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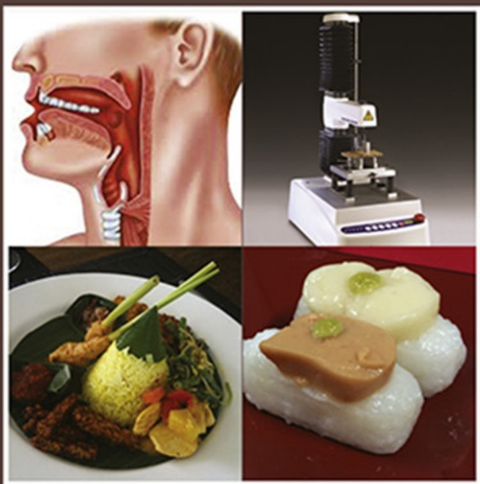

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Edited by Jianshe Chen and Andrew Rosenthal

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Modifying Food Texture

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L. Demonteil CNRS, UMR6265 Centre des Sciences du Goût et de l'Alimentation, F-21000 Dijon, France; INRA, UMR1324 Centre des Sciences du Goût et de l'Alimentation, F-21000 Dijon, France; Université de Bourgogne, UMR Centre des Sciences du Goût et de l'Alimentation, F-21000 Dijon, France

L.M. Duizer University of Guelph, Guelph, ON, Canada

K. Field University of Guelph, Guelph, ON, Canada

F. Hayakawa National Food Research Institute, NARO, Tsukuba, Japan

P. Ho University of Leeds, Leeds, UK

D. Johnson National Association of Care Catering, West Sussex, UK

S. Nicklaus CNRS, UMR6265 Centre des Sciences du Goût et de l'Alimentation, F-21000 Dijon, France; INRA, UMR1324 Centre des Sciences du Goût et de l'Alimentation, F-21000 Dijon, France; Université de Bourgogne, UMR Centre des Sciences du Goût et de l'Alimentation, F-21000 Dijon, France

M. Papageorgiou Alexander Technological Educational Institute of Thessaloniki (ATEITh), Thessaloniki, Greece

A.J. Rosenthal Coventry University, Coventry, UK

E. Rothenberg Kristianstad University, Kristianstad, Sweden

G. Sala Wageningen University and Research Centre, Wageningen, The Netherlands; Top Institute Food & Nutrition, Wageningen, The Netherlands

E. Scholten Wageningen University and Research Centre, Wageningen, The Netherlands; Top Institute Food & Nutrition, Wageningen, The Netherlands

A. Skendi Alexander Technological Educational Institute of Thessaloniki (ATEITh), Thessaloniki, Greece

C. Tournier CNRS, UMR6265 Centre des Sciences du Goût et de l'Alimentation, F-21000 Dijon, France; INRA, UMR1324 Centre des Sciences du Goût et de l'Alimentation, F-21000 Dijon, France, Université de Bourgogne, UMR Centre des Sciences du Goût et de l'Alimentation, F-21000 Dijon, France

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Preface

Food texture is a key sensory feature not only well appreciated by consumers but also used by consumers as a quality indicator of a food product. The study of food texture has become a very active scientific area of the food science and technology and has received growing attention from scientists of food science and related disciplines. In the past few decades, some significant progresses have been made in the fundamental understanding of the textural properties and practical applications of such knowledge in the development of healthy and tasty food products. The major developments in food texture study can be briefly summarized in three areas. The first achievement is a much better understanding of the underlying scientific principles of food texture and its sensation and perception. This is shown by the establishment of the physical, mechanical, and (micro)structural nature of food textural properties and the associated physiological and psychological factors that influence texture sensation and perception. Such developments provide a solid foundation for food texture study as a scientific discipline. Second, objective assessment of food textural properties has always been a research focus for its important implications to both fundamental understanding and industrial applications. A wide range of instrumental devices and experimental techniques have been developed, and many of them are now commercially available. These include various rheometers for the precise characterization of texture-related physical and mechanical properties, various empirical devices for fast characterization of some specific textural properties, and various instruments that mimic eating and oral processing and offer easy quantification of textural properties and prediction of consumers' perceptions. The third major development is the emergence of food texture modification in the past few decades for the purposes of either improved textural properties of a food product or altered texture of a food to suit the needs of consumers who have difficulty consuming normal food. This area has attracted much attention currently from both academic and industrial researchers due its close relevance to the fundamental understanding of food texture and microstructure and the growing needs in industrial applications. It is this latest development that has led to the production of this book.

The driving force behind the increased activities in food texture modification comes from two very different needs: the growing demands from consumers for healthy tasty food and the urgent needs of properly texturized food for safe food consumption by some specific consumer groups. For the former, food manufacturers have to find a balance between the health benefits and the sensory enjoyment of the food. With fast-changing lifestyles and the abundant availability of food, an oversupply of nutrients leads to negative consequences to human health and therefore becomes a concern to governments as well as consumers. Overweight and obesity are the two most obvious health-related problems as a result of food overconsumption. Food with reduced contents of fat, sugar, and salt has become a preferred choice by many consumers. However, the major technical challenge to the food industry is not to reduce these components, but how to address the balance between the health benefit and sensory enjoyment. As a general principle, a food must be able to provide sensory enjoyment, a key function of the food that has profound influences on one's psychological and social well-being. A product that provides no sensory pleasing effect simply can hardly be categorized as a food, however healthy it claims to be.

Another very important reason for texture modification is the urgent need of properly texturized food for safe and easy consumption by some specific consumers who have difficulty in consuming normal food, including infants, elderly populations, and hospital patients. Proper modification of food texture is absolutely essential for the safety and well-being of these consumers. In recent years, provision of texture-modified food has been seen as a great business opportunity to the food industry. With a forecasted rapidly growing elderly population, a vast and fast-growing market is predicted for texture-modified food and also for functional ingredients and techniques needed for texture modification. Major food companies have put a lot of resources and efforts into exploring this opportunity, though many technical challenges remain to be solved.

The aforementioned two challenges imply the urgent need of the knowledge and techniques by the food industry on texture modification of food products. The focus of this book is exactly for this need, by addressing various aspects (both technical and practical) of food texture modification and specific needs of disadvantaged consumer groups for texture-modified foods. Unlike other textbooks where knowledge and applications are often the main focus, the primary concern of this book is on consumers' needs and well-being. Five essential aspects of food texture modification, including ingredients, methodologies, processes, products, and target populations, are arranged into two sequential volumes.

Volume 1 begins with our chapter to introduce the entire concept of texture modification. The chapter outlines the background knowledge of food texture and discusses progress in food texture study from its historical perspective. By setting food texture in its broad context, the chapter also explains the structural aspects of texture creation, texture oral breakdown, and oral appreciation. This is followed by chapters on the use of some novel food ingredients as effective functional components for texture formation and modification. This includes a chapter by Dr. Lin Chen on the food emulsifiers for microstructure creation of dispersed food systems; a chapter by Dr. Christos Ritzoulis and Dr. Panayotis Karayannakidis on food proteins, their structure-forming and stabilizing effects and various factors that influence such functionalities; and a chapter on another very important structural forming ingredient, the enzymes, authored jointly by Drs. Dilek Ercili-Cura, Thom Huppertz, and Prof. Alan Kelly. The third part of volume 1 is on the methodologies for texture creation and modification, which include a chapter by Dr. Shekhar Kadama, Dr. Brijesh Tiwari, and Dr. Colm O'Donnell on the improved thermal processing techniques for much desirable texture; a chapter by Dr. Cheryl Chung and Prof. David J. McClements on the structure and texture of food emulsion products and the use of emulsification technique; a chapter by Dr. Hassan Firoozmand and Prof. Dérick Rousseau on the phase behavior and controlled phase separation for texture modification; and a chapter by Drs. Morten Dille, Kurt Draget, and Magnus Hattrem on the emulsion gels and the use of filler particles for texture modification. The last part of the volume 1 deals with the texture of two major types of food products: a chapter on cereal breakfast and extruded products (by Dr. Frédéric Robina and Prof. Stefan Palzerb); and a chapter on soy-based products, a type of Oriental food growing popular in Western countries (by Dr. Jian Guo and Prof. Xiao-Quan Yang).

Volume 2 has two main focuses: the characterization of food textural properties and the needs and requirements of texture modification of target consumers. The volume begins by a chapter by Dr. Fumiyo Hayakawa on the vocabularies and terminologies of food texture and texture appreciation. This is followed by three chapters on the characterization of the textural properties of food, by taste panel analysis and by quantitative measurements using various instruments. Statistical analysis of taste panel data is discussed in detail by Dr. Peter Ho, whereas instrumental characterization of food texture are dealt with separately by Dr. Andrew Rosenthal on solid and semisolid (or soft solid) foods and by Drs. Guido Sala and Elke Scholten on fluid food. The second part of volume 2 contains topics on the need of texture modification for target populations. This include a chapter on the "free from" food by Drs. Maria Papageorgiou and Adriana Skendi, in which practices and techniques applied for the design and production of gluten-free food are discussed as a typical example. The need of texture modification for elderly populations are addressed in a chapter by Prof. Lisa Duizer and Ms. Katy Field on the weakened sensory capability of elderly and a chapter by Dr. Elisabeth Rothenberg and Prof. Karin Wendin on the practices of texture modification for elderly consumers who have developed difficulties eating and swallowing due to natural aging. Food provisions to hospital patients, in particular those who are diagnosed with dysphagia, are given in the chapter by Dr. Julie Cichero. On the other end of the spectrum, infants and babies also have specific requirements of food texture due to incomplete development of their eating capability. Texture modification of infant food is discussed in detail in a chapter authored jointly by Drs. Sophie Nicklaus, Lauriane Demonteil, and Carole Tournier. Finally, the book concludes with a chapter by Mr. Derek Johnson on the legislation and practices for texture-modified food for institutional food, with a particular focus on the cases of hospital food provision in the United Kingdom.

In addition to a brief abstract and a list of keywords for convenience of literature search, each chapter also has a final section that provides further relevant information so that readers can expand their reading when it is needed. We hope that, by addressing some key aspects of food texture modification, this book provides the knowledge and guidance urgently needed by R&D researchers in the food industry and those who seek to explore new business opportunities in the growing competitive global market. Many chapter topics of the book are also closely relevant to some food science textbooks, and therefore this book could also be used as a useful reference for undergraduate and postgraduate students studying food science and technology. However, we must also express our slight regret that the topic coverage of the book has not been as wide as we had initially planned. During the editing process, we had to drop a few chapters, largely due to a lack of literature on those chapter topics.

We would like to take this opportunity to thank all the contributors; their expert knowledge, enthusiasm, and hard work enabled us to put together a unique food texture book from very different scientific perspectives. We would also like to thank editorial staff at Woodhead (now Elsevier) for their support and advice through this process. And finally, we would like to thank our families for bearing with us through the long nights and weekend hours.

Jianshe Chen (Hangzhou, China)
Andrew Rosenthal (Coventry, UK)

Part One

Sensory analysis and consumer preference of food texture

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Vocabularies and terminologies of food texture description and characterisation

1

F. Hayakawa
National Food Research Institute, NARO, Tsukuba, Japan

1.1 Introduction

Texture is a sensory property and comprises multi-parameter attributes (Szczesniak, 2002). Thus, it is essential to understand the structure of texture vocabularies and hierarchy of texture terms so that consumers' appreciation of and preference for food texture can be appropriately explored for better food design. Without precise description and understanding of texture features, R&D researchers in food design and formulation will not be able to directly address consumers' texture concerns. Another factor of critical importance to texture terms and hierarchy is their use in instrumental characterisation of food texture. Without appropriate descriptive terms, it will be very difficult to give objectively measured physical parameters a sensory meaning and such measurements will become irrelevant to consumers' perception.

Indeed, vocabularies and terminologies of texture are also important in sensory evaluation. Experimenters or panel leaders dedicate their efforts to selecting and defining appropriate terms as descriptors for precision and validity of their sensory evaluation. In selecting these descriptors, more careful consideration is needed for texture attributes than for flavour because setting a reference sample for a texture attribute may be more difficult than for flavour attributes. For example, we can use sucrose solution as a reference for sweetness. The intensity of reference can be easily controlled by changing its concentration. Since panellists can assess sweetness in reference to the sucrose solution, their disagreement on the nuance of the descriptor is usually small. In contrast, disagreement on the meaning of a texture descriptor sometimes directly increases the dispersion of the data.

Organising descriptive texture words into a texture lexicon is the first and most important step in food texture research. In fact, as noted by Szczesniak (2002), the classification and organisation of texture terms instigated a profiling method of texture applicable to both instrumental measurements (Bourne, 1978) and sensory evaluation (Szczesniak et al., 1963).

Developing texture lexicons and classifying texture terms in various languages has been a concern for texture researchers since Szczesniak and her colleagues published their articles regarding texture terms in the English language (Szczesniak, 1963; Szczesniak and Kleyn, 1963). Comparing texture lexicons among languages is also an important topic for texture studies. However, since any language contains so many

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nuances, studies in this area are rather complicated. This chapter will review studies of texture terms/lexicon and discuss various issues and problems associated with food texture terms and its classifications.

1.2 Early frameworks for developing texture lexicon

Szczesniak and colleagues provided a framework for classifying and defining texture terms. They first demonstrated that texture was highly recognisable by consumers along with flavour features (Szczesniak and Kleyn, 1963). They conducted a word association test among 100 people using 74 types of food names. The respondents gave the first three words that came to their mind upon hearing the name of a food. The frequency of mentioning texture was high enough even if compared with any other food attribute (e.g., flavour, colour and form). The authors concluded that texture is a discernible characteristic of food and that its recognition equals that of flavour. Later, Szczesniak confirmed the meaningfulness of texture to consumers as a food attribute using two additional word association tests (Szczesniak, 1971; Szczesniak and Skinner, 1973). These studies also yielded a list comprising many texture-descriptive words.

Szczesniak then proposed classification and definition of texture characteristics, which was based on rheological principles and human perception (Szczesniak, 1963). This was the first rational classification for a scientific description of food texture. In this article, she classified various texture characteristics into three major categories: mechanical, geometrical and other (moisture and fat content of a product). Individual texture parameters were then classified hierarchically within each of the three characteristics (Table 1.1). Some popular words used to describe each parameter were also listed in the classification (Szczesniak, 1963).

Thereafter, Szczesniak et al. (1963) further developed standard rating scales of six mechanical texture parameters: hardness, brittleness, chewiness, gumminess, viscosity and adhesiveness. Each point on the scale was represented by a food product. Brand, manufacture, type, sample size and temperature of each reference product were also specified. The scales covered the whole intensity range found in food products during that time. For example, nine products were selected to represent points at regular intervals on the hardness scale: (1) cream cheese, (2) hard-cooked egg white, (3) frankfurters, (4) cheese, (5) olives, (6) peanuts, (7) uncooked fresh carrots, (8) peanut brittle, and (9) rock candy. The scales with reference products proposed by Szczesniak et al. (1963) helped researchers to understand the concept of the attribute and worked particularly well in panel training. Szczesniak and her colleagues provided good examples that reference products sometimes complemented verbal definition.

Unfortunately, the standard scales and reference products may not work well today in actual sensory evaluation. Chauvin et al. (2009) demonstrated that some panellists failed to recognise distinctions of hardness intensities among softer foods (e.g., cream cheese, hard-cooked egg white, frankfurters, cheese and olives), even though products were similar in terms of brand, manufacture, type, sample size and temperature to those in the original test. According to the authors, the confusion was partly attributed to the change of food formulations over time. In fact, the workable range of food hardness test is a softer part of the original scale (possibly under 6 or 7) in most cases of

Table 1.1 Classification of texture characteristics proposed by Szczesniak

1. Mechanical characteristics
Hardness
Cohesiveness
Brittleness
Chewiness
Guminess
Viscosity
Elasticity
Adhesiveness
2. Geometrical characteristics
Particle size and shape
Particle shape and orientation
3. Other characteristics (moisture and fat content of a product)
Moisture content
Fat content
Oiliness
Greasiness

This table was made by the author based on the original data in Szczesniak (1963).

food sensory evaluation. Thus, experimenters may have to reselect reference products both for texture appreciation and panel training.

In addition to the practical use of standard scales in food sensory evaluation, studies conducted by Szczesniak and colleagues were seen by many as epoch making. Further modifications of the approach have been made by other researchers. Brandt et al. (1963) tried applying the classification and rating scales to a smoother and more practical sensory evaluation. They designed a sensory procedure through which the texture attributes were assessed over time, namely, from the first bite through complete mastication (Table 1.2).

Furthermore, Sherman (1969) modified texture classification with more emphasis on food rheology. The study organised texture attributes into four steps: initial perception, initial perception on palate, mastication (high shearing stress) consisting of mechanical properties and disintegration and residual masticatory impression. The mechanical properties in tertiary characteristics were then classified into three categories corresponding to food types (solid, semi-solid and fluid) (Table 1.3).

Jowitt (1974) further converted Szczesniak's classification into a glossary of texture terms, including written definition, senses (i.e., touch, sight and/or hearing) and antonyms as British standards. For example, *firm* belonged to the section of 'terms relating to the behaviour of the material under stress or strain', which corresponded to 'mechanical attributes' in the original classification and was defined as 'adjective; possessing the textural property manifested by a high resistance to deformation by applied force; sense, touch; antonyms, *soft*'. Results were presented it in the *Journal of Texture Studies* with some comments he had obtained about the glossary (Jowitt, 1974).

Several papers by Szczesniak and colleagues influenced texture researchers beyond English-speaking countries. Yoshikawa et al. (1970a–c) collected Japanese

Table 1.2 **Texture profile proposed by Brandt et al.**

1. Initial (perceived on first bite)
    - Mechanical
        - Hardness
        - Viscosity
        - Brittleness
    - Geometrical
        - Any characteristics, depending on product structure
2. Masticatory (perceived during chewing)
    - Mechanical
        - Gumminess
        - Chewiness
        - Adhesiveness
    - Geometrical
        - Any characteristics, depending on product structure
3. Residual (changes made during mastication)
    - Rate of breakdown
    - Type of break down
    - Moisture absorption
    - Mouthcoating

This table was made by the author based on the original data in Brandt et al. (1963).

Table 1.3 **Mechanical properties (masticatory characteristics) in the modified texture profile proposed by Sherman**

1. Solid
    - Hard
        - Crisp, brittle, powdery
        - Moist, dry, sticky
        - Tough, tender
    - Soft
        - Rubbery, spongy, tender, plastic
        - Moist, dry, sticky, soggy
        - Smooth, coarse
2. Semi-solid
    - Pasty, crumbly, coherent
    - Moist, dry, sticky, soggy
    - Lumpy, smooth
3. Fluid
    - Thin, watery, viscous
    - Creamy, fatty, greasy
    - Sticky

This table was made by the author based on the original data in Sherman (1969).

texture descriptive terms. They asked 140 female students to describe the texture of 97 kinds of food and collected 406 texture descriptive words. Rohm (1990) conducted word association tests in Austria, similar to those conducted by Szczesniak, and collected 105 German texture terms. He then compared the ten most frequently used texture terms in the United States of America, Japan and Austria, respectively, and differences between different languages and cultures were also noted (Rohm, 1990).

The classification and rating scales proposed by Szczesniak and colleagues were generally accepted among food scientists and technicians. Their works provided the base of the texture profile published by the International Standard Organization (ISO, 1994a).

1.3 Classification of texture terms

1.3.1 Two strategies of classifying texture terms

As has been noted by Szczesniak (2002), classification of texture terms and clarifying texture vocabulary are necessary for proper understanding of consumers' texture appreciation. She grounded this suggestion in the fact that texture is a multi-parameter attribute and a large number of words and terms are used to describe it. This is an insightful and appropriate suggestion. Furthermore, classifying texture terms will hugely benefit international communications in food texture and food sensory studies. Classifying a large number of texture terms into certain categories will help to clarify the structure of associated vocabularies in each language and culture. In other words, classification can streamline texture vocabularies in each language and make texture description easily understandable at an international level.

Many researchers worldwide tried to classify texture terms in their own languages. Two different strategies have been adopted to classify texture terms: the categories/classes are either set in advance or not. In the former case, terms are allocated into logical groups with properly defined physical meanings by the researchers. Allocation of terms is made by researchers' own judgment or by survey (i.e., questionnaires or interviews) of expert or professional assessors. In contrast, in the latter strategy, categories are derived from panellists' responses to grouping tasks without reference to their physical meanings. Terms are grouped according to a certain method of sorting or pairing comparisons, in which respondents answer the similarities relating to terms' sense. Afterwards, researchers interpret each term group and set an appropriate heading title. Both methods have their pros and cons, as noted in the following two sections.

1.3.2 Examples of classification defined by researchers

A typical example of the first strategy is the classification defined in English by Szczesniak (1963). This classification is still highly valuable and widely referred today (Nishinari et al., 2008). Recently, Nishinari et al. (2008) proposed a revision of the classification in the comparative study of texture terms. In this revised classification, a dynamic perspective (i.e., from non-oral to residual feeling) was incorporated and a melting sensory property was added as the sixth primary parameter to mechanical attributes (Table 1.4). The classification is logical, meaningful and easily understandable for food texture researchers.

