics to the consumer. Excluding raw material cost, durum wheat protein requirements in the pasta industry will vary, depending upon processing systems, manufacturers' quality philosophy, consumer demands, product line, raw material availability, blending capabilities (with common wheat or wheat of differing origins), etc. In general, however, a minimum protein content for durum wheat destined for pasta manufacturing is about 14 to 15 percent dry matter basis. Due to loss of protein during the milling process, the corresponding semolina protein content would be 13 to 14 percent dry matter basis.

Another closely-related selection criterion is the gluten strength or protein quality of a durum sample. Strong gluten is universally acknowledged as an important prerequisite for good pasta-making quality. Compared to weak gluten varieties of comparable protein content, strong gluten varieties exhibit less sticky dough with better extrusion properties and superior cooked spaghetti textural characteristics. There are a number of factors associated with cooking quality including bite, chewiness, stickiness, and resistance to overcooking, appearance, flavor and residue in the cooking water. Scientific evidence obtained so far indicates that the continuity and strength of the protein network

is directly related to the textural characteristics of the cooked spaghetti. These characteristics are influenced by the total protein content since as protein content increases so does the extent of the network. Protein quality is believed to affect the properties of the protein network. It has been shown that certain gluten proteins, in particular some low molecular weight glutenin subunits, play a direct role in the formation of the gluten network.[35,36] Some of these subunits are more effective than others in forming a good network and influence the plasticity and elasticity of the resultant dough, and the extent of the protein network around starch granules.

A number of tests are used to determine gluten strength. For example, a simple wheat test is the sodium dodecyl sulfate sedimentation test (SDS).[37] SDS measures the volume of sediment from a suspension of ground wheat or semolina after a specified time, strong gluten being associated with higher volume. Minimum semolina SDS sedimentation values are imposed by some pasta manufacturers on semolina millers. The gluten index method[38,39] is another test that is commonly used to determine gluten strength. The gluten index is the measure of the proportion of wet gluten that resists passing through a screen during centrifugation. Stronger gluten is associated with more retention of gluten on the screen. Thus, as the gluten index increases, on a scale of 0 to 100 percent, the gluten strength increases. A durum sample with a gluten index of around 40 percent is typical of the strength associated with conventional Canadian and American (North Dakota) durum wheat. Some markets also like to include some durum wheat with very strong gluten characteristics primarily for blending purposes.[40] The gluten index values of these durum varieties can be in the order of 90 percent or slightly higher. Such strength is typical of some European varieties, recently developed extra-strong varieties from Canada (such as AC Pathfinder as shown in Fig. 6.5), and American desert durum varieties (from southwestern United States).

Physical dough tests such as the Farinograph, Mixograph and Alveograph are also used in various parts of the world to give an indication of dough mixing characteristics. Figure 6.5 shows some Canadian varieties with physical dough properties characteristic of conventional strength (Plenty, Kyle), medium strength (AC Morse), and extra-strong strength (AC Pathfinder). The mixograph is used widely in the United States, but the Alveograph appears to be gaining favor internationally. Parameters derived from the Alveograph (P, pressure, related to the height of the curve; L, the length, P/L, the ratio of height to length and W, work, related to the area of the curve) are used by some companies for selection purposes.

The influence of drying technology on pasta properties has brought some of the traditional criteria for durum wheat selection related to protein content and gluten strength into question. For example, there is evidence that under HT and UHT drying conditions protein strength has less influence on pasta cooking quality than under LT drying conditions.[34] Thus, protein content is the most important quality consideration in the selection process. Coincidentally, the widespread acceptance of HT and UHT drying has made it possible to produce

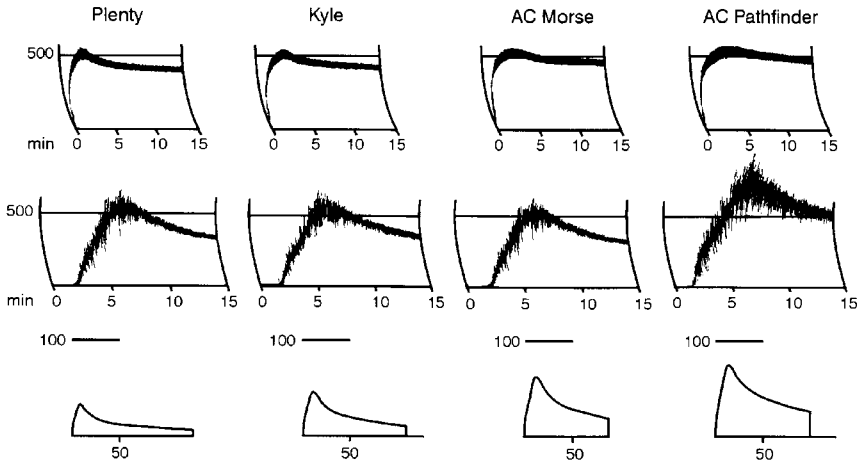


Fig. 6.5 Comparison of the dough strength characteristics of some Canadian durum varieties as determined by alveograph (bottom), mixograph (middle) and farinograph (top) curves (Marchylo *et al.*[40]).

reasonable quality pasta products using low protein semolina. Some countries, however, such as Japan, the USA and Spain, have legislation and labeling laws in place, which stipulate minimum protein levels in the finished product. This requirement, of course, impacts on selection criteria since minimum wheat protein levels must be obtained no matter what the quality potential is for the final product using HT drying.

While HT and UHT drying have become very popular, it is by no means universal. Many different drying regimes are in practice around the world. Some leading manufacturers continue to use LT drying because of tradition, and in the belief that HT and UHT products do not have the texture, flavor and color associated with premium quality LT pasta. In situations where drying temperatures are lower, gluten quality or strength remains a very important selection criterion.

For dried pastas, in particular long goods, major North American and European pasta manufacturers claim that strong gluten durum wheat is preferable. For example, in response to market demand, Italian breeders are developing durum varieties with Alveograph P/L values of about 1.5 to 2.5, and Alveograph W values of around 200 to 250. For top quality long goods, some manufacturers request durum wheat with a W over 300.[40] Similarly, in response to market demand Canada has recently developed durum wheat varieties with far stronger gluten than conventional strength varieties (Fig. 6.5).

The increasing popularity of instant pastas also may impact on gluten strength requirements, since these pasta have thinner walls and need more strength to stand up to processing. On the other hand, for laminated pasta, which includes much of the increasingly popular fresh pasta, processors have indicated that durum wheat with more extensible and somewhat weaker gluten is preferred

because of superior sheeting properties. Thus, durum wheat or semolina specifications for gluten strength will vary depending on the type of final product being processed, as well as the production and marketing philosophy of the processor.

Another important set of selection criteria is associated with semolina refinement and color and, ultimately, the appearance of pasta. Aesthetics is an integral part of pasta marketing, as evident from the ubiquitous use of transparent packaging which gives customers the opportunity to consider pasta appearance in their purchasing decision. Consumers generally prefer pasta with a deep translucent amber color, although there may be some exceptions in certain countries or segments of the population within a country.

Black specks and bran specks in semolina are important semolina specifications. Black specks and brown specks may be due to poor durum wheat physical condition. Poor milling techniques may also cause them. Black specks can arise from inadequate cleaning, leaving impurities such as ergot and weed seeds in the durum wheat. Bran specks can be the result of improper milling technique, especially improper purifier settings.

In general, pasta color deteriorates (becomes more brown and less yellow) as semolina extraction rate increases because of the combined effects of more bran contamination and elevated levels of oxidative enzymes such as lipoxygenase, polyphenol oxidase and peroxidase.[41,42] The ash content of the endosperm, from which semolina is derived, is much less than that of the outer regions of the kernel. As a result ash content in semolina is an important specification because it is an indication of semolina refinement. In some countries, such as Italy and France, semolina ash cannot exceed limits specified by government regulations. A limitation of ash content as a semolina refinement index is that endosperm ash content differs widely due to differences among varieties and environment. An alternative method for estimating semolina refinement that relates better to pasta color is to determine the brightness of a wet semolina slurry with a reflectance spectrophotometer.

The yellowness of the final product is influenced by milling, pasta processing conditions as well as by the raw material quality (wheat pigment level). The aesthetic appeal of a bright yellow color makes it a desirable characteristic in durum semolina, although there is no apparent relation between yellowness and cooking quality. The yellow color in durum semolina comes from a carotenoid pigment, xanthophyll. The traditional direct measurement of yellow pigment content in wheat or semolina is to extract with n-butanol or ethanol, followed by spectrophotometric determination at an absorbance of 435.8 nm. The development of affordable computerized spectrophotometers has made rapid precise color analysis of dry semolina possible. Specifications based on tristimulus color coordinates (L*, a*, b*) are becoming more widespread. Care must be taken to ensure that a consistent particle size is used when determining dry semolina color, since semolina will appear increasingly pale as granulation becomes finer. For this reason, in Europe semolina color is often measured instrumentally using discs of dough.

6.6 The future

In many ways the future of the pasta industry is already upon us. In the past twenty years or so there have been major innovations in pasta manufacturing technology that have improved the final product. In particular, as discussed earlier, modern pasta plants are now computer automated. They are also considerably more compact and efficient as the application of modern extrusion and high and ultra high drying technologies have vastly increased production capacity. Further increases in efficiency and product quality have also been achieved through vertical integration of pasta plants and semolina mills. In the future, this will undoubtedly mean that these companies will also become more aware of milling quality as an important processing characteristic in addition to the pasta processing quality of the semolina.

As with many other industries in the world, globalization has impacted on the pasta industry. Large pasta manufacturers or multinational food companies have acquired pasta plants in many countries worldwide. The evolution of the industry undoubtedly will continue along these lines with the world seeing more of the same. The fierce global nature of the competition in this industry will see further rationalization and consolidation of capacity. This development will have implications on durum wheat quality requirements since the philosophy of pasta manufacturing of the parent companies will be integrated into the subsidiaries or branch plants.

The building of super plants with huge capacities will result in increased efficiencies, but with the risk that production problems that shut down lines will be associated with major product losses. These new plants will demand that the durum wheat and semolina that they purchase must be of consistent and uniform quality to minimize any disruptions or plant problems. In addition, the appearance of the finished pasta with specific reference to a bright amber color will probably become more universally important.

The popularity of pasta will continue to increase in many countries with notable potential in Latin America, Asia and the Pacific Rim. Demand for pasta in these parts of the world will increase, and the demand for higher quality pasta made from durum wheat will increase as economies and standards of living improve. As global demand for durum increases, production may lag, and the blending of durum wheat with common or bread wheat may increase in some countries to meet the demand for affordable pasta. Application of higher drying temperatures will enhance the quality of blended products. At the same time, the impact of higher drying temperatures on nutrition, which is currently viewed as an issue mainly in Italy, may become an important consideration, especially where the protein in pasta is viewed as an important source of protein.

The future requirements in the area of durum wheat quality in many ways will not change. In particular, high protein content will continue to be the single most important quality criteria, although it may become less available. The impact of intensive cultivation and crop management practices on the environment, and increased variability in weather conditions, may make it

more difficult for farmers to grow high protein durum wheat. Of course, fluctuating durum wheat prices will influence farmers' decisions on fertilization and, consequently, impact on availability of durum protein. In general, it will be important for plant breeders to develop new durum wheat cultivars with improved potential for protein production under less intensive management practice.

Along with this breeding for higher intrinsic protein potential, plant breeders and quality specialists will need to revisit the traditional concepts of durum wheat and semolina quality. For example, much of the early work that showed the importance of gluten strength to cooked pasta texture was performed at lower traditional drying temperatures. This quality characteristic has been shown, however, to be less important at HT and UHT drying temperatures. Therefore, the specific qualities for durum destined for drying at high temperatures must be determined and incorporated into new durum wheat varieties.

The breeding for durum varieties with novel characteristics for specific markets will also increase in the future. For example, durum wheat varieties may be developed with protein or other quality features specifically aimed for the production of frozen microwavable, instant or retortable pastas. These wheat varieties may have starch characteristics (high amylose) specifically designed to improve cooked pasta quality for such products. Similarly, as people become more health conscious, there may be a niche market for nutraceutical durum wheat (higher fiber, β-glucan) for pasta production. These wheat varieties may be bred using conventional breeding procedures or alternately through genetic modification, depending on consumer acceptance. Currently, durum wheat does not appear to be a target for genetic modification and it remains to be seen when economics and consumer reaction will make this approach more attractive. In general, in the future there will be a wider choice of high quality durum wheat varieties exhibiting a range of quality features, suitable for different products.

6.7 References and further information

1. UNIONE INDUSTRIALI PASTAI ITALIANI (ITALIAN PASTA ASSOCIATION), 'Estimate of pasta consumption', <http://www.unipi-pasta.it/index_economia.html> Oct. 25, 1999.
2. MBABAALI S, 'The North American Pasta Industry', *Bi-Weekly Bulletin*, 1997 **10** 1–8.
3. NATIONAL PASTA ASSOCIATION, 'The Nutrient Profile of Pasta', National Research and Education Committee of the National Pasta Association, Arlington, Virginia, 1984.
4. ANON, Data compiled by National Pasta Association, *Pasta Journal*, 1997 **79** 12–18.
5. MATSUO R R, 'Durum wheat – Production and processing', pp. 779–807,

Grains and Oilseeds, Vol. II, 4th Edn, Canadian International Grains Institute, Winnipeg, MB, Canada, 1993.
6. KEMPF C, 'From buttons to bowties: The evolution of pasta machinery in the United States', *Pasta Journal*, 1998 Oct. 14–26.
7. AGNESI V, 'Alcune Notize Sugli Spaghetti. Racolte di Vincenzo Agnesi', Imperia, Italy, 1975.
8. DAVIS R, 'The evolution of pasta equipment in Europe', *Pasta Journal*, 1998 Dec. 18–23.
9. HUMMEL CH, *Macaroni Products: Manufacturing, Processing and Packing*, The Alcuin Press (Welwyn) Ltd., Leicester, UK, 1966.
10. GIESE J, 'Pasta: New twists on an old product', *Food Tech*, 1992 **46** 117–26.
11. ANTOGNELLI C, 'The manufacture and applications of pasta as a food ingredient: a review', *J. Food Tech*, 1980 **15** 125–45.
12. BARONI D, 'Manufacture of pasta products', pp. 191–216, *Durum: Chemistry and Technology*, G Fabriani and C Lintas (eds), American Association of Cereal Chemists, St. Paul, MN, 1988.
13. DICK J W and MATSUO R R, 'Durum wheat and pasta products', pp. 507–47, *Wheat: Chemistry and Technology* Vol. 2, Y Pomeranz (ed.), American Association of Cereal Chemists, St. Paul, MN, 1988.
14. MILOTOVIC L J and MONDELLI G, *Pasta Technology Today*, Chiriotti Editori, Italy, 1991.
15. DALBON G, GRIVON D and PAGANI M A, 'Continuous manufacturing process', pp. 13–58, *Pasta and Noodle Technology*, J E Kruger, R R Matsuo and J W Dick (eds), American Association of Cereal Chemists, St. Paul, MN, 1996.
16. MATSUO R R, DEXTER J E and DRONZEK B L, 'Scanning electron microscopy study of spaghetti processing', *Cereal Chem*, 1978 **55** 744–53.
17. DALBON G, 'Technical innovation and quality of durum wheat pasta', *Technica Molitoria*, 1996 **47** 656–65.
18. DALBON G and OEHLER W, 'Einfluß von Rohstoffqualität und Trocknungsdiagramm auf die Qualität der Teigwaren', *Geitreide Mehl und Brot*, 1982 **36** 298–302.
19. PAVAN G, 'L'Impiego dell'alta temperaturra nel processo di essiccamento delle paste alimentari', *Technica Molitoria*, 1979 **30** 362–70.
20. MANSER J, 'High temperature drying of pasta products', *Buhler Diagram*, 1980 **69** 11–12.
21. ABECASSIS J, ALARY R and FEILLET P, 'Influence de la température de sécharge sur l'aspect et la qualité des pâtes alimentaires', *Ind. Cereales*, 1984 **31** 13–18.
22. MALCOLMSON L J, MATSUO R R and BALSHAW R, 'Effects of drying temperature and farina blending on spaghetti quality using response surface methodology', *Cereal Chem*, 1993 **70** 1–7.
23. SCHLICHTING L M, MARCHYLO B A, DEXTER J E and AARTS W, 'Interrelationships among gluten strength, drying temperature and spaghetti color',

Cereal Chem, (manuscript in preparation), presented at the annual meeting of the American Association of Cereal Chemists, Minneapolis, MN, 1998.

24. DEXTER J E, MATSUO R R and MORGAN B C, 'High temperature drying: effect on spaghetti properties', *J. Food Sci*, 1983 **46** 1741–46.
25. DEXTER J E, MATSUO R R and MORGAN B C, 'Spaghetti stickiness: some factors influencing stickiness and relationship to other cooking quality characteristics', *J. Food Sci*, 1983 **48** 1545–51.
26. KOBREHEL K and ABECASSIS J, 'Influence de la température des pâtes alimentaires sur l'activité et la composition des peroxydases en relation avec la couleur des produits', *Lebensm.-Wiss. U.-Technol*, 1985 **18** 277–80.
27. CUBADDA R, 'Effect of the drying process on the nutritional and organoleptic characteristics of pasta. A review', pp. 79–89, *Pasta and extrusion cooked foods*, Ch Mercier, and C Cantarelli (eds), Elsevier Appl. Sci. Publ., London, 1985.
28. POLLINI C M, 'THT technology in the modern industrial pasta drying process', pp. 59–74, *Pasta and Noodle Technology*, J E Kruger, R R Matsuo and J W Dick (eds), American Association of Cereal Chemists, St. Paul, MN, 1996.
29. DEXTER J E and EDWARDS N M, 'The implications of frequently encountered grading factors on the processing quality of durum wheat', Association of Operative Millers Bulletin, 1999 Oct, 7165–71.
30. FEILLET P, and DEXTER J E, 'Quality requirements of durum wheat for semolina milling and pasta production', pp. 95–131, *Pasta and Noodle Technology*, J E Kruger, R R Matsuo and J W Dick (eds), American Association of Cereal Chemists, St. Paul, MN, 1996.
31. DEXTER J E, MATSUO, R R and KRUGER J E, 'The spaghetti-making quality of commercial durum wheat samples with variable alpha-amylase activity', *Cereal Chem*, 1990 **67** 405–12.
32. MATSUO R R, DEXTER J E, KOSMOLAK F G and LEISLE D, 'Statistical evaluation of tests for assessing spaghetti-making quality of durum wheat', *Cereal Chem*, 1982 **59** 222–28.
33. AUTRAN J C, ABECASSIS J and FEILLET P, 'Statistical evaluation of different technological and biochemical tests for quality assessment in durum wheats', *Cereal Chem*, 1986 **63** 390–94.
34. D'EGIDIO M G, MARIANI B M, NARDI S, NOVARO P and CUBADDA R, 'Chemical and technological variables and their relationships: a predictive model for pasta cooking quality', *Cereal Chem*, 1990 **67** 275–81.
35. NIETO-TALADRIZ M T, RUIZ M, MARTINEZ M C, VAZQUEZ, J F and CARRILLO J M, 'Variation and classification of B-low molecular weight glutenin subunit alleles in durum wheat', *Theoretical and Applied Genetics*, 1997 **95** 1155–60.
36. AMES N, CLARKE J, MARCHYLO B, DEXTER J and KOVACS M, 'The effect of durum wheat gluten strength on pasta quality', pp. 228–33, *Wheat Protein – Production and Marketing*, D B Fowler, W E Geddes, A M Johnston and

K Preston (eds), University Extension Press, University of Saskatchewan, Saskatoon, SK, 1998.

37. DEXTER J E, MATSUO R R, KOSMOLAK F G, LEISLE D and MARCHYLO B A, 'The suitability of the SDS-sedimentation test for assessing gluten strength in durum wheat', *Can. J. Plant Sci*, 1980 **60** 25–29.
38. CUBADDA R, CARCEA M and PASQUI L A, 'Suitability of the gluten index test for assessing durum wheat and semolina', *Cereal Foods World*, 1992 **37** 866–69.
39. MACDONALD C E, 'Collaborative study on wet gluten and gluten index determinations of wheat flour or meal (AACC method 38-12)', *Cereal Foods World*, 1994 **39** 403–5.
40. MARCHYLO B A, DEXTER J E, CLARKE J M and AMES N, 'Effects of protein content on CWAD quality', pp. 53–62, *Wheat Protein – Production and Marketing*, D B Fowler, W E Geddes, A M Johnston, and K Preston (eds), University Extension Press, University of Saskatchewan, Saskatoon, SK, 1998.
41. MATSUO R R and DEXTER J E, 'Comparison of experimentally milled durum wheat semolina to semolina produced by some Canadian commercial mills', *Cereal Chem*, 1980 **57** 117–22.
42. FEILLET P, AUTRAN J C and ICARD-VERNIÈRE C, 'Pasta browness: an assessment', *J. Cereal Sci*, 2000 **32** 215–33.

7

Asian noodle processing

D. W. Hatcher, Canadian Grain Commission, Winnipeg

7.1 Introduction

7.1.1 History

Noodles can be traced back over 6000 years to northern China.[1,2] Some attribute their origin to a small hamlet of Shanxis near the source of the Yellow River where *Yu* noodles, similar to spaghetti were first formed.[3] The Han dynasty (206 BC–220 AD) had a well-established hand-made (so-men) noodle industry and by the Sung dynasty (960–1279 AD) variations in preparation and cooking styles had developed. The first exchange of noodle technology took place between 25 and 220 AD during the Eastern Han Dynasty when the Japanese envoy to China returned home. Noodles disseminated from China and were quickly adopted by other countries of South East Asia: Korea, Philippines, Thailand and Malaysia, and were well-established in Japan by the 16th century.[4] Buckwheat flour, which had been used as a substitute for rice in Japan, was incorporated into buckwheat (soba) noodles by the seventeenth century.[5] A relatively recent event was the development of the automated deep-fried instant noodle (ramen style) in Japan in 1957[1,2,3] by Nissin Foods where they were quickly adopted as a convenience food. By the 1970s the instant noodle had migrated successfully to the United States.[1] In 1997 it was estimated that 40 billion[6] servings of instant noodles were consumed annually. The importance of noodle products throughout South East Asia can best be summarized by the fact that they account for 30–40 percent of most countries total wheat flour consumption.[1] The limited scope of this chapter does not allow us to explore the diversity of noodles unique to individual regions but will be confined to the dominant forms which have a range of quality and processing requirements.

7.1.2 Changing trends

The Asian region is perhaps one of the fastest evolving areas of our global village. This phenomenal force for change is driven by a number of factors including a burgeoning population, increasing GDP with concomitant discretionary personal income as well as an evolution in trade practices.

For decades the primary focus of wheat product research has been disproportionately emphasizing bread. The increasingly prevalent economic shift projected for Asia and the anticipated interest in food quality has led to a reassessment of research and technological priorities. During the 1992–96 period the Asian-Pacific region imported 32.9 million tonnes (MT) of wheat which is anticipated to rise to 34.5 MT by 2003 and 39.5 MT by 2008.[7] China, in particular the northern region, uses wheat as a staple with consumption over 90 kg per capita which is higher than North American standards.[8] Thailand, the world's second largest rice exporter has seen annual wheat consumption rise by 7.5 percent, while Indonesia has been increasing at 7.8 percent annually (Table 7.1).[8] In South Korea wheat flour consumption has fluctuated between 32.1–39.5 kg per capita of which, in 1995, 47.5 percent was used for making noodles. In Japan wheat consumption, although still only half that of rice, has increased tenfold to 32.8 kg per capita (1995) with an increase in the standard of living being listed as the most significant reason for this growth.[8] Thailand has even instituted the fortification of noodles with the essential micro-nutrients, iron (5 mg), iodine (50 μg)and vitamin A (267 μg) per serving because of deficiencies of these essentials in the basic Thai diet.[9]

7.2 Noodle diversity

7.2.1 Influence of wheat characteristics

As with all food products the quality of the starting material dictates the performance of the final end product. At present noodle manufacturers prefer white seed coat wheat as the resulting flour and corresponding noodle does not show the bran specks as obviously as a red seed coat wheat.

Table 7.1 Indonesia's production of instant noodles 1993–1997

Year	Production (tons)	Packages (billions)	Growth (%)
1993	168,516	2.25	
1994	210,815	2.81	25.1
1995	472,290	6.30	124.0
1996	590,695	7.88	25.1
1997	649,765	8.66	10.0
1998*	600,000	8.00	−7.0

*projected.
Courtesy of Indonesian Commercial Newsletter.

Most mill operations in South East Asia use a mixed grist composition in their mills to ensure that they can supply the quality requirements of the noodle manufacturers. There are a few newer mills which do separate runs, placing their flours in blending bins and preparing customized quality packets for discriminating customers. However, this is not yet popular due to the additional costs incurred. Test weight and thousand kernel weight can be used to predict milling yield while simultaneously indicating the presence of degrading factors such as damaged, shriveled or frosted grain. Of specific interest to the millers is the recognized protein loss during milling which can range from 0.7 to 1.5 percent depending on the type of wheat and its source. Alkaline noodles are highly dependent upon protein to ensure their unique textural characteristics while white salted noodles, most notably the Japanese 'Udon' noodle are more dependent on the starch characteristics. Falling number (FN) values are normally included in the wheat's specifications as it is an indicator of the enzyme α-amylase. It is not uncommon for dry environments to yield grain with falling numbers above 500 sec^{-1}. The enzyme increases tremendously in sprout damaged wheat with minimum values of 300 sec^{-1} found in sound wheat. Values below this have sufficient α-amylase activity to degrade the starch to simple sugars causing a loss in texture and undesirable color. Other enzymes, in particular peroxidase, associated with noodle discoloration, have been shown to rise thirty-five fold during severe sprouting.[10] It is of interest to note conflicting research findings on the impact of severe sprouting on noodle quality. The use of high quality (60 percent flour yield) patent or straight grade (72 percent yield) flours for the preparation of yellow alkaline noodles (YAN) did not show significant differences in brightness (L*) or yellowness (b*) for fresh (2 h) or aged (24 h) raw noodles prepared from wheat having a falling number between 210–85 sec.[11] Differences from a very sound sample, FN = 485, were, however, significant. Minimal differences were detected in the cooked noodle's textural attributes over the same FN range with the exception of the FN = 485 sample. Assessment of white salted noodles (WSN), both fresh and dried found no statistical difference in the noodle's brightness (L*). Other research[12] suggested that reduced amylograph viscosity values, indicative of sprout damaged flour, were correlated with reduced noodle color.

In most commercial mill operations it is not unusual for the miller to have over 50 streams which they can selectively blend to meet the noodle manufacturer's requirements. Through proper millstream selection polyphenol oxidase (PPO) activity can be reduced to less than 4 percent of that found in the whole grain.[13] In many countries the improved financial situation has allowed governments to deregulate their wheat imports allowing milling companies new options for supply. However, in many cases millers limit the availability of flour with differing quality to only a few specific blends and do not disclose their actual specifications.

7.2.2 General flour characteristics

In many countries the noodle manufacturer's source of flour is usually dictated by price and a guarantee that it will perform adequately. A fine flour (less than 130 μm) with a uniform particle size distribution is required for all noodle production as it ensures uniform water distribution within a specified mixing period. Coarser flour absorbs water at a slower rate while extremely fine flour, often having high starch damage, absorbs water too quickly.[14] The various noodles have their own flour protein specifications as their textural attributes are significantly correlated with protein content. Aside from protein quantity, protein quality is an important factor, especially from the processing perspective. Gluten, the viscoelastic protein composite which results from the mixing of gliadin and glutenin proteins, must have sufficient strength to handle multiple sheeting passes without tearing yet retain elasticity to avoid excessive shrinkage after rolling. Research has indicated a very strong correlation between whole meal flour SDS sedimentation results and the noodle textural characteristics maximum cutting stress (bite) and maximum compression stress (chewiness) for both white salted and yellow alkaline noodles.[15] Wheat lacking the gliadin protein electrophorogram bands 44.5 or 45.0 were found to be of poorer quality for either noodle type. The addition of both alkaline and/or salt to the noodle dough increases its toughness which is reflected in the amount of work/energy input required for processing. In the flourishing instant noodle market, protein content is negatively correlated with oil uptake during processing and thus presents a unique fiscal consideration and increasing health concern.[16]

Starch plays a key role in the structure and texture of noodles, especially the white salted noodles such as the Japanese Udon. The special softness but unique elasticity associated with these noodles is associated with their high swelling and high paste viscosity starch. These characteristics are variety dependent forcing millers to stipulate varieties when importing wheat.[17] Two currently popular Australian varieties are Eradu and Cadoux. Udon manufacturers in Japan and Korea stipulate a minimum 700 BU peak viscosity for their flour purchases.[16] Work by a number of researchers[18–22] have actually shown that high swelling starch flours are not desirable for alkaline noodles.

7.2.3 General processing characteristics

Minimal improvements in front-end processing technology and equipment have been observed in recent years with the key differences to various products being confined to the latter stages of processing.[23] A general process flow diagram can be seen in Fig. 7.1.

Commercially, the addition of the correct amount of water to form the dough requires a 30–35 percent range with the mixing time restricted to less than 20 min.[23] The physical operation of a large-scale commercial mixer generates greater heat output elevating the temperature of the dough, which in turn becomes soft and sticky, and subsequently causes difficulties during sheeting. In some operations the amount of water added is reduced to counter the softening

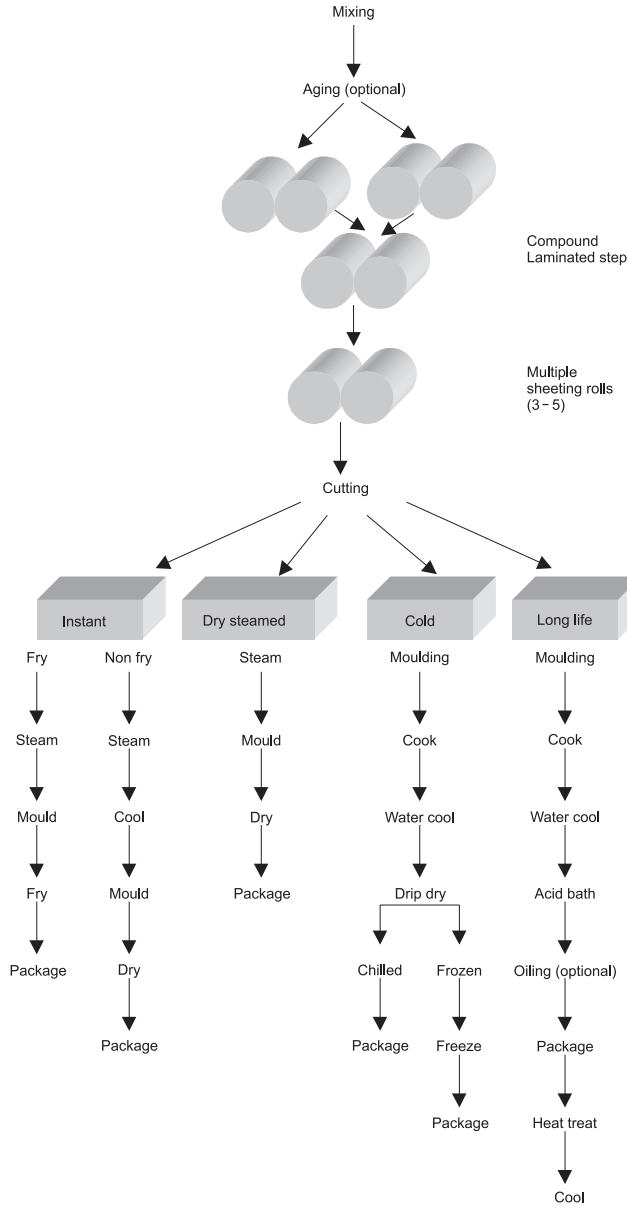


Fig. 7.1 Stages in different noodle processing.

effect which results in a poor internal noodle structure. This causes poor noodle quality and greater loss during packaging and distribution. The introduction of vacuum mixers in some plants has overcome this problem.

Aging the dough before sheeting is beneficial in all noodle production. It improves starch gelatinization and assists in the even hydration of the flour

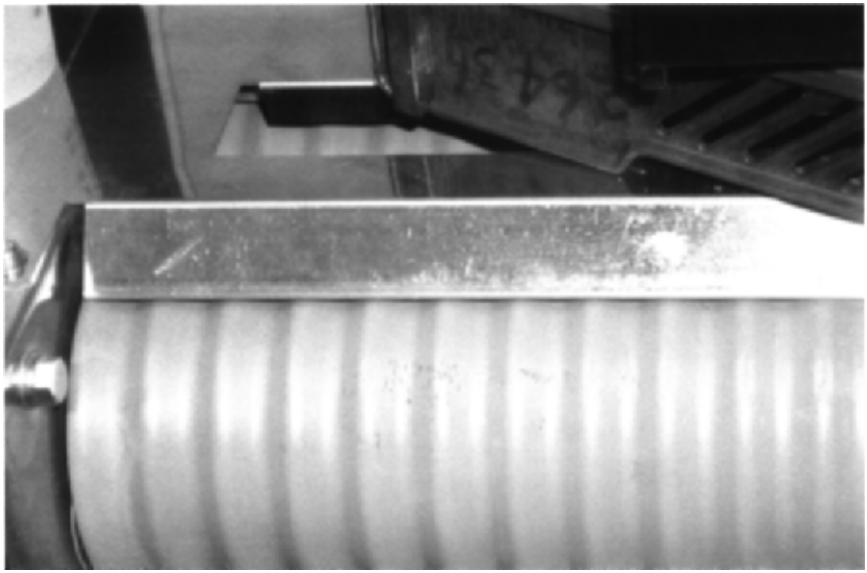


Fig. 7.2 Wavy sheeting rollers used to improve gluten development in noodle production.

particles promoting better gluten development. The added benefit is a smoother noodle surface and associated decreased stickiness both of which are desired by the consumer. During the compression stage of sheeting the gluten initially is developed and becomes more uniform in nature.[24] However, in most small commercial plants a dough-resting or aging step is not used, resulting in uneven hydration and subsequent loss of gluten development. Random areas of poor gluten development result in weak areas within the cut noodle causing increased loss during subsequent packaging and distribution.

