



edited by Kiyoshi Toko

Biochemical Sensors

Mimicking Gustatory and Olfactory Senses



edited by Kiyoshi Toko

Biochemical Sensors

Mimicking Gustatory and Olfactory Senses



PAN STANFORD



PUBLISHING

Published by

Pan Stanford Publishing Pte. Ltd.
Penthouse Level, Suntec Tower 3
8 Temasek Boulevard
Singapore 038988

Email: editorial@panstanford.com

Web: www.panstanford.com

British Library Cataloguing-in-Publication Data

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

Biochemical Sensors: Mimicking Gustatory and Olfactory Senses

Copyright © 2013 Pan Stanford Publishing Pte. Ltd.

All rights reserved. This book, or parts thereof, may not be reproduced in any form or by any means, electronic or mechanical, including photocopying, recording or any information storage and retrieval system now known or to be invented, without written permission from the publisher.

For photocopying of material in this volume, please pay a copying fee through the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923, USA. In this case permission to photocopy is not required from the publisher.

ISBN 978-981-4267-07-6 (Hardcover)

ISBN 978-981-4303-42-2 (eBook)

Printed in the USA

Biochemical Sensors

Preface

Gustatory and olfactory senses receive chemical substances. Recent developments in biochemical and genetic sciences have clarified these mechanisms. As a result, sensor technologies to mimic the mechanisms have appeared and progressed. A taste sensor, i.e., an electronic tongue with global selectivity, can discriminate taste and also quantify it by providing the "scale of taste"; it has begun to be used in food and medical companies all over the world. Global selectivity means the ability to decompose the characteristics of a chemical substance into those of each type of taste and to quantify the taste. As for electronic noses, several types of devices have been developed so far. They are used in many fields such as foods, perfumery, medicine, robotics, as well as safety and security, including protection from terrorism and disaster. Electronic tongues and noses are fabricated using nanotechnology, materials science, biotechnology, biomedical engineering, electronic engineering, information science, chemistry, and biology; i.e., they are nothing but the products of interdisciplinary research.

This book comprehensively treats sensors for gustatory and olfactory senses, and also related topics such as gas sensors, chemical sensors, molecular-recognition devices, BioMEMS, μ TAS, and lab-on-a-chip. Recent development of these sensors has been very rapid. Other kinds of sensors corresponding to the senses of touch, sight, and hearing are already completed and spread. Sensor development, which is related to the above chemical senses and biological viewpoints, is active on the basis of that situation.

Part 1 focuses on the taste sensor and describes its basic principles and applications to foods and medicines. Each gustatory receptor for the five basic tastes simultaneously receives multiple chemical substances and shows a semi-selective property; as a result, the taste of foods is decomposed into each type of taste by each taste receptor, which does not discriminate between individual chemical substances. The taste sensor is a kind of electronic tongue

developed by mimicking the mechanism of the human tongue. Part 1 provides many application examples such as tea, coffee, meat, wine, soup, and several kinds of medicines.

Part 2 reviews electronic noses and highlights the recent developments in related topics such as odor recorder and molecular-wire-type sensor, and concrete application examples. Part 3 presents application examples of the taste sensor, gas sensors, and surface-plasmon-resonance biosensors to the field concerned with safety and security, and also related molecular-recognition devices and the lab-on-a-chip system.

All individual chapters are written by leading experts in the corresponding fields. This book is a practical and user-friendly textbook for researchers and postgraduate students in academics and industry areas who are involved in food and medical production and science, and also in scientific fields such as sensor technology, nanotechnology, materials science, and bioengineering.

I wish to thank all the contributing authors of this book. I would like to give sincere thanks to Ms. H. Chiba and Dr. H. Cui for their editorial help. I also wish to express my endless gratitude to my wife, Kayano, for her warm support.