Table 1.4 **Classification of texture attributes: a new perspective**

Mechanical characteristics

Primary parameters	*Secondary parameters*	*Visual or non-oral*	*Surface*	*Partial compression*	*First bite*	*Chewdown*	*Residual*
Hardness		Firmness		Firmness	Hardness	Hardness of mass	
Cohesiveness	Brittleness				Cohesiveness	Cohesiveness of mass	Tooth pack
					Brittleness	Ease to swallow	
					Crumbliness		
					Crunchiness		
					Fracturability		
					Crispness	Persistence of crisp	
	Chewiness					Chewiness	
						Number of chews to swallow	
	Gumminess				Gumminess	Gummy interface	
Viscosity		Visual thickness		Thickness			
		Spreadability					
		Sponginess					
Elasticity		Moldability		Springiness		Rubberiness	
Adhesiveness		Sitickiness to fingers	Adhesiveness to lips	Adhesiveness		Adhesiveness to palate or teeth	Tacky/ Sticky lips
						Tooth pull	
Melting[a]						Rate of dissipation	
						Rate of melt dissolvability	

Geometrical characteristics

Class	*Visual*	*Surface*	*Partial compression*	*First bite*	*Chewdown*	*Residual*
Particle size and shape	Air cells size	Micro/macro roughness	Grainy	Uniformity of bite	Pulpy	Gritty
			Awareness of particulates	Coating Separation	Awareness of skin Grainy	Loose particles chalkiness
			Coarseness	Mass b/n teeth	Roughness of mass Particle size	
Particle shape and orientation	Stringy	Slickness Slipperiness	Denseness Smooth	Airiness	Fibrousness Flinty/glassy	

Other characteristics

Primary parameters	*Visual*	*Surface*	*Partial compression*	*First bite*	*Chewdown*	*Residual*
Moisture content		Moistness/wetness		Moisture release	Mixes with saliva	
					Moistness of mass	
					Juiciness	
					Moisture absorption	
Fat content	Oiliness	Oily lips				Greasy film
Sound				Crispness	Persistence of crisp	
				Crunchiness		

[a]Parameters not included in the texture classification proposed by Szczesniak (1963).
Nishinari et al. (2008).

In French language, (Nishinari et al., 2008) also tried to organise texture terms using the first way. As one part of the comparative study (Nishinari et al., 2008), Dr. Sieffermann listed 227 candidates for texture terms obtained from another study and asked six texture experts to indicate a category to which each term could belong, after removing the words not describing texture. Four categories were suggested in the questionnaire with the option to remove or modify the categories. The fifth category was added by one of the experts. Many terms were categorised into the five categories (Table 1.5). However, there was minimal agreement even between experts on whether the word belongs to the texture language or the category belonging to the word (Nishinari et al., 2008).

Additionally, Nishinari et al. (2008) also noted the limitation of texture profiling using such a logical terminology approach. The reliance on consumers' judgments has recently increased. Since texture profiling panels and consumers do not always speak the same language, there is always a need of developing consumer-oriented texture vocabularies and of proper clarification of the relationship between consumer vocabulary and the texture lexicon organised by texture researchers.

1.3.3 Examples of classification derived from panellists' responses

Lawless et al. (1997) studied Finnish texture terms by the second approach. Seventy-one terms were categorised conceptually by sorting task, multidimensional scaling and cluster analysis. In their study, both consumers and food professional groups were tested, each consisting of 15 members. Participants were provided with a set of cards each printed with a different texture descriptive word and asked to sort the cards into groups based on perceived similarity of texture sensations. They were also asked to describe the criteria they used to sort the items. Data were analysed using a multidimensional scaling procedure and cluster analysis.

As a result, major categories of the food professionals included the following: (1) particles, (2) particles/sauce-related, (3) fracture, (4) open texture, (5) firm/elastic, (6) thin, (7) elastic, (8) adhesive, (9) moisture, (10) fat-related and one indeterminate group. On the other hand, categories of consumers were as follows: (1) particles,

Table 1.5 Classification of French texture terms by Nishinari et al.

Categories	Number of terms
Mechanical properties	35
Flow properties	19
Structure properties	49
Surface/contact properties	8
Shape/appearance[a]	31[b]

This table was made by the author based on the original data in Nishinari et al. (2008).
The terms selected by at least half of the experts were counted.
[a]Introduced only by one experts out of six.
[b]Four terms out of 31 belong to also the structure properties.

(2) small particles, (3) fracture, (4) open texture, (5) firm, (6) thick, (7) deforms/elastic, (8) elastic, (9) adhesive, (10) moisture, (11) oil-related and (12) bubbles.

Similarities were observed between the two groups with a few minor exceptions. Lawless et al. (1997) pointed out that the exceptions may have arisen from associating food with words. Participants may have been thinking about specific foods when sorting the terms instead of concept or function-based categorisations. For example, the food professional panel formed a group including melting, spreadable and thin, related to the concept of spreads like margarine or butter which are important components of the Finnish diet. Additionally, a few apparently non-logical groupings were demonstrated in the classification. They commented that unusual groupings sometimes occur when cluster analysis is applied to multidimensional scaling data and this was the case.

In general, although the panellist-oriented classification can reveal the main dimensions of texture vocabulary in each language, the obtained categories are sometimes difficult to interpret and to be generalised. It is important to conduct a carefully designed survey for obtaining meaningful word categorisation. It is also necessary to exhibit the details of the survey, e.g., the selection of respondents, methods of grouping and instructions to respondents for sharing results.

Lawless et al. (1997) also conducted the same survey among English-speaking people. Similarities were observed between the two languages. The comparison between them is featured in Section 1.4.1. In addition, they concluded that the dimensions of texture revealed by these categories are similar to the classes derived by Szczesniak (1963).

Hayakawa et al. (2005) reexamined Japanese texture vocabulary and collected 445 terms. They classified Japanese texture terms mainly by means of the second strategy (Hayakawa et al., 2013). First, because Japanese texture terms are too numerous to sort directly, eight experts in food texture studies categorised them into the three texture attributes proposed by the ISO (11036): mechanical, geometrical and other. Terms were then compared within each of the three attributes and their semantic similarities were assessed by 96 texture scientists/technologists. The data were analysed by multidimensional scaling and cluster analysis.

As a result, terms related to mechanical attributes were classified into six superordinate clusters and 29 subordinate clusters. The six superordinate clusters were interpreted as (1) toughness, (2) fracture at low strain, (3) low cohesiveness, (4) deformability, (5) adhesiveness and sliminess and (6) fluidity and smoothness. Terms related to geometrical attributes were classified into six superordinate clusters and 28 subordinate clusters. The six superordinate clusters were interpreted as (1) air, (2) particles, (3) smoothness and homogeneity, (4) roughness and heterogeneity, (5) thinness and (6) denseness. Terms related to other attributes (moisture and fat content) were classified into three superordinate clusters and seven subordinate clusters. The three superordinate clusters were interpreted as (1) fat content, (2) dryness and (3) moisture content.

The results revealed some characteristic texture description unique to Japanese. For example, the Japanese language has many texture terms, including many synonyms. As Bourne (2002) noted, this is partly due to the greater variety of textures presented in Japanese cuisine and partly to the picturesque Japanese language, which uses many onomatopoeic words. Many terms are concerned with adhesiveness and elasticity and may also be unique to Japanese.

Varela et al. (2013) classified Spanish texture terms by a method similar to that of Lawless et al. (1997). They selected 37 Spanish texture terms as the most relevant and familiar to Spanish and Uruguayan consumers (Antmann et al., 2011). Fifty-two Spanish and 47 Uruguayan consumers were asked to sort 37 terms according to their own criteria and to describe each term group. The data were applied to multiple correspondence analysis and cluster analysis.

The categories obtained from Spanish group data were (1) particle-related attributes, (2) sound emission, (3) resistance to deformation, (4) small particles/dryness, (5) difficulty to manipulate, (6) viscosity/creaminess, (7) liquid, (8) soft/smooth and (9) surface and structure-related properties. The classification of terms in Uruguay was very similar to that performed by Spanish, despite the smaller number of groups identified. The categories were (1) particle-related attributes, (2) difficulty to manipulate, (3) viscosity/creaminess, (4) sound emission, (5) water related, (6) resistance to deformation and (7) surface and structure-related properties. Varela et al. (2013) concluded that consumers in both countries (cultures) categorised texture terms in a very similar way, suggesting that they have developed the same memory structure. However, differences were identified in terms of the number of groups used to classify the texture terms and the words used to describe them. The differences in texture description arise from their different cultural experiences, being exposed to different foods and their different use of language (Varela et al., 2013). Classification of texture terms and comparison of the results among different languages/areas can demonstrate culturally unique characteristics.

Although a panellist-oriented classification of terms requires much effort by researchers and sometimes the panellists, it can often demonstrate cultural characteristics, as shown by Hayakawa et al. (2013) and Varela et al. (2013). It may produce good materials for cross-cultural analysis and also helps develop an internationally consist lexicon (Son et al., 2012).

1.4 Comparison of texture vocabularies and translation of terms among different languages

1.4.1 Comparison of texture terms/vocabularies among different languages

Cross-cultural sensory evaluation is needed in today's global age when international trade has become common routine. However, conducting a cross-cultural sensory study is not as easy as it appears to be. With a background of an open Europe and the establishment of free-trade agreements, Cardello (1993) had already noted in the 1990s that the most serious problem for the international sensory evaluation community was the language barrier. To deal with this issue, the need for a common understanding of texture terms among countries has been recognised. Comparison of texture terms/vocabularies among different languages has been conducted by some researchers over the past few decades.

First, Drake (1989) made a polyglot list of 54 English terms for sensory textural properties of foods and their equivalents in 22 other languages. Translation of English terms into the other languages was done by about 50 collaborators of texture expertise who were proficient in English. Drake (1989) pointed out that a single word in one language was sometimes used for multiple texture attributes that were described by distinguishable terms in another language. For example, *katai* in Japanese corresponds to rigid, stiff, hard, firm or tough in English. On the other hand, the Japanese language has a large number of texture terms including synonyms that are considered almost identical in other languages (Drake, 1989). According to him, misunderstanding, confusion and inconsistencies might occur in translation because English words were presented out of context. Although he considered the list tentative, it is very useful to know the candidates of equivalent terms in various languages. Additionally, the list is worth reading because it will stimulate interest in various texture vocabularies in different languages and will emphasise the importance and difficulty of international consistency of texture terms.

Lawless et al. (1997) compared Finnish and English texture vocabularies (see Section 1.3.3). They demonstrated similarities in texture terms and their conceptual groupings between languages even though the two languages have very different linguistic roots. However, they also pointed out the difficulty in comparing Finnish and English. According to the authors, part of the difficulty may stem from inconsistency in multiple meanings of one word. English speakers sometimes use the same word for multiple properties. For example, the English word thick means the physical dimension of a solid or the resistance to flow of a liquid. On the other hand, Finnish is more specific, using *paksu* for dimensional thickness and *jähmeä* for resistance to flow (Lawless et al., 1997).

Nishinari et al. (2008) demonstrated the organised texture vocabularies in English, French, Japanese and Chinese and described the characteristics of these four texture languages. Although they did not conduct the surveys using a common procedure in four countries, they confirmed that the most frequently used vocabularies were for mechanical and geometrical properties and that descriptors for solid foods were more numerous than those for liquid foods (Nishinari et al., 2008).

Since differences in specificity and nuance exist among languages, direct translation of each term is not simple. Thus, it may be difficult to develop a comprehensive and complete polyglot list of texture terms. However, we can still find something in common among texture vocabularies across languages.

Hayakawa et al. (2011) collected foods associated with 445 Japanese texture terms and submitted the table with food and terms for correspondence analysis to understand the structure of Japanese texture vocabulary. The first dimension was the axis contrasting fracture versus fluidity terms and the second dimension was interpreted as the axis related to fluffiness and airiness. Yoshikawa et al. (1970c) also demonstrated the similar plot of Japanese texture terms on the two major dimensions although they interpret the axes with other names.

Lawless et al. (1997) showed two-dimensional solutions after multidimensional scaling for Finnish and English texture terms. For the Finnish terms sorted by both professionals and consumers, the first dimension was the axis contrasting with terms describing fracture, such as *ratiseva* (crunchy) and *hauras* (brittle), versus terms related to fluid, such as *öljyinen* (oily) and *nestemäinen* (liquid). In the second dimension, *kupliva* (bubbly), *kuohkea* (airy) and *lehtevä* (flaky) were plotted negatively high, and terms unrelated to air/bubble such as *taikinamainen* (pasty) and *sitkeä* (tough) plotted positively high. They obtained similar results in English.

Varela et al. (2013) showed two kinds of scatter diagram of Spanish texture terms from multiple correspondence analysis. The data were obtained from Spanish and Uruguayan consumers. Dimension 1 was the axis contrasting fracture versus fluidity terms. However, dimension 2 cannot be interpreted as the axis related to air/bubble. This maybe because Varela et al. (2013) studied only 37 terms as representative and terms related to air/bubble properties were not covered.

The above-mentioned studies were quite different regarding survey procedure, type of panel (consumer or professional) and statistical methods. Weight balances of major dimensions in the reconstructed spaces also differ. However, the general tendency from such studies is that the major dimensions of texture vocabulary are consistent across different cultures.

1.4.2 Comparison of texture vocabularies for specific products among different languages

Zannoni (1997) emphasised that in translating texture terms it was necessary to focus primarily on stimuli rather than on words. This may be a reasonable suggestion because direct translation of texture terms isolated from any context could sometimes be problematic.

Blancher et al. (2008) compared texture profiles of jellies in France and Vietnam and confirmed the possibility of attribute transfer between the two countries. At first, French and Vietnamese panels independently generated and defined descriptors to characterise the sample set and then assessed that set using preselected descriptors. Although some descriptors were different between the two panel groups, Blancher et al. (2008) observed important similarities between them. Next, French and Vietnamese attributes were translated and transferred to two new panels in their respective countries. Based on this study, the authors concluded that it was possible to translate and transfer attributes between the two countries with a high accuracy.

Tu et al. (2010) also investigated the cultural differences in descriptions of soy yoghurts between French and Vietnamese panellists using a conventional descriptive sensory analysis. Each panel generated descriptors for samples independently. For texture attributes, five descriptors were generated in both countries; three descriptors (thick, fatty and melting) out of five were common. A multiple factor analysis was applied to the data including texture, taste and aroma attributes, showing that the two sensory profiles were highly similar.

Son et al. (2012) conducted a cross-cultural study using rice as a model product to understand how people in different languages and cultures describe the same product. The lexicon for cooked rice was developed in four countries (France, Japan, Korea and Thailand) using the same procedure. Descriptors were selected in accordance with the

ISO 11035 (ISO, 1994b) from candidate descriptors generated by a naïve panel. The same key sensory concepts were identified in the four countries, however, the use of individual terms for sample description was influenced by culture. In particular, the richness in vocabulary for aroma and texture was different across cultures. Thai panellists generated more texture terms than panels from other countries and some of these texture terms were semantically similar when translated into English.

Some researchers successfully conducted cross-cultural sensory evaluations for specific products using carefully designed vocabularies in different languages. Hunter and McEwan (1998) reported the international ring trial for descriptive sensory analysis of hard cheese in seven European countries (i.e., Denmark, France, Germany, Italy, Norway, Switzerland and the United Kingdom). Contributors in each country carried out the sensory evaluation using the common protocol. The main part of developing the methodology was establishing a consensus vocabulary for hard cheese. The consensus vocabulary was developed after discussion in English by all contributors with expertise in dairy and sensory science. Seven descriptors for texture in English were rubbery/elastic, crumbly, grainy, hardness, melting, coating/adhesive and dryness. These English terms were then independently translated into sensory panel's language by sensory scientists of that country. As a result, they demonstrated a high degree of agreement between countries on the use of attributes.

However, issues concerning the translation of texture terms and development of a uniform texture lexicon are still unresolved. Each language has its own characteristics and people in each country describe their food using their way unique to each language. In addition, each culture has its own peculiar foods and people do not recognise all of the same texture properties across cultures. Comparison of texture vocabularies and an accurate translation of texture terms among different languages are difficult. For this reason, proper understanding of each culture and language is necessary for cross-culture texture comparison and texture description.

1.5 Future trends

The need of developing texture lexicon for a specific food product will continue to increase. Such lexicons facilitate communication across diverse people who engage in texture appreciation of the product. International publication of lexicons is important despite their focus on domestic products. In fact, developing a lexicon is an important topic in *Journal of Sensory Studies*, as reviewed by Lawless and Civille (2013). An accumulation of various published lexicons helps to establish standardisation of procedures of sensory evaluation (Lawless and Civille, 2013). Moreover, it will lead to an international understanding of texture description across different cultures and development of universal texture lexicons that function across international markets.

In addition, organising texture terms along with dynamic oral processing is essential. Although Brandt et al. (1963) and Sherman (1969) proposed classification of texture terms along time sequence of oral processing, these classifications were too conceptual to be practically meaningful in actual texture analysis. In order to have a better texture design for the need of various consumers such as the elderly, there is a need of proper understanding of texture appreciation throughout the whole oral processing.

1.6 Conclusions

A well-organised texture lexicon would help researchers in sensory characterisation based on both instrumental measurements and taste panel sensory evaluations. Adequate classification of terms leads to a well-organised texture lexicon. Texture terms can be classified using two types of strategies: categories defined by researchers and categories derived from panellists' responses, both of which have their pros and cons.

There is an increasing need for a universal texture lexicon and international understanding of texture terms. Regarding the universal texture lexicon, sensory and texture scientists are aware of the difficulty in developing a comprehensive and complete polyglot of texture terms. In contrast, several studies revealed that fracture versus fluidity and airiness may be primary dimensions of vocabulary that are consistent across cultures. Comparison of texture vocabularies for a specific food product sometimes leads to the successful development of an international uniform lexicon for the product. Classification of texture terms and development of texture lexicon in each language, development of the texture lexicon for a specific product and cross-cultural comparison of texture terms/vocabularies will lead to understanding of texture terms on an international level.

1.7 Sources of further information and advice

Standardised texture lexicons are published by the International Standard Organization and the American Society for Testing and Materials (ASTM). The lexicons are available for download on the following websites:

http://www.iso.org/iso/iso_catalogue.htm
http://www.astm.org

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Changes in sensory perception during aging

2

L.M. Duizer, K. Field
University of Guelph, Guelph, ON, Canada

2.1 Introduction

Humans use all of their senses to evaluate the sensory properties of a food. This evaluation begins before consumption and is based on how the food looks and smells. Visual and olfactory acuity are therefore important to the initial evaluation of a food. Food odor is initially detected via the nose through sniffing of volatile components. This is known as orthonasal olfaction. Once the food is placed in the mouth and masticated, retronasal olfaction occurs through the movement of volatiles through the nasopharynx during chewing (Auvray and Spence, 2008). Therefore food oral processing is also necessary for proper sensory perception. Tastes develop during consumption of a food through the release of tastants from the food during chewing. Upon release, taste compounds mix with saliva and travel to the taste buds where they are perceived as sweet, salt, sour, bitter, or umami. Throughout the chewing process, textures are perceived as food is broken down. This requires input from the muscles of the jaw as well as mechanoreceptors in the mouth. If a product makes a noise when it is consumed, texture perception will also be influenced by input from the auditory canal. In this chapter, the physiology and anatomy of each of these systems will be discussed. The changes that occur to these systems during aging will also be presented. This will be followed by a discussion of the relations between physiological changes with aging and sensory perception and their effect on individual food choice. The chapter will end with a discussion of further information and advice for understanding the effects of aging on sensory perception.

2.2 Anatomy and physiology: changes with aging

Aging is a biological process that occurs after reproductive maturation. Throughout this process, damage at the molecular level impairs normal functioning of cells within the body, and this damage contributes to a host of physiological changes to the body (Olshansky et al., 2002). Reduction of bone mass, loss of muscle mass, and compromised vision and hearing all occur, and all individuals will undergo these changes to varying degrees as they age. Concurrent with healthy aging, some individuals will also undergo physiological and cognitive changes due to diseases commonly associated with aging such as Alzheimer's disease, Parkinson's disease, stroke, and cancer.

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Physiological changes that occur as a result of either healthy aging or age-related diseases will affect an individual's ability to perceive and recognize sensory properties within a food. Understanding the effects of these processes on sensory perception and food choices of older adults is essential for optimum food intake.

2.2.1 Vision

Vision is the first sense that a human will use to evaluate the sensory properties of a food product. The structures of the eye are shown in Figure 2.1. In order to see an image, light is reflected from a stimulus and travels through the cornea to the pupil. From there it travels through the vitreous humor to the retina located at the back of the eye. Found within the retina are rods and cones, the photoreceptor cells that are necessary to convert the light into neural impulses so that an image is perceived. The intensity of light that strikes the retina is controlled by the lens because of its ability to dilate and contract according to how much light is entering the eye. The lens allows the eye to focus on images at different distances.

During aging, changes to the retina, the lens, and the cornea can affect the quality of vision. The shape of the cornea changes with age. It becomes flatter, thicker, and less smooth (Houde, 2007). Because of this change in shape, light will reflect differently and images may become blurry. Astigmatism can also occur in older adults as a result of changes to the cornea (Houde, 2007; Whitbourne, 2002). Age-related changes to the lens can also significantly impact vision. The lens can lose transparency, leading to an inability to discriminate between colors, particularly blue and green shades (Houde, 2007). Cataracts, a clouding of the lens, may also develop as a result of protein buildup in the lens (Kalinga, 1997). Many of these changes begin in the fourth decade and progress with age. The visual acuity of an individual aged 80 is approximately 80% less than that of a person in their 40s (Whitbourne, 2002). This loss of visual acuity may result in older adults having difficulties visualizing the foods that they are consuming.

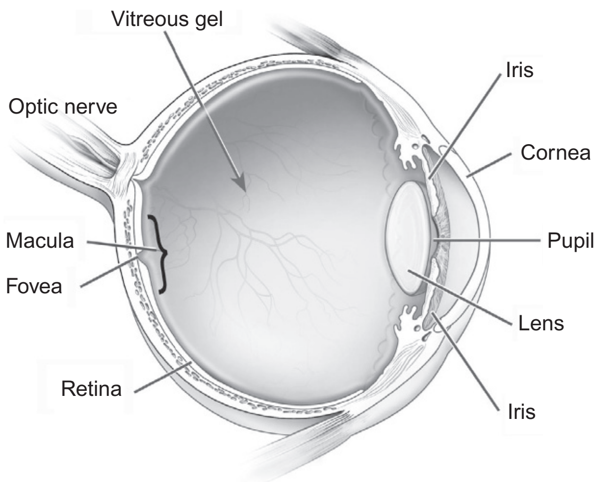

Figure 2.1 The eye. Reprinted from National Eye Institute, 2014, National Institutes of Health Ref#: NEA09.