Compound sheeting using waved rollers, see Fig. 7.2, in a multi-roller system, has been regarded as a significant development in noodle production.[23] The primary goal of this system is to improve the development of the gluten network to achieve noodle quality approaching that of the hand-made noodle.

7.3 White salted noodles

7.3.1 Hand-made noodles

Three forms of noodle making by hand have been used traditionally: hand swung, hand cut and hand stretched. Hand-swung noodles have great appeal as they are considered the optimum noodle quality. Flour and water (55 percent) containing dissolved salts are mixed to form a crumbly dough. Intensive hand labor kneads the dough to develop the gluten. The dough is then rolled into a rope whose ends are held in either hand. Repeated swinging elongates the dough which is folded and twisted and the process repeated. With each elongation the

number of strands doubles to yield increasingly thinner noodles. Hand-swung noodles are cooked immediately after production and requires a skilled person to prepare consistent high quality results. Production of hand-swung noodles is often considered an art rather than a technology.

Hand-cut noodles, normally served fresh, are characterized by their smoothness and firmness. A simple formulation of flour:water:salt in the ratio 100:40–45:3–5 is used in their preparation.[2] The water containing the dissolved salt is slowly added to the flour allowing small dough balls to be formed by hand. A series of these dough balls are individually amalgamated by hand into a larger mass through repeated kneading of the dough which simultaneously develops the gluten matrix. A rest period is used to ensure complete hydration of the flour particles before a second kneading and a second rest period. In commercial operations a 30 min slow speed mixing without the first rest period is common. After mixing, the dough is divided into hand workable pieces that are formed into balls prior to a second rest period. The rest periods allow the developed gluten matrix to mature. The dough is subsequently rolled, dusted, folded and compressed before being cut with a specially designed knife.

Hand-stretched noodles are also simple in formulation but have both higher water and salt ratios (45–55:5) respectively. The dough is prepared in the same manner as hand cut, differing in how they are handled after the gluten has matured. The key difference lies in the dough sheet being cut in an internally spiraling manner with the width of the strand being equivalent to the sheet's initial thickness. The dough is repeatedly unwound and gently stretched, treated with cotton seed oil and allowed to rest. This process is repeated until the dough achieves a thickness of 1 cm at which time the noodle strip is wound in a figure eight pattern around two bamboo rods 45 cm apart. A repeated process of resting and increasing the distance between the rods occurs until the desired thickness of the noodle is achieved. A single production run can take 12–30 h to complete before the noodle is dried or steamed.[2] Due to the labor intensive handling during production these noodles are very expensive as compared to mass-produced noodles. The market is showing a general shift away from hand-made noodles due to cost and the continuing improvement of mass-produced machine noodles.

7.3.2 Udon noodles

Flour ash for these noodles usually ranges from 0.30–0.40 percent although higher contents of 0.45 percent have been reported. Australian standard white (ASW) is the principal source of Japanese flours supplemented by US western or domestic Japanese wheat in a mixed grist.

Udon noodles, a subset of white salted noodles, WSN, are prepared from soft wheat with a preferred protein level of 8–10 percent. In Japan the appeal of fresh Udon noodles continues to grow compared to a stagnant market for dried noodles.[25] Preferred characteristics include the unique elastic texture followed

by appearance, taste and volume on cooking. Too low a protein level results in noodles with a poor cooking performance while too high results in undesirable brightness loss in both the raw and cooked noodle. Noodle elasticity has been correlated with protein quality based upon the mixograph test's time to maximum bandwidth. A positive correlation between protein content and noodle firmness has been found repeatedly thus enforcing tight specifications for noodle manufacturers.

Starch has been shown to be the key component responsible for this unique noodle texture. Primary starch, the major component of flour, is the predominant component contributing to the desirable viscoelastic noodle texture. However, on an equal weight basis, the starch tailings have been shown to have a significant influence as well. High starch swelling cultivars are beneficial to the quality of Japanese Udon noodles. They are associated with the absence of a series isozymes called granule bound starch synthase (GBSS) located on a single gene on chromosome 4A. As common wheat is a hexaploid, all three waxy loci can be controlled individually resulting in the formation of waxy (less than 1 percent amylose), partially waxy, and normal (22–24 percent amylose) starches. The water-holding capacity of the flour has been positively correlated with noodle texture. Higher levels of amylose decrease the water binding capacity of the cooked noodles and reduce firmness and elasticity.

Heating a starch slurry above 50ºC causes irreversible swelling of the granules. This forces the linear amylose from the granule and into the continuous paste matrix. A working model[26] of starch in a noodle proposed that large, highly swollen granules at the noodles' surface are enmeshed in a thin gluten matrix or attached to the matrix by leached amylose. These large deformed granules fill vacancies on the noodle surface to yield a smooth clean noodle. Low swelling flours with small starch granules yield cooked noodles with a rougher surface and a duller appearance due to greater light diffraction. Within the salted noodle, high swelling starch imbibes extra water forming a noodle with a softer bite. The lower levels of hot amylose leached from the granules improves the noodle elasticity as it cools and gels. This imparts the unique chewiness associated with a Udon noodle. Starch swelling is also inversely correlated with flour lipid level.[26]

Starch damage during milling increases water uptake during mixing, decreases the breaking strength of the dried noodle and produces an undesirable darkening of the noodle.[27] Viscograph paste parameters of starches, in particular breakdown and final viscosity, have been shown to have a high correlation with quality measurements of Japanese WSN.[28] The lower amylograph gelatinization temperatures observed for Australian standard white wheat (ASW) have been suggested as a factor in yielding soft, pliable noodles.[29] Higher wheat PSI (particle size index) values corresponding to 'softer' wheat were correlated with improved eating quality and noodle scores while elevated wheat protein was associated with poorer quality.

White salted noodle flour requirements

Recently in China new specifications were established for the quality of flour used in making noodles. First and second grade flour ash content should not exceed 0.55 percent and 0.70 percent, wet gluten should not be less than 28 and 26 percent and farinograph stability not less than 4.0 and 3.0 min respectively.[30] They also indicated that the wheat used to prepare this flour must have a falling number greater than 200 sec. The SDS sedimentation test which measures protein quality has been found to be correlated significantly with the sensory noodle textural attributes of firmness and chewiness.[15] Standards for Japanese noodle flours are listed in Table 7.2.

7.3.3 White salted noodle processing

Production of Japanese WSN requires mixing for 10–15 min in horizontal mixers, preferably vacuum mixers, Figs 7.3 and 7.4, although vertical mixers are used occasionally. The salt concentration varies (2–3 percent) according to the product and the time of year with less salt being preferred during the winter months.[5] The mixing time required is a function of the quality of the flour, concentration of water (28–45 percent) and salt, as well as the room temperature and humidity.

The crumbs produced by mixing are divided and each portion passed through separate sheeting rolls (180 mm diameter). The two sheets are then laminated/combined by passing the two sheets through a larger diameter sheeting roll (240 mm) at the initial noodle thickness to impart a large amount of work and develop the gluten matrix,[5] see Fig. 7.5. It is not uncommon for the sheet coming off these rolls to be collected on a spool and set aside for resting. The normal resting period varies but is usually 30–60 min which results in improved sheeting characteristics. The lamination process is often repeated just before the start of the final sheeting process.[5] Gluten filaments align parallel to the sheeting direction. Differences due to this alignment can be detected in noodle texture.

It has been announced recently that Nisshin Flour Milling has developed a rolling system capable of producing three noodle layers, each from a different dough, and then wafering them together in rollers to produce a triple layer effect. This will allow production of a wide variety of noodle textures depending on the nature of the doughs layered together.[31]

Subsequent sheeting takes place on a series of rolls, with each reduction in noodle thickness being limited to only 15–33 percent as dramatic changes in noodle thickness can disrupt the established gluten network.[5] This increases the number of sheetings and allows further development of the gluten. The size of the reduction rolls declines from a diameter of 240 mm to 120 mm just before cutting. The cutting rolls form two types of edges: a rounded versus the more popular square cut noodle with the thickness being 75 percent of the noodle's width. Special cutting blades causing depression in the noodle can significantly reduce the subsequent cooking time while retaining the desired textural attributes (see Table 7.3).[5]

Table 7.2 Classification of Japanese flours used in noodle production

Type	1st Grade		1st semi		2nd Grade		3rd Grade		Off Grade	
	Ash	Protein	Ash	Protein	Ash	Protein	Ash	Protein	Ash	Protein
Hard	0.38	11.8	0.42	12.0	0.50	12.5	0.9	14.5	>1.5	–
Semi-hard	0.38	11.5	0.44	11.8	0.52	12.0	0.9	13.5	>1.5	–
Ordinary	0.38	8.0	0.42	8.5	0.48	9.0	0.9	10.0	>1.5	–
Soft	0.38	7.0	0.42	7.5	0.52	8.5	0.9	9.5	>1.5	–

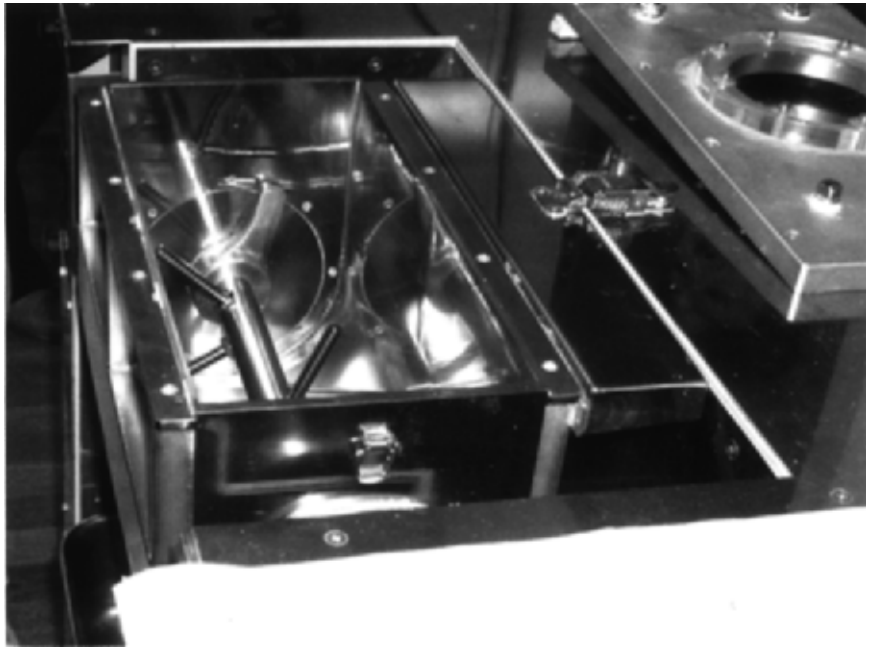


Fig. 7.3 Laboratory-scale horizontal vacuum mixer.

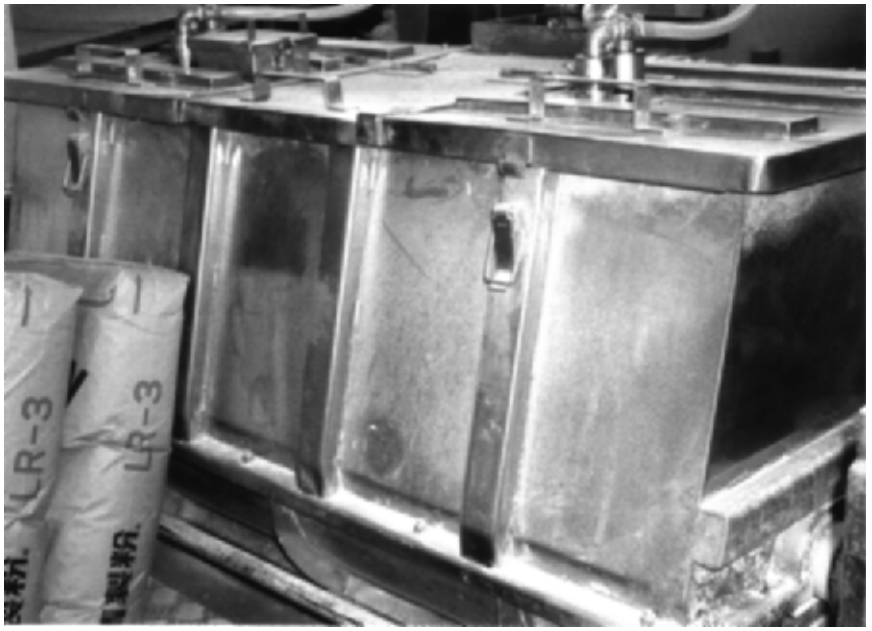


Fig. 7.4 Commercial-scale horizontal vacuum mixer.

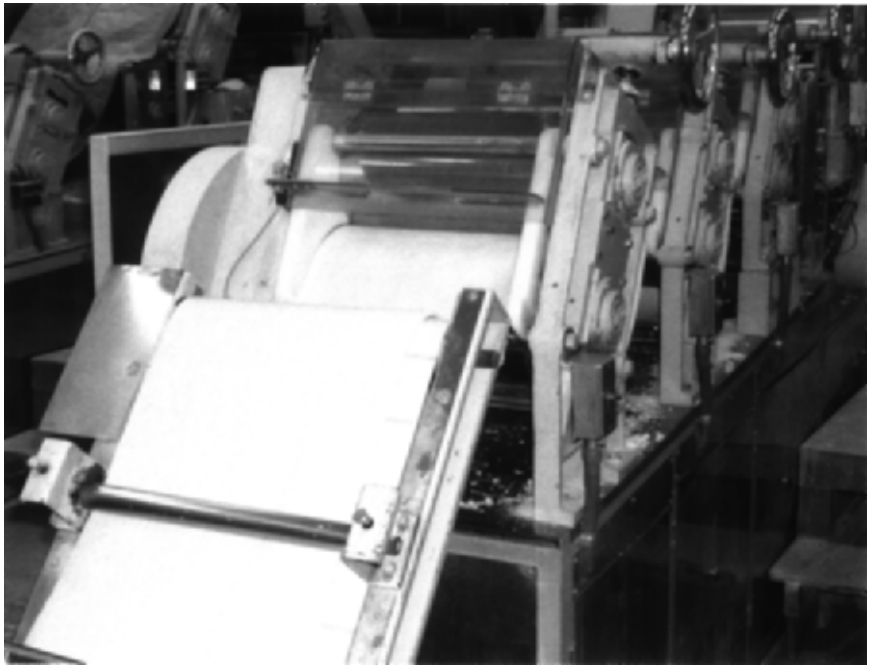


Fig. 7.5 Commercial-scale roller lines normally consist of 5 to 7 roll passes.

Dried noodles are usually considered to have less than 14 percent moisture[2] and are available in a wide assortment of shapes and sizes. In the production of dried salted noodles the drying stage can significantly influence the quality of

Table 7.3 Texture variables for samples of white salted noodles optimally cooked (Oh *et al.* 1983)

Noodle sample	Noodle protein	MCS (g/mm^2)	Work to cut (g/mm)	Compression slope (g/mm^3)	RTC (%)	REC (%)
SWF1	9.3	21.8	23.8	7.80	22.0	23.8
SWF2	10.1	26.8	28.9	8.20	32.0	40.9
HWF1	12.7	28.2	31.5	8.43	30.2	42.0
HWF2	12.6	30.5	36.4	7.82	30.0	43.0
HWF3	15.2	43.9	53.4	8.89	42.6	54.2
Com 1	10.4	28.4	24.7	12.32	39.5	45.3
Com 2	11.3	26.7	25.5	9.63	35.0	42.3
Com 3	9.3	25.9	22.4	9.62	30.0	45.0
LSD (p=0.05)		1.5	1.9	0.28	1.7	1.4

SWF1–2, Soft wheat flours
HWF1–3, Hard wheat flours
Com 1–3, Commercial noodle flours

Fig. 7.6 Commercial noodle manufacturer's continuous removal of white salted noodles from temperature and humidity controlled drying areas.

the final product. A two-stage process is normally used to remove the water. In the first stage, low temperatures, less than 20ºC, are used to remove surface moisture. To remove the internal water from the noodle a slow (3–5 h) drying at 40ºC and 70–75 percent humidity is used for 3–5 h.[5]

Drying is a critical step in dried noodle manufacturing as improper methods result in cracking, deformation, or elongation resulting in a lack of uniformity throughout the noodle. In many countries fresh noodles are draped on rods and are dried outside of the plant. In some operations the noodles are suspended from rods attached to moving belts in a high air exchange enclosure, as shown in Fig. 7.6. Dried noodles require considerably longer cooking time as they are quite dense delaying water penetration and subsequent starch gelatinization. The longer cooking time often results in a stickier noodle than the corresponding fresh noodle.

7.4 Alkaline noodles

Alkaline noodles are distinctive from white salted as the presence of alkaline compounds, sodium and potassium carbonates or sodium hydroxide causes a

shift in dough pH to 9–11.5. At this pH the endogenous and normally colorless flavanoid compounds undergo a chromophoric shift and display a yellow color. There is considerable diversity in the various types of alkaline noodles throughout Asia. It is believed that they originated in the southern provinces of China, Guandgdong, Fujian and Guangxi.[32] In terms of popularity the fresh 'Cantonese' and the partially cooked 'wet' Hokkien are the preferred noodle types. Instant noodles, although a subset of this type, have become so popular that they are discussed elsewhere in this text.

7.4.1 Flour requirements

In Japan the Chinese or Cantonese style noodles are associated with very high quality mill streams, 0.32–0.40 percent[5,21] ash content and display excellent color derived from hard wheat used in bread production. In many other countries the demands on ash content is not as stringent and allowable levels of 0.50–0.55 percent are not uncommon. Bran contamination is extremely critical as the raw noodle must have good color stability over a 24 h period. It is not uncommon for flour color grade to take precedence over a specific ash content in the selection process for some firms. Microscopic investigations of raw noodles have shown that undesirable discoloration is associated with non-endosperm material. Auto-oxidation of the endogenous phenolics in an alkaline environment can cause severe discoloration of the product over time.

In Japan flour protein content ranges from 10.5–12 percent while in other countries a maximum of 13.5 percent is common. The addition of alkali reagents toughens the dough, reducing farinograph development time and dough extensibility while increasing extensograph maximum resistance. Optimum flour protein for the popular Hokkien noodle is approximately 10.5 percent.

Sensory evaluations of alkaline noodles indicate that a flour protein level below 10 percent yields a poor eating quality noodle. Strong correlations between the nature of the protein, as determined using the SDS sedimentation test, rather than simply the amount were found for alkaline noodle textural characteristics maximum cutting stress and maximum compression force.[15] Brightness of the noodle is, however, inversely related to flour protein requiring a compromise between the noodle texture and appearance. Flour ash content and color grade were found to be positively correlated with the noodle yellowness, b*. Patent flours yield brighter noodles while straight grade flours yield yellower but duller noodles.[18]

Starch pasting characteristics of the flour were found to be correlated with textural attributes.[18,23,33,34] They found that breakdown (paste stability) was positively correlated with noodle smoothness and negatively correlated with firmness. Flour peak viscosity's usefulness for texture prediction is still debatable[21,34,35] although inactivation of amylase with silver nitrate improved the correlation greatly (see Table 7.4).[21] Flour swelling volume has also been found to be inversely correlated with alkaline noodle texture.[21] Reconstitution studies showed that the eating quality, particularly the elastic texture of the

Table 7.4 Starch pasting characteristics (RVA viscosity units, RVU) of a variety of Asian flours used in noodle manufacture in the presence of silver nitrate (0.05M)

Company/ sample	Peak viscosity	Trough	Breakdown	Final viscosity	Setback
A-Commercial 1	270.3	75.1	195.3	157.4	82.4
A-Commercial 2	274.6	78.7	195.9	166.7	88.0
A-Commercial 3	279.0	80.8	198.3	176.8	96.0
A-Commercial 4	232.6	73.1	159.5	147.1	74.0
B-Commercial 5	243.9	71.2	172.7	144.0	72.8
B-Commercial 6	281.5	75.4	206.1	153.9	78.5
B-Commercial 7	304.9	83.3	221.6	174.9	91.6
C-Commercial 8	268.4	77.4	191.0	160.3	82.9
C-Commercial 9	282.0	89.1	193.0	192.0	102.9
D-Commercial 10	314.9	80.7	234.2	166.9	86.2
D-Commercial 11	258.9	83.4	175.5	171.5	88.1
Mean	301.1	86.8	214.3	181.1	94.3
Std. deviation	7.9	6.0	9.9	7.8	9.6

alkaline noodle, was attributable to its starch properties.[36] It is not uncommon for Hokkien noodle flour to be supplemented with tapioca starch to improve the gelatinization characteristics.

Noodles prepared with caustic soda (sodium hydroxide, NaOH) tend to be stickier and not as firm as those made with *kansui* reagents (a mixture of sodium and potassium carbonates in different ratios). It has a detrimental effect on gluten development as well as causing premature starch gelatinization and increased noodle stickiness. The composition of the alkaline solution (*kansui*) added to the flour can have a significant effect on the brightness (L*) and yellowness (b*) of the alkaline noodle (see Table 7.5).[37] Flour used to prepare alkaline noodles has been found to contain lower amounts of non-starch lipid, most noticeably the neutral/polar lipids, as compared to those used for the production of salted noodles.[38] Alkaline noodle flours tend to have larger particles than salted noodle flours.[39]

7.4.2 Processing

Aside from Korea and Japan the majority of noodle processors are small family-operated businesses catering to local or neighborhood clients. Usually these small operations have only a few bags of flour dropped off on a daily basis. Many mills provide technical expertise for these small operations identifying which of their flour products are best suited to their clients' needs. In these small operations flour specifications are not usually discussed although a client will immediately contact his supplier if the final product is unacceptable for any reason. Larger noodle processors generally have one or two flour silos on site which are filled continuously on a regular basis. A large plant can process over 240 tonnes per 24 hours. It is not uncommon for the flour companies to build

Table 7.5 HunterLab L* and b* values of raw alkaline noodles prepared using different alkali formulations.

Solution	L*(2h)	L*(24h)	b* (2h)	b*(24 h)
1	80.01±0.07d	72.87±0.55e	28.05±0.40b	27.47±0.45b
2	80.41±0.18cd	73.56±0.24d	27.35±0.29c	27.44±0.32b
3	80.85±0.32ab	74.23±0.32c	27.68±0.11b	27.87±0.08b
4	80.86±0.03ab	74.17±0.20c	27.38±0.61c	27.45±0.14b
5	81.26±0.48a	74.35±0.42c	27.43±0.33c	27.89±0.04b
6	80.38±0.20d	74.38±0.24c	27.20±0.07c	25.66±0.31c
7	80.82±0.23bc	76.40±0.17b	27.10±0.21c	23.08±0.24d
8	81.07±0.08ab	79.41±0.16a	32.95±0.01a	34.79±0.60a

a–e Samples followed by different letters are statistically different ($P<0.05$)
(Kruger *et al*. 1992)

Solution 1 Potassium carbonate:sodium carbonate:sodium phosphate:potassium phosphate (80:15:3:2)
Solution 2 Potassium carbonate:sodium carbonate:sodium pyrophosphate:dibasic sodium phosphate (90:6:1:3)
Solution 3 Potassium carbonate:sodium carbonate:dibasic sodium phosphate (60:37:3)
Solution 4 Potassium carbonate:sodium carbonate (62:38)
Solution 5 Potassium carbonate:sodium carbonate:dibasic sodium phosphate:sodium pyrophosphate:sodium metaphosphate (30:57:7:4:2)
Solution 6 Sodium carbonate:potassium carbonate (40:60)
Solution 7 Sodium carbonate:potassium carbonate (50:50)
Solution 8 Saturated sodium hydroxide (100)

these silos for their larger volume clients to ensure their retention and market share.

Alkaline salts are added at the 1–5 percent level with water addition maintained at approximately 32–35 percent. It is standard practice, however, for the noodle manufacturer to adjust the water content based on the intrinsic feel of the mixed crumbly dough. Common salt, 1–3 percent, is often added to the flour as well as additional ingredients such as riboflavin or food coloring.

In most operations, even moderately sized plants, pin mixers with up to a 200 kg capacity are used. It is only in the automated plants of Japan and Korea where the continuous flow mixers are observed. As is the case for WSN, the mixing process is primarily for ingredient incorporation and not for gluten development. Processing is identical to that observed with WSN in that a lamination step followed by a series of reduction passes is used to develop the gluten matrix, see Fig. 7.7. Depending on the operation, a resting period can be incorporated into the processing either through setting aside the sheets of dough or by slowing the passage on a conveyor belt from the laminating rolls to each reduction roll. The noodles are then cut on rollers yielding square or rectangular noodles (0.5–2.5 mm) whose final length is cut depending on packaging weight. Fresh alkaline noodles are usually sprinkled with fine flour before packaging to prevent the noodles from sticking together.

In the production of Hokkien noodles the cut strands are immersed in boiling water for 0.5 to 2.0 min to partially cook and gelatinize the starch. Traditional

Fig. 7.7 Lamination step in alkaline noodle production using compound rollers.

cottage type production tends to immerse the noodles, in a batch mode, for a longer cooking time before removal and immersion in cool water. Automated conveyor systems tend to cook for only 30–40 sec before rinsing with a series of sprayers arranged in tandem. The cooking water is constantly monitored and fresh water added to remove the buildup of cooking loss materials such as starch, protein and the alkaline salts. The rate of noodle introduction into the cooking water in an automated system significantly affects the accumulation of these undesirable cooking loss materials. The quality of the final product can be degraded significantly by excessive material in the cooking water. Noodle surface breakdown is enhanced by elevated pH and ionic strength. A series of fans suspended above the conveyor belt cool and help remove water off the surface of the noodles before lightly coating them with palm or sometimes peanut oil. The finished product has a 50–60 percent moisture content. The noodles are then packaged in plastic bags or containers by weight and normally consumed within 24 h of production. Quick boiling or frying is the normal

method of preparation with the noodle displaying a firm elastic bite, free of stickiness and exhibiting a clear, bright, pale yellow color.

7.5 Instant noodles

7.5.1 Description

Instant noodles are the fastest growing sector of the noodle industry and play a key role in the nutritional requirements of many Asian countries. The number of servings is estimated to grow from 43 billion packs in 1998 to 100 billion by 2010.[40] They are a low profit margin product depending upon high sales volumes. In Thailand the government increased the price per serving from US$0.12 at which it had been fixed for sixteen years, to US$0.14–0.16. A normal fast food product by comparison is priced at US$0.50–0.60.[9] In Korea, instant noodles are classified on the basis of price as common or high-quality noodles with further segregation due to their packaging as either bag or cup-based.[41] The cup-type noodles are thin to allow rapid cooking and water uptake while the bag-type are much thicker and require up to 5 min for optimum cooking. A definite trend towards high-quality and cup noodles has been observed in both Korea and Japan in recent years. In Korea, instant noodles account for 90 percent of the total wheat noodle production while in Japan approximately 23 percent.[41] Flour protein requirements vary with the type and quality of the instant noodle produced ranging from 7–9.5 percent for a general high-quality noodle to 11.5–12 percent for a cup noodle. Not only is protein quantity important but so is the nature of the protein as it is critical that a moderately strong viscoelastic glutenin be formed to stabilize and impart the desired chewiness to the noodle. Elasticity in the noodle dough is also important from a processing aspect as too strong a dough will cause shrinkage after each roller pass. Within South East Asia instant Udon-type noodles are also available but have the lower 8–9 percent protein levels. Ash content also varies from 0.40–0.54 percent in the common noodle but higher levels have been reported. Fat content is highly dependent upon the economic target market with values as low as 12 percent (Korea) to in excess of 20 percent.[24] There are significant variations in the size of packages across and within a country.

7.5.2 Processing

In Japan instant noodles are prepared with a lower amount of alkaline salt, 0.2 percent on a flour basis[5] which is similar to Korea.[41] Koreans use an alkaline mixture of equal portions of potassium sodium carbonate while the Japanese prefer a 60:40 ratio. The Koreans also prefer to use higher concentrations of common salt, 1.5–2.0 percent, as compared to the Japanese, 1 percent. Other countries in the region commonly use up to 3 percent alkaline reagent. The Koreans additionally make a high quality instant noodle without adding alkaline reagent. Instant noodles made in Korea use a low water content, 30–31 percent,

with the necessary ingredients dissolved in the water. Salt has the effect of decreasing farinograph absorption; however, in the presence of alkali, its impact is masked by the alkali's dominant strengthening effects.

A two-stage mixing regime involving a short initial high speed mix followed by a longer slow mix is used. The amount of mixing time is a function of the quality of the noodle being prepared. Common noodles have a much shorter mixing time due to a reduction in the slow mix phase. The use of vacuum mixing in Japan, in conjunction with correct mixing moisture, 36–40 percent, can produce a higher quality noodle as it allows for greater water addition. The addition of extra water in this manner allows the flour starch to gelatinize and swell more than a reduced water content noodle during the steam processing stage. This will reduce the consumer's subsequent cooking time, a highly desirable trait, as well as limiting the loss of cooking solids to the broth. The additional water added during mixing also allows for better development of a gluten matrix ensuring improved noodle texture during steeping and a better overall appearance.[23] A uniform gluten matrix is essential for a high-quality product.[42]

Instant noodles get their unique waved shape due to either the use of diverter flaps just behind the cutting blades or by a reciprocating conveyor belt. The wave structure allows for more efficient steaming and subsequent frying as the noodle strands are separated. It is important for the developed gluten, which becomes a permanent structure at a lower temperature than starch, to be set before the subsequent starch swelling.

The cut noodles can be steamed for varying lengths of time, 100–240 sec based on the noodles' quality.[41] The steamed noodles are then passed on a conveyor belt under a series of cooling fans to rapidly reduce their temperature. The noodles are then placed in single serving molds on a weight basis before being conveyed to a frying chamber.

Palm oil, or a mix with beef tallow is common throughout most South East Asian countries although Korea uses mainly palm oil. The average Korean instant fried noodle has 16.7 percent lipid comprised of C16:0, C18:1 and C18:2. The ratio of saturated to mono-unsaturated to polyunsaturated is 1.0:0.77:0.19.[43] Frying conditions and length of time are a function of the quality of the noodle being made. It is normal in Korea to maintain the temperature at the end of the chamber at a slightly higher temperature than the inlet.[44] Antioxidants such as tert-butylhydroquinone (TBHQ), butylated hydroxyanisole (BHA) and δ-tocopherol can be added to the frying oil to retard rancidity although in many countries the oil is used well past its best condition. Addition of either TBHQ or BHA to the oil at 200 ppm increases the noodle shelf-life twofold. A combination of TBHQ (200 ppm) and disodium ethylene diamine tetraacetate (EDTA) extends the noodle shelf-life fivefold over antioxidant free frying. Even coating the inner packaging surface with TBHQ (200 ppm) doubles the product's shelf-life.[45]

The frying (1–2 min) in high temperature oil, 140–150ºC, causes the immediate conversion of the noodle's water to steam resulting in a spongy

internal noodle structure being formed. The spongy structure is the reason for the rapid hydration and cooking of the instant noodle. However the limited processing of the noodle before frying does not allow complete swelling of the starch and as such instant noodle texture improves with boiling, to cause complete gelatinization, over simple rehydration at a lower temperature. This is due to the competition for water by both the gluten and the starch. Low protein, high starch flours usually retain more frying oil than high protein flours with oil levels in the final product ranging from 15–40 percent. The nature and content of the oil plays a key role in determining the shelf-life of the instant noodle. Problems due to oil rancidity are not uncommon in low-quality products.

7.6 Buckwheat noodles

7.6.1 Soba noodles of Japan

Buckwheat has the benefit of acting as a functional food in South East Asia. It is incorporated in noodles as its starch characteristics are very similar to those of wheat[46] while increasing dietary fiber. Buckwheat is gluten free with a stronger and sweeter flavor. The fresh noodles have the benefit of being cooked quickly (1–3 min) as compared to regular fresh wheat noodles. Japanese millers produce five different types of buckwheat flour which are incorporated into the noodles. Quality soba noodle shops in Japan insist on stone ground flour which maximizes the sweet taste and fragrance[47] and use the highest quality buckwheat. Mass production usually involves dried noodle types. Buckwheat is indigenous to Japan, although a significant amount is now imported, with regions specializing in their own unique noodle composition. High-quality noodles are free of preservatives or additives.

