PHYSICAL PROPERTIES OF FOODS

Edited by
Ronald Jowitt
Felix Escher
Bengt Hallström
Hans F. Th. Meffert
Walter E. L. Spiess
Gilbert Vos

APPLIED SCIENCE PUBLISHERS

PHYSICAL PROPERTIES OF FOODS

Edited by

RONALD JOWITT
Formerly, National College of Food Technology, Weybridge, UK

FELIX ESCHER
Department of Food Science, Swiss Federal Institute of Technology, Zurich, Switzerland

BENGT HALLSTRÖM
Department of Food Engineering, Lund University, Sweden

HANS F. Th. MEFFERT
Sprenger Institute, Wageningen, The Netherlands

WALTER E. L. SPIESS
Federal Research Institute for Nutrition, Karlsruhe, Federal Republic of Germany

GILBERT VOS
Commission of the European Communities, Brussels, Belgium

APPLIED SCIENCE PUBLISHERS
LONDON and NEW YORK

APPLIED SCIENCE PUBLISHERS LTD
Ripple Road, Barking, Essex, England

Sole Distributor in the USA and Canada
ELSEVIER SCIENCE PUBLISHING CO., INC.
52 Vanderbilt Avenue, New York, NY 10017, USA

British Library Cataloguing in Publication Data

Physical properties of foods
1. Food industry and trade—Congresses
2. Food—Quality—Congresses
I. Jowitt, Ronald
641.1 TP368

ISBN 0-85334-213-X

WITH 45 TABLES AND 116 ILLUSTRATIONS

Publication arrangements by: Commission of the European Communities, Directorate-General Information Market and Innovation, Luxembourg

Printed in Great Britain by Galliard (Printers) Ltd, Great Yarmouth

Editorial Note

The editing of these Proceedings was delegated by the COST 90 COST–Community Coordinating Committee (CCCC) to the COST 90 'Executive Committee' which comprised:

Bengt Hallström, *Chairman, COST 90 CCCC and 'Executive Committee'*
Walter E. L. Spiess, *Vice Chairman, COST 90 CCCC, Chairman, Water Activity subgroup*
Felix Escher, *Chairman, Rheology subgroup*
Hans F. Th. Meffert, *Chairman, Thermal Properties subgroup*
Gilbert Vos, *COST 90 Project Technical Secretary*
Ronald Jowitt, *COST 90 Project Leader, with overall editorial responsibility*

Statements and opinions expressed in these Proceedings are those of the individual authors and not necessarily those of the editors, the publishers, the Commission or other participants in the COST 90 Project.

Foreword

A consumer spends more money for nutrition than for any other single purpose. Materials from agriculture, horticulture or aquaculture are rarely suitable for direct consumption. In some cases they will be remodelled completely as is grain to bread; in other cases it is a matter of preserving the sensitive material, as in freezing of green peas. Preservation is needed because the raw materials and the consumers are usually far apart, both in place and in time. As a result, the food industry in its widest sense is of a vast size and any improvement, however small, on an international scale will have a potentially large influence leading to higher quality or lower price to the consumers.

Food availability and food distribution are primarily socio-economic and political matters. However, many of the associated problems are of a scientific and technological nature and some are suitable for international cooperation. Better understanding of such problems, and solutions to them, will promote trade in industrially processed food products and thus be beneficial to the food and allied industries and to the consumers.

In July 1974 the Swedish government suggested the idea of COST projects in the area of food technology. The idea was well received at a COST Senior Officials meeting and a formal proposal was submitted by Sweden in a letter to the Secretary General of the Council of the European Communities dated 4 December, 1974. Three projects were recommended:

1. Physical properties of food.
2. Quality attributes of food.
3. Nutritional properties of food.

Concerning physical properties of food, it was stated in the official letter that 'knowledge of physical properties is needed for process development and control. The change of rheological properties (i.e. consistency, texture, etc.) with temperature and flow velocity, and the change of thermal properties when mixing ingredients, are important examples'.

The following activities were suggested for this project:

a. Coordination and structuring of national efforts to collect data on physical properties of foodstuffs. A European centre should be appointed to collect, classify and make data readily available.

b. Development and standardisation of methods for measuring physical properties of foodstuffs. Testing of methods in practical work.

c. Experimental studies with the aim of developing simple methods for measuring physical properties which correlate with quality properties.