2.2.2 The olfactory system

The exterior nose, the part that is visible when looking at an individual, is made up of bone and cartilaginous tissue. The nasal cavity is a large cavity located behind and above the exterior nose. It is divided into left and right cavities by the septum. It acts as a humidifier, heater, and filter of incoming air. Three turbinate bones (Figure 2.2) extend from the lateral walls of the nasal cavity, increasing the surface area and creating turbulence in the flow of air entering the nose. The nasal mucosa (the tissue that lines the inside of the nose) receives its blood supply from both the external and internal branches of the carotid artery. Sensory innervation to the nose is through various branches of both the ophthalmic and maxillary divisions of the trigeminal nerve (CN 5). The olfactory nerve (CN 1) is responsible for an individual's sense of smell (Cheesman and Burdett, 2011; Hansen, 2010).

The olfactory mucosa is a specialized region located anteriorly inside the nasal cavity, lining the cribriform plate, superior turbinate, and regions of the septum and middle turbinate (Leopold et al., 2000). For an odor to be sensed, it must first reach this region. Air containing odor molecules enters the nose, either through the nostrils (orthonasally), or through the back of the nose (retronasally) (Cheesman and Burdett, 2011). Odor molecules then dissolve in specialized mucus of the olfactory region (Getchell and Getchell, 1992), which facilitates their transit to and interaction with the olfactory epithelium (Doty and Kamath, 2014). The olfactory epithelium (Figure 2.3) is made up of a number of different cell types, only one of which has a chemosensory function: the bipolar sensory receptor cells. The olfactory receptors, which bind with odor molecules, are located in the cilia of these cells. The binding of an odorant leads to the generation of an action potential in the receptor cells. The axons of olfactory receptors pass through the

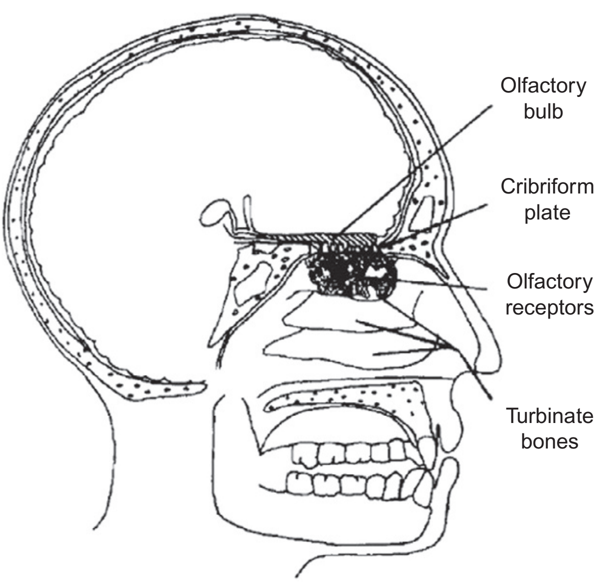

Figure 2.2 The nasal cavity and olfactory region. Reprinted from Jackson (2008).

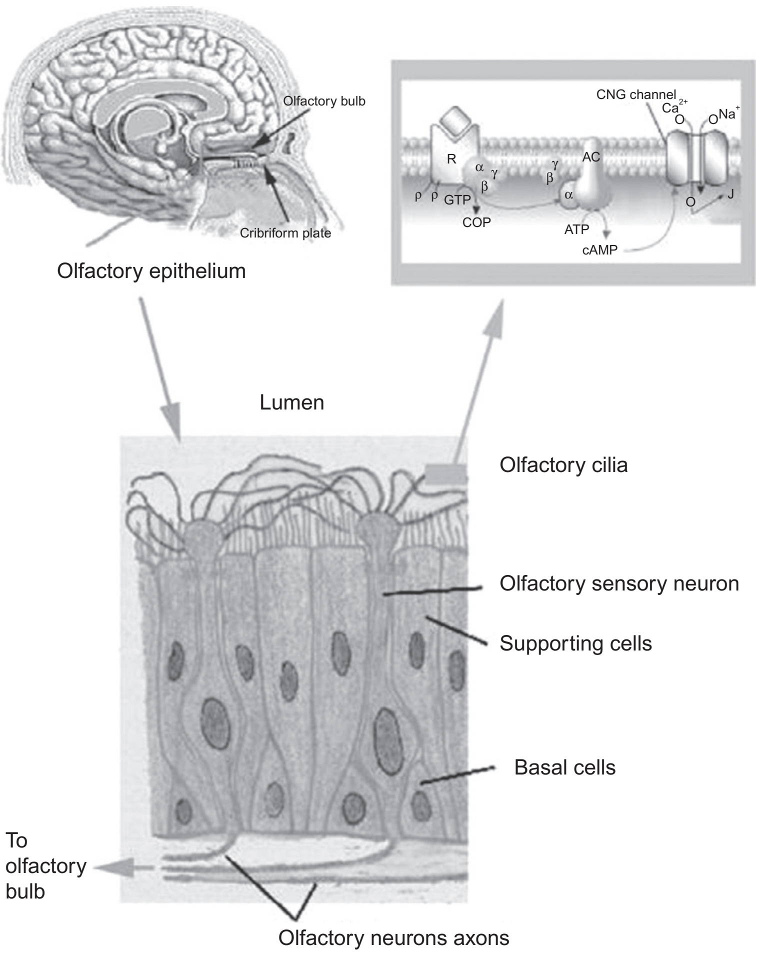

Figure 2.3 Olfactory receptor cells.
Reprinted from Gaillard et al. (2004).

cribriform plate, where they aggregate into neural structures known as the olfactory bulbs. These structures then send an impulse to the primary olfactory cortex of the brain (Stockhorst and Pietrowsky, 2004).

Olfactory receptor cells contain specific receptor proteins. There are more than 1000 receptor proteins, with each cell expressing only one type of receptor protein (Chess et al., 1994). Binding of odor molecules to these receptor proteins is selective, with each receptor only able to bind a select range of odor molecules. Likewise, each odor molecule is only able to bind with certain receptors (Holley et al., 1974). Thus, an odor is perceived by its specific pattern of receptor binding (Johnson and Leon, 2007). For many years it was estimated that humans were capable of detecting more than

10,000 different odors. However, more recent evidence suggests that this number may be closer to 1 trillion (Bushdid et al., 2014). The magnitude of this capability is due not only to the large number of odor molecules detectable by humans, but also to the formation of new and distinct odors arising from complex mixtures of these molecules (Bushdid et al., 2014).

A number of age-related changes that impact the olfactory system have been identified. These include changes to the structure and function of the nose, the olfactory tissue, and regions of the brain responsible for olfactory perception (Doty and Kamath, 2014). For example, an important structural change observed with aging is a reduction in the size of the foramina in the cribriform plate through which olfactory receptor axons must pass before synapsing in the olfactory bulbs (Kalmey et al., 1998). This can lead to damage to the olfactory receptor axons, leading to alterations in the conveyance of olfactory signals to the brain. Age-related changes in the olfactory tissue itself have also been reported, such as thinning and reduced vascularization of the epithelium, a decline in the number and specificity of receptors, and a reduction in the size of the olfactory bulb (Doty and Kamath, 2014). These changes may be due in part to alterations in the cell cycle associated with aging, but are believed to be largely a result of the cumulative damage incurred from exposure to environmental toxins and other noxious substances over the lifespan (Doty and Kamath, 2014).

Age-related changes in brain size and structure (Segura et al., 2013), neurochemical changes (de Almeida et al., 2013) and the presence of neurodegenerative conditions such as Alzheimer's disease have also been implicated in a reduction of olfactory capabilities (Doty and Kamath, 2014). In fact, olfactory function is often used as an early indicator of neurodegenerative diseases (Attems et al., 2014; Hüttenbrink et al., 2013). A number of other health-related factors have also been associated with olfactory function. For example, advanced age is associated with an increase in the prevalence of conditions such as rhinosinusitis and nasal polyposis, which have been repeatedly identified as risk factors for decreased olfactory performance (Hüttenbrink et al., 2013; Schubert et al., 2012). More recently, cardiovascular health has been identified as an important risk factor. A recent study found that markers for cardiovascular disease were associated with impairments in olfactory function (Schubert et al., 2012). One of these markers, the thickness of the carotid artery wall, is an indicator for atherosclerosis, and it has been suggested that these atherosclerotic processes could be causing arterial damage in the olfactory region as well. However, further research is needed to support this theory.

2.2.3 Structures of the mouth

When a food is put in the mouth and masticated, many sensory properties are perceived and age-related changes to oral structures can have a significant impact on sensory perception. The mouth comprises the lips, the teeth, the gums (gingiva), the tongue, and the jaw. In addition to these structures, within the mouth are mechanoreceptors and muscles that are required for mastication of a food. Also found in the mouth are salivary glands which, among other things, function to lubricate the food during chewing.

There are two jawbones found in the mouth. The upper jawbone is known as the maxilla and the lower jawbone is the mandible. The mandible is attached to the temporal bones of the head by the temporomandibular joint (Figure 2.4c). It is through this joint that the mandible moves against the maxilla to bring the teeth together for the grinding and chewing of food (Boyar and Kilcast, 1986). Each of the jawbones is covered with fibrous tissue known as the periosteum and on both the upper and the lower jaw surface of normally dentate individuals are teeth. The roots of the teeth are

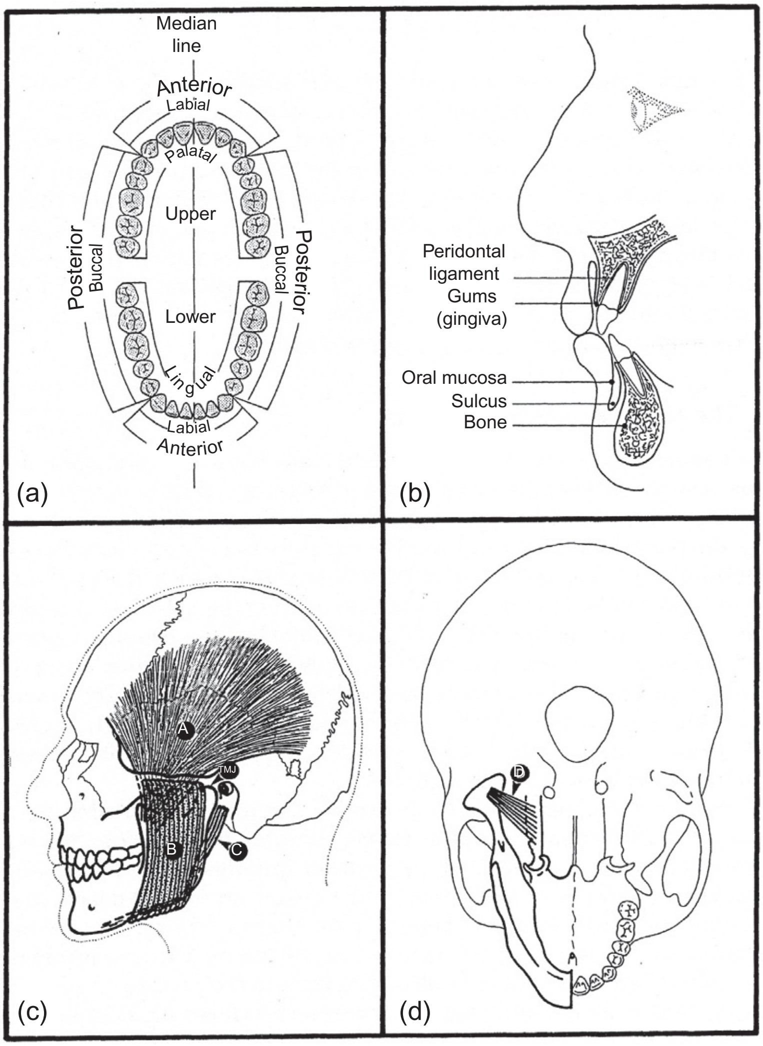

Figure 2.4 Structures of the mouth. (a) The surface of the teeth. (b) Structure of the teeth within the maxilla (upper jaw) and mandible (lower jaw). (c) and (d) Muscles of mastication. A, Temporalis; B, Masseter; C, Digastric; D, Lateral pterygoid; TMJ, temporomandibular joint. Reprinted from Harker et al. (1997).

attached to the bone by the periodontal membrane. The function of this membrane is two-fold. First, it is required for support and positional adjustment of the teeth. The second function is for sensory perception while chewing (Boyar and Kilcast, 1986). At the front of each of the jaws are four incisors and two canine teeth (Figure 2.4a) and at the posterior region of each jaw there are two premolar and three molar teeth on each side (Figure 2.4a).

Teeth are required for food breakdown during mastication. Aging brings about wear to the teeth. Four different types of wear have been identified: abrasive, adhesive, fatigue and corrosive (d'Incau et al., 2012). During aging, abrasive wear leads to the flattening of the crown and an increase in surface area (d'Incau et al., 2012). Another common effect of aging is tooth loss. Rates of tooth loss or edentulism with aging vary worldwide, with prevalence ranging from 1.3% to 78%; the percentage of individuals without teeth has decreased in developed countries while the opposite is true for less developed countries (Polzer et al., 2010). Edentulism results from the removal or loss of teeth due to dental caries and periodontal disease. Osteoporosis can also affect dentition (Mioche et al., 2004). Some individuals will replace lost teeth with partial plates or full dentures, while others will remain toothless throughout life.

During mastication, a variety of muscle groups is required to move the mandible. The locations of these muscles are outlined in Figure 2.4c. The masseter, internal pterygoid, and temporalis muscles are responsible for elevation of the mandible (Agrawal et al., 1998), while the external pterygoid muscle is responsible for the depression of the mandible (Boyar and Kilcast, 1986). When the mandible is depressed, the temporalis muscle becomes elongated and the masseter and pterygoid muscles stretch to allow the mouth to open. During elevation of the mandible, these muscles then contract and the mouth closes. The closure of the mouth contributes to the bite forces necessary to break down a food.

Muscles work in combination with mechanoreceptors during mastication to detect the position of the jaw as well as to detect items within the mouth (van der Bilt et al., 1995). Mechanoreceptors are cells that can detect pressure and frequencies of vibration and convert the pressure and vibratory stimulation into an electrical signal (Gillespie and Walker, 2001). Within the mouth, mechanoreceptors are present in oral mucosa, the periosteum, the salivary duct, the periodontal membrane, the temporomandibular joint capsule and the bony structures of the jaw (Harker et al., 1997; Sakada, 1983). Upon closure of the jaw during chewing, the electrical signal that is generated by the mechanoreceptors and the muscle spindles travels to the brain via neural pathways. Once the signal has been received by the brain, the information is then processed. This aids in the perception of texture of the product in the mouth.

As an individual ages, bite force strength decreases (Bakke et al., 1990). There is also a decrease in the muscle mass and density of the masseter, temporalis, and medial pterygoid muscles (Newton et al., 1993; Palinkas et al., 2010). The loss of muscle mass, known as sarcopenia, is the result of general age-related changes in muscle mass that occur throughout the entire body. The process of sarcopenia leads to a reduction in both the number and the size of muscle fibers, and in particular, fast twitch fibers, which are involved with contractions involving strength (Whitbourne, 2002). These changes may have an effect on chewing ability of older adults. A comparison of mastication patterns between young adults and older adults shows that older adults use more chewing cycles to break down a food and have a longer chewing duration than younger adults (Mishellany-Dutour et al., 2008). This becomes even more prevalent in individuals with dentures. A loss of chewing efficiency (the ability to reduce food during mastication) of between 50% and 85% has been observed in edentulous individuals (Mishellany-Dutour et al., 2008).

A key requirement for the production of a bolus during mastication is the presence of saliva. Bolus formation is one of the many functions of saliva. Humans have three sets of salivary glands in their mouths: the major salivary glands are the parotid and the submandibular and sublingual (SM/SL) glands. The parotid is the largest salivary gland. It produces saliva, which contains amylase and proline-rich proteins but does not contain mucins (Carpenter, 2013). The greatest stimulated salivary flow is from parotid glands, whereas SM/SL glands contribute significantly to resting salivary flow rate (Carpenter, 2013).

Saliva production and flow occurs due to tasting and chewing food and to a lesser extent when smelling a food (Carpenter, 2013). Salivation can also be triggered by the appearance of foods. Not all foods, however, contribute to salivation. The appearance of sour or pungent foods such as pizza and lemon slices induces salivation in humans, whereas other foods such as chocolate cake, processed cheese, and gelatin do not (Christensen and Navazesh, 1984). Perceived palatability of the foods, however, does not have an effect of salivation. When a food is ingested, salivary flow rate is influenced by mastication through the repeated closure of the mandibular muscles (Bourdiol et al., 2004). Higher masticatory bite forces lead to greater salivary flow rates (Yeh et al., 2000). Because of this association, it is intuitive, therefore, that a soft food, which does not require a great deal of mastication, will lead to a reduced salivary flow and food that requires a great deal of work to break down will increase salivary flow (Dawes, 1970).

There appears to be no effect of aging on overall salivary secretion when chewing foods (Bourdiol et al., 2004; Kapur and Garrett, 1984; Mishellany-Dutour et al., 2008). Additionally, Bourdiol et al. (2004) have observed that resting salivary flow rate is not affected by age. Others however, have found that there is a significant effect of aging on salivary flow. In nonmedicated older adults, a lower flow rate of unstimulated whole saliva and SM/SL saliva was observed when compared to a group of young adults (Yeh et al., 2000). This may explain xerostomia (dry mouth), a common complaint of older adults.

The tongue has an important role during food oral processing, as it is essential to our sense of taste, and for food manipulation and swallowing (Pereira, 2012). The tongue is a mass of striated muscle, held in place by extrinsic muscles, which connect it to the surrounding bones of the jaw. The tongue covers the floor of the mouth, and continues into the oropharynx. The upper surface of the tongue, known as the dorsum, is often referred to as two distinct parts based on physiological location. The "oral part" consists of the anterior two-thirds, and the "pharyngeal part" makes up the posterior one-third (Pereira, 2012).

The tongue consists of four paired intrinsic muscles: the superior longitudinal, the inferior longitudinal, the verticalis, and the transversus muscles. Additionally, there are four paired extrinsic muscles that help control movement and positioning of the tongue: the genioglossus, the hypoglossus, the styloglossus, and the pallatoglossus muscles (Hansen, 2010; Pereira, 2012). The extrinsic muscles are mainly responsible for repositioning of the tongue in the oral cavity. The genioglossus allows for tongue protrusion, the hypoglossus for tongue depression, the styloglossus for tongue elevation and retraction and the pallatoglossus for elevation at the back of the tongue and depression of the soft palate. The intrinsic muscles maintain control over the shape of the tongue, for example: lengthening and shortening, curling and uncurling of the edges, or flattening and rounding of the surface (Pereira, 2012). These muscles play an important role during preparation and transit of the bolus when consuming food. However, as we age a decrease in tongue strength is often observed (Alsanei and Chen, 2014; Fei et al., 2013). A loss in stereognostic function (the ability to recognize the form of an object) of the tongue has also been observed in advanced age. This reduces an individual's ability to sense the size and shape of the bolus during food oral processing (Kawagishi et al., 2009).

The upper surface of the tongue (the dorsum) is covered with papillae, of which there are four distinct types: filiform (thread-shaped), fungiform (mushroom-shaped), circumvallate (ringed-circle), and foliate (Figure 2.5). All except the filiform papillae contain taste buds (Scanlon and Sanders, 2010; Engelen, 2012). In addition to the surface of the tongue, taste buds are also located on the epithelium of the palate. Taste buds are chemosensory organs made up of many taste receptor cells (TRCs). These receptors are responsible for detection of the five basic tastes: sweet, sour, salty, bitter, and umami. Small openings in the epithelial tissue, known as taste pores, allow saliva, along with dissolved tastants, to come into contact with the TRCs (Chandrashekar et al., 2006).

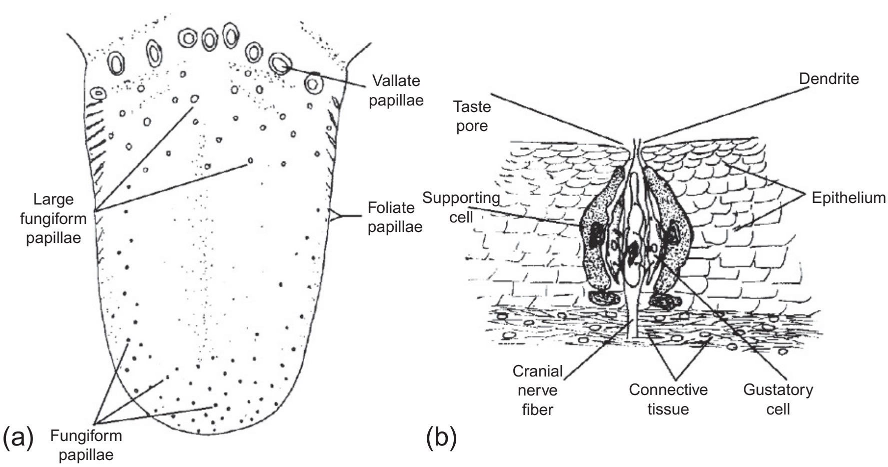

Figure 2.5 Receptor cells on the tongue. (a) Location of papillae on the tongue and (b) structure of the taste buds.
Reprinted from Jackson (2008).