Kiyoshi Toko
Spring 2013

Contents

Preface

xxi

PART 1 TASTE SENSOR

1A. Basic Principles of Taste Sensor

1. Advanced Taste Sensors Based on Artificial Lipid Membrane 5

Yoshikazu Kobayashi and Hidekazu Ikezaki

1.1	Introduction	6
1.2	Multichannel Taste Sensor	7
1.2.1	Artificial Lipid-Based Membrane	7
1.2.2	Fabrication of Taste Sensors	9
1.2.3	Measurement System	11
1.2.4	Response Mechanisms	12
1.2.5	Measurement Procedure	14
1.3	Techniques for Taste Sensor Design	16
1.3.1	Requirements for Advanced Taste Sensors	16
1.3.2	Optimization of Electric Charge Density of Membrane	20
1.3.3	Optimization of Hydrophobicity of Membrane	23
1.4	Characteristics of Taste Sensor	24
1.4.1	Types of Taste Sensors	24
1.4.1.1	Umami sensor	26
1.4.1.2	Saltiness sensor	27
1.4.1.3	Sourness sensor	27
1.4.1.4	Bitterness sensor	27
1.4.1.5	Astringency sensor	27
1.4.1.6	Sweetness sensor	28

1.4.2	Thresholds	28
1.4.3	Global Selectivity	29
1.4.4	Definition of Information	32
1.4.5	Detection of Interactions between Taste Substances	34
1.5	Summary	37
2.	Taste Sensor for Sweetness	45
	<i>Kentaro Toyota, Hong Cui, and Masaaki Habara</i>	
2.1	Introduction	46
2.2	Basic Characteristics	46
2.2.1	Concentration Characteristics	46
2.2.2	Response to Sugars and Sugar Alcohols	47
2.2.3	Response to Brown Sugars	49
2.2.4	Examples of Data	50
2.3	Response Characteristics	52
2.3.1	Similarity to Human Sensation with Regard to pH	52
2.3.2	Similarity to Human Sensation with Regard to Other Tastes	53
2.3.3	Similarity to Human Sensation with Regard to Temperature	55
2.3.4	Background Behind the Similarity	56
2.3.5	Usefulness of GL1 Sensor	57
2.4	Summary	58
	1B. Application to Foods	
3.	Techniques for Objective Evaluation of Tea Tastes	63
	<i>Nobuyuki Hayashi and Ronggang Chen</i>	
3.1	Introduction	63
3.2	Standard Solution and Estimated Intensity of Taste	64
3.3	Evaluation of Astringent Taste Intensity of Japanese Green Tea	66

3.3.1	Sample Preparation, Measurement, and Grading	66
3.3.2	Relationship between EIT Values and Amount of the Taste Substances	68
3.3.3	Detection of Depression of Catechin Astringency by Pectin	69
3.4	Evaluation of Umami Taste Intensity of Japanese Green Tea	70
3.5	Evaluation of Astringent Taste Intensity of Black Tea	72
3.6	Conclusion	73
4.	Characterization of Tea Taste in Terms of Degree of Fermentation	75
	<i>Masashi Omori and Ronggang Chen</i>	
4.1	Introduction	76
4.2	Evaluation of the Taste of Tea	77
4.2.1	Changes in Taste due to Fermentation Processes	77
4.2.1.1	Sample preparation	77
4.2.1.2	Evaluation of change in the taste of tea due to fermentation	78
4.2.2	Tastes of Different Types of Tea	79
4.2.2.1	Sample preparation	79
4.2.2.2	Evaluation of difference in the degree of fermentation of various teas	80
4.3	Conclusion	80
5.	Application of Taste Sensor to Blending of Coffee	83
	<i>Tomohiro Ishiwaki</i>	
5.1	Introduction	84
5.2	Materials and Methods	85
5.3	Tastes of Coffees Captured by Taste Sensor	85
5.4	Application of Taste Sensor to Blending of Coffee	87