The Committee of Senior Officials decided in April 1975 to set up an *ad hoc* Working Party to study, examine in detail and finalise a proposal from the Swedish delegation for setting up a COST Working Party on Food Technology with the aim of encouraging research in the food industry sector.

In such a vast area as food technology with appreciable research activities going on in the 19 member countries, it has been important to define certain criteria which would be the basis for project selection and project priorities. The Working Party agreed on the following criteria in the course of the preparation of the report:

1. The project shall make an important contribution to research and development for the food and related industries.
2. The project shall draw specific advantage from the fact that several nations are involved.
3. The project shall stimulate industrial development and trade in Europe.
4. The project shall lead to improvements for the consumer.
5. The project shall give rapid and practical results for the industry.

The EEC Council of Ministers' decision to start COST 90—'The Effect of Processing on the Physical Properties of Foodstuffs'—was taken on 20 February, 1978. It is rewarding for all the participants and others to see how much has been achieved during its three to four years, as the final seminar in Leuven has proved. The participants, particularly the Project Leader and the Executive Committee, are to be congratulated on a splendid result.

The project has been important not only from a scientific and technical point of view, but has also shown that 'concerted action' is a feasible way to cooperate with a minimum of administration. This is promising for the other projects, COST 91 and COST 90 bis. I am sure there will be more food technology projects supported by COST in the future.

Erik von Sydow

Preface

COST 90, the first food technology project of COST and the first within the European Economic Community, was eventually initiated by a decision of the Council of Ministers on 20 February, 1978. Participating in the project were the 10 Community states (Belgium, Denmark, Eire, Federal German Republic, France, Greece, Italy, Luxembourg, The Netherlands, United Kingdom) and three other COST member states (Finland, Sweden and Switzerland). Towards the end of the project a seminar was held at Leuven, Belgium, on 9–11 September, 1981. This book is a collection of all the contributions to that seminar.

The primary objective of the seminar was to present the results of the three years' work of the project. The main part of this book therefore consists of contributions by members of the three project subgroups—Water Activity, Rheology and Thermal Properties, compiled and edited by the subgroup Chairmen. Further, at the seminar, invited external specialists gave their valuable views on the subject matter of the project and on the results. These contributions are also included in the book. Papers for the seminar were preprinted so that thorough and detailed discussion could take place and this, compiled and edited by the Project Leader, is also reported in this volume.

Since the Leuven seminar took place work has continued in the laboratories involved and the first year of a new project, COST 90 bis, is being devoted to finishing off the work on the three physical properties mentioned above. Further reporting will therefore be necessary and part of this will be published in well-known international journals.

This subsequent project, COST 90 bis, will deal with three further groups of physical properties (electrical/optical, mechanical and diffusion) and with data collection. The need for more permanent arrangements for physical property data will also be considered.

The editing of this book has been a joint task of the Executive Committee of the project. The main task has, however, been carried out by the Project Leader. I would like to take this opportunity to thank everybody who contributed to the seminar and to this book. I am especially indebted to my friends and colleagues in the Executive Committee, Felix Escher, Ronald Jowitt, Hans Meffert, Walter Spiess and Gilbert Vos.

BENGT HALLSTRÖM
Chairman, COST 90 CCCC and Executive

Contents

Editorial Note v

Foreword vii

Preface ix

List of Contributors xv

1. History and Orientation 1
B. HALLSTRÖM and R. JOWITT

Part 1: Water Activity

2. The Need for, and Practical Applications of, Sorption Data 13
S. GAL
Discussion

3. The Theory of Water Sorption by Biological Materials 27
I. C. WATT
Discussion

4. Using the 'G.A.B.' Model to Construct Sorption Isotherms 43
H. BIZOT
Discussion

5. A Survey of Existing Sorption Data 55
J. CHIRIFE
Discussion

6. The Results of the COST 90 Project on Water Activity . 65
W. E. L. SPIESS and W. R. WOLF
Discussion

A Note on the Systematic Errors in Water Activity Measurements of MCC Caused by Radiative Heat Loss . 88
A. C. JASON

