

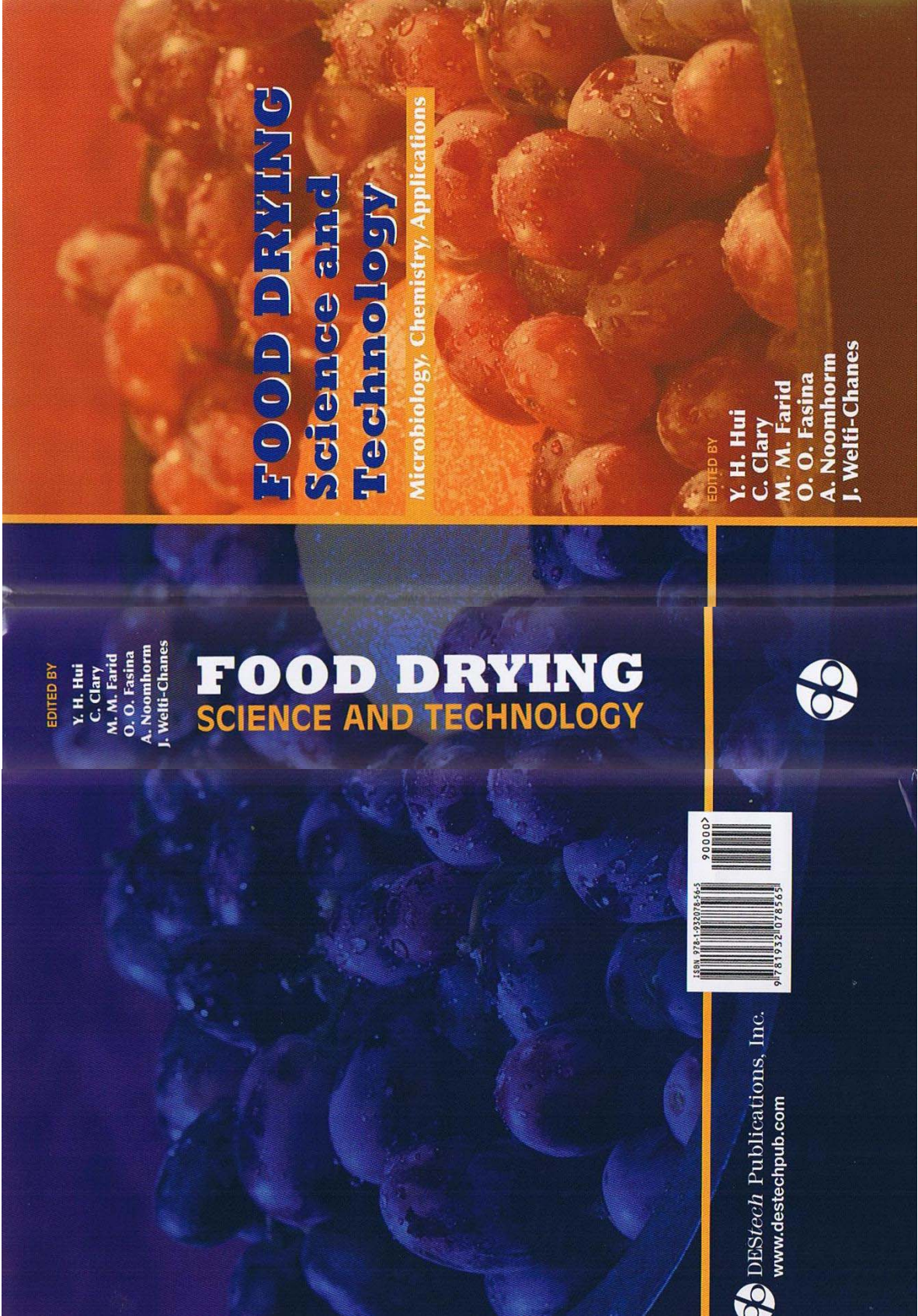


FOOD DRYING **Science and** **Technology**

Microbiology, Chemistry, Applications

EDITED BY

Y. H. Hui
C. Clary
M. M. Farid
O. O. Fasina
A. Noomhorm
J. Welti-Chanes



FOOD DRYING Science and Technology

Microbiology, Chemistry, Applications

EDITED BY

Y. H. Hui
C. Clary
M. M. Farid
O. O. Fasina
A. Noomhorm
J. Welti-Chanes

EDITED BY

Y. H. Hui
C. Clary
M. M. Farid
O. O. Fasina
A. Noomhorm
J. Welti-Chanes

FOOD DRYING SCIENCE AND TECHNOLOGY



DEStech Publications, Inc.
www.destechpub.com

FOOD DRYING **Science and** **Technology**

Microbiology, Chemistry, Applications

EDITED BY

Y. H. Hui, Ph.D.
Science Technology Systems

Carter Clary, Ph.D.
Washington State University

Mohammed M. Farid, Ph.D.
The University of Auckland

Oladiran O. Fasina, Ph.D.
Auburn University

Athapol Noomhorm, Ph.D.
Asian Institute of Technology

Jorge Welti-Chanes, Ph.D.
University De Las Americas-Puebla



DEStech Publications, Inc.