Buckwheat noodles are usually a combination of 70 percent hard wheat flour, 30 percent buckwheat and 28 percent water. Salt is not used because of the low water content and to avoid changing the flavor of the noodle.[5] They have a number of nutritional benefits; high lysine content, elevated fiber and vitamin B complex.[47] Attempts to increase buckwheat noodle shelf-life have been extremely limited due to high enzyme activity and rapid flavor deterioration. They are usually consumed on the same day of their manufacture to preserve their optimum flavor. Buckwheat noodles are one of the most common fully cooked noodles available although cooking time varies from 7–20 min.[2] Flour quality is not as critical as the boiling reduces problems caused by pigments and enzymes.

7.6.2 Naengmyon noodles of Korea

Naengmyon noodles are very popular during the summer months and represent approximately 3.5 percent of the Korean noodle market.[48] Their formulation requires a minimum of 5 percent buckwheat. Unlike the Japanese soba noodle, naengmyon noodles are extruded, contain salt and optionally potato starch. They have a dark brown to black color, slightly greyish, and a very rubbery texture.

7.7 Future of the industry

7.7.1 New emerging products

Non-fried instant noodles (dry steamed)

As consumers become more health conscious there is an increasing demand for alternatives to using the saturated 16:0 palm oil, for the production of instant noodles. An alternative to this is the dry steamed noodle which, after the normal steaming to gelatinize the starch, are dried using hot air. The primary current drawback is the slightly longer cooking time, approximately 5 min, and poorer noodle brightness. At present the use of vacuum mixing to improve starch gelatinization during the steaming stage, high-temperature (multi-stage) drying to increase pore size, and the use of low ash, small particle size flours are all being examined to reduce cooking time.[23] Increasing the initial water absorption by 2 percent with a special low ash (0.39 percent) flour reduces cooking time by 20 percent and also addresses the issue of color. There are two types of non-fried instant noodles; non-expanded and expanded with the difference being based on the internal noodle structure.

To achieve the quick steeping time, *non-expanded noodles* are generally thinner or have a large percentage of pregelatinized starch (20 percent) incorporated into the flour mixture. The non-expanded noodles rely heavily on vacuum mixing with the associated higher water absorption to improve their quality by developing the gluten matrix and hydrating the starch. This ensures the desired chewy texture. The non-expanded noodles are primarily alkaline and are normally dried at a lower temperature, 60–80ºC, to avoid undesirable discoloration through phenolic oxidation. The general flour requirement is for a moderate protein content, above 11 percent, minimum starch damage, small particle size (less than 70 μ) and excellent color through low ash content (less than 0.40 percent).

Steaming is usually maintained at 98ºC for 2–3 min in the 1 kg/cm^2 pressure range. It is not uncommon for manufacturers to spray water or emulsifiers onto the noodles before steaming to aid gelatinization and improve subsequent rehydration rates. Removal of some of the surface moisture after steaming but prior to drying has been shown to improve the noodle firmness. The drying phase is an essential feature for these noodles and is primarily hot air drying with or without humidity control. Air temperature, speed and humidity will affect the final quality of the noodle. The benefits of additional humidity control (25–40 percent) are to ensure an even moisture distribution throughout the noodle, improve appearance and reduce subsequent cooking loss.[23]

The *expanded noodles*, as the name suggests, have a thicker more porous structure compared to the non-expanded noodles. The expanded noodles use a rapid high temperature conversion of water to steam, without frying, to produce the same porous structure seen in regular instant noodles. The increased porosity of the expanded noodle within a continuous supporting gluten matrix is the key difference from non-expanded noodles. No differences due to the manufacturing process or equipment are required.[23] The difficulty lies in developing the gluten

matrix to provide support and the desirable chewy texture versus sufficient pore space to allow rapid starch hydration and swelling. Control of the number and size of the pores is critical. The number of pores can be influenced by chemical leavening, fermentation or modification of pores. Addition of chemical leaveners takes place in two stages. The leavening agent is dissolved in the water initially being added to the flour while an acid compound is added at the final stages of mixing to limit gas bubble production. The gluten matrix in wheat dough stabilizes bubble nuclei but any change in size must happen before starch gelatinization (80ºC) occurs and sets the noodle's internal structure. Temperature gradients are formed from the exterior noodle surface to the interior during steaming. Existing bubble nuclei will expand in the hotter outer portion and form pores when they break the surface.

Subsequent drying through controlled conditions allows rapid expansion of bubbles located within the interior of the noodle, which had not previously reached the starch gelatinization temperature, thus increasing the noodle's porosity. There is minimal expansion of the noodle during the steaming stage and is confined primarily to the drying stage. Noodle expansion is a function of the mixing moisture, drying procedure and temperature, the degree of gluten development, noodle surface hardness and stresses imparted on the noodle during sheeting and cutting.[23] The final texture of the expanded instant noodle is determined by the number and size of the noodle pores after rehydration.

Chilled and frozen noodles

Frozen noodle technology has been applied to both Udon and Chinese-style noodles. The key marketing feature for both these products is that the noodle has already been optimally cooked thus requiring only a rapid defrosting or heating, 30 sec, to return to its optimal texture. Chilled noodle production has reached ¥400 billion annually while frozen noodles have achieved annual sales of ¥70 billion. Although they are primarily sold to restaurants, they are making inroads to supermarket and convenience stores.[23] The reduction in cooking time by vacuum mixing and additional water decreases the amount of material loss during rehydration and limits stickiness. The increased swelling of the starch subsequently limits the starch's retrogradation rate thus extending the noodle shelf-life. Water absorption levels used during mixing, noodle aging, cooking time and cooling water temperature all influence the texture of the final noodle.

Boiled noodles are rinsed or immersed in 5ºC water and immediately packaged and refrigerated at 4–10ºC if they are being sold as chilled noodles. In the production of frozen noodles more than 30 min are required to freeze noodles at −40ºC using either a combination of air blast or contact freezer.[5] A critical feature to the frozen noodles is the idea that they have been cooked to their optimum state before flash freezing. Immersion of the frozen noodle in boiling water for 20–60 sec then returns the noodle to optimum condition, particularly in terms of their textural attributes. A moisture gradient is developed with the surface having absorbed 80 percent of its water, while the core 50

percent, thus allowing the core to have good elasticity while the surface maintains a soft smooth texture.

Long-life noodles

There are two types of long-life noodles, acidified (pH<4.5) which predominates and non-acidified. Processing is identical to other noodles with boiling and cooling but the noodle is then acidified by a short immersion in a dilute (3 percent) acid bath. Common acids include citric, malic, lactic, gluconic and acetic acid in a pH range of 1.9–2.5. The subsequent noodle has a pH of 3.7–4.3, although gluconic is usually mixed with lactic to lower the pH into the acceptable range. Each acid or combination imparts a different flavor to the noodle. Addition of extra water via vacuum mixing helps impart a greater moisture gradient between the noodle's surface and interior improving the noodle quality during thermal treatments.

If a boiled noodle, with an extended shelf-life is desired, the noodle is cooked for an optimum length of time to ensure the best noodle texture. Under certain conditions the pH of the cooking water may also be adjusted to slightly acidic pH. Lactic, malic or citric acid are used to adjust the pH.[5] Water uptake during cooking should yield a 2.5–4-fold increase in weight. If longer term storage is desired the cooked noodles are again treated in a dilute acid solution before packaging where they undergo steam pasteurization.

Acidifed noodles undergo low temperature processing (98–100ºC) while non-acidified noodles are usually canned and subject to much higher temperatures. This final heat treatment can cause a serious stickiness problem for the packaged noodles. The quality of these noodles will deteriorate if too much water was absorbed during the cooking stage, and ideally the moisture content before the next low temperature processing should be 55–65 percent.[23] This can be achieved by reducing the initial noodle cooking time or by altering the starch content or nature (pre-gelatinized) to limit acid penetration into the noodle. Use of emulsifiers, altering the shape of the noodles (i.e. waving) and degree of package filling can ameliorate this problem.

A typical shelf-life for these types of noodles is 100–180 days primarily due to the loss of moisture from the noodle. Noodle texture is significantly degraded although the introduction of the enzyme transglutaminase during the initial mixing has improved the retention of noodle texture.

7.8 Summary

Production of different types of Asian noodles all share a high degree of commonality. Although noodles have an extended history, scientists constantly face an evolving set of challenges as this industry matures. The objective of this chapter has been to present the similarities as well as the significant differences involved in noodle production.

7.9 General sources of information

BLAKENEY A B and O'BRIEN L (eds) 1998. *Pacific People and Their Food*. American Association of Cereal Chemists. St. Paul, MN.

HOU G and KRUK M 1998. Asian Noodle Technology. *AIB Technical Bulletin* XX: 12. American Institute of Baking, Manhattan, KS.

KRUGER J E, MATSUO R B and DICK J W (eds) 1995. *Pasta and Noodle Technology*. American Association of Cereal Chemists. St. Paul, MN.

7.10 References

1. MISKELLY D M 1993. Noodles – a new look at an old food. *Food Australia* 45 496–500.
2. CHEN P M T 1993. Noodle manufacturing technology. In *Grains and Oilseeds: Handling Marketing, Processing*. Vol. II Canadian International Grains Institute. Winnipeg, MB., Canada pp. 809–30.
3. KUBOMURA K 1998. Instant noodles in Japan. In *Cereal Foods World* 43 (4) 194–7. American Association of Cereal Chemists, St. Paul, MN.
4. NAGAO S 1981. Soft wheat uses in the Orient. Chapter 7 in: Y. Yamazaki and C. Greenwood (eds.) *Soft Wheat: Production, Breeding, Milling and Uses.* American Association of Cereal Chemists, St. Paul, MN, pp. 267–304.
5. NAGAO S 1996. Processing technology of noodle products in Japan. In: J.E. Kruger, R.B. Matsuo and J.W. Dick (eds.) *Pasta and Noodle Technology*, American Association of Cereal Chemists, St. Paul, MN, pp. 169–94.
6. SAKAMAKI S 1997. Business Aside: Ando-San's Revolution. *Far Eastern Economic Review*, April.
7. The market competitiveness of Western Canadian Wheat: A joint study by the Manitoba Rural Adaptation Council Inc. and the Canadian Wheat Board. 1999.
8. OLESON B 1998. Changing cereal consumption trends in the Pacific region. In: A B. Blakeney and L O'Brien (eds.) *Pacific People and Their Food.* American Association of Cereal Chemists, St. Paul, MN, pp. 1–12.
9. CHAVASIT V and TONTISIRIN K 1998. Triple fortification of instant noodles in Thailand. *Food and Nutrition Bulletin* 19(2)164–7.
10. KRUGER J E and LABERGE D E 1974. Changes in peroxidase activity and peroxidase isozyme patterns of wheat during kernel growth and maturation. *Cereal Chem.* 51 345.
11. KRUGER, J E, HATCHER D W and DEXTER J E 1995. Influence of sprout damage on oriental noodle quality. In: K. Noda and D J Mares (eds) *PreHarvest Sprouting in Cereals.* Center for Academic Societies Japan, Osaka, p. 9–18.
12. YANAGISAWA A and AMANO Y 1995 Degradation of flour colour in wheat damaged by rain in Hokkaido. In: K. Noda and D J Mares (eds)

PreHarvest Sprouting in Cereals. Center for Academic Societies Japan, Osaka, pp. 19–26.

13. HATCHER D W and KRUGER J E 1993. Distribution of polyphenol oxidase in flour millstreams of Canadian common wheat classes milled to three extraction rates. *Cereal Chem*. 70 51–5.
14. DEXTER J E 1995. Asian noodle products In: G L Christen and J S Smith (eds) *Food Chemistry: Principles and Application, A Workbook*, American Food and Nutrition Center, Cutten, CA (accepted for publication).
15. HUANG S and MORRISON W R 1988. Aspects of Proteins in Chinese and British Common (Hexaploid) Wheats Related to Quality of White and Yellow Chinese Noodles. *J. Cereal Sci*. 8 177–87.
16. MISKELLY, D M 1998. Modern noodle based foods – raw material needs. In: *Pacific people and their food*. A B Blakeney and L O'Brien (eds) American Association of Cereal Chemists, St. Paul, MN. pp. 123–42.
17. MORRIS C 1998. Evaluating the end-use quality of wheat breeding lines for suitability in Asian noodles. In: *Pacific people and their food*. A B Blakeney and L O'Brien (eds) American Association of Cereal Chemists, St. Paul, MN, pp. 91–100.
18. MISKELLY D M and MOSS H J 1985. Flour quality requirements for Chinese noodle manufacture. *J. Cereal Sci*. 3 379–87.
19. CROSBIE G B, LAMBE W J, TSUTSUI H and GILMOUR R F 1992. Further evaluation of the flour swelling volume test for identifying wheats potentially suitable for Japanese noodles. *J. Cereal Sci*. 15 271–80
20. KONIK C M, MISKELLY D M and GRAS P W 1993. Starch swelling power, grain hardness and protein: Relationship to sensory properties of Japanese noodles. *Starch/Starke* 45(4) 139–44.
21. CROSBIE G B, ROSS A S, MORO T and CHIU P C 1999. Starch and protein quality requirements of Japanese alkaline noodles (ramen). *Cereal Chem*. 76(3) 328–34.
22. ROSS A S, QUAIL K J and CROSBIE G B 1997. Physiochemical properties of Australian flours influencing the texture of yellow alkaline noodles. *Cereal Chem*. 78 814–20.
23. WU T P, KUO W Y and CHENG M C 1998. Modern noodle based foods-Products Range and Production Methods. In: A B. Blakeney and L O'Brien (eds.) *Pacific People and Their Food.* American Association of Cereal Chemists, St. Paul, MN, pp. 37–90.
24. AZUDIN M N 1998. Screening of Australian Wheat for the Production of Instant Noodles. In: A B. Blakeney and L O'Brien (eds.) *Pacific People and Their Food.* American Association of Cereal Chemists, St. Paul, MN, pp. 101–22.
25. NAGAO S 1998. Traditional and changing food consumption trends for wheat based foods. In: A B. Blakeney and L O'Brien (eds.) *Pacific People and Their Food.* American Association of Cereal Chemists, St. Paul, MN, pp. 13–24.
26. WANG L and SEIB P A 1996. Australian Salt-Noodle Flours and their

Starches Compared to U.S. Wheat Flours and their Starches. *Cereal Chem.* 73(2) 167–75.

27. OH N H, SEIB P A and CHUNG D S 1985. Noodles III. Effects of processing variables on quality characteristics of dry noodles. *Cereal Chem*. 62 437–40.
28. KONIK C M and MISKELLY D M 1992. Contribution of starch and nonstarch parameters to the eating quality of Japanese white salted noodles. *J. Sci. Food Agric*. 58 403–6.
29. NAGAO S, ISHIBASHI S, IMAI S, SATO T, KANABE T, KANEKO Y and OTSUBO H 1977. Quality characteristics of soft wheats and their utilization in Japan. Evaluation of wheats from United States, Australia, France and Japan. *Cereal Chem*. 54 198–204.
30. HUANG S 1995. China – The world's largest consumer of paste products. In: J E. Kruger, R B. Matsuo and J W. Dick (eds) *Pasta and Noodle Technology*, American Association of Cereal Chemists, St. Paul, MN, pp. 301–30.
31. ANON. 1998. Nisshin Develops Triple Layer Noodle Maker. *New Food Products in Japan.*
32. MISKELLY D M 1996. The use of alkali for noodle processing In: J E. Kruger, R B. Matsuo and J W. Dick (eds) *Pasta and Noodle Technology*, American Association of Cereal Chemists, St. Paul, MN, pp. 227–73.
33. SHIRAO Y and MOSS H J 1978. Suitability of Australian wheat and flour for noodle production. In: *Proc. 28th Aust. Cereal Chemistry Conf. RACI*, Australia, pp. 37–8.
34. KONIK C M, MIKKELSON L M, MOSS R and GORE P J 1994. Relationships between physical starch properties and yellow alkaline noodle quality. *Starch/Starke* 46 292–9.
35. BATELY I L, CURTIN B M and MOORE S A 1997. Optimization of rapid-visco analyzer test conditions for predicting Asian noodle quality. *Cereal Chem*. 74 497–501.
36. AKASHI H, TAKAHASHI M and ENDO S 1999. Evaluation of Starch Properties of Wheats Used for Chinese Yellow-Alkaline Noodles in Japan. *Cereal Chem*. 76(1) 50–5.
37. KRUGER J E, ANDERSON M J and DEXTER J E 1994. Effect of flour refinement on raw Cantonese noodle colour and texture. *Cereal Chem*. 71 177–82.
38. JUN W J, CHUNG O K and SEIB P A 1998. Lipids in Japanese noodle flours. *Cereal Chem*. 75 826–9.
39. JUN W J, CHUNG O K and SEIB P A 1998. Characteristics of noodle flours from Japan. *Cereal Chem*. 75 820–5.
40. ANON. 1999. Group says ramen demand to double by 2010. *Milling and Baking News* 77(51) 8.
41. KIM S K 1996. Instant noodle technology. *Cereal Foods World*. 41(4) 213–18.
42. MOSS R, GORE P J and MURRAY I C 1987. The Influence of Ingredients and Processing Variables on the Quality and Microstructure of Hokkien, Cantonese and Instant Noodles. *Food Microstructure*. 6 63–74.

43. KIM J H, KIM B S, PARK G Y, KIM E S and LEE G H 1998. Lipid content and fatty acid composition of commercial fatty process food. II. Fried instant noodle. *J. Korean Soc. Food Sci. & Nutrition*. 27 35–7.
44. KIM S K Instant noodles. In: J E Kruger, R B Matsuo and J W Dick (eds) *Pasta and Noodle Technology*, American Association of Cereal Chemists, St. Paul, MN, pp. 195–226.
45. RHO K L, SEIB, P A, CHUNG O K and CHUNG D S 1986. Retardation of rancidity in deep-fried instant noodles (ramyon). *J. Am. Oil Chem. Soc*. 63 251–6.
46. LORENZ K and DILSAVER W 1982. Buckwheat (Fagopyrum esculentum) starch physico-chemical properties and functional characteristics. *Starch/ Starke* 34 217–20.
47. UDESKY J 1988. *The Book of Soba*. Kodansha International 99 Ltd., Tokyo, Japan.
48. KIM S K 1997. Overview of Korean Noodle Industry. *Foods and Biotechnology.* 6(3) 125–30.

8

Breakfast cereals

R. B. Fast, Consultant, Robert B. Fast Associates Inc., Poultney

8.1 Introduction

When we speak of breakfast cereals today primarily we are talking about ready-to-eat (RTE) cereals. These are cereal grains which have been processed in ways which make them suitable for human consumption. This chapter is a brief introduction into the varied technologies of the unit operations employed in making the grains edible, and digestible, by the human body.

The use of grains for human consumption goes back well before the time of Christ – both raw, in whole form; dried, in whole form or ground to flour; and in cooked or baked form. However, the present industry as we know it really started in the late nineteenth century in the little town of Battle Creek, Michigan, USA. Its roots are really centered in the teachings of the Seventh-Day Adventist Church (SDA Church).[1]

In 1855 the SDA Church established a publishing office in Battle Creek, and made Battle Creek its national headquarters. The Kellogg brothers, John Harvey born in 1852, was later to become the physician-in-chief of the SDA Church's Battle Creek Sanitarium, and Will Keith (WK) born in 1860 was to become the inventor of the modern form of breakfast cereal presented to 'San' (short for sanitarium) residents as a more digestible substitute for bread. Dr John Harvey Kellogg filed a patent application for 'flaked cereals and a process of preparing same' on 31 May 1894. His patent included flakes of wheat, corn, oats, barley and other grains.

Also in 1894 a former patient of the Sanitarium, C.W. Post, invented a coffee substitute from a mixture of roasted wheat, bran, and molasses.[2] He called it Postum and formed The Postum Cereal Co. Ltd. In 1898 he made a second coffee substitute which had poor consumer acceptance so he sold it in granular

form as a breakfast food. He called it Grape-Nuts, still on the market 100 years later.

The third major player in our present day cereal market was begun by Cadwallader C. Washburn who began a flour mill in Minneapolis, MN, USA. He entered a partnership with John Crosby, and Washburn Crosby Co. later became General Mills.[3] In the early 1920s Washburn Crosby Company introduced a wheat flake, which in a few years was called Wheaties. These individuals, their inventiveness and market skills, formed the basis of the worldwide breakfast cereal industry that we know today. True, there are many, many more smaller players who have been around for decades, but space does not permit mention of all of them.

8.2 The industry and its structure

The industry has been dominated by a relatively few key, large producers. The worldwide leader has been, and still is, Kellogg. The number two spot is held by General Mills. The Postum Cereal Co. evolved into the Post Division of General Foods, now Kraft Foods, and continues as the number three cereal producer.

In 1895 Henry D. Perky, a Denver lawyer, patented wheat in shredded biscuit form. The Shredded Wheat Co. of Niagara Falls, New York and Ontario Canada and Welwyn Garden City, England fame was purchased and continued by National Biscuit Co. in the 1920s. This product line, also being produced in England, was sold in the 1990s to a combine of General Mills and Nestlé, and is now continued by a company known as Cereal Partners Worldwide.

In England a major producer and marketer of cereals behind Kellogg is Weetabix. This company is also an offshoot of the SDA Church, having been formed in 1936. Their major product is a unique biscuit comprised of compressed wheat flakes. It is a very popular cereal form. It is also produced by Weetabix in Canada, and sold from there in the United States and to other countries worldwide.[4]

The SDA Church was also originator of Van Brode Milling Co., a cereal producer in the USA now known as Weetabix, which produces breakfast cereal forms used in other foods, such as, candies and confections, breads, muffins, etc.[4]

The SDA Church was also instrumental in the formation of the Sanitarium Health Food Company in Australia. Sanitarium, likewise, is a major player behind Kellogg, in all of South East Asia. It too produces a compressed wheat flake biscuit as well as other popular forms of processed cereal grains.[5]

Tables 8.1–8.4 list the approximate market shares of the largest companies in various parts of the world as they were in the latter part of 1998.

8.2.1 Developments before World War II

The industry grew rapidly before World War II. The main thrusts were in the area of advertising and marketing – making individual products into household

Table 8.1 USA: Percentage of market share by company, in US dollars, for year ending 1998

	%
Kellogg	31.71
Gen Mills/Ralston Mfg Total	31.68
General Foods	16.29
Quaker	9.02
Store Brands	7.73
Malt O Meal	2.50
Generic	0.02

Courtesy Information Resources Inc., Chicago, Il USA.

Table 8.2 United Kingdom: Percentage of market share by company, in tonnes, for year ending 1998

	%
Kellogg Ltd	40.9
Weetabix Ltd	14.7
Nestlé Ltd (Cereal Partners Worldwide)	11.0
Quaker Ltd	2.6
Private Label	30.0

Table 8.3 Australia: Percentage of market share by company, in Australian dollars, for year ending 1998

	%
Kellogg	50
Uncle Toby's	28
Sanitarium	16
Others	6

Table 8.4 New Zealand: Percentage of market shares by company, in New Zealand dollars, for year ending 1998

	%
Sanitarium	45
Kellogg	29
Hubbards	11
House Brands	14
Others	1

words. Jobbers and brokers were enlisted in the sale of the products. Great sales pressure was applied by the Kelloggs and Posts, and the competition was hot and heavy. One innovation introduced was the house-to-house sampling of products. Product samples were delivered door-to-door, often by whole crews employed just for this purpose. Another was the use of multi colors in magazine ads. Newspaper ads were used extensively.

A switch of emphasis occurred early in the 1900s from promoting corn flakes as a health food to a breakfast food that 'tastes good'. This occurred especially after barley malt extract and sugar were added to enhance the flavor of the basic toasted corn flakes. Cereal producers in those early 1900s also turned to prominent artists to paint scenes of 'the wholesome life situations' that always included the product being advertised in a prominent position. This avenue, however, was short lived due to the high cost of the artists' talents.

The one single event, however, that was the real explosive force propelling breakfast cereal marketing was the widespread development of radio in the mid to late 1920s. Its use as 'the' marketing and sales tool continued on through the 1930s and 1940s. The other big promotional event which occurred was the use of premiums, or 'gimmicks' as they came to be known, inserted in each cereal box. These giveaway premiums in the cartons were all directed at children. They were heavily advertised on children and all family radio programs, as well as in magazine and newspaper ads.

Several events also took place outside the cereal industry which would in later years have a major impact. Among these was the discovery that vitamin B_1 or thiamin, was the missing nutrient when the disease beriberi struck. Enriching rice with B_1 did a lot to correct this public health menace in the early 1900s. Likewise niacin was shown to prevent pellagra. Vitamin C, of course, earlier had been known to prevent scurvy on board trading ships. In the 1920s it was discovered that ultraviolet irradiation activated the vitamin D in cereals and then when fed to rats prevented rickets. All these developments would later play a big role in breakfast cereal nutritional improvement and marketing tactics.

8.2.2 Developments after World War II

The breakfast cereal industry really blossomed with maturity during and after World War II. So many men and women of all ages were involved in the war effort that nutritional intake was a major concern of government. It was early in the 1940s that government food scientists in the US decided that breakfast cereals were a food, along with bread, that was well received by large segments of the population, and would be good vehicles for vitamin restoration. The cereal and flour milling industries were approached, therefore, about their 'restoring' certain vitamins, and the mineral iron which were lost during normal manufacturing processes to cereal and flour products. Thus the B vitamins, thiamin, riboflavin, and niacin, and the mineral iron were added to breakfast cereals and wheat flour, i.e. 'enriched flour', in levels sufficient to restore them to the natural whole grain level.

Other major changes and innovations took place in the 1950s and 1960s. Use of cooking extruders came into use as continuous cookers to augment batch cooking. The development of extruded/expanded corn-based snacks led to the development of low bulk density extruded/expanded breakfast cereals in many grain combinations, shapes, flavors, and colors. Automation of the gun puffing process also proceeded. Both fully continuous and automated batch guns were patented, and put into use which greatly increased the output per hour. In addition the technology employed to form intricate shapes of pastas was transferred over to the precooked cereal grain/flour formulas. Once formed the cooked shapes were dried, conditioned, and gun puffed. Early products were plain, but these were soon the bases used for presweetened breakfast cereals aimed at the children's market of 5–12 year olds. Forced air oven toasting was perfected and introduced to augment the classic rotary drum toasting ovens for flakes. Its use was also widely adopted for the drying of the applied sugar coatings.

Postwar shredding developments were completed successfully in moving from cumbersome belt pinching and cutting devices to rotary wheel cutting. Rotary cutting opened the door to the introduction of bite-sized products, and products made with grains other than wheat; normally, rice and corn, and products with added flavors, such as sugar, salt, and malt.

In the late 1970s and well into the 1980s much stricter factory safety regulations were instituted. Occupational and safety regulations regarding workers' eye, ear, and total bodily protection were enacted. Breakfast cereal processors worked diligently to reduce noise levels, for instance, in such operations as gun puffing and shredding.

Market forces also drove the quest for more nutritious cereals. The emphasis was aimed at stressing the importance of breakfast as the day's most important meal in a world whose pace was beginning to accelerate faster and faster. A 'vitamin's horsepower' race soon evolved where manufacturers and marketers tried to outdo each other with vitamin additions and marketing strategies. The marketplace saw the introduction of protein fortified RTE cereals in addition to merely vitamin and mineral supplements.

The number of choices in shape, flavor, color, texture, eye appeal, resistance to sogging in milk, etc., seemed to grow to endless boundaries. New varieties were added in every way, shape and form. Additives included nuts of all kinds, raisins, date pieces, other dried fruits – even freeze-dried fruits and ice cream coating on products made brief appearances before proving to be too extravagant in price for the market to bear.

The breakfast cereal industry from post-World War II to the 1990s was anything but a stagnant marketplace. It was exciting, fast paced, and extremely competitive. All of this, mind you, only in the predominant English-speaking parts of the globe. The expansion of RTE's into non-English-speaking global sectors was in its infancy in 1990. With the downfall of Communism, and the opening of worldwide communications and economies, the RTE cereal field, as we have known it, is on a new threshold ready to burst forth again.

8.3 Recent trends and technology developments

The 1990s has seen voluminous technical developments brought into RTE manufacturing processes. It will be easiest to examine each unit operation of an RTE process and highlight some of these outstanding developments.[6] In all truthfulness most of these have been driven by the desire to reduce labor costs, lower human error, elevate the quality of the work environment, increase output of in-specification finished product, i.e. better product quality control, and improve safety in the workplace. The driving innovation of all of these changes in how much technical hardware is now used in cereal manufacturing has been the widespread adaptation of the microchip. It has been to cereal processing what radio development in the 1920s was to cereal marketing.

8.3.1 Developments in weighing

The first step in the cereal process is the measurement of the ingredient quantities to be used in each recipe. Measurements of bulk dry ingredients can now be taken directly at the storage silos if they are mounted with load cells. Batch usages can be taken, and in addition inventory monitoring is available so that reorder times are easily readable. Likewise liquid ingredient measurements for bulk ingredients for both batch and continuous operations can be displayed accurately using coriolis flow meters.

In batching major dry ingredients, the use of weighbelt feeders is common. Screw feeders are also commonly used, both volumetric for very uniform bulk density materials, and gravimetric for materials with variable flow characteristics or bulk density. Gravimetric screw feeders are mounted on load cells, or a load cell platform, and flow is sensed via loss-in-weight from the feeder hopper. This same loss-in-weight principle has been applied successfully to the delivery of liquids. Uniformity of delivery is sensed by the load cell supporting the liquid reservoir tank. The weight signal is used to drive the delivery pump speed either slower or faster as the weigh signal calls for it. When the reservoir empties to a 'low level' position, the pump locks onto its last set point speed while the reservoir is refilled. This delivery while refilling is volumetric, but the time needed for refill is so short in overall operating time, it makes no observable changes in finished product quality.

The importance of these electronic upgrades in ingredient weigh systems cannot be overstated. Uniformity of finished product is first and foremost dependent on uniform weighing of each and every ingredient used in the recipe.

After mastering techniques to measure accurately bulk dry and liquid ingredients, much remained to be accomplished in the automated measurement of minor ingredients – both solid and liquid. These areas have now both been successfully and accurately brought to high levels of microprocessor sophistication. Granted, many of the units operate sequentially – one ingredient measurement after another – but they are accurate.

8.3.2 Developments in blending

For batch cereal operations, batch ribbon blenders are still the industry workhorse for blending. They are easily loaded, unloaded, and cleaned; by hand, by screw conveyor, or by pneumatic conveyer. Most are double ribbon blenders; that is one ribbon pushes the material toward one end, while the opposing ribbon pushes the material to the other end. The level of fill in these units is somewhat critical. For optimum blending in the shortest time, the blenders should be filled between 50–75%. In no case, however, should they be filled over the level of the ribbons. If this is done, the top part of the load is in a dead mixing zone.

Microprocessors can again come into play in this unit operation in several ways. The whole unit can be mounted on load cells and serve as a receiver and weigh hopper vessel. Blending times and speeds, of course, can be controlled via programmable logic controllers (PLCs), as well as load and discharge opening and closing functions. Cycle time is always the sum of loading time, blending time, and discharge time. In order to make best use of the blending time, it pays to keep the openings for loading and discharge as large as possible. Also, as an alternative to using the blender itself as a weigh hopper, time is saved by using a weigh hopper/receiver above the blender to preweigh all dry ingredients, and a receiver below the blender big enough to accommodate several batches of dry blended ingredients. In addition to standard ribbon blenders, conical blenders can also be used.

There are in addition many ways that continuous blend systems can be set up to preblend the dry ingredients, and then even add the liquid flavor mix before cooking in batches. In extrusion cooking it is customary to add the preblended drys to the extruder, and liquids to the extruder, via separate ports – more on this in Section 8.3.3.

Any dry blend set up should have as a consideration the pros and cons of clean-in-place (CIP). These systems can be added easily if engineered into the initial design and layout. CIP systems also run off PLC control systems. We will limit our discussion here on liquids blending to the four basic flavor materials; water, sugar, salt and malt. The workhorse mixing vessel for these has been, and still is, the steam jacketed kettle. Liquid sucrose, dry salt, and liquid malt extract are slurried in water in a kettle equipped with agitation, and a steam jacket sufficient in capacity to heat the mix to 125ºF (52ºC). This is a high enough temperature to make a good useable slurry of such viscosity for ease of handling. If dry sugar and dry malt flour are used, these can be incorporated in the dry blend with the other dry ingredients.

In making liquid flavor mixes in batches it is common to use a kettle large enough to accommodate flavor aliquots for multiple batches of dry materials. When doing so it is best to weigh the aliquots of liquid flavor for each batch of drys. Metering of liquid flavor batches introduces more chances for batch-to-batch variability than weighing the increments due to the on/off withdrawal cycles from the kettle. Slight drops in temperature can cause significant viscosity and flow character changes.

In continuous cooking or extrusion cooking processes, continuous liquid mix systems can be used. As noted earlier, loss-in-weight liquid feed systems, as well as good liquid meter systems adapt themselves to this unit operation.

8.3.3 Developments in cooking

The cooking operation has seen great changes in the last two decades. The general trend has been toward extrusion cooking and away from batch cooking. Significant upgrades have been made in batch cookers and their control, however.