7. Future Needs in Water Sorption in Foodstuffs . . . 93
R. B. DUCKWORTH
Discussion

Part 2: Food Rheology

8. Relevance of Rheological Data in Food Processing . . 103
F. ESCHER

9. The Use of Rheological Data in Structure Analysis and their Application in Food Engineering 111
A.-M. HERMANSSON

10. Results of the Collaborative Study on Measuring Rheological Properties of Foodstuffs 123
J. H. PRENTICE and D. HUBER

11. Guidelines for the Measurement of Rheological Properties and the Use of Existing Data 185
A. PRINS and A. H. BLOKSMA
Discussion

12. Implications for the Collection and Use of Rheological Property Data of Experience from the Collaborative Study . 193
B. LAUNAY and B. MCKENNA
Discussion

13. Disperse Systems: Dependence of Rheological Properties on the Type of Flow with Implications for Food Rheology . 205
H. GIESEKUS

14. Comments on Cost 90 Project Relating to the Rheological Properties of Liquid Foods 221
P. SHERMAN

Part 3: Thermal Properties of Foods

15. History, Aims, Results and Future of Thermophysical Properties Work within COST 90 229
H. F. TH. MEFFERT

16. Calculation of Thermophysical Properties of Foods . . 269
C. A. MILES, G. VAN BEEK and C. H. VEERKAMP

17. The Measurement of Thermal Properties 313
T. OHLSSON
Discussion

18. Critical Evaluation of Thermophysical Properties of Foodstuffs and Outline of Future Developments 331
J. D. MELLOR
Discussion

19. Information Systems for, and the Prediction of, Physical Properties of Non-Food Materials 355
R. ECKERMANN
Discussion

Part 4: General Considerations

20. Some Observations on COST 90
(1) J. T. CLAYTON 381
Discussion
(2) P. P. LEWICKI 384
(3) H. SCHUBERT 390
(4) A. KLOSE 393

21. General Conclusions and Recommendations 399
B. HALLSTRÖM and R. JOWITT
Discussion

22. Closing Address 407
J. P. CONTZEN
Discussion

Participants 415

Index 419

1

History and Orientation

B. HALLSTRÖM
Lund University, Sweden

and R. JOWITT*
Formerly, National College of Food Technology, Weybridge, UK

HISTORY

Introduction

There has for some years been widespread and varied interest in the physical properties of foodstuffs and in particular numerical values for particular properties of specific foodstuffs, fresh and processed. This information is required by the food professions for various purposes such as quality evaluation and the design, installation, operation and control of processes, plant and equipment concerned with food. Indeed, it is worth remembering that of all the wide variety of operations which are performed on foods, by far the greatest majority are concerned with subjecting the food to controlled physical or mechanical conditions even when the ultimate aim is to achieve or to minimise changes which are themselves chemical, biochemical, biological, microbiological or organoleptic. A knowledge of the physical properties of foodstuffs and their response to process conditions is necessary not only because they are of importance in their own right and because they affect the physical treatment received during processing, but also because they are the commonest indicator of other properties and qualities.

In this respect foodstuffs are, of course, not unique, in that many materials which are industrially processed have physical properties of great importance, and product specification in modern trade and industry is often in terms of a range of physical characteristics. However, food differs from most other industrial commodities in several important ways. In the first place, food being a biological material its composition, structure and hence

* Present address: c/o Department of Applied Biology and Food Science, Polytechnic of the South Bank, Borough Road, London SE1 0AA, UK.

its physical characteristics vary within a group of ostensibly identical products due to season, soil, climate, post-harvest handling differences, varietal differences, etc. One effect of this is that it is never possible to specify precisely the processing conditions for a particular foodstuff once and for all. It is desirable to be able to adapt the process continually in order to achieve optimum product quality. Another way in which food differs from other industrial materials is that it invariably completes its journey as individual portions on the consumer's plate or in the consumer's mouth. It must achieve consistently high levels of acceptability if it is not to be rejected at the final stage and it must of course consistently achieve levels of wholesomeness, purity and safety of the highest order. A third characteristic of foods is that organoleptic properties are assessed by the consumer with a degree of sensitivity and discrimination which still has no equal in instrumentation or analysis for many of its manifestations. For example, although food texture is essentially a physical characteristic, it is extremely difficult still to assess the texture of a foodstuff by instrumental means with the accuracy, consistency, sensitivity and discrimination of which even the most 'ordinary' consumer is capable.