Food Drying Science and Technology

DEStech Publications, Inc.
439 North Duke St., 1st Floor
Lancaster, Pennsylvania 17601 U.S.A.

Copyright © 2008 by DEStech Publications, Inc.
All Rights Reserved

No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of the publisher.

Printed in the United States of America
10 9 8 7 6 5 4 3 2 1

Entry under main title:
Food Drying Science and Technology: Microbiology, Chemistry, Applications

A DEStech Publications book
Bibliography: p.
Includes index p. 781

Library of Congress Catalog Card No. 2006935305
ISBN No. 978-1-932078-56-5

HOW TO ORDER THIS BOOK

BY PHONE: 866-401-4337 or 717-290-1660, 9AM-5PM Eastern Time

BY FAX: 717-509-6100

BY MAIL: Order Department
DEStech Publications, Inc.
439 North Duke St., 1st Floor
Lancaster, PA 17601, U.S.A.

BY CREDIT CARD: American Express, VISA, MasterCard

BY WWW SITE: <http://www.destechpub.com>

Contents

Preface xiii

1. Fundamentals of Food Dehydration	1
<i>Shyam S. Sablani and M. Shafiur Rahman</i>	
Introduction	1
Mechanisms of Mass Transport	2
Molecular Diffusion/Moisture Diffusivity in Foods	5
Mass Transfer Coefficient	11
Water Activity and Water Sorption Isotherms	16
Drying Rate Curves	25
Quality of Dried Products	27
Nomenclature	34
References	35
2. Unified Approach to the Analysis of the Different Drying Processes	43
<i>Mohammed Farid</i>	
Introduction	43
Numerical Analysis of Moving Boundary Problems	45
Quasi-Steady State Analysis for Drying of Flat Geometry (The Unified Approach)	47
Model Validation Against Some Experimental Measurements (Flat Geometry)	49
Quasi-Steady-State Analysis for Spherical Geometry (The Unified Model)	55

Theoretical Prediction of Complete Drying/Frying Time of Foods of Different Geometry Using the Unified Model	57
Validity of the Unified Model for the Prediction of Drying/Frying Time of Food Materials Having Different Geometry	59
Nomenclature	63
Acknowledgment	64
References	64
3. Food Dehydration and Developing Countries	67
<i>Chua Kian Jon and Chou Siaw Kiang</i>	
Introduction	67
Solar Drying	68
Infrared Drying	72
Biomass Dryer	73
Low Cost Convective Dryers	75
Fluidized Bed Dryer	77
Spouted Bed Dryer	79
Conclusions	80
References	81
4. Solar Assisted Drying of Foods	83
<i>Aurelio López-Malo and Luis Ríos-Casas</i>	
Introduction	83
Food Dehydration Basis	84
Solar Drying	85
Types of Solar Dryers	86
Air-Heating Collectors	90
Effect of Drying on Food Products	94
Conclusion	95
Acknowledgments	96
References	96
5. Rotary Drum Dryers	99
<i>Sudhagar Mani and Shahab Sokhansanj</i>	
Introduction	99
Classifications	100
Design Considerations	104
Heat and Mass Transfer Model	106
Residence Time Model	111

Dryer Control System	114
Cost Estimation	117
Conclusions	120
Nomenclature	120
References	122
6. Microwave Drying	127
<i>Heping Li and Hosahalli S. Ramaswamy</i>	
Introduction	127
Microwave Theory and Characteristics	129
Mechanisms of Microwave Heating	131
Microwave Drying	135
Selection Considerations for Microwave Drying	141
Microwave Drying Equipment	145
Microwave Drying Applications	149
Conclusions	153
References	154
7. Far Infrared Dehydration and Processing	157
<i>S. Cenkowski, S. D. Arntfield, and M. G. Scanlon</i>	
Fundamental Laws	157
Direct Radiative Heat Transfer	160
Penetration Depth and Absorptivity	162
IR Heat Sources	167
Mathematical Modeling of IR Drying	170
Benefits of IR Processing of Foods and Feeds	189
Future Directions	197
References	197
8. Vacuum Drying	203
<i>Athapol Noomhorm and Imran Ahmad</i>	
Introduction	203
Mechanism of Drying Under Vacuum	204
Equilibrium Moisture Content Under Vacuum	205
Applications of Vacuum Drying	205
Alternate Heat Sources	206
Vacuum Drying Effects on Food Quality	208
References	212
9. Spray Drying and Powder Properties	215
<i>Bhesh Bhandari</i>	
Introduction	215