First, has been the total redesign of the shape of the pressure vessel itself. The old style perfect, straight-sided cylinder, has now been replaced by a 'cylinder-like' vessel whose center horizontal diameter is approximately 15% larger than the diameter at the end of the cylinder. The ends of the cylinder are no longer flat, and at 90º to the horizontal sides, but are shaped more like a flattened parabola. These two design changes have obviated the need for the four internal lifting flights that were welded at an angle on the internal surface of the old cylinder shape cookers. These flights were needed to ensure the cooking grain could mix while being rotated during cook time, and also, more importantly, cause the cooked grain to dump from the cooker hatch when cooking was complete. Elimination of the internal flights has eliminated contamination in product flow from overcooked grain which stuck to the flights, and was cooked repeatedly before finally breaking loose, and dumping.

The next feature incorporated in these new designs is automated hatch cover closing and opening mechanisms. This has greatly increased operator safety and reduction in steam burns which occurred with older style hand operated covers.

The third upgrade comes in the control of steam injection and exhaust. These changes are the direct application of PLC and computer control operation. In some designs, injection and exhaust are alternated from one end of the cooking vessel to the other on a preprogrammed cycle basis. The advantage is that the steam exhaust port screens are constantly cleaned when inlet and exhaust steam is changed from one end to the other. PLC and computer control, and automation of hatch cover opening and closing, have greatly improved operator safety of the batch cooking unit operations. Accuracy of cooking times is controlled totally and uniformity of cooked grain improved.

The move to extrusion cooking has been sparked to a great extent by the perfection of twin screw extruders. This development redirected and brought under control the tremendous excesses in shear imparted to the grain formula during extrusion cooking in single screw units. This excessive shear was apparent in the finished products as a 'dead' gray, unappetizing appearance. The bowl-life of the finished product was also shortened by the over gelatinization of starch caused by mechanical overworking.

The flexibility in set-up of the screw elements in a twin screw, along with greater flexibility in screw speed and heat input, have brought the extrusion cooking process under very exacting control. These control constraints coupled

with rapid product gelatinization measurements while running have greatly enhanced extrusion cooking acceptance. While all these features would seem to weigh in favor of extrusion cooking over batch, it must be pointed out that the two methods do not yet produce identical products. They have drawn closer and closer, but small differences still exist, and preference for one system over the other is a matter of finished product character choice.

8.3.4 Developments in drying

'Drying' unit operation in RTE processing is a necessary step between cooking and forming, i.e. flaking, shredding, gun puffing, etc. Most cooked grain recipes exit the cooker or extruder cooker at 25–30% moisture content. They are then dried to ranges of moisture between 9 and 17% for the forming operation. The units used for this step are still predominantly flat belt conveyor dryers – either single pass or multiple pass.

The two developments that stand out are in the areas of humidity control and unit sanitation. Humidity control impinges heavily in the area of dryer efficiency, and, just as importantly or even to a greater extent, affect condition quality of product exiting the dryer. Use of humidity increases efficiency of the dryer heat use, since exhaust air carrying the entrained moisture from the product can be reduced to the bare minimum. Reducing exhaust air naturally reduces the need for heated make-up air thus cutting down on fuel usage on the supply air side of the dryer.

The quality of product exiting a dryer with humidity control is greatly improved. The improvement is noted in that 'case hardening' of product particles during drying is much less severe. Product particles dry because the drying air sweeps away the microscopic layer of moisture from the particle surface. This causes a migration of moisture from the interior of the particle to the surface, when another, and another layer after layer of moisture are taken away. If, however, the drying air is too dry or too hot, a dry film forms on the particle surface which acts as a barrier to further moisture migration from the interior. This dried surface condition is referred to as 'case hardened'.

8.3.5 Developments in tempering

The next step after drying is tempering, a step used to allow equilibration of moisture within the particles and from one particle to another. If the particles are case hardened, temper times must be much longer to allow equilibration to take place. Use of humidity greatly reduces the amount of in-process material, and equipment needed to hold it, for this temper to take place.

It is hard to believe that advances can be made in a unit operation in a process that merely allows the product-in-process to just sit. Great light, however, has been shed on the tempering process in the last two decades. Early breakfast cereal scientists wondered in the very early years after World War II whether the physical and chemical changes that took place in breakfast cereal tempering

were parallel to those changes being published by scientists studying the staling of bread, namely, the retrogradation of starch amylase. One of the earliest revelations of this theory was made by E. G. White in his US patent number 4,179,527.[7] In that patent White discloses the methods of reducing the tempering or holding time for cooked wheat before shredding by chilling the wheat to 34–54ºF (1–12ºC). It was the revelation that refrigerating bread caused more rapid staling, that led to this adaptation to breakfast cereal processing.

Basic research in these two recent decades has left little doubt that that is exactly what is occurring. These theories have evolved, and been enlightened on tremendously by the glass transition phase work carried out by Drs Louise Slade and Harry Levine, and others in the field.[8]

Up to this point in the text there are four areas in which there can be no compromises accepted. They are:

1. Accurate recipe ingredient weights
2. Cooking – either batch or extrusion
3. Drying
4. Tempering conditions

A fifth and sixth, often overlooked, are consistent water quality and consistent food contact steam quality.

8.3.6 Developments in forming

Recent trends in the development of forming cooked grain formulations into their final shapes is most easily explained by taking each shape individually, i.e. gun puffed shapes, shredded shapes, flakes, extruded shapes, etc.

In the case of *extruded shapes*, a good explanation of how to design an extruder die hole or holes is given by Miller in *Breakfast Cereals and How They are Made*.[6] By following his suggested procedures good progress can be made in a short period of time. Much time and money can be wasted by just using trial and error methods. With all of this said, there has not been a plethora of new extruded shapes on the market. Rather what has evolved has been the refinement of shapes that appeared many years ago. Letters of the alphabet in one breakfast cereal, for instance, show much better definition and less distortion than when first introduced. In a few instances multiple extruders are in use extruding the same formulation each in a different color and flavor so that a mixed, for instance fruit cereal, is produced. Multiple extruders are also in use to produce mixed shape products.

Advances in die designs have evolved from the many and varied pasta shapes that are available. Transforming these into extruded breakfast cereal-shaped pieces, however, is much more difficult since the ever present expansion deformation of the piece must be overcome.

Strides have been made in cutting mechanisms, and in knife blade design. Some blades now have spring loaded mountings so that the blade edge may run in direct contact to the die face yielding much cleaner cuts.

Some double extrusion products have made brief appearances on the market. These, of course, are made by using two extruders pumping dough into the same die simultaneously – one being the casing the other being the filling. It is unique technology; however, in some of the products tried, due to the heavy weight of the filling, non-competitive carton weight cereals resulted, i.e. they were too heavy and therefore required too high a price. Several of these have survived, however, where the second product introduced is only a color mix. In these instances producers are able to keep carton weights competitive. One finds these products in the children's category of RTE cereals.

Gun puffed shape technology, however, has been on the decline, or at least been stagnant, and for a good reason. In order to make a shape for puffing one must first cook the grain formulation, form it in a forming extruder into the desired shapes, dry the shapes to a very narrow moisture range, and temper them. All this must be accomplished before gun puffing can take place. The rapid advancement in the development of twin screw extrusion of puffed shapes has replaced all of the steps listed above, and, in fact accomplishes all those steps, including the puffing, in one piece of highly controlled equipment.

The major gun puffing advance that has come to light in the 1990s, however, is the prominence of two world class manufacturers of automatic guns. Most automatic or continuous puffing guns have been developed in-house by those companies who wanted to produce gun puffed products. However, today a manufacturer in Belgium and another in Italy are actively supplying automatic batch guns. These units rely on technology taught in such patents as 'Cereal Puffing Apparatus' by Elmore F. Maehl.[9] This teaches the preheating of grain before introduction into the heated gun body, then once in the heated gun chamber, pressurizing the chamber by direct steam injection, and then releasing the hot, cooked, pressurized grain back to normal atmospheric pressure through a very quick opening valve. These automatic guns can fire in the order of forty times an hour instead of six times for pure, older style batch guns.

Changes in *shredded* cereals have seen additions in numbers of products on the market. However, the shapes are still limited to geometric shapes, such as squares, rectangles, or triangles, and not to curvilinear shapes which would necessitate scrape pick-up and reuse. The number of layers has been reduced to as low as two layers in some cereals from the early ones on the market of ten or twenty layers. Shredding has also seen the introduction of a two layer–two grain cereal composed of one layer of corn and one of rice. This is quite an accomplishment since shreds of both of these grains must be expanded or bubbled in the toasting step or the shreds are hard, flinty, and inedible.

Some of the most significant developments have taken place in the technology of building shredding lines. Water-cooled shredding rolls are in common usage now. The cooling reduces roll wear which in turn maintains groove dimensions longer, and therefore more uniform shredded piece weight. Drives have been reduced in size and noise level by the use of hydraulic motors on each roll in place of big, horsepower electric varispeed units. Metal bucket chains used to collect the webs of shreds under each roll pair have been replaced

with quiet fabric belting. Cutting is now done with low noise producing rotary wheels in place of metal, sprocket driven cutting belts. The roll adjusting devices have been changed to pneumatic cylinder adjusters in place of hand operated adjusting screws. A great many of these functions can now be controlled via PLC with more uniformity and accuracy than done formerly by human operators.

Similar technology upgrades have been incorporated into *flaking* roll manufacture. Roll stand frames are now produced with fewer points where common dust and filth can accumulate. Roll adjustment mechanisms are now such that, even if one or both rolls are spring loaded, they can be brought into close tolerance to produce flakes with no fear of ever having the two rolls touch and run against each other when no product is running through them. Preheating the rolls to running temperatures can be done before starting product flow, so that little, or no adjustment is necessary to compensate for change in roll temperature and this in turn minimizes product waste.

While rotary ovens are still in use for toasting, they have been augmented by the acceptance of fluidized bed jet-tube ovens. Both styles feature better air flow in and around each flake being toasted, and improved heat transfer rates. Controls now lend themselves to PLC operation. As in shredder designs, improvements have been made to reduce noise levels, particularly air handling noise levels.

Numerous new coating improvements have been, and are in use today. One of the biggest advances is in the availability of self-cleaning, non-clogging spray nozzles. This has improved greatly the overall running efficiency of sugar spray coating. It has also allowed for usage of a wider variety of coating formulations previously limited because of nozzle plugging problems.

Cooperative efforts between food producers, coating ingredient producers, and coating equipment manufacturers has led to the development of 'tack' ingredient formulas used to attach such enhancers as nut pieces, baby oat flakes, dry powder flavors, etc., to foods without the use of fats or sugar syrups as binding materials.

Coating drums are now available that allow multiple spray applications in small amounts, with drying steps in between, to be used to build up to the final desired level of coating. This has proved beneficial in some cases over applying one heavy coating application followed by a longer drying time.

8.3.7 Quality control improvements

Major advances have been made in quality control (QC) instrumentation which have proved to be of tremendous value to the industry. The three primary QC checks made of finished cereals are color, moisture, and bulk density. All of these previously were accomplished by collecting on-line samples, taking them to a QC lab in the factory, and analyzing for each. Out of specification results were then communicated to the production floor for correction.

However, moisture for instance, is now routinely determined on-line using either near infrared (NIR) technology or capacitance measuring. Capacitance

sensing is translating the dielectric behavior of the product (caused by its moisture content) into moisture readings. Both of these methodologies are highly developed, readily available, and backed by good service capabilities.

Color, likewise, is measured on-line by measurements of reflectance in the red, blue and green bands of the spectrum. Then by using built-in computed algorithms a numerical readout is given which translates to product color. In both moisture and color measurements by instrument it is first, of course, necessary to establish normal high and low acceptable limits through thorough statistical analysis and product evaluations.

Bulk density may also be measured on-line. One such system employs a computer-driven cup, which on system command, enters the product stream. Then on retraction, the contents in the cup are leveled, and once fully retracted into the machine, the net product weight is taken. Results can then be translated into any desired units of bulk density.

I will leave it to others in other parts of this text to explain the present availability and usage of automated machine analytical procedures of moisture, protein, fat, fiber, and ash on raw grains. These would only be of limited value in a very few breakfast cereal processes, since they are now common dependent variables as they would be perhaps, say, in the flour milling industry. Standard, approved laboratory analytical methods would be the preferred usage for determination, and verification, of label nutrient declaration.

8.4 The future of the industry

The technology of the industry is running rapidly in the direction of computer control of its total manufacturing systems. This is because of desired tighter process control moving QC functions back onto the processing floor, and out of a plant laboratory, relieving operators of repetitive tasks so they can concentrate on more important areas, and relieving operations of relying on a few ‘expert’ operators.

The first steps were taken with individual process unit operations being placed under PLC control systems. After material handling, which is namely on/off conveyor control, the first major area was in ingredient weighing and batching. Control of weighing major ingredients came first, but technology is now available for weighing minor ingredients and liquids in very small quantities, and with good accuracy. The Instrument Society of America has published an industry standard (SP88) to address terms and concepts that should be common for those writing software in this area. Weighing also addressed the control of master ingredient and slave ingredient flows. Integrated PLC operation performs beautifully in these instances.

Other individual unit operation functions put under PLC control were cooking, cooling, drying, flaking, toasting, and coating. Temperatures, pressures, processing times, gap settings, delivery rates, etc., are all examples of variables moved from hard-wire, or human adjustment, to electronic control.

With the addition of personal computers on breakfast cereal processing floors, the integration of these stand-alone control functions with a unified operating system began. It was then possible to introduce data recording and control functions in the same control unit. Runtime, downtime, material usage and inventory control can now be introduced into the system. By interfacing these many pieces of manufacturing information, a whole pictorial landscape of the manufacturing plant is developed for use by management on a real-time basis.

In summary, PLC and computer control of cereal processing has evolved over the past two decades and is highly developed. There are many companies worldwide prepared to assist cereal manufacturers in moving to this higher level of total plant control. It is definitely the move to the future.

8.5 Sources of further information

Service directories via computer:

1. www.preparedfoods.com
2. www.foodprocessing.com
3. www.foodmanufacturing.com
4. www.kwpc.com
5. www.herbs.org
6. www.scisoc.org/aacc/
7. www.ift.org
8. www.verticalnet.com
9. www.foodproductdesign.com
10. www.foodingredientsonline.com
11. Search engines
    a. Yahoo
    b. Lycos
    c. Infoseek
    d. Alta Vista

Publishers in Cereal Science:

Eagan Press, 3340 Pilot Knob Road, St. Paul, MN 55121-2097, USA

Product development and pilot plant facilities available for product and process development:

1. APV Baker, Peterborough, England
2. University of Nebraska, Lincoln, NB, USA
3. Custom Food Processors Inc., Blue Earth, MN, USA
4. Buhler Ltd., Uzwil, Switzerland

8.6 References

1 POWELL H B, *The Original Has This Signature WK Kellogg*. Englewood Cliffs, NJ, USA, Prentice Hall Inc, 1956.

2 BRUCE S and CRAWFORD B, *Cerealizing America*. Winchester, MA, USA, Faber and Faber Inc., 1995.

3 HEGELE FRED, General Mills, Minneapolis, MN, personal communication, 1999.

4 STALKER JOHN A C, Weetabix, Cobourg, Ontario, Canada, personal communication, 1999.

5 HALOVIAK BERT, Seventh-Day Adventist Church, Silver Spring, MD, personal communication, 1999.

6 FAST R B and CALDWELL E F, *Breakfast Cereals and How They are Made* 2nd edn. St. Paul, MN, USA, American Association of Cereal Chemists, 2000.

7 WHITE E G, Process for Manufacturing a Whole Wheat Food Product, US Patent No. 4,179,527, Dec. 18, 1979.

8 SLADE L and LEVINE H, Beyond Water Activity: Recent Advances Based on an Alternative Approach to the Assessment of Food Quality and Safety. *Critical Reviews in Food Science and Nutrition* 30, 2&3, 1991.

9 MAEHL E F, Cereal Puffing Apparatus, US Patent No. 3,128,690, April 14, 1964.

9

Malting

G. Gibson, Consultant, Cowan & Linn, Glasgow

9.1 Introduction

This chapter covers the processing of barley to produce malt for, principally, the brewing and distilling industries. Initially, the ‘on site’ intake and storage of green barley are discussed, followed by information on barley drying and dried barley storage. Each production stage of the malting process is then described, with a general description of the structures, plant and equipment currently favoured. Finally, storage and dispatch of the finished product are outlined.

9.2 The UK malting industry

In the United Kingdom, there are three major producers of malted barley for brewing and distilling; the Brewer Maltster, the Distiller Maltster and the Sales Maltster. The Brewer and Distiller Maltsters have traditionally produced malt in quantities substantially below their own requirements, relying on Sales Maltsters to top-up any shortfall. If, for example, there is a fall in the overall production of beer and whisky, the Brewer and Distiller Maltsters can normally continue to operate their own maltings at full production, their lower overall requirement resulting in a reduced demand from the Sales Maltster. Some Sales Maltsters produce malt on contract for Brewers and/or Distillers. The arrangement in the UK whereby Sales Maltsters make up the deficit for the end user who produces only a proportion of his own malt requirement is also found in many other parts of the world.

Over the last 25 years or so, the demand for malted barley in the United Kingdom has fluctuated greatly, and this has made life difficult for the Sales Maltster, who is particularly vulnerable to reduced demand, for whatever reason, both at home and abroad.

The UK malting industry recorded steady growth in the years leading up to 1974, when the distillery market peaked; external factors, such as the oil crisis and contraction of world markets, resulted in an overall drop in production for some years thereafter. In that year, the demand for brewing and distilling malt in the UK reached a high point at about 1 370 000 t, with approximately 680 000 t processed by brewers and 690 000 t by distillers. The demand for brewing malt continued to increase until about 1979, when approximately 735 000 t of malted barley was processed.[1]

A downward trend in overall UK malt requirement followed for some years, although some improvement occurred before 1990, when the total figure was approximately 1 270 000 t, with the brewers showing a slight increase in the 1974 figures, up to 700 000 t; distilling malt had dropped substantially to around 570 000 t. Since 1990 there has again been a general downward trend, although fluctuations have occurred from year to year. The 1998 figures show a small decrease in total production compared with the previous year, with exports rising marginally, and home requirements falling slightly.

The position after 1974 was exacerbated by a large increase in capacity from new plant, constructed by Brewers, Distillers and Sales Maltsters, following a perceived increase in demand which, however, was short lived; in particular, the requirement for distilling malt dipped sharply in the early 1980s. As a result of the increased capacity, the situation arose where excess malt produced by Distiller Maltsters was sold on the open market, making life even more difficult for the traditional Sales Maltsters. This continuing uncertainty, both at home and worldwide, has led inevitably to the consolidation of sales malting companies in the UK, in an effort to maintain a trading profit in these difficult times. This overall pattern of mergers and acquisitions, and the need to produce malt to a multitude of specifications, has led to the demise or takeover of many smaller Maltsters, and the closure of uneconomic units.

Not long after the Second World War, there were perhaps 70 or 80 malting companies, decreasing to about one quarter of this figure in the early 1970s.[2] At the present time, there are only five major malting groups in the UK, with a small number of Brewer Maltsters and Distiller Maltsters still producing a substantial quantity for their own requirements. A handful of small specialist Maltsters also continues to trade; a few traditional floor maltings are still in use. The current major Sales Maltsters are:

1. *Bairds Malt*
   This company was formed in 1998 as a result of a joint venture between Hugh Baird & Sons Ltd, and Moray Firth Maltings plc. This group has seven active maltings, from Essex to Inverness, but the recent merger may result in rationalisation of production.

2. *Crisp Malting Group*
   This group has four major maltings, and has remained relatively unaffected by merger or acquisition for a number of years. Malting capacity is currently concentrated in Norfolk, but a plant to serve the need for distilling malt was constructed in North East Scotland, early in the 1980s.

3. *Muntons Malt*
   This company operates three maltings in Norfolk, Yorkshire and Fife, the latter principally devoted to distilling malt.

4. *Pauls Malt Ltd*
   This group is by far the largest Sales Maltster in the UK, and was recently acquired by Greencore, an Irish conglomerate, from the parent company Elementis (formerly Harrison & Crosfield). The combined malting capacity of the Greencore Group, which also has plants in Belgium and Ireland, makes them fourth largest in the world at present. Pauls currently operate seven maltings, stretching from Oxfordshire to Moray. Their plant at Bury St Edmunds is the largest maltings site in the UK, capable of producing over 150 000 t of malt per annum.

5. *J. P. Simpson & Co.*
   This Maltster operates two major units, in Berwick and Norfolk.

The largest Brewer Maltster is Bass, with the main concentration of production in Burton-on-Trent, including the recently acquired Allied Malting Tower. Carlsberg Tetley also produce a limited amount of malt.

The largest Distiller Maltster is United Distillers, operating four plants in Scotland. A number of other distillers produce malt, but are not self sufficient. To illustrate the development of the largest UK Maltster, Pauls Malt, Fig. 9.1 shows the extent of acquisitions and mergers since the early 1960s, and also indicates their current position within the Greencore Group.

The present situation in the UK is one of relatively steady production by Brewers and Distillers, with Sales Maltsters having to concentrate on overseas selling into a market suffering recent downturn, due to the financial situation in the Far East, South and Central America. Over the past few years this has resulted in depressed trading for these companies, some of which sell more than 50 per cent of their production overseas.

9.3 Basic malting process

In the United Kingdom, malt for brewers and distillers is normally produced by the germination of selected dried barley under controlled conditions of moisture and temperature, until the requisite degree of growth has taken place in the grain, after which the germinated barley is dried by gentle heating to produce ‘malt-in-culm’ (i.e. malt with the rootlets formed during germination still attached). The malt-in-culm is then ‘dressed’ mechanically to remove the rootlets, leaving a friable granular product, malt. This is normally stored for some weeks, before dispatch to the end user.

To the untrained eye, malt appears to be generally similar in appearance to the original barley, but the malt corn, with a lower moisture content, is more brittle, and has a malty taste when bitten. This compares with the tasteless nature

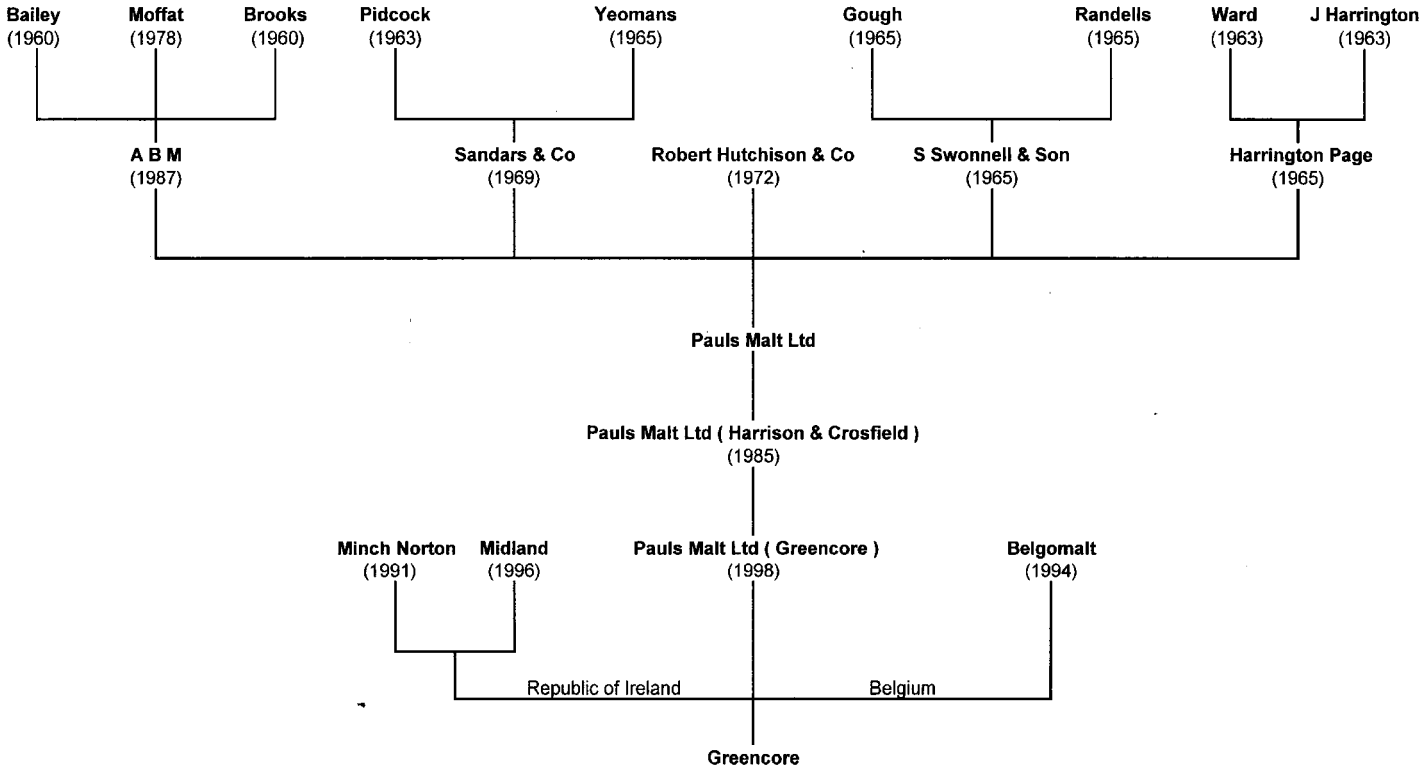


Fig. 9.1 Pauls Malt Ltd structure.

of a barley corn. Significant biochemical changes have taken place in the process. The barley used for malting will have been harvested some time previously, dried, cleaned, probably graded, and will have been stored in large bulk storage units, either sheds or bins, for sufficient time to allow the natural dormancy of the grain to cease. It is essential that the raw material has been expertly selected and carefully husbanded until ready for malting, so that it is capable of up to 100 per cent germination. A diagrammatic layout of the basic malting process is shown in Fig. 9.2.

The first stage in the process is steeping, where a weighed batch of dried barley is divided equally into a number of steeps, normally circular stainless steel vessels. After the steeps are filled, clean water is introduced to promote absorption into the grain, thus raising the moisture content. The grain swells, and this initial wetting starts growth in the barley. Steeping typically continues for two days, and during this cycle the grain is subjected alternately to wetting and drying, with concomitant aeration of the barley during wetting, and extraction of carbon dioxide during the dry periods.

When the moisture content of the grain has reached, typically, 43% to 46%, and initial sprouting of the corn has occurred (‘chitting’), the moist grain is transferred onto the perforated floor of a germination unit. Here, under controlled conditions of humidity and temperature, growth of the barley is encouraged, and rootlets gradually develop. The relative humidity of the air passed through the bed of grain is maintained as near 100 per cent as possible, within a temperature range of approximately 12ºC to 19ºC, depending on barley variety and malt specification. Under conditions of high ambient temperature, refrigeration may be necessary to prevent overheating of the grain. A typical germinating vessel is shown in Fig. 9.3. During germination, which might typically take four to five days, enzymes within the grain are released, these converting the insoluble starch cells in the barley into sugars and more soluble starches, dextrins. When this process of ‘modification’ has reached the appropriate stage, the batch of ‘greenmalt’, as the material is now known, is transferred to the kiln, for the third and final stage of processing.

In the kiln, the grain is spread on a perforated floor, and warm air passes through the bed under fan pressure. Gentle heat is applied, causing withering and initial drying, arresting the germination process, and stabilising the structure of the grain. Kilning continues for some time under relatively constant temperature, until the moisture content is significantly lowered, after which the air flow is steadily decreased, and temperature increased, to achieve the desired curing and final moisture content of the malt. Malt of differing characteristics, including colour and flavour, can be produced by varying the curing regime of air flow and temperature, to meet the particular specifications which might be required by the Brewer or Distiller. Most kilning cycles in modern kilns take approximately 24 to 30 hours. A typical kiln is shown in Fig. 9.4.

After kilning, ambient air is passed through the grain bed, and the cooled grain, with the rootlets still attached, is transferred to a holding bin before dressing and storage for subsequent blending and dispatch. Ideally, malt is

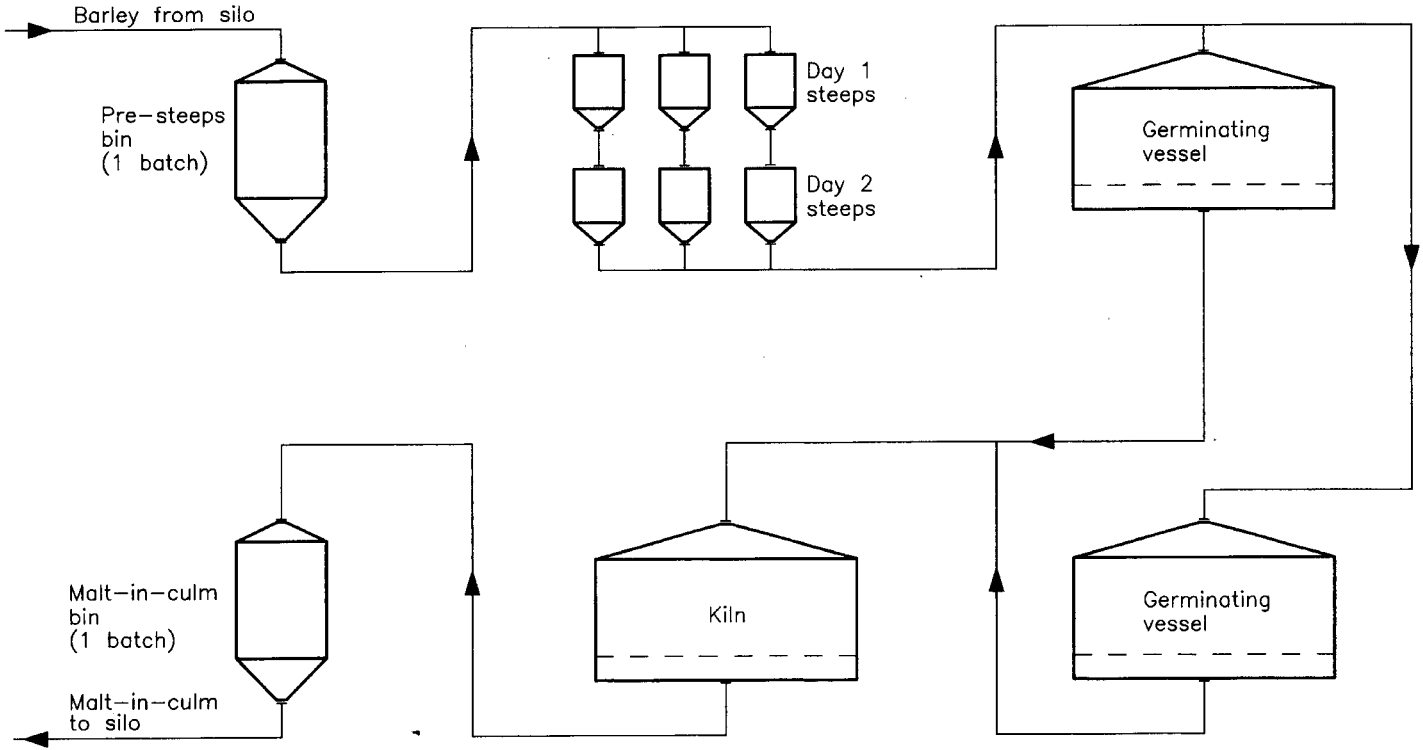


Fig. 9.2 Flow diagram of typical malting process.

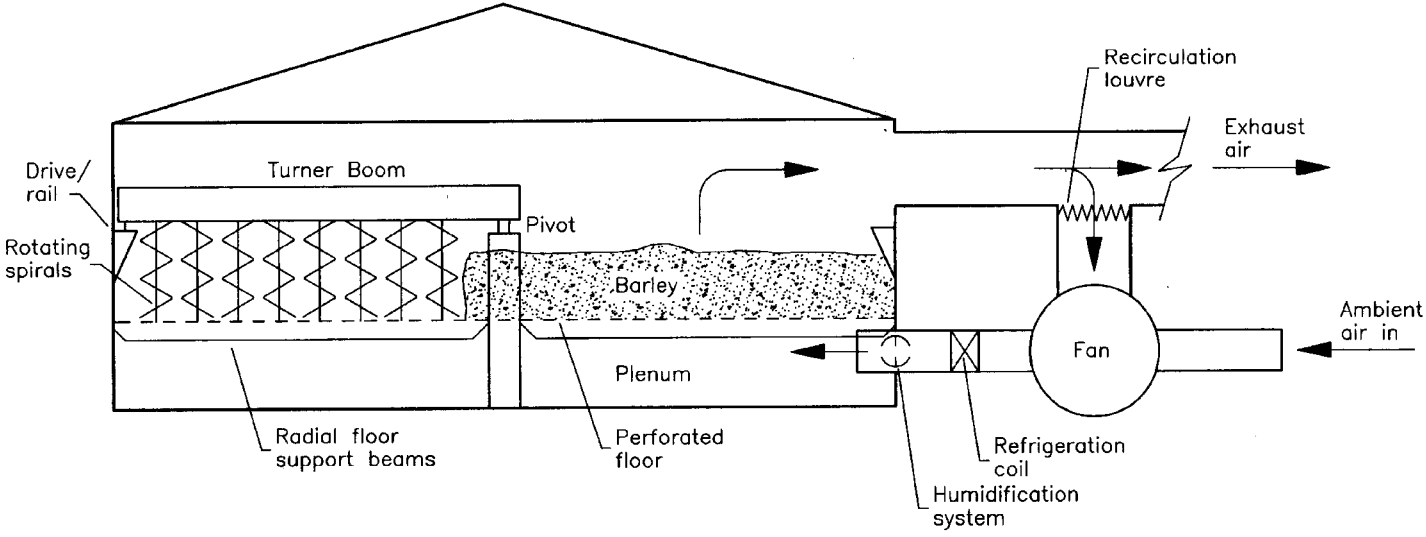


Fig. 9.3 Diagrammatic layout of circular germinating vessel.