Each of the basic tastes has specific tastants that are capable of eliciting a sensation as outlined in Table 2.1 (Chandrashekar et al., 2006). For example, sugars elicit a sweet taste while sodium elicits a salty taste. Likewise, different types of receptors are responsible for these perceptions. Although earlier research suggested that receptors for the various tastes were present only on distinct areas of the tongue, it is now widely accepted that receptors for all tastants are distributed over the whole tongue (Chandrashekar et al., 2006). When a tastant comes into contact with its corresponding receptors, an impulse is sent via the nerves to the gustatory regions of the parietal-temporal cortex of the brain (Scanlon and Sanders, 2010). Taste buds have an average lifespan of 8–12 days. New cells are continuously regenerated and they develop and mature, while older cells undergo apoptosis (cell death). With aging, this cycle may become irregular, leading to a loss of taste bud homeostasis; however, this is an area of research that is not yet well understood and the implications of such changes are unclear at this time (Chandrashekar et al., 2006). Many illnesses may also impact taste perception, as inflammatory factors can disrupt the process of taste bud regeneration. Inflammation occurs with many illnesses, such as infection, autoimmune disorders, and cancer (Feng et al., 2014). Elderly patients often suffer from poor oral health, and this may impact taste abilities as well. For example, increased bacterial growth has been associated with impaired taste (Solemdal et al., 2012). Finally, the increased dependence on medications may impact taste as well, because various medications have been found to alter taste perception (Frank and Hettinger, 1992).

Table 2.1 Basic tastes and tastant compounds contributing to those tastes

Taste perception[a]	Tastant types	Examples of tastants
Umami	Amino acids	L-Glutamate, L-AP4
	Nucleotide enhancers	IMP, GMP, AMP
Sweet	Sugars	Sucrose, fructose, glucose, maltose
	Artificial sweeteners	Saccharin, acesulfame-K, cyclamate, aspartame
	D-Amino acids	D-Phenylalanine, D-alanine, D-serine (also some selective L-amino acids)
	Sweet proteins	Monellin, thaumatin, curculin
Bitter		Cyclohexamide, denatonium, salicin, TPC, saccharin, quinine, strychnine, atropine
Sour	Acids	Citric acid, tartaric acid, acetic acid, hydrochloric acid
Salty	Halide anion or metal cation[b]	NaCl (pure salt taste), KCl, NH_4Cl

[a]Table adapted from Chandrashekar et al. (2006).
[b]Source for salt tastant types: Kilcast and den Ridder (2007).

2.2.4 The auditory system

The auditory system is divided into three sections: the outer ear, the middle ear, and the inner ear (Figure 2.6). The outer ear is composed of the pinna, which is the visible part of the ear, and the auditory canal. Within the middle ear are the ossicles, three small bones commonly known as the hammer, the anvil, and the stapes (Kiang and Peake, 1988). Within the inner ear is the cochlea, which is the most important part of the auditory system. The cochlea has three distinct chambers: the scala vestibuli, the scala tympani, and the cochlear duct. Each of these chambers contain fluid: perilymph in the scala and endolymph in the duct. These fluids are separated by the Reissner's membrane and the basilar membrane. The basilar membrane stops short of the end of the cochlea to allow the fluid to flow between the scala vestibuli and scala tympani via a small opening known as the helicotrema. Two membrane-covered windows, the round window and the oval window, are located on the cochlea on opposite sides of the basilar membrane. Resting on the membrane of the oval window is the foot-plate of the stapes.

When sound waves are detected, they are first localized by the pinna and then travel down the auditory canal toward the eardrum (also known as the tympanic membrane) at the end of the canal. The eardrum then vibrates and the ossicles transmit these vibrations through the middle ear. The vibration of the foot-plate of the stapes leads to a

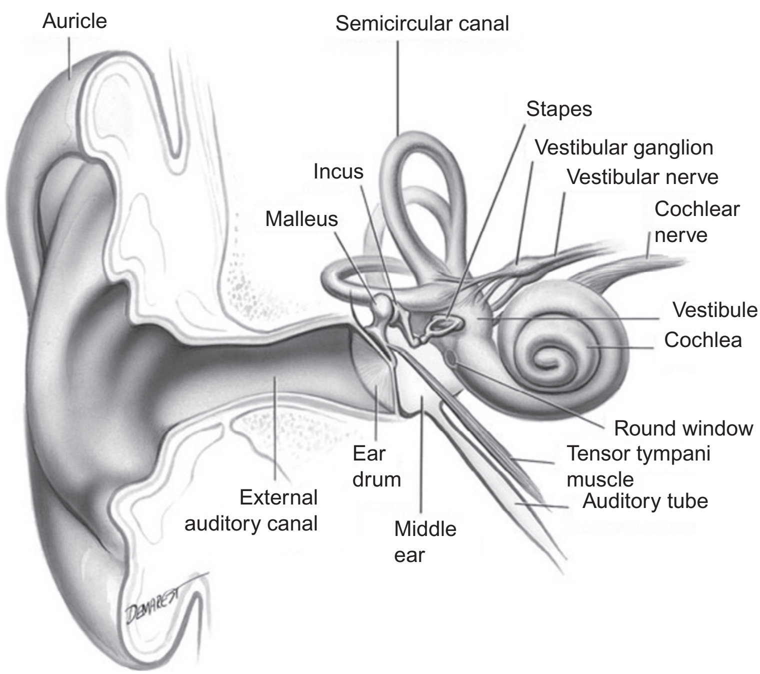

Figure 2.6 The auditory system.
Reprinted from Strominger et al. (2012).

pressure change in cochlear fluids. These fluids are responsible for the movement of the basilar membrane from the base of the cochlea to its apex. Hair cells within the organ of corti convert the movement of the basilar membrane into a neural response through the release of neurotransmitters (Moore, 1982).

Hearing-related losses with aging are common. It has been found that between 25% and 40% of individuals over the age of 65 exhibit some hearing loss and by the age of 80, approximately 80% of individuals demonstrate hearing loss (Gates et al., 1990). Age-related hearing loss can occur as the result of accumulation of extrinsic damage to the ear (such as exposure to noise) or it can be due to degeneration of the cochlea (Liu and Yan, 2007). This can take the form of degeneration of the organ of Corti, ganglion cell loss, strial atrophy, or basilar membrane stiffness (Liu and Yan, 2007). Age-related hearing loss originates with high-tone hearing loss and continues on to the loss of lower-frequency sounds. This can alter threshold levels for sound identification (Liu and Yan, 2007).

2.3 Sensory perceptions: effects of age-related changes in anatomy and physiology

Given that there are a multitude of changes to anatomy and physiology with aging, it is logical that these changes will have an effect on the perception of the sensory properties of a food. In the following section, the effects of aging on perception of tastes, odors, and textures will be discussed.

2.3.1 Tastes

Taste perception within a population of individuals can be assessed in a number of ways. Most studies analyzing the impact of age on taste perception utilize one or more of the following measures: detection threshold, identification threshold, or suprathreshold intensity (Methven et al., 2012). Taste sensitivity can be assessed using foods with known variations in certain ingredients, such as salt or sugar. However, tastants dissolved in aqueous solution are more often utilized for these tests. With the exception of umami, taste strips are also available (Landis et al., 2009). These measures can be used to assess each of the five basic taste perceptions described above; however, very few studies have included umami when assessing taste sensitivity (Methven et al., 2012).

Studies assessing taste loss with age have found varying results. A recent meta-analysis of these studies concluded that a loss in taste sensitivity is observed for all tastes. However, the degree of loss varies among tastes, with a reduction in salt and sour sensitivities in 80% of studies reviewed, and sweet and bitter sensitivity reduction in 70% of the studies (Methven et al., 2012). However, other studies directly comparing the degree of loss in each taste have reported greater losses in sour and bitter tastes with aging (Solemdal et al., 2014). The degree of taste loss observed was found to vary based on the particular tastant used to assess a taste (i.e., citric acid vs. acetic acid), whether tastants were dissolved in water or tested in a food matrix, as well as various aspects of experimental design (Methven et al., 2012). For example, olfactory function has been found to modulate perceived taste sensitivity (Mojet et al., 2003), but few studies have accounted for this interaction when assessing taste perception. Many of these studies have also failed to screen for health status and medication use (Methven et al., 2012). Thus it is difficult to determine the true degree of taste loss experienced by older adults in these studies.

2.3.2 Odors

Olfactory dysfunction has been identified in various populations of older adults (Murphy et al., 2002; Schubert et al., 2012) and this decline in olfactory sensitivity has been associated with a reported decrease in the enjoyment of food (Seligman et al., 2013). Although this impairment is exaggerated in individuals with Alzheimer's disease and mild cognitive impairment, changes have also been observed in healthy populations (Seligman et al., 2013). These changes have been demonstrated using a wide variety of different methodologies, which can be categorized as psychophysical, electrophysiological, and psychophysiological tests (Doty and Kamath, 2014).

Psychophysical tests are those in which participants must provide a conscious response. These tests generally determine a participant's ability to detect, identify, or discriminate between various odors. One example of such tests is the University of Pennsylvania Smell Identification Test (UPSIT) (Doty et al., 1984), which measures the ability of participants to identify 40 different common odors using a self-administered test with a scratch and sniff template. Using this test it was estimated that more than 50% of older adults between the ages of 65 and 80 and more than 75% of those over 80 years of age experience substantial olfactory impairment. Many variations to this test are also available, such as the Brief Smell Identification Test, a shortened version of UPSIT (Krantz et al., 2009); the San Diego Odor Identification Test, which uses aqueous odor solutions and is administered in a laboratory setting (Schubert et al., 2012); and "Sniffin' Sticks", which utilize a pen-like odor dispensers (Hummel et al., 1997). Age-related deficits in olfactory function have been repeatedly demonstrated by these tests (Doty and Kamath, 2014).

Psychophysiological tests, such as the Sniff Magnitude Test (SMT) (Frank et al., 2003), are used to measure autonomic responses. Though not commonly employed, they may prove to be an ideal method for assessment of olfactory function of older adults as they are not dependent on cognitive abilities, such as memory and learning (Frank et al., 2006). Results from SMT have been found to correlate with those of the more well-recognized psychophysical tests described above, such as UPSIT (Tourbier and Doty, 2007). Finally, electrophysiological tests can be used to measure the action potentials generated in the olfactory tissue when an odor is present. However, no such tests have been used to compare olfactory function in aging populations.

2.3.3 Textures

Texture is defined as "the sensory and functional manifestation of the structural, mechanical and surface properties of foods detected through senses of vision, hearing and kinesthetics" (Szczesniak, 2002). It is clear from this definition that there is a multi-sensory aspect to texture perception. Of each of the senses involved in texture attribute generation it is the senses associated with kinesthetics, namely touch and pressure, which are the main contributors to texture perception. Age-related changes occurring to any of the identified senses may have an effect on texture perception.

Vision and hearing are required for perception of certain textures to a lesser degree than touch and pressure. Vision is typically the first sense used to evaluate texture. It is often stated that visual texture is used as a means of judging the quality and edibility of a food; a food which does not look like it normally should is generally judged to be "not good to eat" (Szczesniak and Kahn, 1971). Texture terms often generated from visual texture assessment include terms related to characteristics of the surface of the product (roughness), the product homogeneity (lumpiness) as well as characteristics related to oiliness or wetness of the product. Texture attributes associated with hearing are those that are perceived through sound waves that are propagated through air (air-conduction) and bone (bone-conduction). Textures such as crispness, crunchiness, and crackliness are all commonly associated with sounds generated during chewing.

There is little work published that studies the effect of age-related changes of vision and hearing on sensory perception. Research conducted on healthy young adults showed that masking of visual cues when eating crisp biscuits does not have an effect on perception of any texture attribute of the biscuit (de Liz Pocztaruk et al., 2011). Masking of auditory cues leads to lower scores for "sound" (defined as the amount and loudness of sound) and "snapping" (defined as loud, sharp, short sound) when individuals have no previous knowledge of the food. Other sound-related texture attributes such as crunchiness are not affected by auditory masking. Obviously the bone-conducted sounds occurring due to vibrations through the skull while chewing contribute significantly to the perception of "noisy" texture attributes, which is a phenomenon that has been shown by other researchers (Christensen and Vickers, 1981). These results lead to the assumption that the loss of hearing that may occur as an individual ages can have an effect on perception of some attributes (such as those directly associated with sound generation), while other attributes that can be perceived with the help of bone-conduction will not be affected. Age-related changes associated with vision, however, should have minimal impact on texture perception.

As stated earlier, touch and pressure are the main contributors to texture perception. Such sensations are typically generated when a food is orally processed. Therefore, in order to understand the effects of aging on perception of textural properties it is necessary to understand how foods are processed in the mouth. Intra-oral manipulation of a food is influenced by its structure. From a structural perspective, foods can be classified as fluid, semisolid, or solid (Koç et al., 2013). Fluids rapidly move through the mouth and are swallowed with little to no oral processing. Texture attributes used to describe fluids are typically mouthfeel attributes such as thickness, creaminess, and mouthcoating. By contrast, semisolids and solids require greater oral processing. Semi-solids require manipulation by the tongue and compression against the hard palate concurrent with mixing with saliva in order for bolus formation to occur. Similarly, solids require tongue movement but additionally, the food must be broken down by the teeth and mixed with saliva for bolus formation. For breakdown to occur, an adequate amount of force must be generated by the muscles of the jaw so that the food will be broken by the teeth.

For semi-solid and solid foods, a number of different texture attributes are generated throughout the mastication process. Texture attributes such as particle size, uniformity of particles, stickiness, and roughness require input from mechanoreceptors found in the tongue, soft palate, cheeks, and lips (Guinard and Mazzucchelli, 1996). The masticatory muscles as well as receptors associated with the periodontal membranes are used for perception of attributes associated with the resistance of the food to breakdown, which includes attributes such as firmness, elasticity, springiness, and chewiness (Çakır et al., 2012). It is clear that there are a number of different oral physiological parameters that are important for food breakdown and texture perception, including dentition, strength of the jaw closure muscles, saliva addition and movement of the tongue.

During aging, the changes that occur to oral physiology and anatomy will impact chewing of foods. Few studies, however, have examined how these changes affect sensory perception of textures. It has been suggested that the changing dental state of older adults is responsible for the greater number of times that hardness is selected as a dominant attribute during testing using temporal dominance of sensations, a technique for characterizing important sensory attributes perceived during chewing a food (Hutchings et al., 2014). It may also be due to differences in bite force capabilities. Jaw muscle activity decreases with age and compression bite forces are reduced (Mioche et al., 2004). This is particularly prevalent in denture wearers. These changes in masticatory ability, however, do not appear to translate into alterations in perception of intensities of sensory responses. Denture wearers have been shown to perceive tenderness of meat similarly to fully dentate subjects during sensory testing (Veyrune and Mioche, 2000).

Within fluid foods, there is currently no clear agreement on the effect of aging on texture perception. When presented with custards and cream soups with different textures, older adults, in comparison to younger adults, perceived these foods to be less creamy (Kremer et al., 2005, 2007b). In more recent work, however, it has been found that there is no reduction in texture perception of dairy beverages when tested by an older and younger adult population. It was found, however that older adults had a higher acuity for mouth-drying (Withers et al., 2013).

It is clear from this discussion that the effect of aging on texture perception requires further study. While there is a large body of literature studying changes in oral processing with age, there is much less work published assessing how these changes contribute to different sensory perceptions.

2.4 Physiological changes and food avoidance

Due to the changes in physiology associated with aging, older adults often avoid or modify foods that are difficult to consume. Oral health conditions, such as poor dentition, dry mouth, and oral pain have been associated with increased food avoidance as outlined in Table 2.2. In some cases, individuals with poor dentition have reported modifying the food to make it easier to consumer. Examples of these modifications are shown in Table 2.3. The level of modification and/or avoidance observed is often directly related to the severity of symptoms. For example, in individuals who experience dry mouth, the level of modification/avoidance increases with the severity of symptoms (Quandt et al., 2011). Likewise, chewing ability is directly associated with dentition (Hildebrandt et al., 1997).

Table 2.2 Oral physiology characteristics and their contribution to food avoidance

Characteristic	Number of foods avoided, *N* (%)			
	Total	**0**	**1–2**	**3–14**
Self-rate oral health				
Excellent, very good, good	347 (55.0)	161 (66)	86 (52.3)	100 (44.9)
Fair, poor	284 (45.0)	83 (34)	78 (47.7)	123 (55.1)
Periodontal disease				
Yes	310 (48.9)	81 (33.0)	102 (61.5)	127 (57.2)
No	324 (51.1)	165 (67.0)	64 (38.5)	95 (42.8)
Bleeding gums				
Yes	135 (21.4)	20 (8.3)	36 (21.6)	79 (36.1)
No	495 (78.6)	225 (91.7)	130 (78.4)	140 (62.9)
Oral pain				
Yes	70 (11.0)	17 (6.8)	19 (11.3)	34 (15.2)
No	565 (89.0)	229 (93.2)	147 (88.7)	189 (84.8)
Dry mouth				
Yes	309 (48.7)	91 (36.9)	79 (47.6)	139 (62.3)
No	326 (51.3)	155 (63.1)	87 (52.4)	84 (37.7)
Number of teeth				
0	328 (47.1)	42 (17.1)	116 (69.9)	170 (76.1)
>0	369 (52.9)	204 (82.9)	112 (67.7)	53 (23.9)
Removable prosthesis				
Yes	381 (60.0)	99 (40.1)	112 (67.7)	170 (76.1)
No	254 (40.0)	147 (59.9)	54 (32.3)	53 (23.9)
Dentures ill fitting				
Yes	135 (21.4)	22 (8.9)	34 (20.7)	79 (35.9)
No	496 (78.6)	224 (91.1)	130 (79.3)	142 (64.1)
Functional occlusal units, anterior				
0	95 (27.7)	27 (17.6)	28 (26.5)	40 (49.3)
1–3	56 (16.3)	13 (8.2)	24 (22.9)	19 (22.6)
4–6	192 (56.0)	115 (74.2)	54 (50.6)	23 (28.1)
Functional occlusal units, posterior				
0	105 (30.4)	35 (22.5)	30 (27.6)	40 (49.3)
1–3	89 (25.8)	30 (19.1)	32 (30.1)	27 (32.9)
4–10	151 (43.8)	91 (58.3)	45 (42.3)	15 (17.8)

Adapted from Quandt et al. (2010).

Table 2.3 Number and percentage of older adults reporting food modification practices due to poor oral health

Food modification practice	*N* (%)
Apples	
Any modification	397 (67.8)
Peel	325 (51.2)
Slice thin	299 (47.1)
Chop into small pieces	158 (24.9)
Cook	69 (10.9)
Scrape	33 (5.2)
Steak, pork chops, or roast	
Any modification	349 (56.6)
Chop into small pieces	268 (42.3)
Cook a long time or stew	218 (34.4)
Slice thin	155 (24.5)
Tenderize	66 (10.3)
Beans like butterbeans, lima beans, black-eye peas, or field peas	
Any modification	148 (23.8)
Cook an extra-long time	142 (22.4)
Mash	30 (4.7)
Add ingredients	1 (0.2)
Carrots	
Any modification	253 (45.4)
Cook an extra-long time	200 (31.6)
Chop into small pieces	128 (20.2)
Shred	71 (11.3)
Baby carrots	17 (2.7)
Leafy green, like collards or cabbage	
Any modification	241 (39.2)
Chop into small pieces	237 (37.4)
Cook an extra-long time	93 (14.7)
Cream	5 (0.7)

Quandt et al. (2010).

The types of foods avoided by older adults are often associated with certain textures, such as stringy and crunchy (Hildebrandt et al., 1997). Dry solid foods are often difficult for older adults to consume due to difficulties chewing, and swallowing poorly chewed foods. In some situations, individuals with swallowing difficulties may avoid solid-textured foods entirely and consume only pureed foods to ensure safety during consumption. Food avoidance and some forms of modification may result in reduced nutritional quality of the diet as certain food groups, such as raw vegetables and whole grains, may be avoided. In fact, a recent study found that biomarkers of key micronutrients are significantly lower in those with poor dental health (Walls and Steele, 2004). This indicates that the avoidance of certain foods may be detrimental to the health of an older adult.

2.5 Physiological changes and food liking and consumption

The knowledge that sensory capabilities diminish with age has led researchers to explore the contribution of flavor and taste enhancement to liking and pleasantness of foods. Enhancement of the tastes and flavors of a number of different foods and beverages has been examined (Cordelle et al., 2004; de Graaf et al., 1996; de Jong et al., 1996; Essed et al., 2009; Griep et al., 2000; Hooks et al., 1990; Koskinen et al., 2003; Kozlowska et al., 2003; Kremer et al., 2005, 2007a; Laureati et al., 2008; Michon et al., 2010a,b; Murphy and Withee, 1986). Amplification of chemical irritants and textures has also been studied through the addition of white pepper and xanthan gum to soups (Forde and Delahunty, 2002). Although a great deal of research has been published in this area, there is no clear evidence of a trend for liking of enhanced foods by older adults. Some researchers have found that liking and pleasantness scores for enhanced products are higher for older adults than for a younger population (de Graaf et al., 1996; Hooks et al., 1990; Kozlowska et al., 2003; Murphy and Withee, 1986; Zandstra and de Graaf, 1998) and it has been hypothesized that this is due to the compensatory effects of enhancement on liking. Conversely, others have found no effect of enhancement on liking (Kremer et al., 2007a,b; Laureati et al., 2008; Mojet et al., 2005). One hypothesis is that this may be due to the fact that reduction in sensory capabilities is so gradual that individuals are not aware that it is happening (Mojet et al., 2003). It could be that food memory is a stronger influence for perception than the actual physiological response.

One challenge with measuring liking of foods by older adults is the scaling approach used. It has been observed that, in comparison to younger adults, older adults use a higher part of the nine-point hedonic scale when making their evaluations. This may be a result of trying to please the researcher and it has been concluded that this methodological difference may be the reason for the higher liking scores observed in some studies (Forde and Delahunty, 2002). Additionally, cognitive impairments may mean that older adults may not entirely understand the task to be completed (Kozlowska et al., 2003). Therefore ensuring that the task is appropriate for older adults to complete is essential for understanding preference and liking.

It has been assumed that an enhancement of tastes and flavors in food leads to a larger portion of food being consumed by older adults. This, however, is not always the case. Griep observed that over a two-day period, hospitalized older adults ate a larger amount of flavor-enhanced yogurts than yogurts without flavor addition (Griep et al., 1997). This confirms results from Schiffman, who found that, over a three-week period, institutionalized older adults ate more food when it was flavor enhanced than when it was not (Schiffman and Warwick, 1993). However, others have found that liking does not correlate with food intake. Although older adults have been found to like breakfast foods enhanced with sucrose and main dish foods with added monosodium glutamate, higher intakes of these foods have not been observed when eaten as part of a meal (de Jong et al., 1996; Essed et al., 2009) or when eaten in the home (Koskinen et al., 2005).