It is for such reasons that design and operation of food processes are still much less advanced than is the case with other industrial processes. Many food operations are empirical, involving subjective judgement which cannot cope with unfamiliar eventualities and it has not yet become possible to relate changes in such food processes or products to physical conditions and properties which can be measured instrumentally. There is a great need, therefore, for greater information, data and understanding on the physical properties of foodstuffs in order that products and processes can be amenable to the rapidly increasing range of new technologies serving the process industries in general.

It might be that a complete description of food products and process conditions in purely physical terms will never be achieved, but equally it is certain that better physical property data will permit better control of both process and product for the benefit of producer, processor and consumer.

Recent History

One of the landmarks in this history was a paper presented at the European Food Symposium in Bristol in 1968 by Jason and Jowitt[1] on the importance of physical properties of foodstuffs in engineering design. Examples were given, along with a classification of foodstuffs and physical properties[2] and a comprehensive selection of references to published data. In addition, it was suggested that the task of data acquisition for the great range of foodstuffs which are normally processed was so prodigious as to require international collaboration. The latter (Jowitt) offered to provide, at the National College of Food Technology, an initial 'clearing house' for this collaboration, which led to the setting up of a PPFS (Physical Properties of Foodstuffs) nucleus there and to the formation of a PPFS working group within the Food Working Party of the European Federation of Chemical Engineering. This was enlarged in 1973 as a PPFS working group of the International Union of Food Science and Technology—IUFoST, in order to include interests in other parts of the world. Its work was, however, hampered due to lack of funds, despite support from certain quarters such as the Sainsbury Memorial Trust. The *Classification of Foodstuffs and Physical Properties* was later revised and published in English and German,[3] and a French version was produced within the period of this project.

Other Centres of Activity

For many years the Food Engineering Section of the Institute for Food Industry in Prague, under the leadership of Ing. Miloslav Adam, has conducted pioneering work in both the measurement of physical properties of foods and in the publication of two well-known bibliographies. The book by Tschubek and Maslow on 'Thermophysical Constants for Foodstuffs and Intermediates' was translated from the original Russian and published in German in Leipzig in 1973.[4] Kostaropoulos's book on 'Thermal Conductivity of Foodstuffs and Methods of Determination' was published also in German from Karlsruhe in 1971.[5] A number of books on the rheological properties of foodstuffs have appeared in recent years, as have Mohsenin's well-known volumes, *Thermal Properties of Foods and Agricultural Materials*.[6] Publications on food texture and its relation to physical properties of foodstuffs have appeared in North America, Europe and Japan, and a compendium of chapters under the title of *Theory, Determination and Control of Physical Properties of Food Materials* by a number of authors and edited by ChoKyun Rha was published in North America and Europe in 1975.[7] A more recent volume published in English, Polish and Russian in Warsaw in 1978 entitled *Physical Properties of Plant Materials and Their Influence on Technological Processes* recorded the transactions of an international conference organised by the Polish Academy of Sciences in Lublin in September 1976.[8]

Increasingly, data have been published in journals, conferences and symposia and several individuals and centres have become identified with property measurement—Heiss in Munich, Riedel *et al.*, and Spiess *et al.* in

Karlsruhe, Clayton and Rha in Massachusetts, Jason *et al.* in Aberdeen, Meffert in Wageningen, Mellor in Sydney, Chirife in Buenos Aires, etc.

The COST Approach

Despite the widespread interest in collaboration in this field and support for the IUFoST Working Party, there was clearly a need for financial support and it was at the initiative of Erik von Sydow of Sweden, who at the time was General Secretary of IUFoST, that an approach was made to COST in December 1974. With support from other European colleagues a proposal was constructed which, after some three or so years, was adopted by a decision of the Council of Ministers on the 20th February 1978 'adopting a concerted action project of the European Economic Community on the effect of processing on the physical properties of foodstuffs'.[9] This project became known as 'COST 90' and by means of agreements between the Community and Finland, Sweden and Switzerland, these three countries became full participants in the project. The project bears the number '90' because it was the first (O) project in the food field which bears the generic initial digit '9'. A sister project on the 'effect of thermal processing and distribution on the quality and nutritive value of food' was the subject of a Council decision in October 1979. This project is designated 'COST 91'.