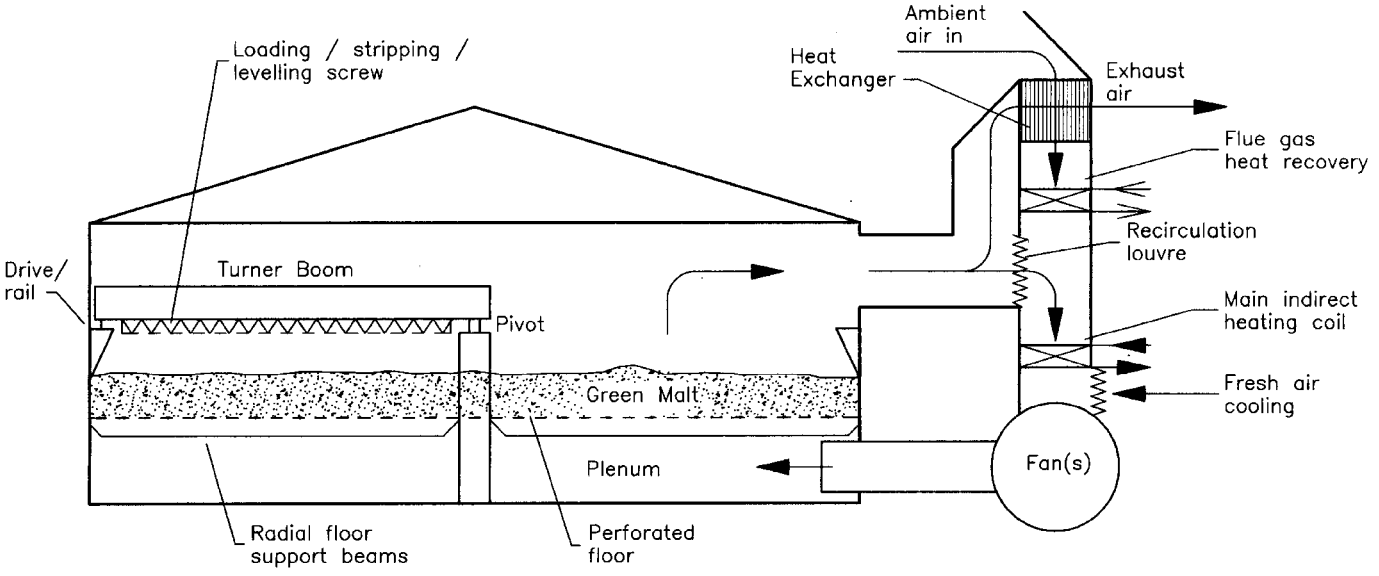


Fig. 9.4 Diagrammatic layout of circular kiln.

stored in relatively small hoppered silos, up to a few hundred tonnes capacity, to allow separation of batches produced to different specifications, and to minimise possible damage to the friable malt through over-handling. Before dispatch, the malt is finally dressed and cleaned to ensure the highest possible product quality.

In the brief description above, it has been assumed that steeping, germination and kilning occur in discrete sets of vessels. There are instances, however, where two or more elements of the process have been combined in one vessel; steeping and pre-germination may be carried out together, germination and kilning may be carried out in suitable units without requiring the movement of grain, and in a few instances steeping, germination and kilning are carried out in single vessels. These options will be described in more detail later in the chapter.

9.4 Barley intake, wet bin storage, and drying

After harvesting, barley must be prepared for storage during its period of dormancy before conversion to malt, under conditions minimising the risk of infestation from insects, fungal attack, etc., which can lead to spontaneous heating. To achieve this, it is necessary to dry the 'wet' or 'green' grain from the fields for long-term storage, down to a moisture content of 12 per cent, although initial drying down to 15 per cent could be acceptable, providing that further drying is carried out later in the season. To allow the drying of the large quantities of grain which are harvested within a short time, large drying complexes have been set up, both by Merchants and Maltsters.

9.4.1 Barley intake and wet bin storage

In any maltings or grain drying complex, due consideration must be given to the design of deliveries to site, the raw material intake and the planned drying regime. The first essentials are to determine the maximum weekly throughput of the drying plant, and the programme for green barley deliveries, to ensure the availability of the raw material as required. Thereafter, the barley intake rate, wet bin storage capacity, drying capacity, and handling rate can be calculated. For example, if intake takes place over five days per week only, averaging ten hours per day, and, say, 5000 t is the required dryer input per week, then barley must be taken in at an average of 100 t per hour. As there is always time lost at the intake, it would be wise in this case to install a minimum intake conveying system of 150 t per hour. This would allow a 25 t capacity lorry to discharge in ten minutes.

The minimum plant incorporated in the intake system should be effective magnets and a pre-cleaner with dust extraction, these to match the intake capacity.

If drying is likely to take place seven days a week, 24 hours a day, then it should be assumed that operations might be limited to, say, 160 hours per week allowing downtime for cleaning, delays, etc. The average input to the dryer,

therefore, would need to be in excess of 30 t per hour. The actual throughput will vary, depending on various factors discussed elsewhere, but the dryer should be sized on the basis of a reasonable initial moisture content for the geographical location of the plant. This may vary from perhaps 16 per cent up to 20 per cent or higher as the site progresses northwards.

If there is no barley intake from, say, Friday afternoon until Monday morning, then there must be a minimum of at least 60 hours storage of wet barley adjacent to the dryer, to maintain uninterrupted drying operations, and the wet bin capacity should therefore be not less than 2000 t. Although the intake capacity to the wet bins would be adequate at 150 t per hour, the conveying and elevating equipment to the dryer, and from the dryer to storage would be lower, but should be rated well in excess of the nominal capacity of the dryer, to take account of periods when the field moisture content of the barley is significantly lower, allowing a throughput above nominal dryer capacity.

During conditions of lower moisture content in the barley, and on the assumption that the weekly throughput of the dryer would be increased because of this, the intake time would need to be extended beyond the average ten-hour day, five days a week, to ensure that the available wet bin storage is adequate for any period when there is no intake operating.

If 2000 t of storage of wet barley were to be provided, then this should be divided into smaller units of, say, 500 to 700 t each, to allow cyclical emptying of the bins, ensuring that no wet grain remains in any bin for an excessive length of time, and to permit basic separation of barleys if required, for example, into different varieties, nitrogen values, moisture contents, etc. The bins should be hopper bottomed, self emptying, with sufficiently large outlets to minimise blockage from straws and other impurities which may have passed the pre-cleaner.

9.4.2 Barley drying

Normally, dryers can be classified as either continuous or batch.

Continuous dryers may be of a vertical or horizontal format, although the former is very much in the majority. In these, grain is in continuous vertical movement, being fed in at the top level, and allowed to gravitate through the drying column, the rate being controlled at the point of discharge, to achieve the required moisture content. In horizontal dryers, a layer of grain is transported on a horizontal moving perforated floor, with warm air passing vertically through the bed.

The essentials of good drying are:

1. Sufficient clean ambient air.
2. A heat source of adequate capacity to raise the incoming air from ambient to the required air-on temperature.
3. A method of ensuring that the grain has maximum contact with the heated air at low relative humidity, to evaporate moisture. It is necessary to ensure that the grain has sufficient time within the drying sections of the unit to

allow gentle drying without subjecting the corns to excessive heat, affecting its viability as malting barley.

4. Final cooling of the grain in the lower part of the drying column, to ensure a safe air-off temperature for storage. If adequate cooling of the grain is not achieved, there are potential risks of moisture migration during further cooling, insect infestation or fungal growth.

The air is normally heated by oil- or gas-fired burners, and the products of combustion can either be passed directly through the grain (direct firing) or through a suitable heat exchanger, so that the air which passes through the grain mass does not contain any of the products of combustion (indirect firing). Indirect fired units are likely to incorporate air-to-air heat exchangers, or hot water radiators.

Direct firing offers a cheaper installation, with minimum heat loss, and is generally of simpler construction, but grain in the dryer can be contaminated by the products of combustion, and there is a risk of fire in the grain from the ignition of debris passing across the burners. Indirect dryers are more expensive, and less economical, but have the advantage of minimising contamination and the risk of fire.

Various factors affect the capacity of any grain dryer, including the initial moisture content of the green barley, ambient conditions of temperature and relative humidity, the temperature of the air applied to the grain, and the final discharge temperature. All of these factors must be defined when new drying plant is being specified.

Batch drying is principally carried out in maltings where kilns can be made available for drying during the harvest period. It is likely that the drying time will be in the order of 12 to 14 hours; the capacity of the kiln for drying will be approximately 50 per cent more than the tonnage of original barley for which the kiln had been designed as a malting unit. For example, a kiln designed to handle greenmalt from an original barley batch of 200 t, drying on a 24-hour cycle, is likely to be able to handle batches of approximately 300 t of field barley.

9.4.3 Current trends

In the past ten to twenty years, there has been little in the way of development of intake systems, wet bin storage or dryers in the UK. Relatively little demand for additional process capacity has resulted in minimal investment in new drying plants; most of these which were installed during the 1970s and 1980s are still proving to be satisfactory. It is unlikely that any major changes will take place in drying procedures in the foreseeable future.

9.5 Dry barley storage

After drying, malting barley is maintained in long-term storage at a moisture content of around 12 per cent, and, if kept at normal ambient temperatures,

preferably not exceeding 15ºC, the grain should be safe from infestation, spontaneous heating, and subsequent loss of germination. The majority of long-term barley storage units are aerated, using ambient air; this provides the means of counteracting any rise in temperature, if pockets of grain show signs of overheating. Temperature monitoring should be installed, with automatic sensing, to locate and identify significant rises in temperature.

Each Maltster has his own regime as to the amount of barley purchased at harvest, in relation to his foreseen annual demand. This barley would normally be dried and stored under his direct control on site, or at Merchants' premises. Some Maltsters tend to hold little barley at the maltings; a few have the facility to dry and store upwards of 90 per cent of their anticipated annual requirements.

Currently, by far the greatest proportion of barley is stored in one of four forms:

1. Large sheds ('flat stores') of up to about 30 000 t.
2. Large circular steel bins, with flat concrete slab bases, of up to about 4000 or 5000 t.
3. Round hopper-bottomed steel bins, of limited capacity, around 750 to 1000 t.
4. Reinforced concrete silos of varying capacity; few, if any, concrete silos have been built for the malting industry in the past thirty years, due to the high cost of construction.

Brief details of each type are given below.

9.5.1 Flat stores

Many flat stores have been constructed, principally up to the mid 1980s, with capacities up to around 30 000 t. These are the cheapest way to store large quantities of single-grade barley, although some sub-division can be achieved with either permanent or movable internal partitions. This sub-division, however, greatly decreases the potential storage capacity, due to the limitation on height of internal walls. Where greater separation of varieties is required, circular bins are normally used, but with a significant cost penalty.

Most flat stores consist of structural steel frames with steel or concrete grain retaining panels around the perimeter. The floor is normally of reinforced concrete. The roof sheeting can either be of fibre cement, which absorbs a certain amount of moisture, or of steel decking which, however, can lead to problems of condensation, unless insulation is incorporated; this significantly increases the cost of the roofing.

In some instances, concrete aeration ducts are formed in the sub-floor, with perforated steel cover plates at floor level. These are not common, and a much cheaper expedient is to install on-floor perforated steel ducts of large diameter; these are, however, inconvenient to use and prone to damage while the sheds are being emptied. Aeration fans supplying ambient air to the ducting are normally

situated externally, on the perimeter of the shed, and may be portable, one fan serving several aeration duct laterals.

If the roof is steeply pitched, beyond the normal roof slope, a filling conveyor can be located on a walkway immediately under the ridge, clear of the grain. Typically, if a shed is 30 m to 40 m wide, a roof slope of about 30º will allow this arrangement, assuming a natural angle of repose of the dry grain of about 23º.

The normal method of filling is by overhead conveyor, with multiple outlets allowing maximum filling capability. To ensure complete filling of the corners, up to the height of the retaining panels, additional grain throwing or mobile conveying equipment is required. Normally, emptying is by tractor fitted with a large bucket, but this is labour intensive and relatively slow. A few sheds have been constructed with under-floor conveying, or other automatic unloading system, and although this clears a high proportion of the barley from the shed without the need for labour, a tractor with blade or bucket is still required to recover the remaining grain.

Based on a retained height of 6 m around the perimeter, and assuming the corners are filled, the approximate capacities of single compartment sheds of varying widths and heights is shown in Fig. 9.5.[3] The grain is assumed to be dry barley, with a density of 705 kg/m^3, and a natural angle of repose of 23º.

9.5.2 Flat bottomed circular steel storage bins

A very significant proportion of dry barley stored before malting is held in large capacity circular galvanised steel bins, holding from about 1000 to 5000 t per bin. Bins of larger capacity are available, but have not found favour with UK Maltsters, who would be more inclined to use flat stores, or a series of smaller bins for such large quantities of single-quality barley.

Flat bottomed steel storage bins are normally erected from thin, curved circumferential corrugated sheets, reinforced with vertical steel posts, preferably external to minimise grain 'hang-up' and infestation problems. The roof is normally conical, constructed from bolted steel segments. Flat bottomed bins are available in a large range of diameters and heights, from about 8 to 20 m diameter, and to heights in excess of 20 m. Figure 9.6[3] shows the potential barley capacity for bins of varying diameter and height, again based on the standard figures of 705 kg/m^3, and an angle of repose of 23º.

The bin bases are normally constructed with a circumferential reinforced concrete beam, infilled with hardcore, and topped with a reinforced concrete floor slab. When aeration is incorporated, it is normal to construct ducts as part of the floor slab, with perforated steel covers, fitted flush with the concrete slab. An external fan is used to provide ambient air. This duct configuration is essential to allow rotation of the sweep auger, which is pivoted at the centre of the bin; this device clears the last of the grain from the bin to the central hopper after perhaps 90 per cent of the contents have been discharged by gravity through the central hopper, into the conveying system.

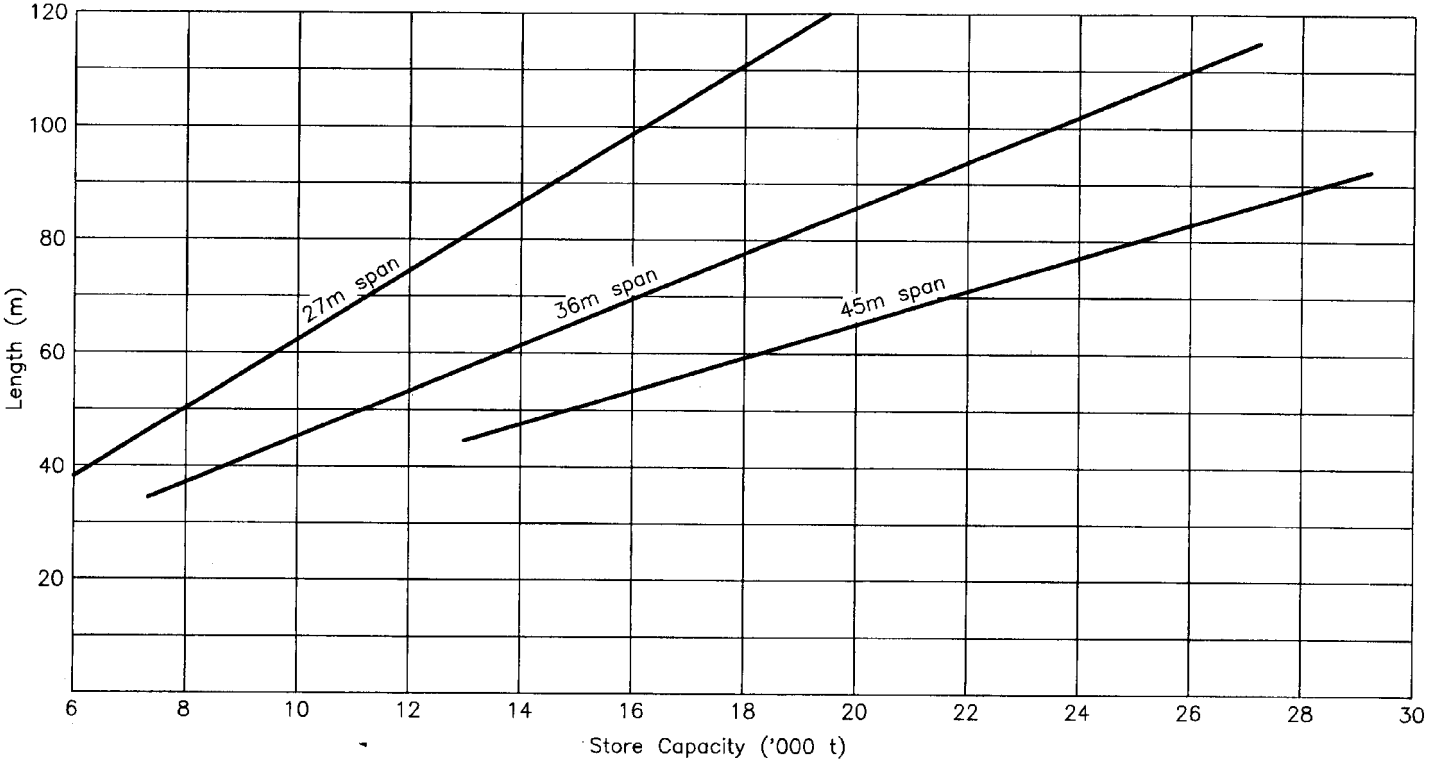


Fig. 9.5 Capacity of single compartment barley stores.

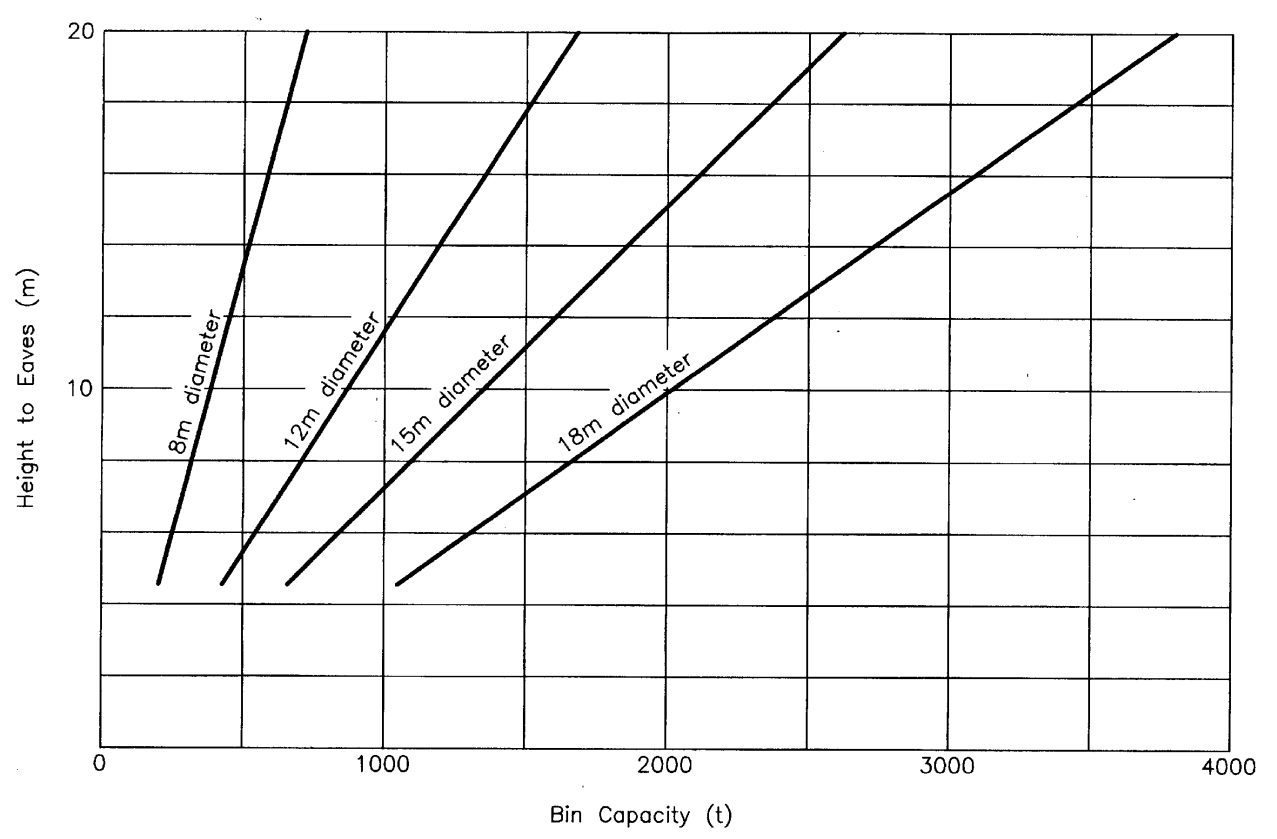


Fig. 9.6 Capacity of circular flat bottomed bins.

The machine carrying barley from the central hopper under the slab is normally a circular tube auger, discharging to the main conveying system located outside the bins. Filling is achieved by an over-bin conveying system or spouting, situated on gantries normally bolted to the bins at eaves level.

The construction of circular corrugated steel bins is relatively flimsy, and they can readily distort if asymmetrical loading is applied to the walls, for example if eccentric spouts are used for filling or emptying the bins. It has been known for bins to collapse where the design requirement of central filling and emptying has been ignored.

9.5.3 Square and round hopper-bottomed bins

It is frequently of advantage to the Maltster to store small quantities of barley for specific purposes, such as batches about to be processed, which require to be transferred rapidly to the steeps, and by-products, such as screenings, pellets, dust, etc. This type of bin is relatively expensive, with the cost per tonne rising steeply when the capacity exceeds around 500 t.

With the current trend of processing large batches of barley, it is essential to have the requisite weight readily available for high speed transfer from a pre-steep bin to the steeps themselves. With this set-up, the barley required for steeping can be cleaned and weighed at low capacity, the pre-steep bin being used to hold the measured quantity. This bin would normally be located as close as possible to the steeps, to minimise the use of high capacity transfer equipment.

Circular hoppered bins are available with corrugated or flat sides; most square or rectangular bins are constructed of corrugated side panels, but bins with flat panels, externally stiffened, are also available, these providing a nominally smooth internal wall, which minimises the accumulation of dust.

As the cost of hoppered bins is considerably greater than for larger flat bottomed bins or grain sheds, described above, the use of these hoppered bins for barley is restricted to requirements for low capacity storage.

9.5.4 Concrete silos

Reinforced concrete silos make good use of restricted ground area, as they tend to be ‘high density’ storage, the height of the concrete silo being normally much greater than the alternative storage methods already described. This type of silo is normally divided into hoppered cells, either circular, hexagonal, or square, which can be used flexibly for relatively small parcels of different types of barley (or malt).

In the 1950s and 1960s, most major Maltsters constructed reinforced concrete silos, but since then, with the increase in size of batches, Maltsters have found it necessary to store barley in quantities larger than can be accommodated in the average cell in a reinforced concrete silo. This has led to the development of the larger types of bins described above, although many Maltsters have found it

convenient to convert their reinforced concrete barley bins into storage for malt, which is normally stored in smaller quantities, to allow blending to meet customers' specifications.

In the UK, the cost of large cell concrete silos is prohibitive for Maltsters, and this type of storage is no longer an economic consideration for malting barley.

9.5.5 Current trends in dry barley storage

The current inclination of Maltsters is to adopt large capacity circular steel bins for longer-term barley storage, this giving maximum versatility in the separation of varieties, good control over the condition of the barley, and the ability to fill and empty storage units without the use of labour, apart from nominal cleaning.

Barley storage sheds, previously constructed in considerable numbers, and relatively cheap to construct, can be expensive to operate. The storage of different varieties of barley is uneconomic, and the cost of labour and machinery for filling and emptying has become significant. The use of the circular flat bottomed steel bin is therefore likely to continue as the favoured method of storage in the foreseeable future.

9.6 Malting plant

The past thirty or forty years has seen a considerable polarisation of the type of equipment used for malting barley. In the first stage of the process, cylindro-conical steeps (i.e. circular steeps with a vertical walled portion, and conical hopper below), were used almost exclusively in the 1960s and 1970s. The development of the flat bottomed steep followed, this being essentially a large circular open-topped tank, with a perforated floor onto which the grain was loaded. A shallow plenum below the perforated floor ensured good distribution of air while the barley was being aerated. Automatic loading provided a uniform depth of barley and the whole area of the steep was subjected to consistent conditions during processing.

Major disadvantages were the amount of water required to fill the plenum prior to submerging the grain, and the difficulties in cleaning below the perforated floor. Consequently, with increased demands on hygiene, there has been a tendency to revert to cylindro-conical steeps, of stainless steel construction, with automatic aeration and carbon dioxide extraction facilities.

During the development of maltings in the late 1950s and 1960s, Maltsters used various types of germinating units, all incorporating similar features. Apart from the continued use of floor maltings, although in ever-decreasing numbers, Maltsters tended to favour the rectangular Saladin or Wanderhaufen Boxes; the adoption of drums by some Maltsters followed in the late 1960s and 1970s. The capacity of rectangular boxes increased from perhaps 30 t to around 150 t or more, whereas the majority of drums were restricted to about 30 t capacity. Over the last twenty years or so, there has been an almost universal movement in the

UK towards the introduction of much larger circular stainless steel vessels for germination. These are essentially large enclosed tanks, with the grain loaded onto an intermediate perforated floor. The plenum below the floor provides the means of uniformly distributing the humidified air to the barley during germination.

Rectangular kilns of brick and/or concrete which were common in the 1960s and 1970s have, like germination units, gradually given way to circular vessels with perforated floors; the principle is essentially the same as in germination, with warm air from the heat source being passed into the plenum below the perforated floor, and upwards under pressure through the bed of germinated barley. Various features such as recirculation, cooling and heat recovery are normally incorporated. The construction of the vessel shell is again predominantly of stainless steel, this providing the best means of achieving the required standards of hygiene. Loading and stripping (unloading) are automatic.

In the 1950s and early 1960s, it was normal to process a barley batch of around 30 to 50 t, this figure increasing with the availability of larger Saladin or Wanderhaufen boxes, up to around 150 to 200 t. Circular vessels have given the Maltster the facility to process much larger batches efficiently. The largest in the United Kingdom at present have a batch size of over 500 t of barley, although this would not be universally acceptable; this plant was designed to produce large quantities of single-quality malt for distilling.

Recent plants have batch sizes ranging from 200 to over 300 t. The size of batch is governed by the annual capacity required from the plant. The normal procedure for maximum efficiency is to kiln one batch each day, regardless of the combination of steeping/germinating/kilning vessels. For example, a batch of 200 t of original barley, based on kilning one batch per day, over 350 days per year, would give an output of approximately 60 000 t of malt per annum, which is perhaps currently about the lowest capacity economically viable for a completely new malting plant. The recently constructed plant at Bury St Edmunds has a batch size of 340 t, and is therefore capable of producing in excess of 100 000 t of malt per annum.

The main features which are likely to be incorporated into the design of a modern malting plant are detailed below.

9.6.1 Steeping vessels

In the majority of recently constructed maltings, cylindro-conical steeps have been installed. These are essentially elevated circular tanks, with steeply sloping conical lower sections. These incorporate, as necessary, valves or connections for grain discharge, water filling and draining, pressure aeration, and carbon dioxide extraction. Stainless steel is now used extensively for steep construction, together with the associated pipework, ducting, etc. This allows the highest possible standards of hygiene, and minimises future maintenance costs.

The steeps are normally open-topped, but may have covers where dry filling of the steeps is adopted, to minimise dust in the steeps room. Completely dust-

free filling of steeps can be achieved by first wetting the barley, and pumping a barley/water slurry up to the steeps.

For a given batch size, Maltsters have their own views as to the optimum capacity of each steep. For example, in the case of a 200 t batch, the arrangement of steeps could vary from four at 50 t to eight at 25 t. The smaller steep will minimise both the hydrostatic pressure developed in the barley during steeping, and the variation in depth of barley between the perimeter and the central cone. This will give more uniform treatment during steeping, aeration, and carbon dioxide extraction. All items such as fittings, fixings, etc., increase in number with smaller steeps, resulting in a greater capital cost.

Two-day steeping would normally be designed into the system, and two sets of steeps are therefore required. If the steeped barley is transferred from one set to the other, at the end of day one, rather than remaining in the same steep for two days, then the second day steeps need to be relatively larger to accommodate the swelling of the barley in the later stage of steeping. The steeping process might typically have three periods when the grain is submerged, with rest periods between each wetting.

Pressure aeration of the barley, to assist in the rousing of the grain in the steeps and to maximise uniformity of the mass during wetting, is achieved by passing compressed air into the steeps, via nozzles in the sides of the cone and/or the area adjacent to the steep discharge outlet. The essential removal of carbon dioxide is achieved by suction fans drawing air from the bottom of the steep during the rest period, via a system of large ducts.

To maximise production, Maltsters in some instances have produced a circular, roofed, pre-germination vessel between the conventional elements of steeping and germination, where the grain is subjected to increased volumes of humidified air, to bridge the gap between steeping and germination, so that by the time the grain has been transferred to the germinating unit itself, growth is sufficiently advanced to allow a reduction of the time spent in the germinating vessel. This facility is not widely used, and is expensive, but may provide limited additional capacity, or better quality malt, in existing plants.

9.6.2 Germinating vessels

In the past few years, all new germinating capacity in the UK has consisted of circular vessels, and steel construction has predominated, although concrete malting towers are widely distributed throughout the world. Their high cost in the UK has restricted this form of construction to situations where lack of space or other justification prevails. Only two major concrete tower developments have been constructed in the UK to date, both for brewers in Burton-upon-Trent.

A tower, of whatever construction, has the basic advantage of minimising or eliminating the elevating of wet barley. One main elevator can be used to transfer the original dry barley to the top of the tower, where, ideally, the steeps would be located. From this level, barley can be transferred to the germinating

vessels below by gravity, and subsequently, following germination, to the kiln at ground floor level. To date, no structural steel tower construction in the UK has involved vessels more than two-high, either for germinating or kilning, but technically steel towers of greater height could be developed. As in the case of concrete, the cost of steel construction increases relatively with height, and available space on a particular site will most often dictate the concept adopted.

Since the inception of the circular germinating vessel, little has changed in respect of the basic layout, although engineering improvements can be seen. The construction of the modern circular germinating vessels consists of a series of steel columns around the perimeter of the vessel, with a thin curved stainless steel shell attached to the inside face. This method of construction permits good circularity, essential for rotating equipment. The steel structure of the roof is usually conical in profile, although the stainless steel sheets forming the ceiling of the vessel are normally flat, suspended from the roof structure. The height of the plenum is normally designed to allow personnel access below the perforated floor for cleaning and washing down.

Vertical spiral turners are provided above the perforated floor, to allow turning of the grain during germination. This keeps the grain loose, so promoting better growth and minimising matting of rootlets. Spraying facilities are normally built into the turners, so that water, perhaps with additives, can be added to the grain in process. See Figs 9.3 and 9.7.

Two fundamental concepts of germinating vessel philosophy have been developed, the first where the perforated floor is fixed in position, with the spiral turners mounted on a boom rotating around the centre of the vessel. The second type has a rotating floor, with a fixed boom carrying the turners. There are arguments for and against each type; the fact that both exist shows that there is no one method favoured by Maltsters.

At ground floor level, a reinforced concrete slab would normally be used for the base, although, at upper levels in multi-storey vessels, stainless steel sheets on a structural support would be adopted.

On the basis of providing a plenum with adequate headroom, and taking into account the depth of structure supporting the perforated floor, the grain bed depth, and the height required above the bed for equipment, etc., the overall height internally of a typical germinating vessel would be in the order of 7 m to 8 m.

During germination, ambient air is drawn through a multi-speed fan via a humidification system (usually spinning discs or some form of spray nozzles) into the plenum, below the germinating grain. This ducting is normally stainless steel. The air for germination, as near 100 per cent relative humidity as practicable, is forced from the plenum upwards through the bed of grain, under the pressure generated by the fan.

Where required, refrigeration plant can be incorporated in the system, to maintain accurate control over the air-on temperature to the grain. After passing through the grain bed, the air can either be exhausted to atmosphere, or recirculated in any desired proportion with fresh air, depending on ambient conditions and process requirements.

Fig. 9.7 Fixed floor germinating vessel – loading in progress (photograph courtesy of Seeger GmbH).