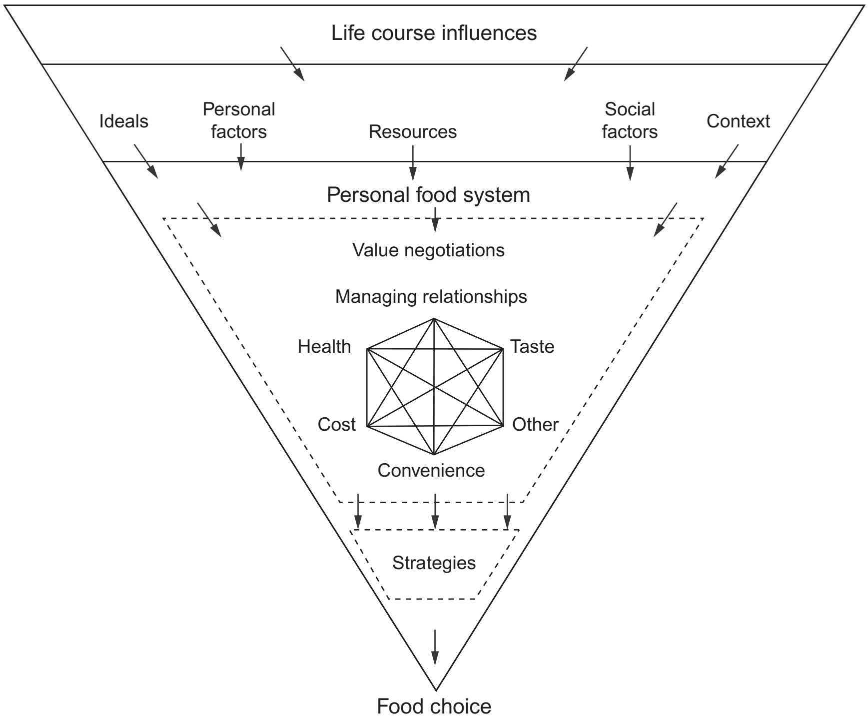

Figure 2.7 Food choice model.
Reprinted from Connors et al. (2001).

One reason for the discrepancy in intake results may be nonfood related factors that have not been taken into consideration during the study. Food choice and consumption have many influences and a number of models have been developed to outline these influences. One such model is shown in Figure 2.7 (Connors et al., 2001). This model integrates a number of life course influences such as resources, social contexts, and ideals into an individual's personal food system. When making a decision about consuming a food, value negotiations are used to make the food choice. These value negotiations involve a number of different considerations including taste, health, managing relationships, convenience, and price. While some of these have been studied, others require further consideration. In order to entirely understand food intake of older adults, the importance of each of these factors and how they are integrated must be examined.

2.6 Future trends

Given the increasing population of individuals over the age of 65 worldwide, there is significant interest in the older adult population. Much of this interest is focused on ensuring that older adults maintain good health as they age. Food is one key element of this. Malnutrition is a concern for all older adults, even those who are healthy agers. Therefore ensuring adequate intakes of nutrient-dense food is important. Continuing to pursue knowledge in the area of designing foods with acceptable sensory properties is instrumental.

There is still much to be learned with regard to the effects of changing sensory capabilities on food intake. Although we have an understanding of the physiological changes that occur as an individual ages, understanding how these changes translate into alterations in sensory perception is still not clear. One reason for discrepancies in results is that sensory perception is not one-dimensional and all senses interact when a food is consumed. Most studies focus on only one sensation while trying to control the remaining sensations, therefore the multimodal aspect of sensory perception is not taken into consideration. In future studies, these interactions should be investigated.

It must be remembered, however, that the sensory properties of a food are only one contributor to food intake. Other aspects of the food choice model must be looked at. One factor that has been identified as important for food choice of older adults is that of tradition (Laureati et al., 2006). Older adults show a stronger preference for foods consumed during childhood as this is the period of time when food preferences are formed. This work has only been conducted on a small group of individuals from one country and needs to be conducted with a larger group of older adults from different cultures to validate the results. Additionally, all aspects of the food choice model must be integrated to understand the importance of each component to food choice and intake.

2.7 Sources of further information and advice

The taste and sniff tests mentioned in the chapter can be sourced from the following suppliers:

Sniffin' Sticks: Burghart Messtechnik GmbH, Tinsdaler Weg 175, D-22880 Wedel. Web site: http://www.burghart-mt.de/

Sniffin' Sticks can also be purchased in North America from US Neurologicals LLC. Web site: http://www.usneurologicals.com/

University of Pennsylvania Smell Identification Test and Brief Smell Identification Test: Sensonics, Inc., P.O. Box 112 Haddon Heights, NJ 08035. Web site: www.sensonics.com

San Diego Odor Identification Test: National Institutes of Health Toolbox. Web site: http://www.nihtoolbox.org/

Sniff Magnitude Test: WR Medical electronics Co, 1700 Gervais Avenue, Maplewood, MN 55109, USA. Web site: http://www.wrmed.com/

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Statistical methods and tools for analysing sensory food texture

3

P. Ho
University of Leeds, Leeds, UK

3.1 Introduction to sensory analysis methods

Numerous sensory methods have been developed for assessing a wide range of food products. These methods can basically be divided into three main types: acceptability and preference methods, discrimination methods and descriptive methods. These methods require different types and number of sensory assessors in order to provide adequate data for their analysis with classical statistical inferential methods. However, all these methods should be conducted by following proper controlled conditions for testing with assessors,[1] use of appropriate sample preparation methods and sample presentation techniques. Acceptability and preference methods should only use untrained assessors, and these methods should be conducted separately from the other two methods that require trained assessors. They also require a much larger number of assessors (typically between 50 and 100) when testing in a laboratory setting (Stone and Sidel, 1993). The exact number should be determined based on the objective of the study and the number of samples that are being compared. Hough et al. (2006) produced a table for the minimum number of assessors required for an acceptability test based on the estimates of standard errors. Discrimination and descriptive methods typically use a much lower number of assessors. The exact number of assessors depends on the particular sensory methods used (Meilgaard et al., 1999).

3.1.1 *Acceptability and preference methods*

Perhaps the most well-known of all sensory tests is the preference test. There are three main methods, which depend on the measurement scale used. The simple preference test consists of presenting a sample from two different products of interest. The assessor is required to evaluate the two samples that are presented together and identify which sample is preferred. The analysis of the data is relatively straightforward and requires counting the number of preferred samples for each product. This set of nominal[2] data can then be analysed by the binomial test. If we have more than

[1] The term ‘assessors’ means panellists or judges in a sensory panel.

[2] Nominal data is obtained when one sample is coded with one number, say 1 for a preferred sample, and 0 for the other sample. Our dataset consists of 1s and 0s.

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two products, then we could use a ranking test. At least three samples should be presented at the same time to the assessor, who has to then rank the samples in order of preference. Rank data is considered to be ordinal and must then be analysed using a statistical rank test, such as the Friedman two-way analysis of variance (ANOVA), which is outlined in Section 3.4.1.1.

The hedonic preference test uses a 9-point hedonic (category) scale and can be used to measure the acceptability of any number of products. Samples should be presented to assessors individually, allowing for individual ratings for each product. This test produces data that is on the ordinal level, although it is common practise to treat this data as interval-scale data, and the paired-*t* test (Section 3.3.1.1) or an ANOVA (Section 3.5.1.1) is normally used to analyse the data. However, these statistical methods should not be used without careful considerations of the statistical assumptions made about the data.

3.1.2 Discrimination methods

Discrimination methods or difference tests require the use of trained assessors. These can be divided into overall difference tests and attribute difference tests. Both of these two types of methods consist of numerous tests that produce nominal, ordinal or interval-scaled data. The triangle and duo-trio tests are the most commonly well-known overall difference tests that, like the simple preference test, produce nominal data that can be analysed using the binomial test. There are many other methods, such as the 'A'–'Not A' and the same/different test. The Chi-square test is normally used to analyse data from these overall difference tests. In some cases, the difference-from-control test might be used when the aim is to determine not only if there is a difference between two or more samples but also the degree of difference between a control sample and another product sample. In this case, the same statistical methods that are used to analyse data from the hedonic preference test can be used.

Attribute difference tests are used when we are interested in determining the difference between two or more products based on a specific sensory attribute or characteristic. If our goal is to examine the difference between the crunchiness of two protein bars, then an attribute difference test should be chosen. Samples should be presented individually, unless a ranking test is used. The choice of which statistical test to use, as has been outlined previously for preference tests, depends on the measurement scale used. Both category rating and line scales can be used. These types of scales require different degrees of control over assessor error, and hence the number of assessors that are required and the amount of training required will vary. Category rating scales[3] produce ordinal data, although if a sufficient number of categories is used they can perform similarly to line scales, which produce interval-scaled data. The same assumptions made about data from the 9-point hedonic scale are made with a category rating scale, so the same rules apply as to the validity of the statistical methods chosen to analyse the data.

[3] The 9-point hedonic scale is an example of a category rating scale.

3.1.3 Descriptive methods

A descriptive method is simply a collection of numerous attribute difference tests that use a category or line scale to rate each attribute. However, the experimental procedures for using these methods, such as the Quantitative Descriptive Analysis or the Spectrum™ Method (Meilgaard et al., 1999), are more complicated than will be discussed here. Essentially a single rating score is produced for each sensory attribute for each product sample. Data can be analysed using any of the statistical methods used for discrimination tests. Multivariate pattern recognition methods, such as principal component analysis (PCA), can also be used when the aim is to produce a sensory profile and a comparison can be made between different products. An example of PCA can be found in Section 3.6.1.3.

3.2 Statistical methods for analysing sensory data

Inferential and multivariate methods are the two main types of statistical methods commonly used to analyse data from sensory tests. An inferential test is a statistical test that is used when we are interested in testing a hypothesis. Multivariate tests, on the other hand, are used to examine more than one sensory attribute at a time. Product samples and all sensory attributes can be represented in a two-dimensional space, providing a kind of sensory profile. There are many different types of multivariate methods that can be used to analyse sensory data from sensory descriptive tests.

3.2.1 Parametric or non-parametric methods

Inferential statistical test are often classified into parametric and non-parametric test. Selecting the correct statistical test for analysing data depends not only on the type of data but also the ‘properties’ of the data. Many of the parametric tests described in this chapter assume that data is normally distributed and different products have samples that have equal variances. Parametric tests are also known to perform poorly when the sample distribution is skewed and if outliers are present. When any of these assumptions are not met by the data that is collected, non-parametric tests are often used. These tests require a relaxation of some of the assumptions made by parametric tests. However, non-parametric tests may still perform poorly if data is non-normal or have skewed distributions (Wilcox, 2012). Parametric tests are normally preferred over non-parametric tests because they are considered to have more power in detecting differences.

3.2.1.1 How do I choose the correct statistical method for my data?

Knowing which statistical test to choose can sometimes be difficult for someone who does not know under which set of conditions a statistical test would perform poorly and results in an incorrect conclusion. When differences between samples are small, then the choice of the statistical method can produce different results. One approach in choosing the correct statistical test is to start by understanding the type of data that is collected. Start by identifying if the data from a sensory test is nominal, ordinal or interval-scaled. The Binomial or Chi-Square tests, which are non-parametric tests, can be used for nominal data. Non-parametric tests, such as the Friedman two-way ANOVA, are used with rank data but can also be used with interval or category scales, when the assumptions for parametric tests are violated. The *t*-test (both the paired and independent forms) and the ANOVA test are both parametric tests and should be used to analyse data from interval scales (e.g., a line scale) and also category scales (e.g., 9-point hedonic scale). If the assumptions made to data regarding the use of parametric tests are violated, these methods might still be used if the original data is transformed by using an appropriate function. The Box-Cox transformation can be used to find an appropriate transformation function (Kutner et al., 2005). Data that is not normally distributed or when unequal variances are found between samples can sometimes be transformed into data with an acceptable degree of normality and unequal variances can be stabilised. The assumptions could then become valid after the data transformation, allowing the use of the parametric test. In either case, after the parametric test is conducted, tests for the validity of assumptions should be made. Often these tests are used in combination with graphical methods that examine the residuals.[4] Residuals are often used when identifying outliers after an ANOVA test. If there is any doubt in the validity of the results due to the possibility of the violation of any assumptions, non-parametric test alternatives can be used. Data that has been analysed using the parametric ANOVA test can also be analysed using a non-parametric test. For example, if the result from an ANOVA test with data from a preference test is in question, the Friedman two-way ANOVA test could be used instead. However, as has already been mentioned, even non-parametric tests make some assumptions about the data that is to be analysed. Recent work has suggested that perhaps robust statistical methods should be used instead of classical methods, as they have been known to outperform those methods (Wilcox, 2012).

3.2.2 Multivariate methods

There are many different parametric and non-parametric multivariate statistical methods and these methods are often classified as supervisory or non-supervisory pattern recognition methods. These methods, together with Neural Networks, can be used for both classification and regression (Ripley, 1999). A supervisory method is a method where prior information regarding which groups samples belong to is given when trying to classify a sample into one of the predefined groups. Linear discriminant analysis (LDA) is an example of one such method. PCA, on the other hand, is an example of a non-supervisory method. These methods are used when it is not known if product samples belong to a particular classification group. Both methods are linear methods, although non-linear versions of these methods have been developed.

[4] A residual is simply the value associated with the difference between the observed and fitted values.

3.2.3 Software

The R software (R Core team, 2014) will be used in the examples given below. R is a freely available statistical software for Linux, Mac OS and Windows. It can be downloaded from http://www.r-project.org/. There are over 6000 packages available at the time of writing this chapter. R packages are made up of a series of functions that can be used directly in the R console or with one of the many GUIs, such as Rcmdr (Fox, 2005), that have been developed by the R community. A brief introduction on using R can be found in the Appendix. You should read this section first, if you are new to R, before trying out the examples in this chapter.

You will also find a flowchart with a step-by-step guide of how to carry out the different statistical tests for each example. A complete set of R code and datasets have been made available from my Google+ community https://plus.google.com/communities/105830318585096638917.

3.3 Attribute difference tests

An attribute difference test can be conducted to compare two samples using a category rating scale or a line scale when the objective is to not only determine if a difference occurs between two samples but when the degree of difference is also of interest. The statistical methods described in this section can be used with any sensory test where the measurement scale is either a category scale or a line scale.

3.3.1 Example 1: creaminess of two yoghurts

Two batches of yoghurts, using two different strains of starter cultures, are compared for differences in creaminess. It is not known which one gives a creamier yoghurt. An attribute difference test was conducted with 12 trained assessors using a 9-point category scale to determine which yoghurt was creamier. The results are presented in Table 3.1.

3.3.1.1 Paired-t test

The usual procedure for analysing data from an attribute difference test with two samples (and also for a paired preference test) is to conduct a paired t-test. A two-tailed (or two-sided) hypothesis test should be conducted, such that

$$H_0: \mu_A = \mu_B$$
$$H_1: \mu_A > \mu_B \quad \text{or} \quad \mu_A < \mu_B$$

where (H_0) is the null hypothesis and (H_1) the alternative hypothesis. In a paired t-test the difference between each batch for each sample is calculated and mean value of the differences are calculated and used to estimate the sample test statistics (t-stat), which is then compared against a value from the Student's t-distribution. This t-critical value is determined by the degree of freedom (df) or $N-1$ where N is the number of

Table 3.1 Data from attribute difference test for two yoghurts for panel I

Assessor	Batch A	Batch B
1	7	6
2	6	5
3	8	6
4	7	5
5	8	6
6	7	5
7	6	6
8	6	4
9	7	5
10	5	5
11	5	3
12	6	5

assessors used in the sensory test and the significance level[5] of the test. A 5% significance level, corresponding to a 95% confidence level, is typically used as the default value in most software programs. One final piece of information that is required depends on the choice of the alternative hypothesis. In our example, we have chosen a two-sided hypothesis test instead of a one-sided test because we had no idea which batch would give us a creamier yoghurt. Hence, we have two possible outcomes: either batch A is creamier than batch B or batch B is creamier than batch A. Figure 3.1 shows a step-by-step guide on what needs to be done in order to make a decision that is based on the results of the paired *t*-test. In addition to conducting the test, the assumption of normality of the data, the absence of outliers and an examination of whether data from each batch is not skewed should be examined to ensure that the conclusions made from the paired *t*-test is valid.[6]

[5] A 5% or 0.05% is the default value used in most software. You may want to set a lower value, such as 1% if you are looking for a much smaller difference between sample means. This would also require a panel that has a better discriminatory ability. In preference tests, you might even want to select a larger significance level, say a 10%. Make sure that you explain why you have selected a particular value. However, most people are happy to use the default value.

[6] If the *p*-value form the paired *t*-test is highly significant, then some degree of departure from normality, a skewed distribution or possibly the presence of outliers would likely not have a large effect on the results and the Wilcoxon Signed rank test would likely provide the same conclusions. In any case, it is good practice to confirm the results of the analysis with an alternative test. An incorrect conclusion could occur when the *p*-value is close to the level of significance that is set for the test. In the event of distributions showing some degree of skewness and the presence of outliers, even the Wilcoxon test could provide an incorrect conclusion. The use of a robust method, as described by Wilcox (2012) is advised.

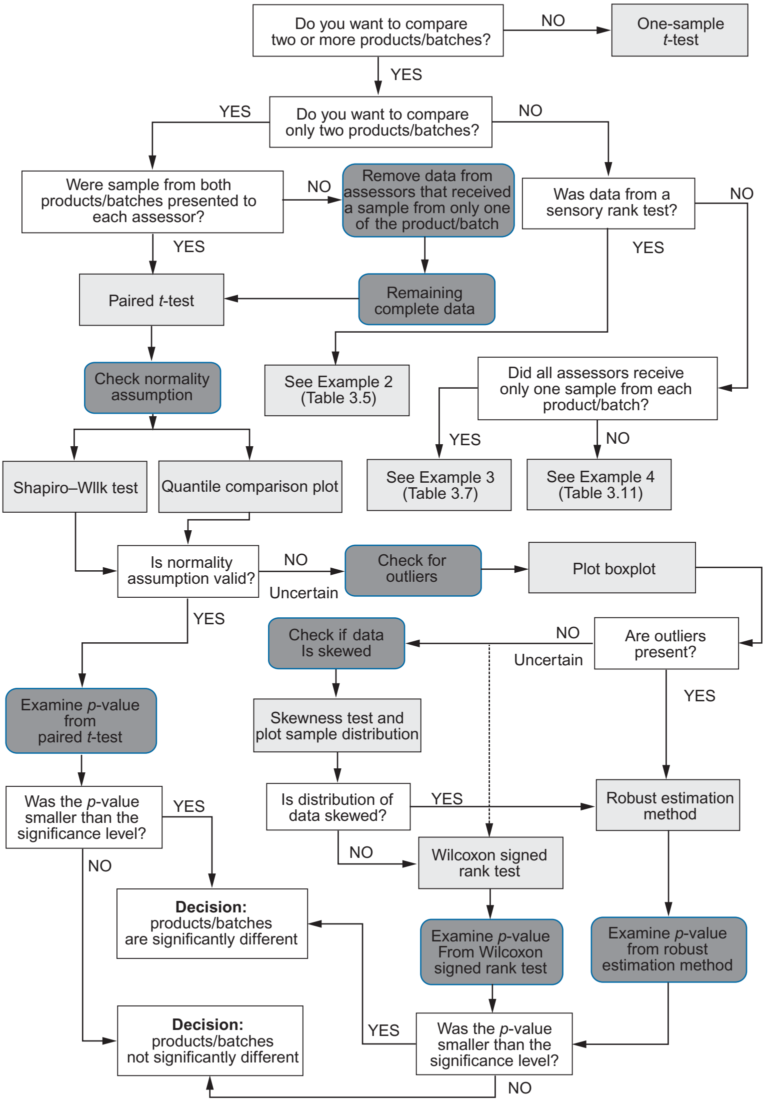

Figure 3.1 A step-by-step guide to the procedures required for analysing data from Example 1.

Data from Table 3.1[7] should first be imported into R by using the `read.table()` function before using the `t.test()` function.[8] The function can be used to conduct

[7] All the R scripts for analysing Table 3.1 can be found in the file Table 3_1.R. See further details in the **Appendix**.

[8] R scripts that have been run in the R console appear red in the Windows OS. The script is preceded by the '>' symbol.

both the paired and independent *t*-tests and so the option `paired=TRUE` should be indicated, together with the 95% confidence level and identifying that the alternative hypothesis is a '`two.sided`'. R output 3.1 shows the results of the paired *t*-test, which can be found in blue[9] in the R console. The test statistic (`t`), degree of freedom (`df`) and *p*-value are given, together with an estimate for the mean of the differences between the samples and the lower and upper levels of a 95% confidence interval. The *p*-value of `0.00006` is a lot smaller than our test significance level of 0.05, indicating that we can accept one of the alternative hypotheses. If we use the `colMeans()` function R output 3.2. Calculating the mean of batch A and B from table 3.1, we find that batch A has a mean value of `6.5` and batch B a value of `5.08`. The result from the paired *t*-test suggests we can state with a 95% confidence level that batch A has a creamier taste than batch B.

```
> with(table3.1, (t.test(Batch.A, Batch.B, alternative='two.sided',
+ conf.level=.95, paired=TRUE)))

        Paired t-test

data:  Batch.A and Batch.B
t = 6.1888, df = 11, p-value = 6.823e-05
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 0.912843 1.920490
sample estimates:
mean of the differences
               1.416667
```

R output 3.1 Result of paired t-test for table 3.1.

```
> colMeans(table3.1[,2:3]

Batch.A     Batch.B
6.500000    5.083333
```

R output 3.2 Calculating the mean of batch A and B from table 3.1.