Any further COST projects in the food field will presumably be numbered serially—COST 92, 93, etc. However, the work of COST 90 is being extended under project 'COST 90 bis'.

ORIENTATION

The early history and background to the COST 90 project have been dealt with in the first part of this paper. This section will deal with the more recent history of the project since its creation by the decision of the Council of Ministers on 20th February 1978 and with the general organisation and activities of the project. A dry account of organisational details can be tedious but in the process of understanding the possibilities and limitations of a project such as this it is important to appreciate how the project as a whole as well as its constituent parts is organised and works. A booklet on COST in general was published in 1981.[10]

Concerted Action

There are three types of European project:

Direct Action, in which the whole of the project is funded by the Community;

Indirect Action, in which only a proportion of the funds is provided by the Community; and

Concerted Action, in which the funding by the Community is limited to the payment of the costs involved in coordinating the work of participating States.

COST 90 is a Concerted Action project in which work carried out in the participating states' institutions, paid for by national or local funds, is coordinated with that of other participating states' institutions by the European Commission using funds allocated by the Community and by non-Community participating states. It will be noted that in such a project there are no funds available for supporting research work direct. Such funds as are available are used to meet the cost of meetings between participating workers and their travel to the various locations where such meetings are held. The administrative costs of the coordination work by the Commission are also met from the project budget.

The Council Decision

The authority to implement any project involving the Community is provided by a Decision of the Council of Ministers. This Decision is drafted by the Commission following consultation with representatives of Member States (and, where appropriate, non-Member States) and also with appropriate Standing Committees in the Community such as the Committee for Research in Science and Technology (CREST), on which the Community States are represented. The Council Decision embodies the terms of reference for the project and provides for such things as Steering Committees, the exchange of information, specialist work groups and arrangements for the management and funding of the project.

The Concerted Action Committee (CAC)

The Council Decision authorising COST 90 provided for the setting up of a Committee to be known as the Concerted Action Committee with the following terms of reference:

'1 The Committee shall:

1.1 contribute to the optimum execution of the project by giving its opinion on all aspects of its progress;

1.2 evaluate the results and draw conclusions regarding their application;

1.3 be responsible for the exchange of information provided for in Article 5(1);

1.4 keep abreast of national research work being done in the fields covered by the project, in particular by keeping abreast of scientific and technical developments likely to affect the execution of the project;

1.5 suggest guidelines to the project leader;

1.6 have the right to set up, in respect of each of the three physical properties defined in Annex 1, a subcommittee to ensure that the programme is properly implemented.

'2 The reports and the opinions of the Committee shall be communicated to the Commission and the Member States participating. The Commission shall forward these opinions to CREST and to the Standing Committee on Agricultural Research (SCAR).

'3 The Committee shall consist of the project leader and the persons responsible for the co-ordination of the national programmes appointed by the Member States participating. Members may for the duration of the project be accompanied by experts, subject to a maximum of two experts per Member State participating. A Member's term of office may be terminated prematurely by his death or resignation or if the Government of the participating Member State which appointed him requests that he be replaced. His successor shall be appointed for the unexpired period of the original term.'

It is clear from the above that the CAC is in fact the Management Committee of the project. After the formal accession of non-Community States the CAC is known as the CCCC—the Cost-Community Coordination Committee.

The Role of the Commission

In addition to preparing the details and drawing up the proposals for the project, the Commission is given the responsibility for coordination of the work of the Member States forming the programme of the project. The Commission is also responsible for authorising the expenditure under the project budget, for progress reports to the Member States and, at the end of the coordination period, a succinct report on the performance and results of the project.

Project Leader

Article 4 of the Council Decision provided that 'a Project Leader shall be appointed by the Commission in agreement with the Committee (CAC). He shall, in particular, assist the Commission in its task of coordination'.