During germination, the Maltster's requirement is to provide an adequate supply of high humidity air at the desired temperature, the volume and velocity of the fan being designed to maintain as little temperature differential through the bed as is practicable, linked with the need to minimise the loss of moisture by evaporation through the depth of the bed. Ideally, depending on the barley variety and the type of malt to be produced, the temperature should be maintained in a range of about 12 to 16ºC, or 15 to 19ºC. To achieve these targets, the depth of grain bed must be restricted, and a normal design figure would be to adopt a loading on the floor of about 550 to 600 kg/m^2 of original barley. For example, in the case of a 300 t batch of original barley, the area of the germinating vessel floor might therefore be approximately 500 to 545 m^2, or about 26 m in diameter. This would give a depth of steeped barley, after loading, of about 1.2 m. Increasing the depth of the bed not only makes the control of humidity and temperature more difficult, but also increases electrical energy costs for the fan.

The residence time for the barley in the germinating vessel can vary considerably, depending on such factors as the variety of barley, the growth which has taken place in the steep, the method of filling the vessel, temperature, humidity, type of malt required, and additives used, but normally the duration would be in the order of four to five days. Ideally, five germinating vessels would be provided.

Where the plenum has adequate headroom, manual cleaning can be readily executed, although automatic underfloor washing is offered by manufacturers. It is also possible, where a rotating turner unit is incorporated (with a fixed floor) to

provide an automatic system to wash the upper walls and ceiling of the vessel. The requirement of cleanliness and a good standard of hygiene is high on the Maltster's agenda, and the modern design eliminates earlier problems in under-floor access and adequate cleaning. During germination, the temperature and humidity of the air provide ideal conditions for the formation of bacterial fungal growth.

It is now common practice to provide germinating vessels which are completely automated. Both loading and unloading can be achieved in this way, and during processing of the grain the provision of appropriate sensors can control air volumes, humidity, temperature, etc.

9.6.3 Kilning vessels

As with germinating vessels, all recent major kiln developments in the UK have been based on circular stainless steel vessels. Although construction is generally similar to that of germinating vessels, a more complicated system of large ducting is required, for the greater air flow, the larger fans, recirculation of the process air, and heat recovery.

One significant difference between the germinating vessel and the kiln lies in the layout of the loading/unloading unit. While, once again, the boom can be fixed, with the floor rotating, or vice versa, turning of the material after loading is not required in a kiln, hence the vertical spirals of the germinating vessel are absent. In their place is a horizontal loading/levelling screw conveyor, which can be adjusted to vary its height above the floor, so that pre-selected depths can be adopted for loading or stripping (see Figs 9.4 and 9.8).

A further factor to be taken into account in kiln construction is the need for a higher standard of insulation, to minimise heat loss. The kilning operation uses more energy, both in the form of heat and electrical power than any other part of the malting process, perhaps up to 85 to 90 per cent. Most kilns incorporate some form of energy conservation, although with current fuel prices, it is doubtful if the retro-fitting of heat recovery to existing kilns can be justified. In most cases, the principal heat source is gas supplied on an 'interruptible' basis, with oil storage being provided as a standby. Ambient air is drawn into the main heating system (after pre-heating, if heat recovery has been fitted) and thence through a variable speed fan, or fans, into the plenum chamber below the perforated floor on which the grain has been loaded and levelled.

To minimise energy costs, albeit at higher capital cost, it is desirable to reduce the grain bed depth compared with germinating vessels, and an ideal figure for a new kiln design would be around 350 to 450 kg/m^2 of original barley, which in the case of a 300 t capacity kiln would give a diameter of about 30 m. This compares with about 26 m diameter for a similar batch size germinating vessel.

If a single kiln is used in the design for the malting process, and on the basis of a 24-hour cycle, it is necessary to size the fans, heating equipment, ducting, etc., to allow drying and cooling to be completed in approximately 20 hours, allowing approximately four hours for loading, unloading and cleaning.

Fig. 9.8 Fixed floor kilning vessel – fully loaded (photograph courtesy of Seeger GmbH).

At the early (drying) stage of kilning, the heated air passes through the grain bed, picking up moisture in the process, with the saturated air being exhausted to atmosphere. After some hours of drying, when the moisture content of the grain has decreased substantially from the initial 40 to 45 per cent, a start is made to recirculate the air, initiating the curing stage of kilning. Progressively, the 'air-on' temperature is increased, and the air volume reduced. A proportion of the exhaust air is recirculated, and re-heated together with additional ambient air, making up the required volume. This regime continues until the final moisture content has been reached, typically four to five per cent. Initially the drying temperature might be in the range of 60–65ºC, rising during curing to perhaps 65ºC for lager or other lightly kilned malts, to as high as 100–110ºC for traditional ale malts.

During the initial drying stage of kilning, when saturated warm air is being discharged, low grade heat can be recovered from the exhaust, to preheat incoming ambient air. In recent developments, almost without exception, heat recovery has been introduced through the medium of thousands of glass tubes around 20 mm in diameter, arranged in bundles, in the shape of chevrons when viewed from above. There are two fundamental concepts: in the first, the exhaust air passes around the outside face of the glass tubes which are normally disposed

vertically, before discharge to atmosphere. The incoming ambient air is drawn downwards through the tubes by fan suction, heat transfer through the thin glass providing a significant preheat to this air.

In the alternative arrangement, exhaust air is discharged through the tubes, with the ambient air passing around the external faces of the tubes. As before, there is worthwhile transfer of heat. Both arrangements give equally effective heat transfer, the choice being a matter of disposition of plant, or the Maltster's preference, although the latter arrangement may offer better self-cleaning of the tubes. The glass tube units are normally installed at high level, coincident with the level of the main kiln exhaust. A typical arrangement is shown in Fig. 9.4.

To reduce and minimise contaminants in the final malt, indirect heating is normally installed, whereby the ambient air which passes through the grain bed does not come into contact with the products of combustion of the fuel, oil or gas, having obtained its heat indirectly from a heat exchanger, with a primary heat source of hot water, steam, air or thermal fluid, although the latter is not currently favoured.

In some instances, kilns have been constructed with interconnecting ductwork, to improve thermal efficiency, and this can be an attractive proposition, depending on the available cycles matching production requirements. Further development has been the combination of final germinating and kilning into a single vessel, and this is described below.

As in the case of germinating vessels, most modern kilns are computer controlled, not only to automate loading and unloading, but also to provide the facility allowing the Maltster to set up and operate a variety of recipes for the kilning cycle, depending on the malt specification called for.

9.6.4 Combined vessels, steeping, germinating and kilning

A development of the use of separate germinating and kilning vessels has been to combine, in one vessel, the last day of germinating with kilning, based on a 48-hour residence time. When a vessel is used solely for kilning, on a 24-hour cycle, only about 18/20 hours is available for drying, curing and cooling. However, when a combined germinating and kilning vessel is used on a 48-hour cycle, it is possible to devote 24 hours to drying, curing and cooling. The remaining 24 hours can be broken down into four to six hours for filling, stripping and cleaning, and 18 to 20 hours final germination and initial withering. For the same bed depth, a longer kilning time will reduce energy consumption.

To take full advantage of this system, it is essential to have two germinating/kilning vessels operating together, sharing one burner unit, fans and heat exchanger. The construction of the fans ducting, etc., of the heating system allows the air to be switched from one kiln to the other every 24 hours, allowing virtually a full day for kilning/cooling in each vessel. Compared with a dedicated single kiln, the extended drying time available results in lower capacity heating units, fans and heat exchanger, and also provides the Maltster

with greater flexibility. One batch of malt is still produced every 24 hours. If necessary, it is also possible to incorporate humidified air for germination during the last hours in the combined vessel, although most combined vessels constructed to date have not incorporated this facility, the Maltster preferring to allow withering to start during the last hours of germination.

The down-side of this arrangement is the need to provide two germinating/kilning vessels instead of one germinating vessel and one kiln, resulting in some additional capital cost. As with the dedicated kiln, the combined vessel does not have vertical spirals on the loading/stripping machine, so that no turning of the greenmalt is carried out during the last stage of germination. This ensures that the level surface of the grain is not disturbed before kilning, as the furrows which can develop during turning would encourage uneven channelling of the warm air through the grain bed, resulting in drying variations. If germinating/kilning vessels are incorporated, the normal layout would be to adopt four germinating vessels and two germinating/kilning vessels, giving up to about five days germination plus 24-hour kilning.

A further variation adopted in a few maltings has been the combination of all three stages of the process into one unit, thereby avoiding the need to transfer grain from initial loading of the barley until the end of kilning. While this has some advantages, the negative factors probably outweigh these, as there is an excessive requirement for water for steeping, similar to that associated with the flat bottomed steep, referred to in Section 9.6. Again, if the depth of the plenum were minimal, cleaning becomes a problem, with a lower standard of hygiene. With rising effluent treatment costs, it is essential to minimise the use of water for steeping.

In addition, as the optimum depth of grain in each vessel of the three separate stages varies, a design depth has to be evaluated which will give the best compromise between the greater depth acceptable for steeping and the shallow depth preferred for kilning, to minimise energy costs. As turning of the grain during germination is necessary, furrowing of the surface leads to some unevenness of drying during kilning.

Both rectangular boxes and circular stainless steel vessels have been built as combined steeping, germinating and kilning vessels, but these were designed before 1980, since when this combination of process plant has not been adopted to any degree.

9.6.5 Conveying equipment

Where steeping, germinating and kilning are carried out in discrete stages, there are four major conveying operations. Where one batch of malt is produced each day, it is desirable for the operations to be timed to take place during the working day, so that the average time available for each transfer is in the order of two hours, including appropriate vessel cleaning.

The first stage in the daily sequence is to empty the dried malt-in-culm from the kiln to a suitable storage bin, in about two hours, before this is de-

culmed, dressed, etc., later in the day at a lower capacity en route to storage. After the kiln is emptied and cleaned sufficiently, a start can be made to stripping the relevant germinating vessel and transferring its contents to the kiln. Again, a two-hour target is desirable, and it must be borne in mind that adequate cleaning of the germinating vessel must be carried out before re-loading.

The steeped barley can thereafter be discharged from the steeps after the second day into the appropriate germinating vessel, again allowing approximately two hours, including steep cleaning. As the steeps are normally emptied sequentially, cleaning can start before the completion of the transfer. If two sets of steeps are incorporated, then a start can be made to transfer from the upper 'day one' to the lower 'day two' steeps before loading of the germinating vessel has been completed.

The final operation is to re-fill the steeps, usually from a pre-steep bin which contains a weighed batch of barley. This transfer can either be dry (although complete dust suppression is difficult), or by means of a barley/water slurry, which eliminates dust in the steep room, and introduces water to the barley at the earliest possible time. High capacity plant is desirable for this transfer, to ensure that all steeps have similar gross process times.

It can be seen from the above that the requirement to carry out transfers in a specific time establishes the capacity of the conveying equipment required in each operation. For example, in the case of a 300 t batch, if the kiln is to be emptied and made available for re-loading in two hours, the conveying equipment must be sized to cope with minimum of 150 t of original barley, as malt-in-culm, and must take account of possible surges which occur during loading and unloading of vessels. The automatic unloading system for the kiln must also be designed for this capacity. Similarly, when transferring grain from the germinating vessels to kilns, provision must be made to cope with variations in the rate of transfer.

Cleaning of the kiln floor and under-bed area is a dry operation, and, with good design, can require little manual daily input. In the germinating vessels, the conditions of temperature and humidity promote the growth of mould, and adequate time must be allowed for cleaning down on a regular basis.

A wide range of conveying and elevating plant is available, and care must be taken to ensure that the appropriate equipment is selected for each stage of grain transfer. Due attention must be given to the following.

1. The material to be handled, bearing in mind the 'bulking' which occurs in the volume of the original barley during processing, and when being transferred in a conveyor or elevator.
2. The method of cleaning, conveying and elevating equipment where wet grain is being handled. In particular, an efficient cleaning system must be developed for machines handling greenmalt and steeped barley, to maintain an acceptable standard of hygiene. Belt conveyors are favoured for transferring wet grain, as these can be cleaned more easily than enclosed

machines, and an ideal layout, if space permitted, would be to eliminate elevators, all transfers being carried out by inclined belt conveyors.

3. The extraction of dust, where dry transfers are being carried out. This is most likely to occur in the transfer of dry barley to the steeps room, and during the transfer of malt-in-culm from the kiln to an adjacent storage bin. The design of an appropriate dust extraction system is an essential feature of any dry transfer of grain, particularly at high capacity.
4. The problem of noise, when equipment is located in the open air. Noise attenuation must be considered, where environmental aspects must be taken into account. Conveyor manufacturers offer various solutions to this problem, but in spite of this there are still many instances of conveyors producing excessive noise, particularly when running empty.

9.6.6 Current trends in malting plant

From the discussions above, it is evident that the majority of recently constructed plants have followed a common pattern. In steeping, there is preference for cylindro-conical steeps, with effective aeration and carbon dioxide extraction, this giving the simplest and cheapest construction, while affording the best option for optimum hygienic conditions. Where new process units have been provided for germinating and kilning, these have been constructed, almost without exception, in a circular format. In the United Kingdom, these are of structural steel frames, with stainless steel inner wall lining and ceiling. Outside the UK, the adoption of towers constructed in reinforced concrete is widespread, this form of construction being frequently more economic, although the demand for a high standard of hygiene may result in additional costs for an acceptable inner lining of stainless steel or equivalent standard. There is some preference for combining the last stage of germination with kilning, in combined germinating/kilning vessels. The adoption of this type of unit provides a greater flexibility towards the end of germination, and for kilning.

In addition to the provision of heat recovery as a means of reducing fuel costs, combined heating and power has been investigated by a number of Maltsters in the UK, but has not been adopted to any significant degree. While the heat produced can usefully be incorporated into a kiln heating system, where batches of malt are produced daily, there tends to be an overproduction of electrical energy, requiring this to be exported to an alternative user.

The development of handling plant has concentrated on equipment providing the best means of cleaning, with belt conveyors being used extensively. The use of elevators for handling barley as greenmalt in process is kept to a minimum, and such elevators as might be required are being provided with the best possible method of automatic cleaning for maximum hygiene.

As the capacity of each batch dictates the annual output of malt, on the basis that a batch is produced each day, there is no single optimum size. However, as a 300 t batch will result in an annual production of about 90 000 t of malt, it is

unlikely that this size will be widely adopted, with a more likely capacity being around 200 t to 250 t, giving around 60 000 t to 75 000 t per annum of malt.

During the time up to the mid 1970s, when there was considerable investment in new plant, specialist firms, principally from UK and Germany, supplied the major plant items. Unfortunately, with the down-turn in UK maltings development, and the lack of success in obtaining sufficient export work, the two main UK firms fell on hard times, and stopped producing malting equipment. However, the 'know-how' from one firm was procured by a manufacturer in a similar line of business, and they can now offer the relevant specialist malting plant. German firms have, therefore, increased their share of the available UK market, winning a large proportion of recent contracts in this country. Firms from continental Europe are probably the main suppliers globally.

9.7 Malt storage

After kiln drying, malt should be transferred via a high capacity conveying system to temporary storage in a malt-in-culm bin. This allows rapid stripping of the kiln so that refilling can start in about two hours. As the malt-in-culm bin is not required for a further day, the product can be conveyed to long-term storage at a lower capacity, via the appropriate cleaning, dressing and weighing equipment. Dust extraction is highly desirable during this series of operations.

Where malt required for customers has a wide range of specification, it is normally stored in smaller individual quantities than barley. As for barley, there is widespread use of steel bins, either circular or square. Where the capacity is up to about 500 t of malt, hoppered bins are feasible; for larger capacities, flat bottomed circular bins can be used. These are less convenient, and are only viable when large quantities of a single specification are being produced.

When concrete silos were constructed in the 1950s and 1960s, a greater proportion of the storage cells was dedicated to barley, with smaller amounts to malt. With the capacity of many maltings being increased substantially, it has been found convenient to construct large bulk barley storage, and convert the majority of the cells in these concrete silos to the storage of malt, allowing separation of malts of different specifications. No aeration is required for the storage of malt. The total quantity of malt stored on site varies greatly; ideally the Maltster would be looking to have about six weeks' production available on site.

Before dispatch, the malt is weighed, and then cleaned, with generous aspiration, to remove any remaining light impurities. By far the greatest proportion of malt is despatched from the maltings in bulk, either in dedicated vehicles, or by container. Small amounts of malt are still despatched in sacks for specialist requirements.

The current trend in malt storage is, wherever possible, to provide storage of malt in hoppered bins, to minimise damage. As the output at a maltings increases, there has been a move towards converting existing hoppered barley

storage to malt storage. Any additional barley, and that displaced from existing silos, can then be stored in cheaper, flat bottomed bins. Where new malt storage is required, this is provided, ideally, in hoppered bins of capacities up to about 500 t. Unless there is a change in the multitude of specifications required by customers, this arrangement is unlikely to alter.

9.8 Automation

Over the years, as available control systems have become more sophisticated, Maltsters have generally adopted the latest available technology, in an effort to produce consistent quality malt, to a variety of specifications. The majority of maltings built before current control systems were available have been upgraded retrospectively to incorporate higher standards of control, although this does not have the complexity or capability of plants built within the last twenty years where complete automation has been integrated into the initial plant design.

It is now possible in a maltings to provide total control of all aspects of malt production with a PC, from barley intake to final malt dispatch. The malting process is such that two discrete control systems can readily be embraced, one handling the raw material and finished product, the other devoted to the malting process itself.

As the majority of new maltings plants have a pre-steep bin or hopper available for rapid transfer of a batch of barley to the steeps, this forms a convenient 'breakpoint', as the availability of grain for steeping is normally a function of the silo operation. The process control system can 'pick-up' the barley at this point, and control the process completely, from the transfer of the barley into the steeps, through the remainder of the process, to the final drying of the malt in the kiln. From the kiln, the final product, malt-in-culm, is normally transferred from the kiln to a holding bin, and this is a logical point for the transfer of control from the production area back to the silo system. After transfer of the malt-in-culm to the silo complex, all malt weighing, dressing, cleaning, and dispatch can be carried out as part of the silo operation.

In most cases, PLC/SCADA systems have been adopted, which can readily be operated by semi-skilled staff. There is normally a facility for building in various menus and recipes, to allow a wide range of programmes to be incorporated, depending on the type of barley being processed, and the final malt specification required.

In addition to his ability to control the process completely, the Maltster can also extract much useful information for management and auditing purposes, such as stock control, and tabulating of data relating to electricity, fuel, water and effluent.

With the advent of comprehensive control systems, the output of malt per man has risen dramatically, although perhaps the art of malting is being lost forever. Nowadays, there is much less need for the Maltster to process the grain in a 'hands-on' manner, as much of his time is spent in an area remote from the

process. This aspect is further exacerbated by the ease of locating terminals in offices remote from the process itself.

9.9 The future of the malting industry

In Section 9.2, the current picture described was one of rather depressed trading and low profit margins. At the end of 1998, the Maltsters Association of Great Britain recorded that year as being the worst in the memory of those in the industry, with European Maltsters on minimal profit margins, and instances of malt being sold below cost to maintain a customer base. This has been the result of, among other factors, an over-capacity in the European market, with UK Maltsters further pressurised by the high value of sterling. Total production in the UK continues to fall slightly, although a small increase in exports is evident. The UK Maltster will need to rely heavily on export markets for some time.

It is difficult to foresee what events worldwide will lead to a healthier environment, encouraging a substantial increase in malt production within the United Kingdom, and promoting selling prices which would allow major investment in new plant. It is unlikely that any Maltster will find it financially attractive to develop a new greenfield site, due to the high cost of the necessary infrastructure, including such elements as the supply of water, gas, electricity, new roads, effluent treatment, offices, storage, etc. As a guideline, the cost of developing a greenfield site might be in the order of £400/£500 per tonne of malt produced per annum. This figure will vary considerably, as a multitude of parameters can affect the final cost. Of the above figure, perhaps £250/£300 per tonne of malt per annum might be invested in the production plant itself, the remainder covering storage, site ancillaries, services, etc.[3]

Any investment in the mid-term is therefore likely to be restricted to the renovation or upgrading of existing plant, particularly where more efficient production can be achieved at relatively low cost. In the past few years, there have been efforts to increase the ‘tonnes of malt produced per employee’ in major firms, and this attitude is likely to prevail.

With only five major Sales Maltsters in the UK at present, there is little room for further consolidation or amalgamation.

Recently, in the UK, there have been instances of Maltings being sold, on the basis that the new owners (Sales Maltsters) would continue to provide malt on contract to the vendor (Brewer or Distiller). Worldwide also, brewers are looking closely at the function of malting within their core business, with a view to possible disposal, due to the current lack of profitability in producing malt. If this trend were to continue, it is possible that the Sales Maltster might, in due course, find himself producing a higher proportion of global malt requirements. Whether this would be advantageous in terms of profitability remains to be seen.

9.10 Further reading

BRIGGS D E (1998) *Malts and Malting*. Blackie Academic and Professional.

BROWN J (1983) *Steeped in Tradition*. Institute of Agricultural History, Museum of English Rural Life. University of Reading. The Malting Industry in England Since the Railway Age.

CLARK C (1998) *The British Malting Industry Since 1830*. The Hambledon Press.

GIBSON G (1992) *Pauls Brewing Room Diary (1992–1994)*, 83rd edn. Current UK Malting Plant Design, Pauls Malt Ltd, Ipswich.

MAFF (1983) *Grain Drying and Storage Booklets Nos 1, 2 and 3*. HMSO, London.

PALMER G H (ed.) (1989) *Cereal Science and Technology*. University Press, Aberdeen.

STEPHENS P (ed.) (1993) *Newark, The Magic of Malt*. Newark Civic Trust, Nottinghamshire County Council.

WAINWRIGHT T (1998) *Basic Brewing Science*. Published in South Africa. Copies available from the author, 80 Blackborough Road, Reigate, Surrey.

9.11 References

1. THE MALTSTERS' ASSOCIATION OF GREAT BRITAIN, *Malt: UK Annual Statistics*. Newark on Trent
2. CLARK C, *The British Malting Industry Since 1830*. London, The Hambledon Press, 1998.
3. GIBSON G, *Cereal Science and Technology*, (Palmer, G.H. ed.), p. 279, Aberdeen, University Press, 1989.

10

Breadmaking

S. P. Cauvain, Campden and Chorleywood Food Research Association, Chipping Campden

10.1 Introduction

The aim of the breadmaking process is quite simple: namely to convert wheat flour and other ingredients into a light, aerated and palatable food. Bread is probably the oldest 'processed' food. We are unlikely to ever identify the moment when bread was 'discovered' though it is probable that the place of discovery was in the Middle East where the origins of cereal farming also lie in antiquity (Zohary, 1969). Early forms of bread would have been very different from how we see it in industrialized countries today and it would probably be closest in character to the modern flat breads of the Middle East. We will probably never know whether the gathering and cooking of wild grass seeds provided the spur to arable farming or whether the ability to grow and harvest the forerunners of modern wheats provided the impetus for breadmaking. Whichever way round the two events occurred there is no doubt that one depends on the other and this simple relationship is the foundation of all modern breadmaking.

The move to improve the digestibility of the wild grass seed forerunners of early wheat types through fermentation and baking represents a major step in the evolution of human food production. To make this step requires an appreciation, but not necessarily a scientific understanding, of the unique properties of the proteins in wheat with their ability to form a cohesive mass of dough once the flour has been wetted (hydrated) and subjected to the energy of mixing, even by hand. This cohesive mass is the one bakers call 'gluten' and once it has formed into a dough it has the ability to trap gases during resting (fermentation and proof) and baking and this allows the mass to expand to become a softer, lighter and even more palatable food after the final heat processing.

The discovery that dough left for long periods of time would increase in volume without being subjected to the high temperatures of baking identified the basis of fermentation (gas production). There is no doubt that the changes in the rheological character of the dough would have been observed by those in charge of food production. The combined effect of these changes is for the subsequent baked mass to further increase in volume and give a product with an even softer, more digestible character and different flavour. Gradually the appreciation of the actions of wild yeasts and portions of old dough (e.g. starter dough) were to lead to the transfer of fermentation technology from the brewing industry and eventually to the production of specialised bakers' yeast.

There are a few basic steps which form the basis of all bread making. They can be listed as follows:

- The mixing of wheat flour and water, together with yeast and salt, and other specified ingredients in appropriate ratios.
- The development of a gluten structure in the dough through the application of energy during mixing, often referred to as 'kneading'.
- The incorporation of air bubbles within the dough during mixing.
- The continued 'development' of the gluten structure created as the result of kneading in order to modify the rheological properties of the dough and to improve its ability to expand when gas pressures increase because of the generation of carbon dioxide gas in the fermenting dough. This stage of dough development may also be referred to as 'ripening' or 'maturing' of the dough.
- The creation and modification of particular flavour compounds in the dough.
- The sub-division of the dough mass into unit pieces.
- A preliminary modification of the shape of the divided dough pieces.
- A short delay in processing to further modify physical and rheological properties of the dough pieces.
- The shaping of the dough pieces to achieve their required configurations.
- The fermentation and expansion of the shaped dough pieces during 'proof'.
- Further expansion of the dough pieces and fixation of the final bread structure during baking.

10.2 Bread dough development

Dough development is a relatively undefined term which covers a number of complex changes which are set in motion when the ingredients first become mixed. These changes are associated with the formation of gluten, which requires both the hydration of the proteins in the flour and the application of energy through the process of kneading. The role of energy in the formation of gluten is not always fully appreciated but can be observed by the simple experiment which involves placing flour, water, yeast and salt together on a table and waiting for the gluten to form. You should then begin hand mixing of

the ingredients to experience the transformation in the mixture which occurs. Best results, in terms of improved bread volume and crumb softness, will be achieved with vigorous and prolonged hand mixing and kneading. During the process of kneading the dough, and more probably you, will become warmer as energy is generated by the mixing process.

However, there is more to dough development than a simple kneading process. The process of developing a bread dough brings about changes in the physical properties of the dough and in particular improvement in its ability to retain the carbon dioxide gas which will later be generated by yeast fermentation. This improvement in gas retention ability is particularly important when the dough pieces reach the oven. In the early stages of baking before the dough has set yeast activity is at its greatest and large quantities of carbon dioxide gas are being generated and released from solution in the aqueous phase of the dough. If the dough pieces are to continue to expand at this time then the dough must be able to retain a large quantity of that gas being generated and it can only do this if we have created a gluten structure with the correct physical properties.

It is important to distinguish between gas production and gas retention in fermented doughs. Gas production refers to the generation of carbon dioxide gas as a natural consequence of yeast fermentation. Provided the yeast cells in the dough remain viable (alive) and sufficient substrate (food) for the yeast is available, then gas production will continue but expansion of the dough can only occur if that carbon dioxide gas is retained in the dough. Not all of the gas generated during the processing, proof and baking will be retained within the dough before it finally sets in the oven. The proportion that will be retained depends on the development of a suitable gluten matrix within which the expanding gas can be held. Gas retention in doughs is therefore closely linked with the degree of dough development which occurs and as such will be affected by a large number of ingredients and processing parameters which are not necessarily independent of one another.

10.3 Breadmaking processes

Most of the desirable changes resulting from ‘optimum’ dough development, whatever the bread making process, are related to the ability of the dough to retain gas bubbles (air) and permit the uniform expansion of the dough piece under the influence of carbon dioxide gas from yeast fermentation during proof and baking. The creation of dough with a more extensible character is especially important for improved gas retention while reductions in dough resistance and elasticity play a major role in the modification of bubble structures during processing. Until about 40 years ago the necessary changes were achieved by mixing the dough and allowing it to rest for a defined period of time (several hours) as a large mass before dividing the bulk dough and processing the unit pieces.

The development of no-time (i.e. no resting time in bulk before dividing) dough making processes changed traditional bread making. Foremost amongst the process changes was the development and commercialisation of the Chorleywood Bread Process (CBP). In the CBP the development of optimum dough qualities was achieved in the mixer by transferring a defined energy input to the dough (Cauvain, 1998a). The result of the introduction of the CBP was to eliminate the need for bulk fermentation periods with considerable raw material and time savings, as well as to initiate changes in ingredient and processing technologies which are still evolving today. The principles of the CBP were adopted in many countries around the world (Gould, 1998). Even in those bakeries which did not adopt the CBP there has been a similar trend away from long periods of bulk fermentation to shorter processing times and the use of more functional ingredients to achieve more consistent bread quality (Cauvain, 1998a).

10.3.1 The Chorleywood Bread Process

The basic principles involved in the production of bread and fermented goods by the CBP remain the same as those first published by the Chorleywood team in 1961 though the practices have changed with changes in ingredients and mixing equipment. The essential features of the CBP are:

- Mixing and dough development in a single operation lasting between 2 and 5 minutes to a fixed energy input.
- The addition of an oxidising improver above that added in the flour mill.
- The inclusion of a high melting point fat, emulsifier or fat and emulsifier combination.
- The addition of extra water to adjust dough consistency to be comparable with those from bulk fermentation.
- The addition of extra yeast to maintain final proof times comparable with that seen with bulk fermentation.
- The control of mixer headspace atmosphere to achieve given bread cell structures.

As the level of energy per kg dough in the mixer increases bread volume increases and with the increase in bread volume comes a reduction in cell size, increased cell uniformity and improved crumb softness. The role of energy during CBP mixing has yet to be fully explained but may be likened to the effects of natural or chemical reduction and, as such, will increase the available sites for oxidation. Chamberlain (1985) considered that only about 5% of the available energy was required to break the disulphide bonds with the rest being consumed by mixing of the ingredients and the breaking of weaker bonds. The input of energy during mixing causes a considerable temperature rise to occur and typically final dough temperatures fall in the region of 27 to 32ºC.

The cell structure in the final bread does not become finer (smaller average cell size) as the result of processing CBP doughs. In the case of CBP doughs final bread crumb cell structure is almost exclusively based on an expanded

version of that created during the initial mixing process (Cauvain *et al.*, 1999). The creation of bubble structures in CBP doughs, and indeed for many other no-time processes, depends on the occlusion and sub-division of air during mixing. The numbers, sizes and regularity of the gas bubbles depend in part on the mixing action, energy inputs and control of mixer headspace atmospheric conditions. Collins (1983) illustrated how bread cell structure improved (in the sense of becoming finer and more uniform) with increasing energy input up to an optimum level with subsequent deterioration beyond that optimum. He also showed how different mechanical mixing actions yielded breads with varying degrees of crumb cell size.

The requirement to add extra water to provide a softer, more machinable dough is particularly true when the doughs are mixed under partial vacuum in the CBP (Cauvain, 1998a). The lower the pressure during mixing the 'drier' the dough feels and the more water that needs to be added to achieve the same dough consistency as doughs at the end of a bulk fermentation period. This increased dryness with CBP doughs comes in part from the lower volume of gas occluded in the dough at the end of mixing (see below). In practice the reduction of oxygen available for ascorbic acid conversion and the need for some air to be occluded to provide gas bubble nuclei (Baker and Mize, 1941) places a lower limit of about 0.3 bar in the mixer.

The main difference between the CBP and bulk fermentation processes lies in the rapid development of the dough in the mixer rather than through a prolonged resting period. The advantages gained by changing from bulk fermentation to the CBP include:

- A reduction in processing time.
- Space savings from the elimination of bowls of dough at different stages of bulk fermentation.
- Improved process control and reduced wastage in the event of plant breakdowns.
- More consistent product quality.
- Financial savings from higher dough yield through the addition of extra water and retention of flour solids normally fermented away.

Disadvantages include:

- Faster working of the dough is required because of the higher dough temperatures used.
- A second mixing will be required for the incorporation of fruit into fruited breads and buns.
- In some views, a reduction of bread crumb flavour because of the shorter processing times.

10.3.2 Sponge and dough

The other widely used breadmaking process hails from the USA and is commonly called the sponge and dough process (Cauvain, 1998a). Elements of

the processes are similar to those for bulk fermentation in that a prolonged period of fermentation is required to effect physical and chemical changes in the dough. In this case only part of the ingredients are fermented – the sponge. Sponge fermentation times may vary considerably, as may their compositions.

The key features of sponge and dough processes are:

- A two-stage process in which part of the total quantity of flour, water and other ingredients from the formulation are mixed to form an homogeneous soft dough – the sponge.
- The resting of the sponge so formed, in bulk for a prescribed time (floortime), mainly depending on flavour requirements.
- Mixing of the sponge with the remainder of the ingredients to form an homogeneous dough.
- Immediate processing of the final dough, although a short period of bulk fermentation may be given.

The sponge contributes to flavour modification and the development of the final dough. The process of flavour development in the sponge, though complex, is observed as an increase in the acidic flavour notes arising from the fermentation by the added yeast and other microorganisms naturally present in the flour. To maintain the right flavour profile in the finished product the sponge fermentation conditions are closely controlled and care is taken to avoid a build-up of unwanted flavours. During the sponge fermentation period there will be a decrease in sponge pH with increasing fermentation. Under these conditions the rheological character of the gluten formed during initial sponge mixing changes and the sponge becomes soft and loses much of its elasticity. The low pH of the sponge and its unique rheological characters are carried through to the dough where they have the effect of producing a softer and more extensible gluten network after the second mixing. In many cases the addition of the sponge changes the rheological character of the final dough sufficiently to warrant further bulk resting time unnecessary so that dividing and moulding can proceed without further delay.

Improver additions are commonly made in the dough rather than the sponge. Flours used in typical sponge and dough production will be at least as strong as those used in bulk fermented doughs with protein contents not less than 12% and high Falling Numbers. High α-amylase activity could be a problem in the sponge because of excessive softening but is less likely to be a problem in the dough.