Principles of Dehydration of Droplets	217
Components of a Spray Drying System	220
Single- and Two-Stage Drying	231
Thermal Efficiency	233
Key Performance Indicator of Spray Dryers	234
Operating Variables of Spray Dryer	235
Spray Dried Powder Properties	238
References	246

10. Heat Pump and Dehumidification Drying 249

C. G. Carrington

Introduction	249
Heat Pump Drying Technology	251
Design of Heat Pump Dryers	254
Contributions to Product Quality	264
Summary	268
References	269

11. Osmotic Dehydration of Foods 275

John Shi

Introduction	275
Applications of Osmotic Dehydration in Food Processing	279
Major Factors of Osmotic Dehydration	283
Mass Transfer Characteristics During Osmotic Dehydration	287
Review of Existing Models for Osmotic Dehydration	290
Future Development	294
Acknowledgements	295
References	295

12. Novel Drying Technologies 301

Tadeusz Kudra

Intermittent Drying	301
Drying of Liquid and Pasty Materials in a Modified Spouted Bed with Counter-Rotating Streams of Inert Particles	304
Drying With Granulation	311
Multispout Fluid Bed Dryer	312
Pulsed Fluid-Bed Dryer	315
Acknowledgments	320
References	320

13. Vacuum Fluidized Bed Drying	323
<i>B. U. Kozanoglu and J. Weltri-Chanes</i>	
Introduction	323
Hydrodynamics of a Vacuum Fluidized Bed	324
Drying Process in a Vacuum Fluidized Bed	328
Conclusions	335
Nomenclature	335
References	336
14. Packaging and Storage of Dried Foods	339
<i>Qingyue Ling and Yanyun Zhao</i>	
Introduction	339
Functions of Food Packaging	340
Components of Food Packaging	343
Key Factors in Dried Food Packaging and Storage	344
Packaging Materials for Dried Foods	350
Packaging Technologies for Dried Foods	354
Storage for Dried Foods	356
References	357
15. Food Drying Equipment and Design	359
<i>P. K. Bansal and K. Y. Chung (Agnes)</i>	
Introduction	359
Solar Dryers	363
Contact Dryers	370
Spray Dryers	374
Fluidised Bed Dryers	387
Freeze Dryers	391
Dielectric Dryers	393
Selection Procedure of a Drying System	401
Conclusion	401
References	401
16. Freeze-Drying	403
<i>Stella M. Alzamora, Fidel Vergara-Balderas, and Jorge Weltri-Chanes</i>	
Introduction	403
Freeze-Drying Stages	405
Heat and Mass Transfer in Freeze-Drying	407
Influence of Parameters	411
Components of a Freeze-Dryer	413
Conclusions	414
References	415

17. Freeze-Drying of Fruits and Vegetables: Process Variables, Quality, and Stability	417
<i>Aurelio López-Malo and Enrique Palou</i>	
Introduction	417
Process Conditions	418
Quality and Stability	427
Final Remarks	430
Acknowledgments	431
References	431
18. Freeze-Drying of Meats and Seafood	435
<i>A. Valdez-Fragoso, L. D. Argüelles-Piña, O. Martínez-García and H. Mújica-Paz</i>	
Introduction	435
Physical Structure	436
Sensory Properties	438
Stability	438
Glass Transition	442
Conclusions	444
References	445
19. Specialty Foods	447
<i>Daniela Bermúdez-Aguirre, Maria S. Tapia, and Jorge Welti-Chanes</i>	
Introduction	447
Space Mission Foods	449
Military Foods	453
Foods for Special Diets	455
Foods for Sports Groups	458
Foods for Pets	458
Other Freeze-Dried Foods	459
Final Remarks	459
References	460
20. Banana Dehydration	463
<i>Krzysztof N. Waliszewski and Violeta T. Pardo</i>	
Banana as an Industrial Commodity	463
Banana Processing	464
General Considerations of Dehydration	465
Banana Osmotic Dehydration	466
Banana Combined Drying	470
Banana Solar Drying	471
Banana Frying	472