6. Meat 91*Shinobu Fujimura and Keisuke Sasaki*

6.1	Introduction	92
6.2	Beef and Pork	94
6.2.1	Beef	94
6.2.1.1	Taste characteristics of beef	94
6.2.1.2	Early studies of beef evaluation using the electric tongue	94
6.2.1.3	Discrimination of muscle parts of beef by taste sensor	95
6.2.2	Pork Breeds	97
6.2.2.1	Taste characteristics of pork	97
6.2.2.2	Discrimination of pork breeds by taste sensor	97
6.3	Investigation of Novel Taste Components	99
6.3.1	Taste-Active and -Enhancing Peptides in Muscle Foods	99
6.3.2	Investigation of Novel Taste-Enhancing Peptides Using the Taste-Sensing System	99

7. Application of Multichannel Taste Sensor for Winemaking 103*Akira Totsuka*

7.1	Introduction	104
7.1.1	Composition of Wine Taste	104
7.1.2	Sensory Evaluation of Wine Taste	105
7.2	Application of Multichannel Taste Sensor for Wine Palate	105
7.2.1	Process of Vinification and Quality Evaluation	106
7.2.2	Relationship between Yeast Strain and Wine Quality in Premier Fermentation	107
7.2.3	Conversion of Organic Acids by Malo-Lactic Fermentation	108
7.2.4	Determination of Immersion Period of Oak Chips (les Copeaux de Chêne)	109

7.2.5	Change in Wine Quality due to Contact with Lees	110
7.2.6	Reproducibility of Blended Wine and Its Quality	111
7.2.7	Effect of Temperature on Quality of Wine	113
7.2.8	Management of Claims about Wine Taste Using an MCTS	114
8.	Investigation into the <i>Kokumi</i> Taste of Soup Stock Materials	117
	<i>Mikiharu Doi</i>	
8.1	Introduction	117
8.2	Evaluation of <i>Kokumi</i> Taste	118
8.2.1	<i>Fushi</i> Products	118
8.2.2	<i>Arabushi</i> and <i>Karebushi</i>	119
8.2.3	Synergetic Effect	121
8.2.4	Salt Use Reduction Effect	122
8.2.5	<i>Okaka</i> (<i>Katsuobushi</i> Mixed with Soy Sauce)	123
8.2.6	BONIZYME (<i>Kokumi</i> Liquid Seasoning)	123
9.	Rice Quality Evaluation Using a Taste-Sensing System	127
	<i>Uyen Thi Tran and Ken'ichi Ohtsubo</i>	
9.1	Introduction	128
9.2	Analysis of the Tastes of Brown Rice and Milled Rice	130
9.2.1	General Considerations	130
9.2.2	The Relationship between Response Patterns of Sensors and Values from Chemical Analyses and Sensory Evaluation	130
9.3	Detection of Changes in Taste of Different Rice during Storage	132
9.3.1	General Considerations	132

9.3.2	Changes of Stored Brown Rice and Milled Rice at Room and Low Temperature Detected by the Taste-Sensing System	133
9.4	Discrimination of Pre-Washed Rice and Common Rice Using the Taste-Sensing System	134
9.4.1	General Considerations	134
9.4.2	Comparison of the Tastes of Pre-Washed Rice and Common Rice	135

1C. Application to Medicines

10. Quantitative Evaluation of Bitterness of Medicines 145

Takahiro Uchida and Miyako Yoshida

10.1	General Introduction	146
10.2	Quantitative Bitterness Prediction or Bitterness Suppression of Basic Drugs Using a Taste Sensor	148
10.2.1	Introduction	148
10.2.2	Evaluation of Bitterness of Medicines by Taste Sensor	150
10.2.3	Evaluation of Bitterness Suppression of Quinine by Taste Sensor	151
10.3	Quantitative Bitterness Prediction or Bitterness Suppression of Antibiotics, Clarithromycin Using a Taste Sensor	153
10.3.1	Introduction	153
10.3.2	Evaluation of Bitterness Suppression of Clarithromycin Dry Syrups by Jellies	156
10.3.3	Evaluation of Bitterness Suppression of Clarithromycin Dry Syrups Mixed with an Acidic Powder	160
10.4	Taste Sensory Evaluation of Chinese Medicines and Medical Plants	163
10.4.1	Introduction	163
10.4.2	Sensor Analysis of Chinese Medicines	164
10.4.3	The Possible Use of Taste Sensor in Quality Control of Medical Plants	166