Should we accept the results from the paired *t*-test or should we proceed with the steps outlined in Figure 3.1? The *p*-value from the paired *t*-test is a lot smaller than the significance level for the test, so even if there was some departure from the assumption of normality, the result would probably remain the same if data was normally distributed. However, if the *p*-value was much closer to the significance level, the decision could be overturned. Let us first have a look at the results from a second sensory test, conducted this time with panel II. Table 3.2[10] shows the results of a second panel evaluating the same two batches; however, this panel has 20 assessors instead of just 12 from panel I. If we conduct the paired *t*-test for this set of data, we obtain a *p*-value of `0.0317`. This value is now very close to the 0.05% significance level, but still sufficient to accept the null hypothesis that batch A with a mean of `6.2` is creamier than batch B with a mean of `5.45`. Should we accept the result of the paired *t*-test for both panels?

[9] Colours for executed scripts and result outputs may vary depending on which OS is used. The examples given are from the Windows OS.

[10] All the R scripts for analysing Table 3.2 can be found in the file Table 3_2.R. See further details in the Appendix.

Table 3.2 **Data from paired comparison test for two yoghurts for panel II**

Assessor	Batch A	Batch B	Assessor	Batch A	Batch B
1	7	6	11	5	3
2	6	5	12	6	5
3	8	6	13	4	5
4	7	5	14	7	8
5	8	6	15	7	6
6	7	5	16	5	3
7	6	6	17	6	6
8	6	4	18	8	7
9	7	5	19	4	6
10	6	5	20	5	7

3.3.1.2 How reliable is the paired t-test?

The power of the paired-*t* test can be severely affected if data departs from normality and the results can also be biassed if data is skewed (Wilcox, 2012). It should, therefore, be common practise to check for the assumptions of normality and skewness for samples from each batch. The data should also be checked for the presence of outliers.[11] These procedures and the order of analysis can be followed in Figure 3.1. If checks are made that indicate problems with the data, then the Wilcoxon signed rank test, a non-parametric alternative of the paired *t*-test, could be used to verify the results of the paired *t*-test. However, even the Wilcoxon signed rank test might perform poorly if outliers are present or the distribution of data is heavily skewed. Robust methods[12] described by Wilcox (2012) could be used as an alternative procedure, but this does not solve the fundamental problem of a poorly trained panel. If the panel is properly trained, then many of the problems outlined should not be encountered and the statistical methods described in this chapter should suffice. If problems are indicated, then perhaps the best solution is either to retrain the assessors or to remove assessors that are identified as providing data found to be outliers.

3.3.1.3 Checking the assumption of normality

The main assumption made in the paired *t*-test is that data from each group (i.e., our batches of yoghurts) should have a normal distribution. It is important to check the validity of this assumption, because a departure from normality could invalidate the results. There are a range of tests and graphs that can be used to assess normality, some performing better than others. The Shapiro–Wilk test for normality and quantile-comparison plot can be used to determine the normality of data. In addition, the quantile-comparison plot

[11] Outliers can have result in an incorrect estimation of the mean value and standard error.

[12] See the Appendix for details of which methods should be used.

Table 3.3 ***p*-Values from Shapiro–Wilk tests for normality**

Panel	Batch A	Batch B
I	0.1874	0.0152
II	0.0944	0.0985

also allows us to identify data points that might be considered as outliers. The R scripts for both the `Shapiro.test()` and `qqPlot()` functions have not been reproduced here but can be found in the complete R script[13] for Table 3.1. The results from the Shapiro–Wilk test (Table 3.3) indicate that data from batch B from panel I is most likely not normally distributed (*p*-value = `0.0152`), whereas the test indicates no departures from normality for batch A. Both batches from panel II are considered normally distributed. However, if we examine the quantile-comparison plots in Figure 3.2, some of the data points fall outside of the confidence limits (dashed lines) (i.e., at least one point from batch B for panel I and three and four from batch A and batch B from panel II). Outliers could have an effect on normality of data and subsequently affect the results of the paired *t*-test. Using the `boxplot()` function, observations made by assessor 11 from panel I and assessors 11, 14 and 16 from panel II were identified as outliers. If we conduct the D'Agostino test for each batch for both panels, using the `agostino.test()` function, we will find that there is no indication of skewed distributions. Since we cannot be sure what effect these potential outliers have on the results of the paired *t*-test, a non-parametric test or robust method could be used to confirm the results.

3.3.1.4 Wilcoxon signed rank test and robust methods

The Wilcoxon signed rank test is a non-parametric alternative to the paired *t*-test. If the data from both panels were analysed using this methods, the *p*-values from the Wilcoxon signed rank test with continuity correction[14] for panel I was `0.0042` and panel II was `0.0585`. The results now indicate that only panel I was able to determine that batch A was creamier than batch B. No decision can be made based on the results for panel II as to which batch is creamier, if we use the Tukey's three-decision rule (Wilcox, 2012). How can we then make a decision about which batch is creamier if we obtain conflicting results from both panels? How reliable are both results? As we have identified outliers that skewed the distribution of data for batch B from both panels, perhaps this could affect our results. Wilcox (2012) has suggested that using a 20% trimmed mean or their medians could provide a more reliable results under these conditions. Results from Table 3.4 now suggest that both panels were able to identify batch A being creamier than batch B. The data presented here has outlined some important aspects when performing a simple attribute difference test. First, it is

[13] See the Appendix on how to download the complete R scripts.

[14] A better approximation of the test statistic can be determined if we correct our data that is from a discrete distribution. The critical value for the test uses the Chi-square distribution, which is continuous and not discrete.

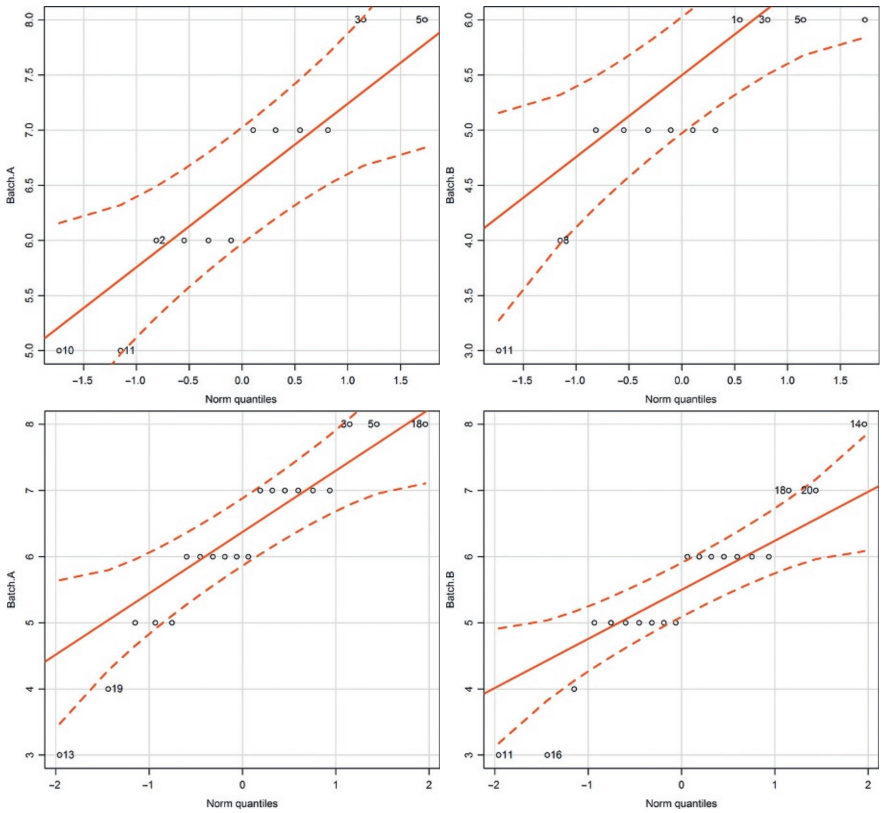

Figure 3.2 A comparison of the results for the quantile-comparison plot between panel I (top) and panel II (bottom).

Table 3.4 ***p*-Values of standard methods compared to robust versions of the paired *t*-test**

Panel	Means[a]	Ranks[b]	20% Trimmed means	Median
I	0.00006	0.0042	0.002	<0.001
II	0.0317	0.0585	0.027	0.012

[a]Paired *t*-test.
[b]Wilcoxon signed rank test.

important to make sure that assessors are consistent in their use of the rating scale. Second, checks for the validity of assumptions made from the paired *t*-test should be made regardless of type or amount of data obtained. Finally, it would make sense to perform more than one test to confirm that the same conclusions can be made regardless of the statistical test that is used.

3.4 Sensory rank tests

A sensory rank test can be used when there are at least three products that are being compared. They are used in both difference and preference testing. The measurement scale is an ordinal scale, which requires the assessor to rank the order of all samples that are presented. The statistical methods described here can also be used for analysing data from difference and preference tests comparing three or more samples. Figure 3.3 outlines the procedures necessary to analyse data from sensory rank tests.

3.4.1 Example 2: hardness of five Cheddar cheese

A local dairy working on the development of a low-fat Cheddar cheese is interested in comparing the hardness of cheese after ripening for 8 weeks at five different ripening temperatures. A ranking test was conducted to determine if there were any differences in the hardness of the three cheeses with 20 trained assessors, each receiving all five samples in a random presentation order based on a balanced complete block design. Assessors were required to rank samples from the hardest sample (ranked 1) to the softest (ranked 5). The results of the ranking test are presented in Table 3.5.[15]

3.4.1.1 Friedman two-way ANOVA test

The usual procedure for analysing data from a rank test is to use the Friedman two-way ANOVA test, followed by a multiple comparison test if the alternative hypothesis from the Friedman two-way ANOVA test is rejected. A two-tailed (or two-sided) hypothesis test is conducted, such that

$$H_0 : \sum R_A = \sum R_B = \sum R_C = \sum R_D = \sum R_E$$
$$H_1 : \text{not all } \sum R_i \text{ are equal}$$

where (H_0) is the null hypothesis, (H_1) the alternative hypothesis. In the Friedman test, the sum[16] of ranks for each product is compared, where the alternative hypothesis states that not all of the sample sum of ranks are equal. The Friedman test statistic is compared to the Chi-square critical value from the Chi-square distribution. If the *p*-value of the test is smaller than the significance level of the test, then the alternative hypothesis should be accepted. This indicates that the rank sum of at least one sample is significantly different from another sample. The built-in R function `friedman.test()` can be used to conduct the Friedman two-way ANOVA test, using a standard formula format that is of the form `name of attribute ~ Sample |Assessor` (R output 3.3). The *p*-value of `0.0001073` clearly indicates that differences in hardness between the five cheeses exist. When the alternative hypothesis, comparing the differences between the rank sums from the Friedman two-way ANOVA, is accepted a multiple comparison test should be conducted to examine all pairwise comparisons between the products.

[15] All the R scripts for analysing Table 3.5 can be found in the file Table 3_5.R. See further details in the Appendix.

[16] An alternative comparison can be made with the average rank scores instead of the sum of ranks.

```
> friedman.test(hardness ~ Sample | Assessor, data=table3.5)

        Friedman rank sum test

data:  hardness and Sample and Assessor
Friedman chi-squared = 23.36, df = 4, p-value = 0.0001073
```

R output 3.3 Results from Friedman 2-way ANOVA for rank data from table 3.5.

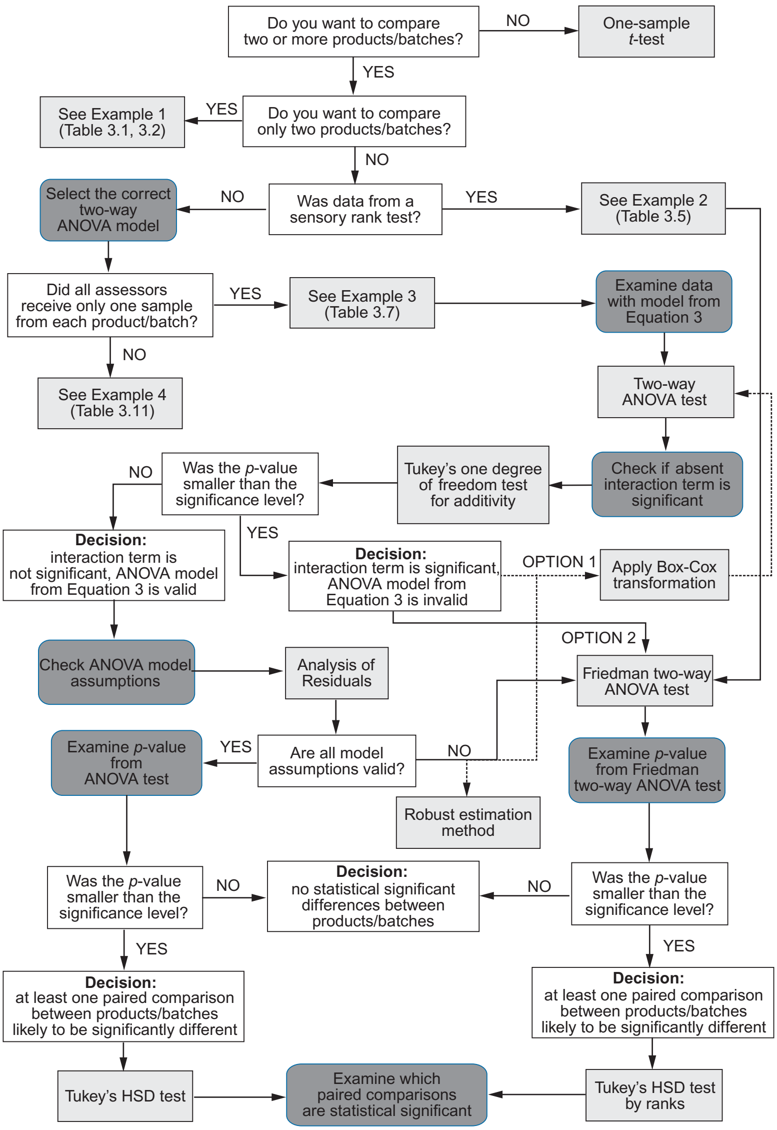

Figure 3.3 A step-by-step guide to the procedures required for analysing for Examples 2 and 3.

Table 3.5 **Attribute rank test for five Cheddar cheeses**

Assessor	Cheese A	Cheese B	Cheese C	Cheese D	Cheese E
1	2	4	5	3	1
2	4	5	3	1	2
3	1	4	5	3	2
4	1	2	5	3	4
5	1	5	2	3	4
6	2	3	4	5	1
7	4	5	3	1	2
8	2	3	5	4	1
9	1	3	4	5	2
10	1	2	5	3	4
11	4	5	3	2	1
12	2	4	3	5	1
13	5	3	4	2	1
14	3	5	2	4	1
15	1	2	5	4	3
16	3	4	5	1	2
17	2	3	4	5	1
18	1	4	2	5	3
19	4	5	3	2	1
20	2	3	5	4	1

Note: Values in the cells are ranked from 1 (hardest) to 5 (softest).

3.4.1.2 Multiple comparison tests

A multiple comparison test between the absolute differences between the rank sums of each product sample can be determined based on the equation suggested by Siegel and Castellan (1988)

$$|R_i - R_j| \geq Z_{\alpha/k(k-1)}\sqrt{\frac{Nk(k+1)}{6}} \quad (3.1)$$

where $Z_{\alpha/k(k+1)}$ corresponds to the critical value based on the normal distribution with a level of significance α comparing k groups with N number of assessors. A significant difference is found between any two rank sums when that value is greater than the critical difference. The `friedmanmc()` function in the pgirmess package (Giraudoux, 2014) can be used to conduct the multiple comparison test based on the method described by Siegel and Castellan (1988). The output from the R console (R output 3.4) shows a table with a list of all pairwise comparisons followed by the observed difference between the rank sums, the critical distance and a decision if the difference was significant (i.e., a TRUE result would indicate that there is a significant difference). The critical distance

```
> library(pgirmess)
> with(table3.5, friedmanmc(hardness,Sample,Assessor))
Multiple comparisons between groups after Friedman test
p.value: 0.05
Comparisons
                         obs.dif critical.dif difference
Cheese  A-Cheese B          28     28.07034      FALSE
Cheese  A-Cheese C          30     28.07034       TRUE
Cheese  A-Cheese D          20     28.07034      FALSE
Cheese  A-Cheese E           8     28.07034      FALSE
Cheese B-Cheese C            2     28.07034      FALSE
Cheese B-Cheese D            8     28.07034      FALSE
Cheese B-Cheese E           36     28.07034       TRUE
Cheese C-Cheese D           10     28.07034      FALSE
Cheese C-Cheese E           38     28.07034       TRUE
Cheese D-Cheese E           28     28.07034      FALSE
```

R output 3.4 Results from a multiple comparison test for rank data from table 3.5.

(`critical.dif`) was found to be `28.07034`, which can also be calculated manually using the `qnorm()` function. The `obs.dif` column gives the difference between the rank sums of any two products. Individual rank sums can be calculated using the `tapply()` function shown in R output 3.5.

```
> with(table3.5,tapply(hardness, list(Sample),sum, na.rm=T))
Cheese  A  Cheese B  Cheese C  Cheese D  Cheese E
       46        74        76        66        38
```

R output 3.5 Rank sums for each product from table 3.5.

If we examine the data carefully, there were two paired comparisons that came close to being not significantly different. The difference between cheese A and cheese B and the difference between cheese D and cheese E, both with an observed difference of `28`, were found to be significantly different at a confidence level of 95%, as the critical distance was `28.07034`. The Siegel and Castellan (1988) method for calculating the critical distance is based on using a critical value based on the normal distribution, which is similar to the least significant difference (LSD) procedure suggested by Meilgaard et al. (1999). The LSD test is known to be a less conservative test than that of the Tukey's honestly significant difference (HSD) test. Tukey's HSD test is a simultaneous multiple comparison test that controls the experiment-wise error rate, instead of the comparison-wise error rate used by the LSD test. What this means in practice is that in cases where the observed difference between samples is very close to the critical distance, the choice of which multiple comparison test is used could change the outcome of whether a significant difference is detected or not. Meilgaard et al. (1999) provided the following equation for conducting the HSD test for rank data

$$|R_i - R_j| \geq q_{\alpha,k,\infty}\sqrt{\frac{Nk(k+1)}{12}} \tag{3.2}$$

where $q_{\alpha,k,\infty}$ corresponds to the critical value based on the studentized range distribution for Tukey's HSD test with a level of significance α comparing k groups with N number of assessors. The `qtukey()` function can be used to manually calculate the value of `27.32765`, which is lower than the critical distance based on the normal distribution. The HSD procedure is similar to that of the large-sample

```
> if (require("multcomp")) {
+ #
##########################################################################
+## all pairwise comparisons                                             ##
+#########################################################################
+#
+ rtt <- symmetry_test(hardness ~ Sample | Assessor, data = table3.5,
+        teststat = "max",
+        xtrafo = function(data)
+        trafo(data, factor_trafo = function(x)
+        model.matrix(~ x - 1) %*% t(contrMat(table(x), "Tukey"))
+        ),
+        ytrafo = function(data)
+        trafo(data, numeric_trafo = rank, block = table3.5$Assessor)
+   )
+#
+
##########################################################################
+##  a global test, again                                                ##
+
##########################################################################
##
+ print(pvalue(rtt))
+#
##########################################################################
+### simultaneous P-values for all pair comparisons                      ##
+#########################################################################
#
+ print(pvalue(rtt, method = "single-step"))
+ }
Loading required package: multcomp
Loading required package: mvtnorm
Loading required package: TH.data
[1] 0.001429609
99 percent confidence interval:
 0.001245390 0.001613829


Cheese B - Cheese  A 0.040962076
Cheese C - Cheese  A 0.022608688
Cheese D - Cheese  A 0.265834318
Cheese E - Cheese  A 0.930674031
Cheese C - Cheese B  0.999644214
Cheese D - Cheese B  0.930678400
Cheese E - Cheese B  0.002951055
Cheese D - Cheese C  0.855489643
Cheese E - Cheese C  0.001395527
Cheese E - Cheese D  0.041013577
```

R output 3.6 P-values from HSD test by ranks for data from table 3.5.

approximation method described by Hollander and Wolfe (1999). The R package *coin*[17] (Hothorn et al., 2008b) can be used to conduct an HSD multiple comparison test, which gives similar results to Tukey's HSD test using the critical distance based on Equation (3.2) (R output 3.6). The difference between cheese A and cheese B and the difference between cheese D and cheese E are now both significant at a 95% confidence level. The `friedman()` function in the R package agricolae (de Mendiburu, 2014) can be used to conduct the Friedman test and the LSD multiple comparison test based on the procedures described by Conover (1999). R output 3.7 shows the results of the LSD multiple comparison tests using this procedure.

[17] The multcomp packages is required by the `symmetry_test()` function from the coin package in order to conduct the multiple comparison tests for each pairwise comparison.

```
> table3.5.mcp1 <- with(table3.5,
+                friedman(Assessor,Sample,hardness,alpha=0.05,group=FALSE))
> table3.5.mcp1
$statistics
  Chisq      p.chisq        F          p.F
  23.36 0.0001072901 7.836158 2.420503e-05

$parameters
  Df ntr  t.value
   4   5 1.991673

$means
          hardness      std  r Min Max
Cheese  A      2.3 1.301821 20   1   5
Cheese B       3.7 1.080935 20   2   5
Cheese C       3.8 1.196486 20   2   5
Cheese D       3.3 1.380313 20   1   5
Cheese E       1.9 1.119210 20   1   4

$comparison
                     Difference   pvalue sig.    LCL    UCL
Cheese  A - Cheese B        -28 0.001756   ** -45.19 -10.81
Cheese  A - Cheese C        -30 0.000848  *** -47.19 -12.81
Cheese  A - Cheese D        -20 0.023214    * -37.19  -2.81
Cheese  A - Cheese E          8 0.357020       -9.19  25.19
Cheese B - Cheese C          -2 0.817414      -19.19  15.19
Cheese B - Cheese D           8 0.357020       -9.19  25.19
Cheese B - Cheese E          36 0.000080  ***  18.81  53.19
Cheese C - Cheese D          10 0.250342       -7.19  27.19
Cheese C - Cheese E          38 0.000034  ***  20.81  55.19
Cheese D - Cheese E          28 0.001756   **  10.81  45.19

$groups
NULL
```

R output 3.7 P-values from LSD test by ranks for data from table 3.5.