10.4 The character of bread

Bread is a staple foodstuff made and eaten in most countries around the world. Bread products have evolved to take many forms, each based on quite different and very distinctive characteristics. Over the centuries craft bakers around the world have developed our traditional bread varieties using their accumulated

knowledge as to how to make best use of their available raw materials to achieve the desired bread quality. In some countries the nature of bread making has retained its traditional form while in others it has changed dramatically. The proliferation of bread varieties derives from the unique properties of wheat proteins to form gluten and from the bakers' ingenuity in manipulating the gluten structures formed within the dough. The rubbery mass of gluten with its ability to deform, stretch, recover shape and trap gases is very important in the production of bread and all fermented products. Of all the cereals wheat is almost unique in this respect.

The term 'bread' is used to describe such a wide range of products with different shapes, sizes, textures, crusts, colours, softness, eating qualities and flavours that the terms 'good' or 'bad' quality tend to have no real meaning, except to the individual making the assessment. A baguette is not a baguette without a crisp crust while the same crust formation would be unacceptable on north American pan bread and the fine cell structure of sandwich bread in the UK has no relevance to the flat breads of the Middle East.

The character of bread and other fermented products depends heavily on the formation of a gluten network in the dough. This is required not just for trapping gas from yeast fermentation but also to make a direct contribution to the formation of a cellular crumb structure which after baking confers texture and eating qualities quite different from other baked products. Look closely at the crumb structures of most baked breads and you will see that the common linking theme is that they are formed of holes of differing shapes, sizes and distributions, each hole being embraced by a network of connected strands, coagulated gluten, in which starch granules and bran particles are firmly embedded. When this crumb is subjected to pressure with the fingers it deforms and when the force is removed it springs back to assume its original shape, at least when the product is fresh. This combination of a cellular crumb with the ability to recover after being compressed largely distinguishes breads from other baked products and these are the very characteristics that bakers seek to achieve in most bread products.

While there are as many opinions on what makes 'good' bread as there are bakers and consumers it is true to say that certain quality characteristics are required for individual bread varieties to be acceptable to the widest cross-section of consumers. For example, baguettes are characterised by a hard and crisp crust and without it we would reject the product, often describing a baguette with a soft crust as 'stale'. On the other hand, sliced pan breads in the USA, the UK and elsewhere are characterised by a thin but soft crust and if the crust were thick and hard it would be rejected by consumers, ironically, also being described as 'stale'.

Loss of product freshness is as much about what we expect a product character to be as it is about its age since original manufacture. Whatever the criteria we use to judge bread staleness it becomes clear that the single most common requirement of fermented products is that it should ideally retain all of the attributes which it had when it left the oven, above all else we expect our

bread to be ‘fresh’. When we collect our bread from the baker and it is still warm to the touch we have no doubt as to its freshness but when we purchase it cold from the store shelf we need convincing as to its freshness. The pursuit of fermented products which retain their ‘oven-fresh’ character for an extended period of time after they have left the oven has been one of the great challenges facing bakers, technologists and scientists for many years and many different strategies have been evolved to meet this challenge. Whether they have been successful can really only be judged by consumers.

To be able to make our particular bread type we must have an understanding of the complex interactions between our raw materials and the methods we will use in the conversion processes from ingredients to baked product. Our raw materials will change and our processes are time and temperature sensitive. Given the intricate nature of the process it is a wonder that we manage to make bread at all. We do so because of accumulated knowledge (craft) augmented these days by scientific and technological understanding.

10.5 Bread flavour

The development of flavour in fermented products is derived from the ingredients and the processing methods which are used. Flour tends to have a fairly bland flavour with most of its contribution coming from the oils of the germ (embryo) and any bran particles present. Since this is the case wholemeal, wholewheat and bran and germ enriched white flours will yield bread with more flavour than white flours. The addition of salt (sodium chloride) to bread is the most obvious of those flavour modifiers, imparting both its own characteristic ‘salty’ taste and working in the mouth to increase our perception of other flavours which may be present. Salt levels vary in fermented products according to local tastes. The level of yeast used in the recipe also makes its own unique contribution to bread flavour. Other common ingredient additions which contribute flavour include fat, sugar, milk and malt products.

During the dough fermentation process new flavour products are generated within the dough. Both the intensity of those flavours and the particular flavour ‘notes’ which are developed change with increasing fermentation time. The most commonly observed flavour changes are those associated with the development of acid flavours from microbial activity in the dough which are readily detected in the flavour of the bread crumb. Not all of this flavour activity will come from the addition of bakers’ yeast, some will come from wild yeasts and bacteria, especially lactic acid bacteria, which are present naturally in the flour. Usually several hours of fermentation are required before there are significant changes to the flavour profile of the bread crumb. In other processes flavour may be enhanced using a ‘pre-ferment’, ‘brew’ or ‘sponge’ which is later mixed with the remaining ingredients to form the dough for final processing.

The process of baking is a major contributor to bread flavour. During this heat setting stage many of the flavour compounds present undergo major

changes, some old ones are lost and many new ones are formed. We most readily see this phenomenon in the formation of a dark, mostly brown crust on the outer surfaces of the dough. These changes are associated with the complex processes commonly referred to as 'Maillard browning' and many of the compounds are highly flavoured. These compounds are very important to our perception of flavour in many baked foods. Our perception of bread flavour is strongly influenced by the ratio of crust to crumb. For example, in the case of baguettes the proportion of crust to crumb is much higher than that of the UK sandwich loaf and so the former will have a greater quantity of compounds which contribute to product flavour.

10.6 Bread types

Many different bread types have been evolved with the passage of time and all require their own individual bubble structures, processing techniques, processing equipment and process control mechanisms. The main bread types can be divided into four broad categories:

1. Pan breads – that is, products based on placing a piece of dough in a metal pan for the proving and baking stages. Commonly the pan will be rectangular, though round pan shapes are known. Sometimes the pan may have a separate lid fitted to more tightly control product shape. Examples are the sandwich loaf (lidded), open-top pan breads, pan coburgs (round, unlidded), milk rolls (round, lidded) and malt loaves (baked under inverted pans).
2. Free-standing breads – that is where the dough product is proved and baked without the aid of a pan to constrain and support the sides of the dough. This approach leads to a crustier product. Examples of this type of product include, bloomers, cottage loaves and coburgs.
3. Baguettes, pain Parisien and other products made as long, stick-shaped loaves. Sometimes placed on indented trays for proving and baking. Typically these products will have a high degree of crust formation and characteristic surface markings.
4. Rolls and other small fermented breads baked on trays or indented pans. These products will have higher levels of sugar and fat in the recipe and so typically will have a sweeter flavour and softer eating character.

The process by which bread quality is determined still relies heavily on subjective assessment (Cauvain, 1998b). Broadly there are groups of attributes which will be taken into account:

- External character which encompasses product dimensions, volume, appearance, colour and crust formation.
- Internal character which considers the sizes, numbers and distribution of cells in the crumb (crumb grain), the crumb colour and any major quality defects,

such as unwanted holes or dense patches, visible in a cross section of the product. Each bread type has its own special cell structure requirements and therefore there is no single standard which can be applied to all products.
- Texture, eating quality and flavour. In assessing texture we are concerned with its mechanical properties such as firmness and resiliency.

10.7 What determines bread quality?

Bread quality is determined by the complex interactions of the raw materials, their qualities and quantities used in the recipe and the dough processing method.

10.7.1 Flour

Since the formation of gluten is an essential component of breadmaking processes and wheat is the contributor of the proteins necessary for its formation it follows that a significant factor which determines final bread quality comes from the wheat via the flour from the mill. The ability to form gluten is almost unique to wheat. The level and quality of the gluten-forming proteins depends heavily on the wheat variety, agricultural practices and environmental effects.

The wheat grain is broadly made up of three components:

- The inner endosperm, comprising mainly starch and protein.
- The outer bran, comprising mainly protein and fibre.
- The germ, comprising protein, fibre, minerals and vitamins.

Wholemeal flour consists of 100% of the wheat grain converted to flour while in the production of white flour the miller will seek to separate the endosperm from the bran and germ (Catterall, 1998).

The protein content of wheat flour varies according to the wheats that are used by the millers and any adjustments they may make in the mill. In general the higher the protein content in the wheat the higher the protein content of the flours produced from it. The higher the protein content of a flour the better is its ability to trap carbon dioxide gas and the larger can be the bread volume. Many north American and Australian wheats have higher protein contents than most European wheats and this has led to the common view that you will get better bread from such wheats. However, with the changes which have occurred in dough making processes this view is out of date. For example, flours from European wheats are well suited to modern breadmaking and large quantities of north American wheats are only required in European milling grists where the product or breadmaking process demands their special qualities. It is possible to supplement the protein content of flours with the addition of extra protein using a dried vital gluten source (Chamberlain, 1984). This technique is especially important when making wholemeal bread where the strength of the dough system is weakened by the presence of bran and germ.

In addition to effects from the protein content aspects of protein quality also influence final product quality. Protein quality is most often judged by some form of dough rheological test though in such cases the prediction of final product quality is less certain because most dough rheological testing methods are carried out using conditions which bear little relationship with the breadmaking process in which the flour will be used. Protein quality testing relies heavily on the interpretation of the rheological data by experts.

Bran does contain protein but this will not have the same functionality as the proteins which are present in the endosperm. The particle size of the bran fragments is important, with smaller sizes causing a greater reduction in bread volume than larger particles for the same quantity of bran. The germ, like bran, is high in less-functional proteins and in addition it contributes natural reducing agents, which weaken dough systems (Cauvain, 1987).

The grade colour figure (GCF) of a flour is a measure of the amount of bran that is present in a white flour. The higher the GCF the lower will be bread volume (Cauvain *et al.*, 1985), in part because of the dilution effect on the functional protein content. With higher values for GCF the crumb colour will be darker.

During the growing cycle for the wheat plant there are a large number of enzymes at work. Of interest to us are the ones known collectively as amylases, and especially α-amylase. The term α-amylase is used to describe a range of enzymes which are capable of breaking down damaged starch granules (starch granules become damaged during the flour milling process) into dextrins and in combination with β-amylase they will produce maltose. α-amylase is produced during the growing cycle and can achieve quite high levels if the period around harvesting is wet. The level of amylase is measured using the Hagberg Falling Number test, the lower the number the higher the α-amylase level.

The dextrins which are produced by the action of α-amylase on damaged starch are sticky and if their level is high enough in the finished bread they build up on the slicer blades and can reduce the blade efficiency to such an extent that loaves can be crushed and damaged. Flour millers adjust the composition of the wheats in the milling grist to deliver flours with known Falling Numbers and usually the flour specification will be based on a minimum Falling Number.

Starch is an important component of the wheat endosperm and as the flour milling process continues large numbers of the starch granules can become damaged depending on the settings used on the roller mills. These damaged starch granules absorb more water than the undamaged granules so that the larger the proportion of damaged starch the higher the water absorption of the flour (Stauffer, 1998).

10.7.2 Yeast

Bakers' yeast (*Saccharomyces Cerevisiae*) comes in a number of different forms (Williams and Pullen, 1998). The main ones in use are the compressed form which comprises around 28–30% dry matter and cream (pumpable) yeast. The

main function of yeast is to produce carbon dioxide gas to expand the dough at its various processing stages, particularly during proof and the early stages of baking. The actions of yeast may be shown in a simplified form as follows:

$$\text{Simple sugar} \Longrightarrow \text{Ethyl alcohol} + \text{Carbon dioxide}$$

$$C_6H_{12}O_6 \Longrightarrow 2C_2H_5OH + 2CO_2$$

10.7.3 Salt

A basic function of salt in bread doughs is to contribute flavour; too little salt and the bread tastes insipid, too much and it tastes too salty. Salt also has an inhibiting effect on the formation of gluten during mixing. In high speed mixing systems the effect is quite small but increases as the mixer speed becomes lower.

There is a strong relationship between the levels of salt and yeast in a given recipe. Salt has a significant effect on the osmotic pressure of the yeast cell and so can be used to control the rate of fermentation. The more salt we use in a given recipe the more yeast will be needed to achieve a given proof time (Williams and Pullen, 1998).

10.7.4 Sugar (sucrose)

In the UK, little or no sugar is used in basic breads while around 6% flour weight may be present in the sponge and dough breads of the USA. Rolls and other small fermented products may have up to 15% sugar. High levels of sugar inhibit yeast activity even though it is fermentable. In modern breadmaking sugars contribute to product sweetness and crust colour.

10.7.5 Fat

Compound bakery fats (mixtures of oil and solid fat at a given temperature) are used to improve the gas retention of dough and thereby increase volume and softness. Increasing the fat level in the recipe will increase bread volume up to a point and thereafter there will be no further significant increase in volume for further additions. This level will vary according to the type of flour being used, with wholemeal flours requiring higher levels of fat addition than white, often 2–3 times (Williams and Pullen, 1998). A proportion of the fat should remain solid in bread dough at the end of final proof, i.e. at 45ºC.

10.7.6 Water

The properties of the dough will vary according to the level of added water; too little and the dough will be firm, difficult to mould (Cauvain and Young, 2000) and will give breads which have small volume and poor external appearance, too much and the dough will be soft, also difficult to mould, will allow the dough to flow in the prover and will give poor quality bread. The ‘optimum’ level of

water is really the maximum quantity we can get into the dough and still be able to mould the pieces and give bread of acceptable quality and depends on many of the flour properties discussed above.

10.7.7 Improvers

This term covers any ingredient added to 'improve' the breadmaking potential of a flour. Different breadmaking processes may utilise different flours and therefore require different optimum improver formulations. Improvers of one form or another have been used by bakers for over a hundred years and today these products are a mixture of a number of different materials. Improver dosage levels are also tailored to specific ingredient/product/process combinations.

The functional ingredients used in improvers vary but typically contain one or more of the following ingredients:

- Oxidising agents to improve the gas retention abilities of the dough. The functions of the oxidant are complex and at the protein molecule level are related to the formation thought to be mostly related to 'cross-linking' of proteins. This would be the equivalent of tying knots in the ends of short pieces of string to gradually form a net. The contribution of oxidants to bread quality is significant. By improving dough development we will get larger product volume and improved crumb softness. In some processing environments we can also get finer cell structure which will give soft bread and a whiter crumb colour.

  Following a number of changes in UK and EU legislation since 1990 the only permitted oxidant is ascorbic acid (or Vitamin C). In the USA, however, potassium bromate, azodicaronamide and other oxidants remain available for addition by the miller and baker. The use of ascorbic acid in breadmaking is not as straightforward as other oxidants such as potassium bromate. Ascorbic acid is classed chemically as a reducing agent and can only function as an oxidising agent in dough after it has been itself oxidised to another form known as dehydro-ascorbic acid. To achieve this conversion we require oxygen. In breadmaking the oxygen we require for this conversion comes from air trapped in the flour and air bubbles incorporated into the dough. Other dough ingredients use oxygen during mixing, most notably the yeast.
- Reducing agents such as L-cysteine may be added to 'weaken' the dough structure. It will only be used at low levels in improvers but by reducing dough resistance to deformation it helps in moulding and shape forming, such as with rolls and baps, without structural damage.
- Emulsifiers may be added to bread to improve its quality, each one acting slightly differently and having its own special effects. There are four commonly used emulsifiers; DATA esters, sodium stearoyl lactylate, distilled monoglycerides and lecithins (Kamel and Ponte, 1993; Williams and Pullen, 1998).

- Enzyme active materials have become important to many sectors of the baking industry following the limitations placed on the use of oxidants. Those most commonly used are the α-amylases (fungal, cereal and bacterial) and the hemicellulases. Proteolytic enzymes may be used in the USA (Kulp, 1993).
- Full fat, enzyme-active soya flour has been used as a functional dough ingredient in the UK since the 1930s. It has two principal beneficial functions, both arising from its lypoxygenase enzyme system. They are to bleach the flour and assist in dough oxidation.

Mould inhibitors and preservatives are added to delay the spoilage of bread and fermented products, all of which have high water activities (Pateras, 1998; Williams and Pullen, 1998). Amongst the most common are propionic acid and calcium propionate. Acetic acid (vinegar) may also be used.

10.8 Current mixing and processing technologies

The essential features of the two main breadmaking processes have been described above and these continue to form the basis of current mixing and processing technologies. In both of these breadmaking processes mixing plays a major role on forming and developing the gluten structure in the dough and incorporating the necessary gas bubbles for cell structure formation in the baked product. It is the latter which makes bread a light, aerated and palatable food.

10.8.1 The functions of mixing

In essence mixing is the homogenisation of the ingredients, whereas kneading is the development of the dough (gluten) structure by 'work done' after the initial mixing. However, in the context of modern breadmaking both processes take place within the mixing machine and so can be considered as one rather than two processes. This is especially true of the two main no-time dough processes considered in this chapter since around 90% of the final bread is determined by the mechanics of mixing and the reactions between the ingredients which take place in the mixer.

The sub-processes taking place during mixing can be summarised as follows:

1. The uniform dispersion of the recipe ingredients.
2. Dissolution and hydration of those ingredients, in particular the flour proteins and the damaged starch.
3. The development of a gluten (hydrated flour protein) structure in the dough arising from the input of mechanical energy by the mixing action.
4. The incorporation of air bubbles within the dough to provide the gas bubble nuclei for the carbon dioxide which will be generated by yeast fermentation and oxygen for oxidation and yeast activity.

5. The formation of a dough with suitable rheological properties for subsequent processing.

10.8.2 Types of mixer

Mixing machines vary widely from those that virtually mimic a hand mixing action, to high speed machines able to intensively work the mix to the required dough condition within a few minutes. Many mixing machines still work the dough as originally done by hand through a series of compressing and stretching operations (kneading) while others use a high speed and intensive mechanical shearing action to impart the necessary work to the dough. In both the CBP and sponge and dough mixing processes the velocity of the dough being moved around within the mixing chamber is used to incorporate the full volume of ingredients into the mix and impart energy to the dough from the mixing tool. Where breadmaking processes are based on this effect they require a minimum mixing capacity for a given mixing chamber capacity in order to remain efficient otherwise the mixing tool does not come into intimate contact equally with all parts of the dough.

The essential features of the Chorleywood Bread Process have been described above. In the UK energy levels of around 11wh/kg of dough in the mixer are common, while in other parts of the world or with products, such as breads in the USA, this may rise to as much as 20wh/kg of dough (Tweedy of Burnley, 1982; Gould, 1998). In the production of US-style breads where fine cell structures and higher energy inputs are required to achieve optimum dough development CBP-compatible mixers may be fitted with a cooling jacket to maintain control of final dough temperatures (French and Fisher, 1981). Because of the CBP requirements motor horse powers will be large. The most common CBP-compatible mixers consist of a powerful vertically mounted motor drive, directly coupled through a belt system to vertically-mounted mixing blades in a fixed, cylindrical bowl. The high velocity of dough being flung off the impeller during mixing aids mechanical development.

In many CBP-compatible mixers control of the headspace atmosphere is incorporated into the mixing arrangements. In its ‘classic’ form this consisted of a vacuum pump capable of reducing the headspace pressure to 0.5bar. With the loss of potassium bromate as a permitted oxidising agent in UK breadmaking the relationship between headspace atmosphere and ascorbic acid became more critical. In response to deficiencies in product quality in some breads a CBP-compatible mixer was developed in which mixer headspace pressures could be varied sequentially above and below atmospheric (APV Corporation Ltd., 1992). With the ‘Pressure-Vacuum’ mixer it is possible to produce a wide range of bread cell structures through adjustment of mixer headspace pressure both above and below atmospheric pressures and in varying sequences (Cauvain, 1994; Cauvain, 1995). In another possible variation of mixer headspace control it is possible with some CBP-compatible mixers to replace the atmospheric headspace gas with different gas mixtures. Most successful has been the

application of a mixture of 60% oxygen and 40% nitrogen based on the principles of providing improved ascorbic acid oxidation (Chamberlain, 1979).

The most common applications of CBP-compatible mixers are the high capacity production of fermented products in plant bakeries running continuously. Mixing plants are available with outputs from 2,000 to 10,000 kg dough per hour. More bread is produced from dough mixed with CBP-compatible mixers in the UK, Australia, New Zealand and South Africa than from any other mixing system. The use of CBP can also be found in India, Germany, Spain, Ecuador and the USA.

Horizontal bar mixers

Horizontal bar mixers are usually capable of mixing large quantities of dough in one batch. In the USA 1,000 lbs of dough at a time is a common size. This large size provides the necessary quantity of dough for very fast production rates. Mixing speeds are commonly lower than those used with CBP-compatible types, typically the maximum speed will be less than 150 rpm. The horizontal mixer is most often used with the sponge and dough process (Stear, 1990).

The mixing action of the horizontal bar mixer depends on the design of the beater arms in the chamber. The two main variations are based on roller bars and elliptical-shaped beaters. In both cases the mixing action is strongly influenced by the relatively small size of the gap between the outer edge of the beaters and the sides of the bowl. The main action tends to be one of stretching and folding of the dough. The dough is picked up by the mixer blades and thrown against the outer side of the bowl but because of the slower speed less energy is transferred to the dough than with CBP-compatible types. Gravity also plays a role in that the bulk of the dough will fall to the base of the mixer where it is partly picked up for further mixing and partly stretched as the mixing tool moves through the dough.

The lower mixing speed means that a longer mixing time is required in order to develop the gluten structure of the stronger flours which tend to be used with sponge and dough processes. The slightly longer mixing time also allows for longer contact times with the mixing bowl and so cooling jackets can therefore be more effective at removing the heat generated from dough mixing.

10.8.3 Cell creation during mixing

The production of a defined cellular structure in the baked bread depends entirely on the creation of gas bubbles in the dough during mixing and their retention during subsequent processing. After mixing has been completed the only ‘new’ gas which becomes available is the carbon dioxide gas generated by the yeast fermentation. Carbon dioxide gas has high solubility relative to other gases and in bread dough cannot form gas bubbles (Baker and Mize, 1941). As the yeast produces carbon dioxide gas the latter goes into solution in the aqueous phase within the dough until saturation is achieved. Thereafter continued fermentation causes dough expansion as the gas is retained within the dough

structure. The two other gases present in the dough after mixing are oxygen and nitrogen. The residence time for oxygen is relatively short since it is quickly used up by the yeast cells within the dough (Chamberlain 1979). Indeed so successful is yeast at scavenging oxygen that no oxygen remains in the dough by the end of the mixing cycle. With the removal of oxygen the only gas which remains entrapped is nitrogen and this plays a major role by providing bubble nuclei into which the carbon dioxide gas can diffuse as the latter comes out of solution.

The numbers and sizes of gas bubbles in the dough at the end of mixing are strongly influenced by the mechanism of dough formation and the mixing conditions in a particular machine. Recent work to measure bubble distributions in CBP bread doughs (Cauvain *et al*., 1999) has confirmed that different mixing machines do yield different bubble sizes, numbers and distributions. However, in one CBP-compatible mixing machine variation of impeller design had a small effect on the gas bubble population. This lack of difference in the characteristics of the dough bubble populations was confirmed by the absence of discernible differences in the subsequent bread cell structures.

The modification of bubble populations through the control of mixer headspace atmospheric conditions has been known for many years, commonly through the application of partial vacuum to CBP-compatible mixers (Pickles, 1968). This control was useful in the creation of the fine and uniform cell structures typically required for UK sandwich breads but was unsuited to the production of open cell structure breads. In more recently developed CBP-compatible mixers which are able to work sequentially at pressures above and below atmospheric it has become possible to obtain a wider range of cell structures in the baked product. When the dough is mixed under pressure larger quantities of air are occluded which give improved ascorbic acid oxidation but more open cell structures. In contrast, dough bubble size becomes smaller as the pressure in the mixer headspace reduces and ascorbic acid oxidation decreases as the pressure decreases. The greater control of dough bubble populations realised in these mixers allows a wide range of bubble structures to be created in the dough (Cauvain *et al.*, 1999). In addition to the fine and uniform structure created from the application of partial vacuum open cell structure for baguette and similar products can take place in the mixing bowl by mixing at above atmospheric pressure (Cauvain, 1994; Cauvain, 1995).

Similar considerations to those discussed above apply to the horizontal bar mixers which are typically used with sponge and dough processes. Air is incorporated in the sponge during the mixing stage and oxygen is lost because of the yeast activity leaving only nitrogen gas bubble nuclei. When the sponge is mixed with the other ingredients at the dough mixing stage quantities of these gas bubbles may be lost as the dough matrix ruptures. However, at the same time fresh air bubbles are incorporated and the process of oxygen depletion by yeast action again takes place. At the end of mixing the gas bubble population will be dominated by nitrogen though carbon dioxide will be present in larger quantities compared with CBP doughs. Nevertheless the same principle applies after

mixing, namely that the gas bubble structure created during mixing will largely be the one expanded during proving and baking.

10.8.4 Dough processing techniques

Dividing

After mixing the bulk dough is divided to generate the shape and size of product required. Dough is generally divided volumetrically with portions of a given size cut either by filling a chamber with dough and cutting off the excess (piston dividing) or by pushing the dough through an orifice at a fixed rate and cutting billets from the end at regular intervals (extrusion dividing). In either case the accuracy of the system depends on the homogeneity of the dough. Different dividers need to be matched to different dough types in order to give optimum dividing accuracy with minimal compression damage. For example, 'strong' North American bread doughs can withstand high compression loads whereas more delicate French baguette doughs are readily damaged.

The two-stage oil suction divider is probably the most common for bread dough. Typical cycle speeds range up to 1800 cycles/minute. Where higher outputs are required multiple dies or pockets are used to achieve outputs of up to 9000 pieces per hour. In suction dividers the dough is pushed into the division box dies under some force and so upon ejection the release of pressure allows an increase in dough volume. This has no effect on individual weight accuracy at this point, but can cause individual dough pieces to touch one another during transfer between division box and belt. Separation is achieved by running a second conveyor running faster than the first to pull.

Extrusion dividers are based on the ability to pump dough, usually by means of a helical screw, through an orifice at a constant rate and density. As dough emerges from the orifice it is cut by a blade or wire at a constant rate to achieve billets of dough of uniform shape and size. The dough is worked considerably during this process and such dividers are best suited to strong doughs which are already highly developed. Typically such dividers are used with the North American sponge and dough bread process.

Single-stage dividers extract the dough directly from the hopper into the measuring chamber where the dough volume is set and cut via the action of a rotary chamber or mobile hopper base. The measuring piston ejects the dough piece directly onto a discharge conveyor.

Damage to the dough from suction dividers can be more serious than from compression dividers, especially if the rate of suction is not compatible with the rheology of the dough or the size and shape of hopper and chamber. Mechanical damage can also occur when dough is pumped or transferred to the divider by a screw drive. This should not be compared with mechanical development, the difference being that the mechanical work done during mixing is uniformly distributed throughout the dough structure, whereas mechanical work during such dough transfer systems is not uniformly distributed and confers different changes in dough properties in different areas of the dough mass.

Rounding and first moulding

After dividing the individual dough pieces are commonly worked in some way to change their shape before first or intermediate proof. The most common shaping is by rounding, an action which mimics that carried out by hand in the craft bakery. The action of mechanical first moulding places the dough under stress and strain which may lead to damage to the existing gas bubble structure in the dough. Some breadmaking processes require the rounder to have a degassing effect, however, if the dough comes from a breadmaking process which leaves little gas in the dough at the end of mixing (e.g. the CBP) then this requirement is unnecessary. A key function of rounding is to generate a uniform, largely spherical dough piece which makes it suitable for handling in pocket-type provers, rolling down chutes, conveying without concern for orientation and delivering a uniform dough piece to the final moulder.

During rounding the dough piece is rotated on its axis between the two inner surfaces of a V- or U-shaped trough, where one side is driven and the other fixed or moving at a lower speed. The dough piece quickly forms the shape of the trough as it moves under the force of the driven side. The differential in speed between the two surfaces is the same but the angular diameter of the dough piece reduces as the two surfaces converge, so that the top of the dough piece is rotated faster than the bottom effectively attempting to twist it about its axis. However, because the dough piece slips on one of the surfaces the action becomes one of spiralling or rolling.

There is a wide variety of rounders available where rotational speed, angle of cone, angle and shape of track, inclination of track and different surface finishes all modify rounder action on the dough. The most common type of rounder consists of a cone which is rotated about a vertical axis with the track of the fixed moulding surface located in a spiral pattern about the outside of it. Some conical rounders have an inverted cone with the rounding track on the inside and others use a track around a cylindrical drum. Shaping belts provide an alternative to rounders.

Intermediate or first proving

In most modern dough make-up processes intermediate, or first proof is used as a period of rest between the work carried out by dividing and rounding and before final shaping. The length of time chosen for this process is related to the dough rheology required for final moulding. Changes occur in dough rheology as it rests, the longer that it rests the greater will be the changes. In no-time doughmaking processes (e.g. the CBP) the changes in dough rheology which may occur in first proof can have a considerable effect on final bread quality and its elimination can lead to a reduction of loaf volume and an increase in damage to the bubble structure in the dough. This is especially the case when ascorbic acid is the only oxidant in the recipe.

The pocket-type prover is the most common form. The pockets are held in frames fixed between two chains carrying swings. The latter move around the proving cabinet from charging to discharging stations and incorporate turn-over

devices which roll the dough piece from one pocket to another. This action allows the temporarily empty pocket to dry.

Final moulding

The key functions of the final moulder are to shape the dough to fit the product concept and to re-orientate the cell structure. The essential features of the final moulder are:

- Passage of the round dough piece through sets of parallel rolls moving at high speed. Sheeting reduces the thickness of the dough piece. The gap between successive pairs of rolls decreases and on leaving the last gap the dough piece has an ellipsoid shape. It is essential that the dough piece is presented centrally to the rollers and is maintained centrally throughout the moulding process (Collins, 1993; Cauvain and Collins, 1995).
- Curling of the ellipse by trapping the leading edge underneath a static chain which creates a 'Swiss roll' of dough.
- Compression and further shaping of the Swiss roll to give a uniform cylinder of dough. This is achieved by compressing the dough piece underneath a pressure board while it is still being moved along the length of the moulder by the action of a moving belt.

Given the above description of the final moulding operation it is clear in order to achieve the necessary product quality the dough must have appropriate rheology (i.e. have a low resistance to deformation). This is particularly true when starting from a rounded dough ball. A cylindrical dough piece with square ends and a length and diameter equal to the length and width of the bottom of the pan is required for many bread types. Modification of the dough piece make take place at the end of the final moulder. One common form is 'four-piecing' in which the dough cylinder is cut into 4 equal lengths (each equal to just less than the tin width) and turned through 90º to lie side by side across the tin. This techniques re-orientates the cell structure in the final bread crumb. Cross-graining also performs this function by turning the dough sheet through 90º as it passes through the final moulder so that the wider plain of the elliptical sheet is presented to the curling chain and moulding board.

10.8.5 Gas bubble control during dough processing

A key feature of no-time doughs is that major degassing of the dough does not occur and indeed should be discouraged. Little change occurs to gas bubble populations during dividing and first moulding operations while in intermediate proof the size of the gas bubbles increases as the carbon dioxide gas diffuses into the gas bubbles present (Whitworth and Alava, 1999).

It is in the final moulding stages that any significant changes occur in the gas bubble populations. There are two main changes: one is a potential elongation of gas bubbles and the other a slight, though potential important degassing, during sheeting. As the round dough piece passes through the sheeting rolls some

elongation of gas bubbles in the direction of sheeting is likely to occur and this orientation is likely to be retained during subsequent curling. Elongation is most likely to occur with the larger gas bubbles located nearer to the surface of the dough during sheeting. It is unlikely that the pressures applied during sheeting will affect the smaller gas bubbles located in the centre of the dough. Nevertheless the elongation of gas bubbles does affect final bread quality because when baked into the bread they tend to be shallower than other surrounding gas bubbles and since they cast less shadow in the cut bread surface they will make the product appear whiter. Elongation also contributes to the physical strength of the breadcrumb during slicing and buttering.

The degree to which a dough may be degassed during the sheeting stages of final moulding depends on the dough rheology and its interaction with the equipment type and settings used. Whitworth and Alava (1999) have shown that the de-gassing of no-time doughs is small but examination of X-ray scans of CBP doughs shows that it does occur. In the X-ray scans the sheeted dough surfaces are visible as white lines because the dough is denser at this point and therefore there is greater X-ray absorbance. A further problem which may be encountered during dough sheeting is the rupture of gas-stabilising films and the subsequent coalescence of two gas bubbles to form one of larger size. Such larger sized bubbles have lower internal pressure and carbon dioxide gas may preferentially migrate to such bubbles causing them grow even larger. Such damage to dough bubble in structures is thought to be a major factor in the formation of large, unwanted holes in breadcrumb (Cauvain and Young, 2000).

10.8.6 Proving and baking

Proving is the name given to the dough resting period, after the moulded pieces have been put into tins or placed in trays, during which fermentation continues in a controlled atmosphere, typically 40–45ºC and 85% relative humidity. When the dough enters the prover, it will be at a temperature of 28 to 30ºC. Bakers' yeast is at its most active at 35 to 40ºC and so running the prover around 40ºC minimises the time required for proof. It is important that the skin of the dough remains flexible so that it does not tear as it expands. Since the dough relative humidity is around 90–95% a moist atmosphere is required to maintain that skin flexibility.