10.5	Quantitative Taste Evaluation of Total Enteral Nutrients	168
10.5.1	Introduction	168
10.5.2	Quantitative Sweetness, Sourness and Bitterness Evaluation of Total Enteral Nutrients	168
10.5.3	Principal Component Analysis of Total Enteral Nutrients by Taste Sensor	171
10.6	Quantitative Bitterness Prediction or Bitterness Suppression of Orally Disintegrating Tablet Using a Taste Sensor	173
10.6.1	Introduction	173
10.6.2	Bitterness Comparison of Famotidine Orally Disintegrating Tablet and Generic Products	173
10.6.3	Evaluation of Bitterness for Orally Disintegrating Tablet by Combination of Taste Sensor and Newly Developed Disintegration Testing Apparatus	177
10.7	Discussion and Future Trend	181
11.	Development and Characterization of Medicines for Children	185
	<i>Katharina Bohnenblust-Woertz, Miriam Pein, and Jörg Breitreutz</i>	
11.1	Introduction	186
11.2	Child-Appropriate Oral Dosage Forms	187
11.2.1	Regulatory Framework	187
11.2.2	Characteristics of Child-Appropriate Dosage Forms	189
11.2.3	Challenges in Taste Assessment of Medications for Children	191
11.3	Liquid Dosage Forms	192
11.3.1	Oral Solutions (Drops, Syrups)	192
11.3.2	Emulsions	193
11.3.3	Suspensions	194
11.4	Solid Dosage Forms	194

11.4.1	Monolithic Solid Dosage Forms	194
11.4.2	Multiparticulate Solid Dosage Forms	195
11.4.3	Orodispersible Dosage Forms	197
11.5	Implementation Strategies of an Electronic Taste Sensor	198
11.5.1	Qualification/Validation	198
11.5.2	Bottom-Up Approach for the Development of Taste-Masked Formulations	199
11.5.3	Top-Down Approach for the Development of Generic Formulations with Similar Taste Properties	200
11.6	Conclusion	201
12.	Herbal Medicines	205
	<i>Yukihiro Goda, Naoko Anjiki, and Nobuo Kawahara</i>	
12.1	Introduction	205
12.2	Taste of Processed Aconite Roots	206
12.2.1	What Is PAR?	206
12.2.2	Taste Patterns of PAR Obtained by the Taste-Sensing System	207
12.2.3	Differences in Taste Intensities among the Four PAR Types	210
12.2.4	Discussion on the Taste of PAR	212
12.2.5	Discrimination among the Four Types of PAR by Taste Characteristics	213
12.2.6	Conclusion on the Taste of PAR	214
12.3	Comparison of Tastes among Kampo Formulae	215
12.3.1	Kampo Medicines and JP	215
12.3.2	Tastes of the Five Kampo Formulae	215
12.3.3	Discussion on the Taste of Kampo Formulae	218
12.3.4	Merits of a Taste-Sensing System for Evaluating the Taste of Kampo Formulae	220
12.4	Taste of Kakkonto and Its Component Crude Drugs	220