Table 3.6 shows the differences in the conclusions made regarding which paired comparisons were significantly different between the three methods. The LSD test is the least conservative, finding more significant different pairs than that of the HSD test and that of the normal approximation method, as the critical distance was much lower. The results demonstrate the importance of selecting the correct method to calculate the critical distance. The HSD test is perhaps the best overall method, as it is not as conservative as the normal approximation method but also ensures that some paired comparisons were not found to be significantly different.

3.5 Preference and acceptability tests

Many of the statistical methods used in analysing data from a difference test are the same methods that can be used to analyse data from acceptability or preference tests. The procedures are the same and as long as the correct methods for the measurement scale are used there should not be anything different about the analysis. Perhaps one of the main differences between the data from these sensory tests in comparison with difference test is the number of assessors used. Data from acceptability and preference test would more likely follow a normal distribution, as it is common to have between 50 and 100 values for each sample (i.e., each assessor provides one value for each sample that is evaluated). However, this does not mean that we can automatically

Table 3.6 Comparison of three multiple comparison tests for rank data

	Difference	Normal	HSD	LSD
Cheese B–Cheese A	28	ns	*	**
Cheese C–Cheese A	30	sig[a]	*	***
Cheese D–Cheese A	20	ns	ns	*
Cheese E–Cheese A	8	ns	ns	ns
Cheese C–Cheese B	2	ns	ns	ns
Cheese D–Cheese B	8	ns	ns	ns
Cheese E–Cheese B	36	sig[a]	**	***
Cheese D–Cheese C	10	ns	ns	ns
Cheese E–Cheese C	38	sig[a]	**	***
Cheese E–Cheese D	28	ns	*	**
Critical distance		28.07	27.32	17.19

ns, not significant; sig, significantly different.
[a] *p*-Values not provided by test.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

assume that the data would be normal and that there are no violation of assumptions made for conducting the particular statistical test.

The paired *t*-test is used when comparing only two product samples using the 9-point hedonic scale; however, when more than one product sample needs to be examined we can use an ANOVA test. A multiple comparison test can be used in the event that a decision that not all samples are the same is concluded from the ANOVA test. Tukey's HSD test can be used to examine which paired comparisons are significantly different at the chosen confidence level.

3.5.1 Example 3: crispiness of potato crisps

A company was interested in determining the consumer acceptability of three of their formulations of potato crisps (potato chips). A preliminary analysis using a texture analyser indicated that there were differences in crispiness by performing a fracture test. The sensory analyst decided to test the acceptability of crispiness using a 9-point hedonic scale. To rate each of the three products separately, 54 untrained assessors were required. The results can be found in Table 3.7.

3.5.1.1 Two-way ANOVA test

The single-factor within subjects ANOVA test (also known as the two-way or two-factor ANOVA test) should be used to analyse data from a preference test when more than three product samples are being compared. Two forms of this ANOVA model can

Table 3.7 **Preference test comparing crispiness of three potato crisps formulations**

Assessor	A	B	C	Assessor	A	B	C	Assessor	A	B	C
1	6	8	8	19	4	7	8	37	6	6	8
2	7	6	8	20	7	6	8	38	6	8	7
3	6	7	8	21	7	6	8	39	5	6	9
4	6	6	9	22	7	6	7	40	7	6	8
5	5	6	8	23	5	6	9	41	7	7	8
6	6	7	8	24	6	7	7	42	6	8	8
7	7	7	8	25	7	7	8	43	7	6	8
8	7	6	8	26	6	6	7	44	6	6	8
9	6	7	8	27	6	7	7	45	7	7	7
10	8	6	8	28	6	7	8	46	6	6	9
11	5	6	7	29	5	8	9	47	7	7	7
12	6	7	8	30	6	6	7	48	5	7	8
13	7	8	8	31	6	7	8	49	5	6	7
14	6	6	9	32	5	7	8	50	7	8	7
15	6	8	7	33	7	8	7	51	5	6	8
16	5	7	8	34	6	6	7	52	5	7	9
17	7	7	8	35	7	7	7	53	5	6	6
18	5	6	7	36	6	7	7	54	6	8	8

Note: Values are from a 9-point hedonic scale.

be used, depending on whether or not the assessors evaluate each product sample more than once. When only one assessment of each product sample is made by each assessor, as in the case of a preference test, the single-factor within subjects ANOVA without an interaction term should be used. The model can be stated in the form of a randomised complete block ANOVA model such that

$$X_{ij} = \mu + T_i + B_j + \in_{ij} \tag{3.3}$$

where X_{ij} is the value of all the responses for the ith sample for each jth assessor, μ is the overall mean, i is the number of product samples ranging from 1,2,. . .,t, j is the number of assessors ranging from 1,2,. . .,b, T_i is the ith sample effect (the single factor), B_j is the jth assessor effect (the block factor), $\in_{ij}$ is the random error or residual.

A two-tailed (or two-sided) hypothesis test comparing the *sample* factor can be conducted, such that

$$H_0 : \mu_A = \mu_B = \mu_C$$
$$H_1 : \text{not all } \mu_i \text{ are equal}$$

where (H_0) is the null hypothesis, (H_1) the alternative hypothesis. The alternative hypothesis states that not all of the sample means are equal. The hypothesis test is conducted by calculating an F test statistic based on the difference between the mean square of the sample factor (MS_{sample}) with that of the mean square of the residual ($MS_{residual}$). The results of an ANOVA test are typical represented in an ANOVA table as shown in Table 3.8.

Figure 3.3 shows the step-by-step procedures required to conduct an ANOVA using data from a sensory test with a category or line scale, where each assessor receives only one sample from each product.[18] The most straightforward method to conduct an ANOVA in R is to use the `aov()` function. The results of the test should be stored in a data object, which will make it easier to use it to obtain the ANOVA

Table 3.8 ANOVA table for a randomised complete block design with fixed effects

Source	Degrees of freedom (Df)	Sums of squares (SS)	Mean squares (MS)	*F* test
Sample	$t-1$	SS_{sample}	$MS_{sample} = SS_{sample/t\text{-}1}$	$MS_{sample}/MS_{residual}$
Assessor	$b-1$	$SS_{assessor}$	$MS_{assessor} = SS_{assessor/b\text{-}1}$	$MS_{assessor}/MS_{residual}$
Error	$(t-1)(b-1)$	$SS_{residual}$	$MS_{residual} = SS_{residual/(t\text{-}1)(b\text{-}1)}$	
Total	$bt-1$	SS_{total}		

t = total number of samples; b = total number of assessors.

[18] All the R scripts for analysing Table 3.7 can be found in the file Table 3_7.R. See further details in the Appendix.

table using the summary() function. The model from Equation (3.3) can be specified within the aov() function, as Acceptability ~ Sample + Assessor, with the name of the data file and the results saved into a data object. The .csv file of the data from Table 3.7 should be imported into R using the read.table() function. In addition, the assessor column, which is a column of numeric data, should be converted into a factor with levels being the values indicating each assessor.[19] This ensures that the correct degrees of freedom are used in the ANOVA test for the assessor factor.

R output 3.8 shows the results of the ANOVA test in the form of the ANOVA table. The *p*-value, Pr(>F), for the sample factor was found to be highly significant. This result should not be accepted until assumption made for the ANOVA model is examined. The assumption of no interaction between the sample and assessor factors needs to be tested before we can proceed any further in our analysis. This can be done with by conducting a Tukey one degree of freedom test for additivity using the tukey.add.test(), which can be found in the asbio package (Aho et al., 2011). R output 3.9 indicates that the interaction term is not significant, as the *p*-value of 0.093 is larger than 0.05. If the results were significant, then the Friedman two-way ANOVA can be used instead.

```
>table3.7.aov <- aov(Acceptability ~ Sample + Assessor,data=table3.7)
>#
>########################################################################
>##Use summary() to get ANOVA table                                    ##
>##Check that df for all factors are correct, the ones incorrectindicates##
>##that you probably did not convert the data column to a factor       ##
>########################################################################
>#
> summary(table3.7.aov)
             Df Sum Sq Mean Sq F value Pr(>F)
Sample        2  79.86   39.93  65.997 <2e-16 ***
Assessor     53  27.73    0.52   0.865  0.718
Residuals   106  64.14    0.61
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

R output 3.8 ANOVA table results for a 2 factor ANOVA model without an interaction term for data from table 3.7.

```
> library(asbio)
Loading required package: tcltk
> #
> with(table3.7,tukey.add.test(Acceptability,Sample,Assessor))

Tukey's one df test for additivity
F = 2.8746895   Denom df = 105    p-value = 0.0929458
```

R output 3.9 Result from the Tukey's test one degree of freedom test for additivity for data from table 3.7.

The significance of the interaction term is not the only test that needs to be conducted. A residual analysis is often carried out by simply applying the plot() function[20] around

[19] This is done by including an additional line, Assessor <- as.factor(Assessor), at the start of the Script Table 3_7.R.

[20] Four graphs in one is plotted if the script, oldpar<- par(oma=c(0,0,3,0), mfrow=c(2,2)), is used before using the plot() function.

the data object `table3.7.aov`. The assumption of normality of the residuals can be examined by looking at the normal *Q–Q* plot. The assumption is valid as there residuals (i.e., points in the graph) form a straight line along the dotted line. Non-normality is indicated by heavy tailing with residuals moving away from the dotted line or when the residuals show an 'S' shape. Another assumption that needs to be examined is the assumption of consistency of error variance, which can be examined from the constant leverage plot. The distribution or range of values for residuals for each sample should be similar, as was in the case of this example. One further assumption that is often examined is the presence of outliers. If an outlier is present, then the observation number will be plotted on the graphs. Table 3.9 shows the values of outliers identified in Figure 3.4 and two additional observations. These values can be obtained using the `stdres()` function[21] in the MASS package (Venables and Ripley, 2002). As a rule of thumb, any values outside of the −3 to +3 range would be considered a statistical significant outlier and these values would likely have an effect on the results of the ANOVA test. Any values between −2 and −3 and +2 and +3 would still be counted as outliers; however, if they account for less than 5% of the total number of residuals (i.e., providing a 95% confidence level) we can assume that the presence of these outliers would not significantly affect the results of the ANOVA test. The Friedman two-way ANOVA can be used if there are violations of any of these assumptions. Our analysis of the residuals suggests that our model assumptions would seem to be valid, so we can continue with analysis and conduct a multiple comparison test.

3.5.1.2 Multiple comparison tests

A multiple comparison test, such as Tukey's HSD test can be used to conduct multiple pairwise comparisons between the mean values for each product sample (Kutner et al., 2005), which can be estimated by

$$|\bar{x}_1 - \bar{x}_2| \geq q_{1-\alpha,t,\,\mathrm{df}_{\mathrm{residual}}}\sqrt{\frac{2\mathrm{MS}_{\mathrm{residual}}}{b}} \tag{3.4}$$

Table 3.9 Table of standardised residuals for identified outliers from Example 3

Observation number	Standardised residual
10	2.30
19	−2.46
29	−2.46
131	2.25
147	2.25

[21] This exercise will be left for the user. See the script Table 3_7.R.

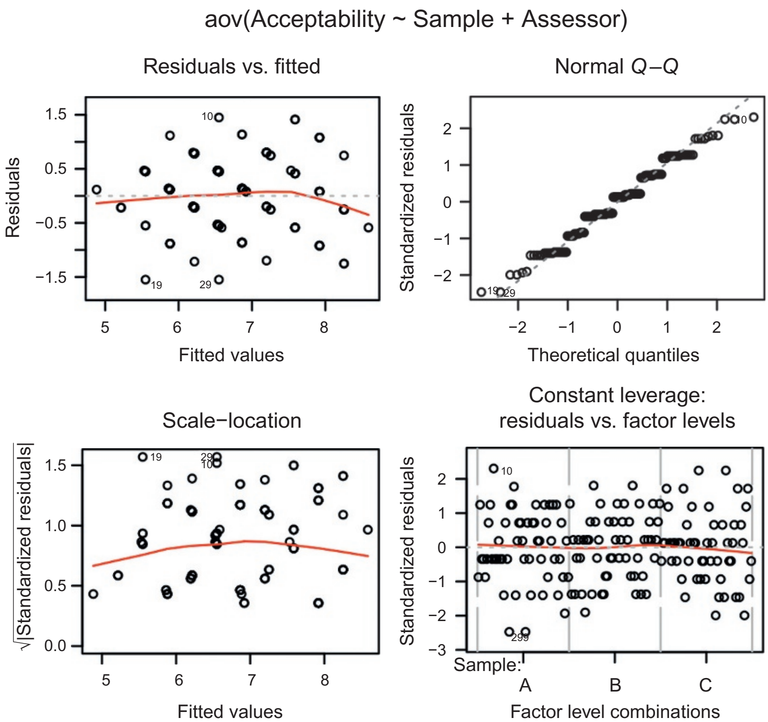

Figure 3.4 A residual analysis showing a residual versus fitted values plot (top left), a normal quantile (*Q*–*Q*) plot (top right), a scale location plot (bottom left) and a constant leverage plot (bottom right).

where $|\bar{x}_1 - \bar{x}_2|$ are the absolute differences between two samples means comparing t samples with b assessors, $q_{\alpha,t,\,\mathrm{df}_{\mathrm{residual}}}$ is the Tukey quantile value, which depends on the $1-\alpha$ confidence limits, the number of samples, t and the residual degrees of freedom $\mathrm{df}_{\mathrm{residual}}$, which together with the residual mean square, $\mathrm{MS}_{\mathrm{residual}}$, can be obtained from the ANOVA table.

Tukey's HSD test can be conducted in R using the `TukeyHSD()` function that is part of the R base package (R Core Team, 2014) and the `glht()` function from the multcomp package (Hothorn et al., 2008a). If a comparison of the results of the HSD test is required against, say, the LSD test, then both the asbio package (Aho et al., 2011) and agricolae package (de Mendiburu, 2014) have functions that will do both these tests.[22] The results from the HSD test from the R output 3.10 clearly show that all paired comparisons were significantly different. The same results can be obtained if the LSD test or the Bonferroni test was conducted instead of the HSD test. The `model.tables()` functions can be used to print out the mean values for each product, showing clearly that sample C was the most preferred with a rating of `7.8`, which was close to being 'liked very much' by the panel.

```
> TukeyHSD(table3.7.aov,"Sample",conf.level=0.95)
  Tukey multiple comparisons of means
    95% family-wise confidence level

Fit: aov(formula = Acceptability ~ Sample + Assessor, data = table3.7)

$Sample
         diff       lwr      upr     p adj
B-A 0.6481481 0.2923039 1.003992 0.0001002
C-A 1.7037037 1.3478595 2.059548 0.0000000
C-B 1.0555556 0.6997113 1.411400 0.0000000
```

R output 3.10 Result from the Tukey's HSD test for data from table 3.7.

3.6 Descriptive analysis

Data from descriptive analysis methods are often examined by ANOVA and multivariate statistical methods. Hypothesis testing is used not only to examine differences between product samples but also used to examine the panel performance. In the example below, we shall examine how these two methods can be used to analyse data from a descriptive analysis.

3.6.1 Example 4: texture profiling of cheese

Three of the low-fat Cheddar cheeses that were found to have differences in the consumer hardness acceptability in Example 2 were examined further by the sensory analyst by conducting a descriptive analysis. A panel of nine assessors were required to attend three training sessions, where they defined a list of six attributes to describe the texture profile of Cheddar cheese samples that had similar characteristics to the three low-fat Cheddar cheeses. They also familiarised themselves with the use of an unstructured category rating scale that consisted of numerical values from 0 to 15, with the ends anchored with the terms 'none' and 'very'. After the initial training session, the panel was presented with the three low-fat Cheddar cheese in three separate sessions using a balanced complete randomised design. The results can be found in Table 3.10.

3.6.1.1 Monitoring the performance of individual assessors

One important aspect in descriptive analysis is ensuring that the panel assessors are reliable and consistent in their use of the measurement scale and have the ability to detect the differences between samples for the set of attributes used in the descriptive analysis. Panel assessors should first be selected and trained using criteria such as the ISO22935-1:2009 standard (British Standards Institute, 2010). After the initial selection and training session, it would make sense that when the panel is presented with samples in a descriptive analysis at least three samples are presented in three separate sessions, using a balanced completed randomised design. This allows us to estimate the discriminatory ability and scoring reproducibility of each individual assessor and the whole panel through the use of an ANOVA (Bárcenas et al., 2000).

Table 3.10 Descriptive analysis of three low-fat Cheddar cheeses

Assessor	Session	Sample	Springiness	Hardness	Fracturability	Cohesiveness	Stickiness	Chewiness
1	1	2	7	8	2	7	2	10
1	1	1	7	12	3	11	6	2
1	1	3	2	3	9	4	12	2
1	2	1	10	8	2	7	2	10
1	2	2	2	2	2	9	4	3
1	2	3	7	6	3	2	3	3
1	3	1	10	8	2	7	2	10
1	3	3	2	2	9	4	12	5
1	3	2	6	6	2	3	6	2
2	1	2	2	1	2	12	11	3
2	1	1	6	11	13	2	0	13
2	1	3	2	1	2	12	10	3
2	2	2	2	1	2	12	12	3
2	2	3	7	11	13	2	0	13
2	2	1	2	2	2	11	10	2
2	3	2	2	2	3	13	11	2
2	3	1	7	11	15	2	0	14
2	3	3	3	3	2	11	12	1
3	1	1	10	10	1	11	1	4
3	1	2	3	4	9	4	7	2
3	1	3	7	6	4	7	6	2
3	2	1	10	10	1	11	2	5
3	2	2	5	3	10	5	5	1

Continued

Table 3.10 **Continued**

Assessor	Session	Sample	Springiness	Hardness	Fracturability	Cohesiveness	Stickiness	Chewiness
3	2	3	9	5	3	8	6	0
3	3	1	10	10	1	11	2	5
3	3	2	4	6	5	6	4	2
3	3	3	8	6	9	7	8	3
4	1	1	12	10	6	3	3	6
4	1	2	6	5	1	3	13	2
4	1	3	9	8	3	5	8	4
4	2	1	12	10	6	6	3	6
4	2	3	2	2	4	3	4	5
4	2	2	6	5	1	3	13	2
4	3	3	9	8	3	5	3	4
4	3	2	6	5	3	3	13	8
4	3	1	12	10	6	6	3	6
5	1	1	13	13	5	10	3	12
5	1	2	6	2	7	7	13	6
5	1	3	4	2	11	5	10	2
5	2	1	13	13	5	11	3	13
5	2	2	6	5	8	5	11	6
5	2	3	4	5	11	9	7	3
5	3	1	13	13	3	11	3	13
5	3	2	6	6	8	9	7	6
5	3	3	3	4	11	5	11	2
6	1	2	2	6	9	3	9	9
6	1	1	11	12	6	6	0	7
6	1	3	6	3	3	9	7	11

6	2	3	6	4	2	9	7	11
6	2	1	10	12	6	0	0	7
6	2	2	2	6	9	7	9	9
6	3	3	2	6	9	3	9	9
6	3	1	11	12	6	6	0	7
6	3	2	6	7	3	9	7	11
7	1	1	9	10	2	12	0	12
7	1	2	3	5	9	3	7	4
7	1	3	6	4	6	5	4	7
7	2	1	6	7	8	6	7	7
7	2	2	5	3	6	3	5	8
7	2	3	8	12	3	9	0	11
7	3	1	4	11	2	9	0	11
7	3	2	5	8	6	5	8	4
7	3	3	8	5	8	6	5	6
8	1	1	4	3	3	9	8	5
8	1	2	5	2	4	12	11	2
8	1	3	10	9	7	5	6	7
8	2	1	3	4	4	12	10	4
8	2	2	5	6	2	11	9	7
8	2	3	8	9	11	3	5	9
8	3	3	1	2	3	10	1	7
8	3	1	3	4	10	7	3	4
8	3	2	8	10	6	3	2	3
9	1	1	1	6	2	4	2	7

Continued

Table 3.10 **Continued**

Assessor	Session	Sample	Springiness	Hardness	Fracturability	Cohesiveness	Stickiness	Chewiness
9	1	2	5	3	5	1	8	3
9	1	3	3	5	4	3	5	5
9	2	3	3	5	4	4	6	5
9	2	1	1	7	2	5	2	8
9	2	2	5	3	5	2	8	3
9	3	2	5	3	6	1	7	4
9	3	1	1	6	2	5	2	7
9	3	3	4	5	4	3	5	5

For each attribute that is assessed by the panel, a two-factor ANOVA should be conducted for each individual using the model described in Equation (3.3). After the data from Table 3.10 has been imported into R, a data frame can be created for each assessor using the `subset()` function. The two-factor ANOVA test and Tukey's one degree of freedom test can be conducted using the `aov()` and `tukey.add.test()` functions respectively for each attribute. Table 3.11 shows the results of conducting ANOVA tests and the Tukey one degree of freedom test for all attributes for all nine assessors in the panel.[23] The table is divided into three parts: the first examines the effect of the sample factor (F_{sample}), the second the session factor (F_{session}) and the last part the interaction effect ($F_{\text{sample}\times\text{session}}$). An individual is considered not to have sufficient ability of discriminating samples if the p-value for the F_{sample} test is greater than 0.5, and an inadequate scoring reproducibility if the p-value for the F_{session} test is less than 0.05 (Bárcenas et al., 2000). An assessor's consistency in evaluating each sample in the same manner can be examined from the interaction effect. A p-value less than 0.05 would suggest that that assessor is not consistent in their assessment.

Table 3.11 indicates that assessor 6, 7 and 8 were unable to identify differences between samples for at least two of the attributes. Assessors 3, 5 and 9 were the best assessors, with high F values for most of the attributes, whereas assessor 1, 2 and 4 were not as good. Almost all of the assessors had acceptable scoring abilities; however, assessor 8 had an F value of 18.05 ($p=0.010$) for stickiness and assessor 8 had an F value of 7.00 ($p=0.049$) for cohesiveness. There were no variations in the scoring of stickiness and cohesiveness for assessor 6 and so the F values could not be estimated from the ANOVA test. However, assessor 6 was the only one found to be inconsistent when scoring samples for hardness ($F=12.57$; $p=0.038$), while assessor 1 was inconsistent when scoring samples for fracturability ($F=50.12$; $p=0.006$).

The two main factors of the ANOVA model allow us to monitor performance of each assessor; however, an examination of the significance of each F value in Table 3.11 does not provide all the information. How can we interpret the results when the interaction effect or the session effect is significant? One way is to construct a dot plot for each assessor, which allows us to compare their ratings of each sample in each session. This can be done with the `ggplot()` function from the ggplot 2 package (Wickham, 2009). The `ggplot()` function can be used to produce many different types of graphs, however a dot plot was produced using `geom_point()` and a graph for each assessor printed out in a lattice grid of 3 columns × 3 rows using `facet_wrap(~Assessor, ncol = 3)`(R output 3.11). Assigning which variables to plot on the x and y axis is done using `aes(session, Hardness, colour = sample)`, where hardness rating scores are on the y axis and the session number on the x axis. Different colours for each sample is assigned by the `colour = sample` option. The option `position = position_jitter(w = 0.2, h = 0.2)` was included inside `geom_point()` to ensure that any points with the same values from different samples would not overlap.[24] The final part of the script `scale_y_continuous(breaks = seq(0, 15, by = 2)` indicates how

[23] You can use the scripts in Table 3_10.R to do all the analyses.

[24] The degree of jitter is controlled by `w = 0.2, h = 0.2` values. Increasing these values results in overlapping points appearing further apart.

Table 3.11 **Two-factor ANOVA for each texture attribute for three low-fat Cheddar cheeses**

Attributes	Assessors								
	1	2	3	4	5	6	7	8	9
F_{sample}									
Springiness	2.633	1.024	84.000	5.959	637.000	8.408	1.615	0.753*	109.000
Hardness	3.754	1.226	39.500	5.250	61.000	77.636	0.879	0.487*	76.000
Fracturability	6.206	1.000	4.348	21.500	50.000	0.314*	0.639*	0.421*	76.000
Cohesiveness	3.562	1.405	61.750	1.750	3.769	0.453*	3.016	0.471*	76.000
Stickiness	2.515	1.286	10.343	36.000	8.714	48.25	1.289	4.789	146.000
Chewiness	0.578*	0.864	10.800	0.775*	494.000	7.000	1.910	5.286	43.600
$F_{session}$									
Springiness	0.089	0.049	4.000	1.000	1.000	0.020	0.077	0.381	1.000
Hardness	0.803	0.029	2.000	1.000	3.000	2.364	0.153	0.138	1.000
Fracturability	1.265	0.023	0.013	0.500	0.500	0.008	0.010	0.131	1.000
Cohesiveness	1.000	0.004	1.000	0.437	0.231	0.027	0.062	0.202	7.000†
Stickiness	1.175	0.009	0.057	1.000	0.510	0.000†	0.026	18.053†	2.000
Chewiness	0.037	0.008	1.600	0.775	2.000	0.000†	0.245	1.714	0.400
$F_{sample \times session}$									
Springiness	0.059	0.033	4.000	0.605	2.778	0.009	0.008	0.251	0.028
Hardness	0.829	0.004	6.480	0.360	7.695	12.573#	0.057	0.008	5.440
Fracturability	50.120#	0.337	0.339	1.373	1.800	1.370	0.090	0.222	5.440
Cohesiveness	0.800	0.831	1.957	0.747	0.005	2.481	0.346	6.192	0.071
Stickiness	4.241	0.000	0.331	0.360	0.575	–	0.008	1.690	2.138
Chewiness	0.595	0.021	2.000	1.434	0.042	–	2.707	0.018	0.003

* $p > 0.5$ for F_{sample}.
† $p < 0.05$ for $F_{session}$.
# $p < 0.05$ for $F_{sample \times session}$.