During proof the starch from the flour is progressively converted into dextrins and sugars by enzyme action. Yeast can feed on the sugars to produce carbon dioxide and alcohol, as described above. The carbon dioxide diffuses into the gas bubbles in the dough causing them to grow and the dough to expand. Progressively the size of the gas bubbles increases (Whitworth and Alava, 1999). If the dough is confined by a tin the gas bubbles are elongated in the direction of movement of the dough, i.e. upwards. The frictional forces between the dough and the tin (even when greased) slow down the movement of the edges of the dough and so most of the dough expansion occurs in the middle. X-ray tomography has shown that dough expansion in the pan can be so uneven

that a point which starts at the centre at the beginning of proof may end up about three-quarters of the way up the dough piece at the end of proof (Whitworth and Alava, 1999).

After proof the dough must be heat-set, that is baked. The process is one of conversion of a foam to a sponge. In the former case the gas bubbles are discrete and separated from one another by gluten films, in the latter the cells of the crumb structure are ruptured and interconnected to one another. Baking temperatures will vary from oven to oven and with product but typically they lie in the region of 220–250ºC. A key parameter of loaf quality is to achieve a core temperature of about 92–96ºC by the end of baking to ensure that the product structure is fully set.

For the centre of the dough piece, the move from prover to the oven has little impact because it is so well insulated by surrounding dough. This means that the centre of the dough gets additional proof. The driving force for heat transfer is the temperature gradient from regions near the crusts, where the temperature is limited to the boiling point of water, to the centre. The heat transfer mechanism is conduction along the cell walls and the centre temperature will rise independently of the oven temperature and approach boiling point asymptotically. There is no significant movement of moisture and the moisture content will be the same at the end of baking as at the beginning.

As dough warms up it goes through a complex progression of physical, chemical and biochemical changes. Yeast activity decreases from 43º and ceases by 55ºC. Structural stability is maintained by the expansion of the trapped gases. Gelatinization of the starch starts at about 60ºC and initially the starch granules absorb any free water in the dough. α-amylase activity converts the starch into dextrins and then sugars and reaches its maximum activity between 60 and 70ºC. Too little amylase activity restricts loaf volume, because the starch structure becomes rigid too soon, while too much may cause the dough structure to become so fluid that the loaf collapses completely.

The formation of a crust provides much of the strength of the finished loaf and the greater part of the flavour. Condensation on the surface of the loaf at the start of baking is essential for the formation of gloss, but quite soon the temperature of the surface rises above the local dew point temperature and evaporation starts. Soon after that the surface reaches the boiling point of the free liquid and the rate of moisture loss accelerates. The heat transfer mechanisms at the evaporation front are complex. There is conduction within the cell walls and water evaporates at the hot end of the cell. Some is lost to the outside but the rest moves across the cell towards the centre and condenses at the cold end of the cell. In doing so it transfers its latent heat before diffusing along the cell wall to evaporate again at the hot end. The evaporation front will develop at different rates depending on the bread types. The crust is outside the evaporation front and here the temperature rises towards the air temperature in the oven. As water is driven off and the crust acquires its characteristic crispness and colour, flavour and aroma develop from the Maillard reactions, which start at temperatures above 150ºC.

The other contributor to crust formation is the continuing expansion of the inside of the dough piece from the final burst of carbon dioxide production from yeast fermentation and the thermal expansion of the gases trapped in the cellular structure of the dough. If the dough is contained in a pan then it can only expand upwards. This effect is most obvious at the top edges of the loaf, where the displacement is greatest and where a split develops as the top crust lifts, exposing a band of elongated inner crust cells, called the 'oven break', 'oven spring' or 'shred'.

Some types of bread are characterised by the crispness of their crust, e.g. baguette. The first few moments in the oven are vital for the formation of a glossy crust. To obtain gloss, it is essential that vapour condenses on the surface to form a starch paste that will gelatinize, form dextrins and eventually caramelise to give both colour and shine. If there is excess water, *paste-type gelation* takes place while with insufficient water *crumb-type gelation* occurs. To deliver the necessary water steam is introduced into the oven.

10.9 Future trends in breadmaking

10.9.1 Ingredients

The trend in the reduction in permitted additives in breadmaking has probably reached its limits in Europe and many parts of the world. The current exception is the USA, which still permits a wide range of oxidants, including potassium bromate and azodicarbonamide which were banned in the UK in 1990 and 1995 respectively. The trend to limit 'chemical' additives has raised the profile of the use of enzyme active materials as more 'natural' additives. While the addition of many enzyme active materials does improve dough gas retention (Cauvain and Chamberlain, 1988) such materials do not perform the same protein cross-linking function of oxidising materials. It is likely that the improving effect many enzyme-active materials contribute to bread quality is related to their ability to change dough rheology and therefore the influence of the moulding and processing operations.

Recently developed and used enzymes may now be the product of the fermentation of genetically modified microorganisms or the result of the fractionation of existing amylase sources. These approaches have developed bacterial α-amylases with heat stability profiles similar to that of fungal α-amylase (Williams and Pullen, 1998). These products give the benefits of improvement in gas retention while avoiding the problem of excessive dextrin formation associated with cereal and 'traditional' bacterial amylases. In addition these newer amylases have been shown to have anti-staling properties over normal bread shelf life. This trend to using more targeted enzymes is likely to continue in the foreseeable future.

Since a significant proportion of bread quality derives from the wheats that are used in the milling grist it is certain that greater attention will be paid to matching wheat/flour quality with end use. This may entail selective breeding or greater attention to agronomic practices.

10.9.2 Mixing and processing technologies

Dough mixing and processing remain as the critical steps in the breadmaking process. Improvements in knowledge regarding the mechanisms by which gas bubbles are incorporated and stabilized in the dough will help in the understanding of the role of the contribution that dough mixing makes to these fundamental issues. Some of the most recent work in this area has started to link gas bubble structures with wheat variety and the energy required to achieve 'optimum' dough development . Other related work has linked dough rheology ex-mixer with the subsequent processing stages which convert the bulk dough into unit pieces ready for proof and baking. Much work on dough processing methods remains to be done but already changes in dough moulding processes are being implemented.

Attempts have been made to run provers commercially at higher temperatures. Higher proof temperatures will warm the dough more quickly, but a steeper temperature gradient through the dough will certainly have an effect on product quality, because it will result in uneven gas production rates and, ultimately, uneven cell structure and texture in the finished loaf. To raise dough throughput rates through prover and oven requires improved understanding of both processes. The application of X-ray tomography using CT-scanners is beginning to provide data which will enable such processing changes (Whitworth and Alava, 1999).

Bread baking remains to some degree an art or craft rather than a science or technology. This is especially true in the areas of process control and quality optimisation which still rely heavily on the 'expert' baker to make the necessary adjustments to the combination of raw materials, formula and process. While many bakeries are now highly automated in the engineering sense most are still relatively primitively controlled in the product quality sense. The application of computer-based technologies has started to be applied to baking processes (Young, 1998) but the potential has still to be fully exploited. In part this is because large parts of the necessary knowledge have still to gathered and structured in a suitable format for use. A start has been made but much more remains to be done.

10.9.3 Product trends

The major challenges for the products of bread bakers have always been the same; namely how to preserve those special 'just-baked' qualities of aroma, taste and texture. In the past this limited the scale of production to the local community but as time has gone by the move has been to more widespread geographical distribution networks and extended shelf life. The factors which limit bread shelf life are well understood (Pateras, 1998) and extensions of product shelf life have been achieved through the application of suitable anti-staling strategies. In the UK the shelf life of some bread products has been doubled though at the cost of adding anti-microbial agents.

Consumer demands for more diverse bread products continue to increase and today the typical bakery shop or in-store bakery offers a wider range of goods

than their predecessors. In trying to meet this demand bakeries have tried using the 'part-baked' product approach with the final bake-off being applied in a local store to ensure freshness. However, there are no shortcuts to product quality as was show by the introduction of the ill-fated Milton Keynes process (Bent, 1998). Based on part-baked product technology and hailed as the new wonder process it lasted barely 18 months because consumers did not like the product and voted with their feet. Bread variety may well be sought by consumers but they also tend to know what quality they are seeking.

10.10 Conclusions

Breadmaking as a skill, craft, technology and science has been around for many thousands of years and many of the key ingredient and process technologies have been established through much trial and error. Tradition in different parts of the world has evolved a wide range of bread products with many different attributes. Modernisation of breadmaking is really the product of the last 50 years. In more recent years there has been a trend to using fewer 'chemical' additives to deliver the necessary product qualities. This trend has placed a greater emphasis on the understanding of the interactions of ingredients and processing methods and improvements in this understanding will undoubtedly lead to further changes in the production of what is probably the original processed food.

10.11 References

APV CORPORATION LTD. (1992) *Dough mixing*, UK Patent GB 2,264,623A, HMSO, London, UK.

BAKER J C and MIZE M D (1941) The origin of the gas cell in bread dough, *Cereal Chem.*, **18**, Jan., 19–34.

BENT A (1998) Speciality fermented goods in (Eds. S.P. Cauvain and L.S. Young), *Technology of Breadmaking*, Blackie Academic & Professional, London, UK, pp. 214–39.

CATTERALL P (1998) Flour Milling in (Eds. S.P. Cauvain and L.S. Young), *Technology of Breadmaking*, Blackie Academic & Professional, London, UK, pp. 296–329.

CAUVAIN S P (1987) Effects of bran, germ and low grade flours on CBP bread quality. *FMBRA Report No. 138*, December, CCFRA, Chipping Campden, UK.

CAUVAIN S P (1998a) Breadmaking processes in (Eds. S.P. Cauvain and L.S. Young), *Technology of Breadmaking*, Blackie Academic & Professional, London, UK, pp. 18–44.

CAUVAIN S P (1998b) Bread – the product in (Eds. S.P. Cauvain and L.S. Young), *Technology of Breadmaking*, Blackie Academic & Professional, London,

UK, pp. 1–17.

CAUVAIN S P (1994) New mixer for variety bread production, *The European Food and Drink Review*, Autumn, 51, 53.

CAUVAIN S P (1995) Creating the structure: the key to quality. *South African Food Review*, **22**, April/May, 33, 35, 37.

CAUVAIN S P and CHAMBERLAIN N (1988) The bread improving effect of fungal α-amylase. *Journal of Cereal Science*, **8**, Nov., 239–48.

CAUVAIN S P and COLLINS T H (1995) Mixing, moulding and processing bread doughs in *Baking Industry Europe* (Ed. A. Gordon), Sterling Publications Ltd., London, UK, pp 41–3.

CAUVAIN S P, DAVIES J A and FEARN T (1985) Flour characteristics and fungal α-amylase in the Chorleywood Bread Process, *FMBRA Report No. 121*, March, CCFRA, Chipping Campden, UK.

CAUVAIN S P, WHITWORTH M B and ALAVA J M (1999) The evolution of bubble structure in bread doughs and its effects on bread cell structure in (Eds. G.M. Campbell, C. Webb, S.S. Pandiella and K. Niranjan) *Bubbles in Food*, Eagen Press, St. Paul, USA, pp. 85–8.

CAUVAIN S P and YOUNG L S (2000) *Bakery Food Manufacture and Quality: Water Control and Effects*, Blackwell Science, Oxford, UK.

CHAMBERLAIN N (1979) Gases – the neglected bread ingredients, *Proceedings of the 49th Conference of the British Society of Baking*, 12–17.

CHAMBERLAIN N (1984) Dried gluten in breadmaking – the new challenge. *British Society of Breadmaking, 30th Annual Meeting and 59th Conference Proceedings*, Nov., 14–18.

CHAMBERLAIN N (1985) Dough formation and development in *The Master Bakers Book of Breadmaking, 2nd Edition* (Ed. J. Brown), Turret-Wheatland Ltd., Rickmansworth, UK, pp. 47–57.

COLLINS T H (1983) The creation and control of bread crumb cell structure, *FMBRA Report No. 104*, July, CCFRA, Chipping Campden, UK.

FRENCH F D and FISHER A R (1981) High speed mechanical dough development, *Bakers Digest*, **55**, October, 80–2.

GOULD J T (1998) Breadmaking around the world in (Eds. S.P. Cauvain and L.S. Young), *Technology of Breadmaking*, Blackie Academic & Professional, London, UK, pp. 197–213.

KAMEL, B S and PONTE J G (1993) Emulsifiers in Baking in (Eds. B.S. Kamel and C.E. Stauffer) *Advances in Baking Technology*, Blackie Academic & Professional, London, UK, pp. 179–222.

KULP K (1993) Enzymes as dough improvers in (Eds. B.S. Kamel and C.E. Stauffer) *Advances in Baking Technology*, Blackie Academic & Professional, London, UK, pp. 152–78.

PATERAS I (1998) in (Eds. S.P. Cauvain and L.S. Young), *Technology of Breadmaking*, Blackie Academic & Professional, London, UK, pp. 240–61.

PICKLES K (1968) Tweedy (Chipping) Ltd. *Improvements in or relating to dough production*, UK Patent No. 1,133,472, HMSO, London, UK.

STAUFFER C E (1998) Principles of dough formation in (Eds. S.P. Cauvain and

L.S. Young), *Technology of Breadmaking*, Blackie Academic & Professional, London, UK, pp. 262–95.

STEAR C A (1990) *Handbook of Breadmaking Technology*, Elsevier Applied Science.

TWEEDY OF BURNLEY LTD (1982) *Dough mixing for farinaceous foodstuffs*, UK Patent GB 2,030,883B, HMSO, London, UK.

WHITWORTH M B and ALAVA J M (1999) The imaging and measurement of bubbles in bread doughs in (Eds. G.M. Campbell, C. Webb, S.S. Pandiella and K. Niranjan) *Bubbles in Food*, Eagen Press, St. Paul, USA, pp. 221–31.

WILLIAMS A and PULLEN G (1998) Functional ingredients in (Eds. S.P. Cauvain and L.S. Young), *Technology of Breadmaking*, Blackie Academic & Professional, London, UK, pp. 45–80.

YOUNG L S (1998) The application of knowledge-based sustems in (Eds. S.P. Cauvain and L.S. Young), *Technology of Breadmaking*, Blackie Academic & Professional, London, UK, pp. 180–96.

ZOHARY D (1969) The progenitors of wheat and barley in relation to domestication and agricultural dispersion on the Old World in *The domestication and exploitation of plants and animals* (Eds. P.J. Ucko and G.W. Dimbleby), Duckworth & Co., London, pp. 47–66.

Index

acid flavours 211
acidified long-life noodles 153
adaptive control 41–2
advanced control techniques 38–42
ageing 135–6
alkali spreading value 84–5
akaline noodles 143–8
  flour requirements 144–5
  processing 145–8
α-amylase 14–15, 121, 214, 217, 226
Alveograph 123
amylases 214, 226
  see also α-amylase
amylographic paste viscosity 85
amylose content 84–5
animal feed 13
animal nutrition 58
anther culture 105
appearance 83, 125
aquaculture 58
aromatic long-grain rice 81, 86, 87
ascorbic acid 216
ash content 125, 139, 140, 144
Asian noodles *see* noodles
aspartate kinase (AK) 66
automated hatch cover opening/closing 165
automatic puffing guns 168
automation
  malting 201–2
  milling 37–42
baby foods 103–4
Bairds Malt 174
baking 59
  improved baking quality wheat 67
  technologies 224–6, 227
bar gene 68
barley 58
biotechnology 62–5
  examples of transformed barley 65–7
  malting *see* malting
  production 7–13
barley yellow dwarf virus 65–6
Bass 175
batch dryers 183
beer production 58, 60–1, 62–5
beta-carotene 70
beta-glucanase 66–7
biotechnology 53–76
  disease resistance 55–7
  examples of transformed cereals
    rice and maize 68–70
    wheat and barley 65–7
  future trends 71
  herbicide resistance 54–5
  improved cereal quality control 65
  improved nutritional properties 57–8, 66, 70
  improved processing qualities 58–65
  productivity, product quality and safety 53–4
  see also genetic modification

biscuit manufacture 13, 15
black specks 125
blackgrass 23
blending 164–5
bran 213, 214
bran colour 82
bran specks 125
breadmaking 204–30
basic steps 205
bread flavour 211–12
bread types 212–13
  character of bread 209–11
  determinants of quality 213–17
  dough development 205–6
  future trends 226–8
  grain quality and 13–15
  mixing and processing technologies 217–26
    dough processing 221–4
    future trends 227
    mixing 217–21
    proving and baking 224–7
  processes 206–9
  product trends 227–8
break system 30–1
breakfast cereals 158–72
  future of the industry 170–1
  industry and its structure 159–62
    after World War II 161–2
    before World War II 159–61
  ready-to-eat rice breakfast cereals 101–3
  recent trends and technological developments 163–70
    blending 164–5
    cooking 165–6
    drying 166
    forming 167–9
    quality control improvements 169–70
    tempering 166–7
    weighing 163
brewer maltsters 173, 174, 175
brewing 58, 60–1, 62–5
brown and yellow rust (*Puccinia* spp.) 23
Bt cryIA(b) gene 68
bubbles, gas *see* gas bubbles
buckwheat noodles 131, 150
bulk density 13–14, 170
bulk fermentation process 206, 208
butylated hydroxyanisole (BHA) 149

canned rice 100
canopy management 20
capacities, machine 33
carbon dioxide 206, 219–21
cascade control 38
case hardened surfaces 166
caustic soda 145, 146
cell wall polysaccharides 57
cereal cyst nematodes 24
cellular crumb structure 210, 219–21
cereal production *see* cultivation
chalkiness 83–4, 90
chemical purity 65
chilled noodles 152–3
China 132
chitinase gene 69
Chorleywood Bread Process (CBP) 13, 207–8, 218–19, 220
circular steel bins 185–8, 189
clean-in-place (CIP) 164
climate 24–5, 91
coarse grains milling *see* milling
coated milled rice 90
colour
  breakfast cereals 170
  pasta 119, 120, 125
  rice 88
combined vessels 181, 196–7
computer control 164, 165, 170–1
computer integrated manufacturing (CIM) 37
concrete silos 188–9
constraint control 38
consumption, pasta 109, 110
continuous dryers 182–3
continuous press 111
control systems
  breakfast cereals 164, 165, 170–1
  malting 201–2
  milling 37–42
conventional controls 38
conveying equipment 197–9
cooking
  developments in breakfast cereals 165–6
  quality indexes for rice 84–6
copper deficiency 19–20
Crisp Malting Group 174
Crispix 103
crop cultivation *see* cultivation
crust formation 225–6
cryIA(b) gene 68–9
cultivation 7–26
  crop establishment 18–19
  crop nutrition 19–21

disease control 23–4
grain quality and market outlets 11–17
harvesting and grain storage 25–6
pest control 24–5
rice 90–5
trends in 7–9
UK regional distribution 10–11, 12
varietal selection 17–18
weed control 22–3
yields 9–10
see also biotechnology
cup noodles 148

damaged kernels 88
debranning 35
degassing 224
degree of milling 88
Della aromatic rice 81, 86, 87
dihydrodipicolinate synthase (DHPS) 66
direct drilling 18
disease
control 23–4
durum wheat 121
resistance 17, 55–7, 65–6, 69–70, 95
distiller maltsters 173, 174, 175
distilling 13, 15, 61
distributed control systems (DCS) 42
dividers 221
dockage 88
double-grinding roller mill 34–5
dough
bread
dough development 205–6
processing 221–4
proving and baking 224–6
physical dough tests 123
dried noodles 142–3
dry barley storage 183–9
dry steamed noodles 151–2
drying 26
barley 182–3
breakfast cereals 166
noodles 142–3
pasta 115–17, 124
technological advances 117–20
durum wheat 112, 121–5, 126–7
dynamic optimisation 46, 47

elongation of gas bubbles 223–4
emulsifiers 216
endosperm texture 14
environmental impact 56–7
environmental stress 69–70
enzymes 217, 226
Erysiphe graminis (mildew) 23, 24
escape of herbicide genes 54–5
expanded non fried instant noodles 151–2
expression of genes, manipulation of 56
extrusion 61
baby foods 104
breakfast cereals 162, 165–6, 167–8
extruded rice 101–2
pasta 114–15
extrusion dividers 221
extrusion presses 111, 115

falling number (FN) 121, 133
Farinograph 123
fat 215
feed forward control 38
fermentation 205, 206, 224
fertile transgenic rice 95
fertilisers 19–21, 93
final moulding 223
first moulding 222
first proving 222–3
flaking 169
flat bottomed circular steel storage bins 185–8, 189
flat stores 184–5, 186, 189
flavour, bread 211–12
flour
Asian noodles 134, 139, 140, 144–5
breadmaking 14, 213–14
milling *see* milling
uses 13–15
see also wheat
forming 167–9
formulated baby foods 104
fracture modelling 43
free-standing breads 212
French process 28–9
freshness 210–11
frozen noodles 152–3
frozen rice 101
fructans 57
fungicides 23, 24
Fusarium 121
fuzzy control 40–1

Gaeumannomyces graminis (take-all) 23
gas bubbles 206, 219–21
control during dough processing 223–4
gas production 205, 206, 224
gas retention 206
gelatinization temperatures 85

gelation 226
General Mills 159, 160
genetic algorithms 45, 48
genetic modification
  rice 93–5, 105
  see also biotechnology
genetic purity 65
germ 30, 213, 214
germination 16, 175, 177
germination vessels 178, 179, 189–90, 191–4
  combined vessels 181, 196–7
global search techniques 45
globalization 126
gluten 204, 205–6, 210, 213
gluten index method 123
gluten strength 123–5, 127
glutenins 67
grade colour figure (GCF) 214
gradient-based optimisation 44–5
gradual reduction system 29, 30–2
grain quality
  biotechnology and improved 59–62
    quality control 65
  and market outlets 11–17
  rice grain quality indicators 80–90
grain size 82, 83
grain type: rice 81–2
grain weight 82
granulated brewer's rice 90
grass weeds 23
gravimetric technology 37
Green Revolution 79
gun puffing 162, 168

hand-cut noodles 137
hand-made noodles 131, 136–7
hand stretched noodles 137
hand swung noodles 136–7
hard vitreous kernel (HVK) 122
harvest index (HI) 17
harvesting 25–6
headspace atmosphere control 218–19
herbicides 22
  resistance 54–5, 68
high-molecular-weight glutenin subunits (HMW-GS) 67
high temperature (HT) drying 116, 117, 118–20, 123–4
Hokkien noodles 144, 145, 146–8
hopper-bottomed bins 188
horizontal bar mixers 219
hull colour 82

human nutrition *see* nutrition
humidity control 166
husk content 16
hydration 112–14

improvers 216–17
Indonesia 132
ingredients 226
insect resistance 68–9
instant noodles 131, 148–50
  non fried 151–2
intake, barley 181–2, 183
integrated control systems 46–7, 48
integrated pest management systems 25
intermediate proving 222–3
iron 161

Japan 132, 148, 150
jasmine aromatic rice 81, 86, 87
junior grade baby foods 104

kansui reagents 145, 146
Kellogg 158, 159, 160
kilning 177, 178
kilning vessels 180, 190, 194–6
  combined vessels 181, 196–7
kneading 205, 206, 217–21, 227
knowledge-based optimisation system 47
Korea, South 132, 148, 149, 150

lamination 139, 146, 147
linear and quadratic programming 44–5
long goods (pasta) 112, 116–17
long-grain rice 81–2, 83, 84–5
long-life noodles 153
low temperature (LT) drying 116, 117, 118, 123–4
lysine 66

machine capacities 33
machine construction 34
Maillard reactions 119, 212, 225
maize 68–70
malt-in-culm 175
malting 173–203
  automation 201–2
  barley
    dry storage 183–9
    drying 182–3
    grain quality for malting 15–16, 59–60
    improved malting quality 66–7
    intake and wet bin storage 181–2, 183

basic process 175–81
future of the industry 202
malt storage 200–1
malting plant 189–200
combined vessels 181, 196–7
conveying equipment 197–9
current trends 199–200
germination vessels 178, 179, 189–90, 191–4
kilning vessels 180, 190, 194–6
steeping vessels 189, 190–1
UK malting industry 173–5
manganese deficiency 19–20
manipulation of expression of genes 56
market outlets 11–17
marketing 159–61
measurement, process 36–7
mechanization 93
medium-grain rice 81, 83, 85
mi fen (rice noodles) 98
microbial purity 65
mildew (*Erysiphe graminis*) 23, 24
milling 27–52, 59, 60
automation 37–42
durum wheat 121
evolution of modern milling 28–9
flour milling process 30–2
future of the industry 48–9
on-line process measurement 36–7
optimisation of processes 44–8
recent developments 33–6
machine capacities 33
machine construction 34
new machines 34–5
research 42–4
rice 84, 88
wheat for noodles 133
milling engineers 33
millstones 28
Milton Keynes process 228
mineralisation 20
Minute Rice 99
mixing
breadmaking 205, 206, 217–21, 227
cell creation 219–21
functions of mixing 217–18
types of mixer 218–19
noodles 134–5, 139, 141, 146, 149
Mixograph 123–4
model-based predictive control (MBPC) 39–40
modelling mill processes 43–4
moisture content
breakfast cereals 169–70
harvesting and grain storage 25–6
rice 86–8
molecular analysis 54
mould inhibitors 217
moulding 222, 223
multi-roller system 136
Muntons Malt 175
mutagenised barley β-amylase 66–7

naengmyon noodles 150
near infra red (NIR) technology 36–7, 46
nematodes 69
Newrex/Rexmont-type rice 82, 86
nitrogen 16, 20–1
non-acidified long-life noodles 153
non-expanded non fried instant noodles 151
non-fried instant noodles 151–2
noodles 131–57
alkaline noodles 143–8
buckwheat noodles 131, 150
changing trends 132
diversity 132–6
flour characteristics 134
general processing characteristics 134–6
wheat characteristics 132–3
history 131
instant noodles 131, 148–50, 151–2
new emerging products 151–3
rice noodles 98
white salted noodles 136–43
novel disease-resistant genes 56
numerical grades 90
nutrition
biotechnology and improved nutritional properties 57–8, 66, 70
breakfast cereals and 161, 162
crop nutrition 19–21
pasta drying and nutritional quality 119

oats
grain quality 16–17
production 7–13
objectionable seeds 90
odours 88–90
off-line optimisation 45–6
oil 149–50
on-line optimisation 45–6
on-line process measurement 36–7
open loop optimisation 45–6

optimisation of processes 44–8
  application 46–7
  flour mill optimisation to date 47–8
  off-line vs on-line 45–6
  technique for milling 45
oxidising agents 216
oxygen inhibition of photosynthesis 69–70

packaging 117
palm oil 149–50
pan breads 212
parboiled rice 98–9
part-baked bread 228
partial vacuum 220
pasta 109–30
  advances in drying technology 117–20
  estimates of consumption 109, 110
  future of the industry 126–7
  history of processing 110–11
  pasta-making process 112–17
  raw material selection 121–5
Pauls Malt Ltd 175, 176
pesticides 25
pests
  control 24–5
  resistance 68–9
  weed pests 92
phosphate 19
photoperiod 92
photosynthesis, oxygen inhibition of 69–70
physical dough tests 123
pin mills 35
plansifters 33
'ploughing out' campaign 8
Polymatik extrusion press 114
Post, C.W. 158–9
post-harvest management 15
Postum Cereal Co. 158, 159
potassium 19
precipitation 91
precooked rice cereal 103–4
pre-germination vessel 191
premiums 161
preservatives 217
pressure vessel 165
proanthocyanidin-free barley 62–4
process measurement 36–7
process optimisation 44–8
processing quality
  improved by biotechnology 58–65
  indexes for rice 84–5
productivity 53–4
programmable automation (PA) 37
programmable logic controllers (PLCs) 42, 164, 165, 170–1
protein content 14
  bread 213
  noodles 144
  pasta 122–4, 126–7
protein quality 14
  bread 214
  noodles 134, 137–8, 139, 14–0
  pasta 122–3
proving 222–3, 224–6, 227
Puccinia spp. (brown and yellow rust) 23
puffed rice cake 104–5
purification system 31–2
purifiers 31

quality
  determinants of bread quality 213–17
  grain quality *see* grain quality
  processing quality *see* processing quality
  product quality and safety 53–4
  raw materials for pasta 121–5
quality control
  biotechnology and cereal quality control 65
  breakfast cereals 169–70
quantitative trait loci (QTL) 94, 95
quick-cooking rice 99–100

random amplified polymorphic DNA (RAPD) markers 94, 95
ratio control 38
raw materials selection 121–5
reducing agents 216
reduction block 32
regional distribution 10–11, 12
release 32
restriction fragment length polymorphism (RFLP) markers 94, 95, 105
ribbon blenders 164
rice 79–108
  baby foods 103–4
  canned and frozen 100–1
  cultivation 90–5
    genetic modification 93–5, 105
  extruded 101–2
  future trends 105–6
  grain quality indicators 80–90
    components of rice quality 82–6
    seeds and objectionable seeds 90

special and numerical grades 90
US rice standards and grades 86–90
variety and grain type 81–2
noodles, parboiled and quick-cooking rice 98–100
processing issues 96
puffed rice cake 104–5
shredded 102–3
snack foods 96–7
transformed by biotechnology 68–70
Rice Chex 103
rice crackers 96–7
Rice Inspection Handbook 86–90
Rice Krispies 105
rice noodles 98
roll packs 34
roller mills 29, 30–1, 31–2, 34
models 43–4
rolling systems 135, 136, 139, 142
rolls, bread 212
rotary cutting 162
rounding 222
rule-based control 40, 48

safety 53–4
sales maltsters 173, 174–5
salt 211, 215
Sanitarium Health Food Co. 159, 160
sap-sucking insects 69
scented long-grain rice 81, 86, 87
seeds 9, 90
semolina 112–15, 125
set-aside 24
Seventh-Day Adventist (SDA) Church 158, 159
sheeting 135, 136, 139, 14–2
short goods (pasta) 112, 115–17
short-grain rice 81, 83, 85
short surface mill 33
Shredded Wheat Co. 159
shredding
breakfast cereals 162, 168–9
rice 102–3
silos, concrete 188–9
Simpson, J.P. and Co. 175
simulated annealing 45, 48
single-input single-output (SISO) proportional integral differential (PID) controllers 38
single-stage dividers 221
six-roller mill 34
snack foods, rice 96–7
soba noodles 150
sodium dodecyl sulphate sedimentation (SDS) test 123
sodium hydroxide 145, 146
solar radiation 92
sowing depth 19
sowing time 18
soya flour 217
special grades 90
specialty US rices 86, 87
specific weight 13–14
sponge and dough process 208–9, 219, 220–1
spring cereals 18, 21
starch 57, 214
mechanical starch damage 32
noodles 134, 138
starch pasting characteristics 144–5
steamed noodles 151–2
steeping 177, 178
steeping vessels 189, 190–1
combined vessels 181, 196–7
stem eelworm 24
stemboring insects 68–9
stick-shaped breads 212
storage
barley
dry storage 183–9
wet bin storage 181–2, 183
harvesting and 25–6
malt 200–1
stripper-saw 117
submergence tolerance genome mapping 95
suction dividers 221
sugar 57, 215
sulphur 19
supervisory control and data acquisition (SCADA) 42

take-all (*Gaeumannomyces graminis*) 23
target plant population 19
technological advances
breadmaking 217–26, 227
breakfast cereals 163–70
flour milling 33–6
pasta drying 117–20
rice production 93
temperate adaptation 95
temperature
pasta drying 116, 117–20, 123–4
rice production 91
tempering 166–7
tert-butylhydroquinone (TBHQ) 149

test weight 82–3, 121
Thailand 132, 148
threonine 66
tillers 18–19
Toro-type rice 81, 86, 87
total milled rice yield 84
towers, malting 191–2
trace elements 19–20
translucency 83
twin screw extruders 165–6

Udon noodles 134, 137–8
ultra-high temperature (UHT) drying 116, 117–20, 123–4
uniformity 82
United Distillers 175
United States
  specialty rices 86
  Standards for Rice 86–90

variety
  barley 15–16
  durum wheat 127
  rice 79, 81–2
  selection 17–18
vitamins 70, 161, 162

Washburn Crosby Co. 159
water
  bread quality 215–16
  hydration of semolina 112–14
  rice production 91
waxy short-grain rice 86, 87
weather 24–5, 91
weeds
  control 22–3
  pests 92
  problems of escape of herbicide genes to 54–5
Weetabix 159, 160
weighing 163, 170
wet bin storage 181–2, 183
wet milling 27–8
wheat
  Asian noodles 132
    influence of wheat characteristics 132–3
  biotechnology 61–2
    transformed wheat 65–7
  durum wheat 112, 121–5, 126–7
  flour and bread quality 14, 213–14
  milling *see* milling
  production 7–13
  uses 13–15, 63
  see also flour
wheat bulb fly 24
wheat feed 30
white flour 30
  see also flour
white salted noodles (WSN) 136–4-3
  flour requirements 139, 140
  hand-made noodles 136–7
  processing 139–43
  Udon noodles 134, 137–8
whole-kernel yield 84
winter cereals 18, 20–1

X-ray fluorescence 36, 37
Xa21 gene 95

yeast 214–15
yield
  cereal yields 9–10
  rice 90–1
    milling yield 84