12.4.1	Taste of Kakkonto	220
12.4.2	Taste of the Component Crude Drugs	223
12.4.3	Discussion on the Taste of Kakkonto and Its Component Crude Drugs	224
12.4.4	Determinant Taste Factor of Kakkonto Formula	227
13.	Quality Engineering Approach to Bitterness-Masked Formulations and Establishment of Bitterness Masking Evaluation System Using Taste-Sensing System	231
	<i>Keijiro Terashita and Osamu Wakabayashi</i>	
13.1	Introduction	232
13.2	Quality Engineering and Bitterness Masking Evaluation System	233
13.2.1	Parameter Design	233
13.2.2	Bitterness Masking Evaluation System	234
	13.2.2.1 Overview	234
	13.2.2.2 Calculation of SN ratio	235
13.2.3	Experiments and Analysis	237
	13.2.3.1 Taste measurement	237
	13.2.3.2 Materials	237
	13.2.3.3 Factors, levels and experimental layout using L18 orthogonal array	238
	13.2.3.4 Sample preparation	241
13.2.4	Results and Discussion	241
	13.2.4.1 Bitterness masking SN ratio on main effect plot	241
	13.2.4.2 Analysis of variance	242
	13.2.4.3 Optimal condition and worst condition	243
	13.2.4.4 Formulation development by estimation of the bitterness masking SN ratio	244
	13.2.4.5 Optimal region for bitterness masking efficiency	245
13.3	Conclusion	246

PART 2 ELECTRONIC NOSES

14. Outline of Electronic Nose	253
<i>Hidehito Nanto</i>	
14.1 Introduction	254
14.2 Outline of e-NOSE System	254
14.3 Odor Sensors	255
14.3.1 Conductometric Types	258
14.3.1.1 MO-type odor sensor	258
14.3.1.2 OCP-type odor sensor	260
14.3.2 Capacitive Types	261
14.3.3 Potentiometric Types	261
14.3.4 Calorimetric Types	262
14.3.5 Gravimetric Types	262
14.3.5.1 Quartz crystal microbalance	263
14.3.5.2 Surface acoustic wave	264
14.3.6 Optical Types	264
14.3.6.1 Surface plasmon resonance	264
14.3.6.2 Fluorescent-type odor sensor	265
14.3.7 Amperometric Types	266
14.4 e-NOSE System and Its Applications	267
14.4.1 Machine Olfaction of Mobile Robots	272
14.4.2 Medical Diagnosis and Health Monitoring	273
14.5 Summary of e-NOSE System	275
15. Odor Recorder and Olfactory Display	285
<i>Takamichi Nakamoto</i>	
15.1 Introduction	286
15.2 Odor Recorder	287
15.2.1 Research Trend	287
15.2.2 Principle Based on Active Sensing	288
15.2.3 Experiment on Recording Fruit Flavors	290
15.2.4 Experiment on Recording Fruit Flavors Using Mass Spectrometry	292

15.3	Olfactory Display	294
15.3.1	Research Trend of Olfactory Display	294
15.3.2	Odor Blending Method	295
15.3.3	Olfactory Display Using Multiple Solenoid Valves	296
15.3.4	Cooking Game with Scents	298
15.4	Teleolfaction	299
15.5	Conclusion	301
16.	Odor Sensors Based on Molecular Wire and Nanofibers	305
	<i>Kenshi Hayashi and Chuanjun Liu</i>	
16.1	AuNPs Nanogap Electrode	306
16.2	AuNP Nanowire Sensor	309
16.3	AuNP Nanofiber Sensor	312
17.	Odor Continuous Measurement Using Electronic Nose	321
	<i>Junichi Kita</i>	
17.1	Introduction	321
17.2	Why Scientific Evaluation of Odors Is So Difficult?	322
17.3	Electronic Nose	325
17.4	Application Example	328
17.5	Summary	331
18.	Sensors for Monitoring Harmful Gases and Organic Floating Particles	333
	<i>Kazuhiro Hara</i>	
18.1	Introduction	334
18.2	Experimental	335
18.2.1	Sensor Configuration	335
18.2.2	Sensor Fabrication	337
18.2.3	Experimental Setup	337
18.3	Sensing Performance	337
18.3.1	Response to Polluting Gases	337
18.3.2	Response to Engine Exhaust Gases	340
18.3.3	Response to Cigarette Smoke	341