Banana Freeze Drying	473
General Conclusions	474
References	474
21. Drying of Mango (<i>Mangifera Indica</i> L.) and Mango Products	477
<i>Ponciano S. Madamba</i>	
Introduction	477
Quality of Dried Mango Products	479
Drying and Dehydration Systems of Fruits and Vegetables	480
Optimization of Drying Processes	496
Appropriate Drying Technologies	497
Conclusions	497
References	499
22. Pear Drying	503
<i>Raquel de Pinho Ferreira Guiné</i>	
Introduction	503
Shrinkage Characteristics	505
Sorption Isotherms	510
Drying Kinetics	517
Moisture Diffusivity	523
Commercial Drying	527
Acknowledgment	533
References	533
23. Drying of Plums	537
<i>Marisa Di Matteo, Luciano Cinquanta, and Silvestro Crescitelli</i>	
Introduction	537
Plum Drying Kinetics and Modeling	538
The Effect of Drying on Plums Quality	546
Nomenclature	551
References	551
24. Chili (<i>Capsicum annuum</i>) Drying	555
<i>Rosa María Galicia-Cabrera</i>	
Introduction	555
Origin	556
Taxonomy and Anatomy	556
Production	559
Harvesting	563

Drying of Ripened Chilies	563
Other Dry Chilies	571
Acknowledgments	572
References	572
25. Onion Drying	575
<i>Maria João Barroca and Raquel de Pinho Ferreira Guiné</i>	
Introduction	575
Chemical and Physical Properties	576
Sorption Isotherms	588
Drying Kinetics	592
Commercial Drying	596
References	597
26. Tomato Dehydration	603
<i>Henry T. Sabarez</i>	
Introduction	603
The Production of Dried Tomatoes	604
Tomato Drying Process	608
Factors Affecting Tomato Drying	612
Methods of Drying Tomatoes	616
Quality of Dried Tomatoes	623
Modeling the Drying Kinetics of Tomatoes	624
References	625
27. Drying Behavior of Starches and Gels	629
<i>Ferhunde Us, E. Aytunga Arik, and Didem Uzman Lenz</i>	
Introduction	629
Sorption Isotherms of Starch	630
The Drying of Starches and Gels	636
Conclusions	642
References	643
28. Deep-Fat Frying of Potatoes	645
<i>Pedro Moyano and Franco Pedreschi</i>	
Introduction	645
Deep-Fat Frying of Potatoes	646
French Fries	648
Potato Chips	649
Oil Uptake in Fried Potatoes	650
Modeling the Deep-Fat Frying Process	651
Microstructure of Fried Potatoes	658

Acrylamide Formation in Fried Potatoes	660
Acknowledgments	663
References	663
29. Pasta Drying	669
<i>A. McNabb and R. S. Anderssen</i>	
Introduction	669
The Composition and Structure of Pasta	670
Water Content of Pasta	671
Porosity of Pasta	672
Volume Changes versus Water Content Changes	675
Equilibrium States	675
Compressive Drying Stresses	676
Compressibility of the Solid Phase	677
Young's Modulus	679
The Dynamics of Drying	681
The Three Phases of Internal Drying	682
Conclusions	686
Appendix 1. Compressive Drying Stresses Due to Surface Tension Effects	688
Appendix 2. Enthalpy Changes during Drying	689
Appendix 3. Enthalpy Changes Due to Surface Tension	690
Acknowledgments	690
References	691
30. Milk Powders	693
<i>P. M. Kelly</i>	
Introduction	693
Milk Powder Properties	695
Relationship Between Spray Drying Conditions and Powder Properties	699
Adapted Processing Protocols for the Manufacture of Different Types of Milk Powders	703
Milk Powder Functionality and Selected Applications	710
Quality Assurance and Food Safety Aspects	714
Conclusions	716
References	716
31. Dehydration of Muscle Foods	721
<i>Antoine Collignan, Sunita Santchurn, and Nadine Zakhia-Rozis</i>	
Introduction	721

Techniques for Meat Dehydration 723
Classification of Dehydrated Meat Products 726
Evolution of Meat Quality During Dehydration
 and Storage 735
Conclusion 738
References 739

32. Fish Drying 745

Jose P. Peralta

Introduction 745
Fish as Food 746
Fish Spoilage 747
Salting as a Compliment to Drying 748
Fish Drying Principles 751
Methods of Fish Drying 759
General Fish Drying Process 763
Product Forms 766
Dried Fish Quality and Defects 772
References 775