```
> library(ggplot2)
> x11()
> pg <- ggplot(table3.10, aes(Session, Hardness,  colour = Sample)) +
+       geom_point(position = position_jitter(w = 0.2, h = 0.2)) +
+       facet_wrap(~Assessor, ncol = 3)+
+       scale_y_continuous(breaks = seq(0, 15, by = 2))
> print(pg)
>
```

R output 3.11 Executed script for plotting dot plots for data from table 3.10 for figure 3.5.

many tick marks to use for the *y* axis. A new graphic device window[25] is opened using `x11()` before the plotting the graph shown in Figure 3.5.

The results for the rating of hardness in Table 3.11 indicated that all assessors apart from assessor 8 had an acceptable discriminatory ability; however, if we examine the *F* values carefully we see that the some values for assessors 1, 2, 4 and 7 are very low

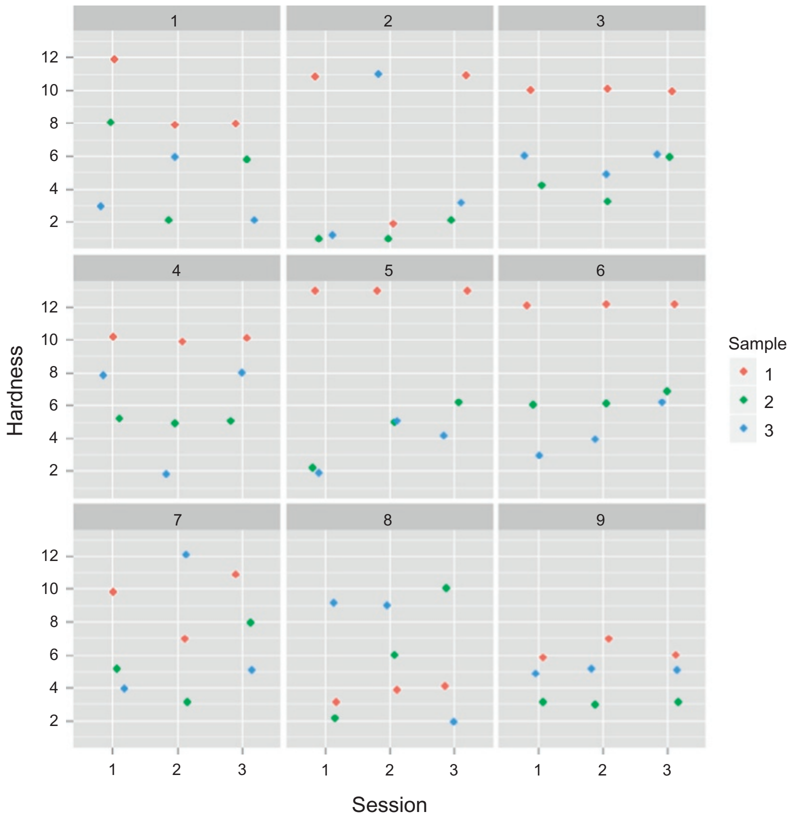

Figure 3.5 Rating of hardness of three low-fat Cheddar cheese samples by a panel of nine assessors in three sessions. Overlapping points have been jittered.

[25] Opening a new graphic device with `x11()` is not necessary when creating a graph; however, when you want to compare more than one graph at a time that is plotted individually, using `x11()` allows for a graphic window to be open for each graph that is plotted.

compared to assessors 5, 6, 9. This can be clearly seen in Figure 3.4. Assessors 1, 3, 4, 5, 6 and 9 rated sample 1 the hardest in all three sessions. However, the rating of samples 2 and 3 varied greatly between assessors. The plots show that assessor 9 used only the bottom portion of the scale, whereas all other assessors had ratings in the lower and higher ends of the scale. Assessor 8 was clearly a poor discriminator as ratings between samples were in different orders between sessions. This would explain the reason why the results for F_{sample} indicated a poor discriminatory ability for assessor 8. The significant interaction effect ($p < 0.05$ for $F_{sample \times session}$) for assessor 6 can be seen in Figure 3.5 by the increase in ratings for samples 2 and 3 from session 1 to 3.

3.6.1.2 Monitoring the performance of the whole panel

Besides examining an individual's discriminatory and scoring ability, Bárcenas et al. (2000) used a three-factor ANOVA to examine the panel's discriminatory ability ($p < 0.05$ for F_{sample}), scoring reproducibility ($p < 0.05$ for $F_{session}$) and agreement between assessors ($p < 0.05$ for $F_{assessors}$). An ANOVA model with all three main effects and their two-way interaction—for example. Stickiness—can be fitted using the formula `Stickiness~(Sample+Session+Assessor)^2` (R output 3.12). The ANOVA table from the R console indicates that the sample factor was highly significant ($p < 0.001$). However, the assessor factor and 2 of the 3 two-way interactions were significant. This could be explained to some extent by examining the results of individual two-factor ANOVAs from Table 3.11, which shows that the session factor and interaction between sample and session factor for assessor 6 and 8 were significant.

```
> anova.all.Stickiness <- aov(Stickiness~(Sample+Session+Assessor)^2,
+                             table3.10)
> summary(anova.all.Stickiness)
                 Df Sum Sq Mean Sq F value   Pr(>F)
Sample            2  401.9  200.93  31.842 2.45e-08 ***
Session           2   13.4    6.70   1.062  0.35751
Assessor          8  114.7   14.33   2.271  0.04755 *
Sample:Session    4   97.2   24.30   3.850  0.01154 *
Sample:Assessor  16  285.0   17.81   2.823  0.00607 **
Session:Assessor 16  102.1    6.38   1.012  0.47007
Residuals        32  201.9    6.31
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

R output 3.12 Three-factor ANOVA for all data from table 3.10.

Bárcenas et al. (2000) suggested removing assessors that were poor discriminators or had poor scoring abilities. Table 3.11 suggests that perhaps assessors 6, 7 and 8 should be removed,[26] as these three were poor discriminators for fracturability, with assessors 6 and 8 also being poor discriminators for cohesiveness. If we remove these three assessors and repeat the analysis we now see that the significant factors in the

[26] Assessors 1 and 4 were also poor discriminators for Chewiness; however, if we also remove them, then there would only be five remaining assessors. A general conclusion could be made that the whole panel should probably be retrained. However, we will continue with our example by removing only three of the nine assessors.

previous ANOVA test for stickiness are no longer significant (R output 3.13).[27] This makes it possible for us to use stickiness as an acceptable attribute for discriminating the different Cheddar cheese samples.

```
> table3.10.subset<-
+      subset(table3.10, Assessor!=6 &  Assessor!=7 & Assessor!=8)
> #
> anova.subset.Stickiness <- aov(Stickiness~(Sample+Session+Assessor)^2,
+                              table3.10.subset)
> summary(anova.subset.Stickiness)
                 Df Sum Sq Mean Sq F value   Pr(>F)
Sample            2  337.1  168.57  20.679 1.35e-05 ***
Session           2   10.0    5.02   0.616   0.5502
Assessor          5   76.1   15.23   1.868   0.1452
Sample:Session    4   71.6   17.91   2.197   0.1062
Sample:Assessor  10  168.2   16.82   2.063   0.0807 .
Session:Assessor 10   28.6    2.86   0.351   0.9540
Residuals        20  163.0    8.15
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

R output 3.13 Three-factor ANOVA for subset of data from table 3.10 with data from Assessors 6, 7 and 8 removed.

Table 3.12 shows the differences between the ANOVA tests for the original panel of nine assessors and the panel with assessors 6, 7 and 8 removed. The panel with six assessors had good discriminatory ability for all attributes apart from fracturability and cohesiveness. However, we would also have to discount springiness as a useful attribute for discrimination because not all assessors rated the samples in the same order.[28] Hardness, stickiness and chewiness are the only three acceptable attributes that can be used as variables for discriminating these samples. Tukey's HSD test described in Section 3.5 could be used to examine differences between samples for those variables. Differences between samples for springiness could be compared using `TukeyHSD()` at the treatment level with the sample:assessor interaction factor; however, the analysis results in too many paired comparisons. It would seem that the best option would be to retrain the whole panel until more attributes could be used for discrimination, although three attributes with six assessors might just be enough.

3.6.1.3 Principal component analysis

PCA is perhaps the most widely used multivariate techniques in examining difference between product samples. The `prcomp()` function is one of many R functions that can be used to conduct a PCA analysis, which is based on a singular value decomposition of the data matrix. This can be done easily in R to produce a biplot[29] of two principal components (PCs) for all nine assessors. In most cases, only the first

[27] The `subset()` function is used in this case to remove data. Compare the R script from Table 3_10.R with that of the example of sub-setting data from a specific assessor and saving it into an individual data frame.

[28] A plot of Springiness with the `ggplot()` function would show this.

[29] A biplot consists of a plot of variables, known as loadings, which appear as arrows from the centre of the plot and a plot of sample points, known as scores.

Table 3.12 Three-factor ANOVA for each texture attribute for three low-fat Cheddar cheeses

Attributes	*F* values for factors					
	F_{SA}	F_S	F_A	$F_{SA:S}$	$F_{SA:A}$	$F_{S:A}$
Nine assessors						
Springiness	16.390***	0.011	5.693***	1.070	4.252***	0.339
Hardness	23.022***	0.352	1.442	2.008	1.834	0.338
Fracturability	1.121	0.121	1.323	0.217	1.736	0.079
Cohesiveness	2.060	0.030	3.069*	0.123	1.588	0.157
Stickiness	31.842***	1.062	2.271*	3.850*	2.823**	1.012
Chewiness	7.356***	0.157	3.338**	0.885	1.717	0.149
Six assessors[a]						
Springiness	16.390***	0.011	5.693***	1.070	4.252***	0.339
Hardness	23.070***	0.250	1.417	0.826	1.072	0.405
Fracturability	1.553	0.128	2.136	0.347	2.656*	0.097
Cohesiveness	2.651	0.033	6.180**	0.555	2.597*	0.224
Stickiness	20.679***	0.616	1.868	2.197	2.063	0.351
Chewiness	8.415**	0.143	1.501	0.539	0.804	0.072

F values for each factor and their two way interactions were F_{SA}, sample effect; F_S, session effect; F_A, assessor effect; $F_{SA:S}$, sample and session interaction effect; $F_{SA:A}$, sample and assessor interaction effect; $F_{S:A}$, session and assessor interaction effect.

[a]Assessors 6, 7 and 8 removed based on results from Table 3.11.

*$p > 0.05$.

**$p > 0.01$.

***$p > 0.001$.

two PCs are plotted because they normally produce the best separation of points if there are clear indications that differences between groups[30] exist. In order to conduct a PCA with the data frame that we constructed from Table 3.10, the formula format is used, whereby no response variable is included on the left-hand side of the formula. This is because PCA is a non-supervisory method and no indication is provided as to which sample each row of results belonged to for the analysis. R output 3.14 shows the total proportion of variance for each after the analysis by calling the `summary()` function. The first two PCs account for 69% of the total proportion of explained variance in the data, with the addition of the third PC bringing this up to 80%. Figure 3.6 shows the plot of the variable loadings and sample scores for the first two PCs. Sample scores are indicated by numbers and each variable loading value is shown with an arrow pointing in the direction where each variable has the highest correlation to the PCs. The degree of correlation of each

[30] In our example, we would hope to see at least three clusters, one for each cheese sample, if they were significantly different in terms of their texture attributes.

```
> table3.10.pca<- with(table3.10, prcomp(~ Springiness+Hardness+
+ Fracturability+Cohesiveness+Stickiness+Chewiness,scale = TRUE))
> summary(table3.10.pca)
Importance of components:
                          PC1    PC2    PC3     PC4     PC5     PC6
Standard deviation     1.6353 1.2119 0.8389 0.76901 0.62992 0.40647
Proportion of Variance 0.4457 0.2448 0.1173 0.09856 0.06613 0.02754
Cumulative Proportion  0.4457 0.6905 0.8078 0.90633 0.97246 1.00000
```

R output 3.14 Principal component analysis of data from table 3.10.

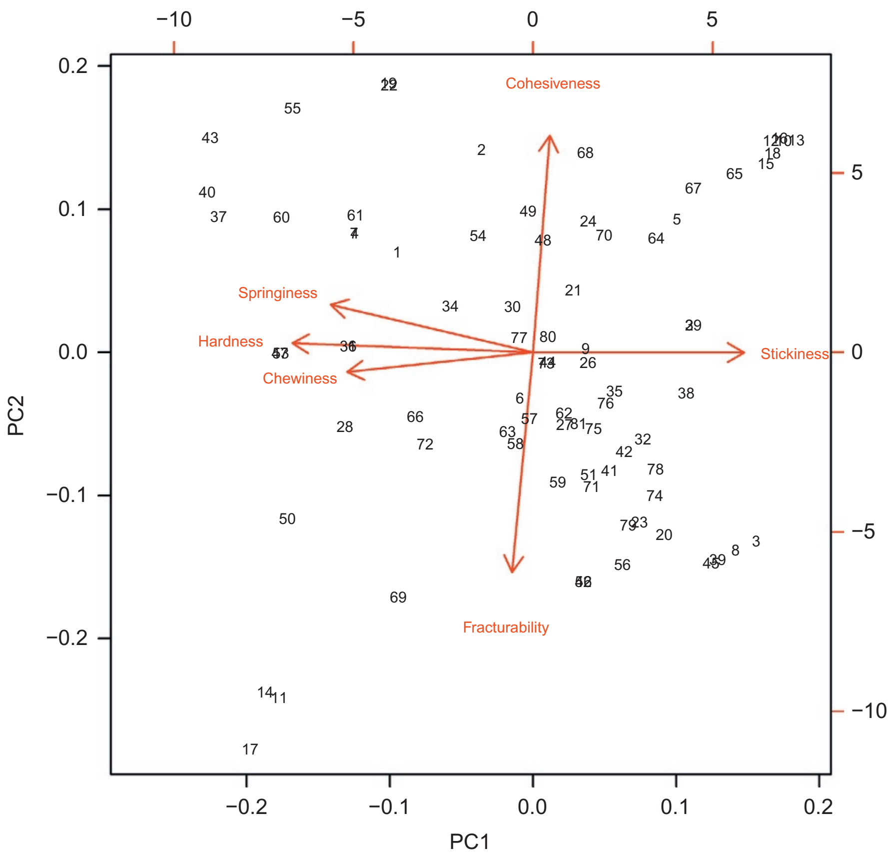

Figure 3.6 Principal component analysis biplot for three low-fat Cheddar Cheese samples by a panel of nine assessors. The plot shows two different scales, one for variables (loadings) ranging from −10 to 5 and one for samples (scores ranging from −0.2 to 0.2. Numbered labels refer to sample observation numbers that equate to row numbers in the data frame.

variable on a PC can be viewed by extracting the information as shown in R output 3.15. We can see that springiness, hardness and chewiness are negatively correlated and stickiness positively correlated on PC1, whereas cohesiveness and fracturability are better correlated on PC2. An examination of the variable loadings on PC3 indicates that there is an improvement in the correlation for springiness and

```
> table3.10.pca$rotation[,1]
   Springiness        Hardness Fracturability   Cohesiveness      Stickiness       Chewiness
   -0.47829461     -0.56968127    -0.05003561     0.03968762      0.49927011     -0.43971377
> table3.10.pca$rotation[,2]
   Springiness        Hardness Fracturability   Cohesiveness      Stickiness       Chewiness
  0.1520444691    0.0300278086  -0.7015984466   0.6926577200   -0.0009095659   -0.0629673358
> table3.10.pca$rotation[,3]
   Springiness        Hardness Fracturability   Cohesiveness      Stickiness       Chewiness
   -0.51037401     -0.15796388     0.19266004     0.38024573     -0.03806929      0.72897997
```

R output 3.15 Variable loading scores for PC1 to PC3 for each texture attribute for data from table 3.10.

chewiness; however, the addition of PC3 to the plot would probably not result in a sufficient improvement in the separation of the three samples by the nine assessors. This is the reason why, in most cases,[31] the first two PCs should be sufficient to indicate if significant difference between sample exists for them to appear as three distinct clusters, assuming that the variables used to describe them are highly correlated on the first two PCs and thereby contributing to the discrimination of these samples.

Figure 3.6 is quite difficult to examine, as each of the observation numbers is used to indicate the row in the data frame. An alternative method of plotting the PC scores could be done by examining the data for each assessor in a lattice plot similar to what has been done for a single variable in Figure 3.5. The R output 3.16[32] shows that we can use the `ggplot()` to plot the scores for samples for each assessor, after we have extracted the PC scores and saved them in a data frame that also includes the sample number column. The lattice plot in Figure 3.7 makes it a lot easier to examine individual sample assessments and it can be seen that most of the assessments made put sample 1 in a different group to the other two samples. This can be clearly seen for assessors 3–6. Some inconsistencies in the assessment of samples can also be clearly seen with regard to sample 1, in the case for assessors 2 and 7.

```
> PC1 <- table3.10.pca$x[,1]
> PC2 <- table3.10.pca$x[,2]
> table3.10.pca.data <- cbind(table3.10[1:3],PC1,PC2)
> library(ggplot2)
> x11()
> pg<- ggplot(table3.10.pca.data, aes(PC1,PC2,colour=Sample))+
+   geom_point(position = position_jitter(w = 0.4, h = 0.4)) +
+   facet_wrap(~Assessor, ncol = 3)
> print(pg)
```

R output 3.16 gglot() script for a lattice plot showing individual PC scores for each assessor for data from table 3.10.

3.6.1.4 Linear discriminant analysis

Classification of samples using pattern recognition methods such as PCA and LDA can often be done using descriptive analysis data. When we have *a priori* information regarding each product, we can use this information to improve the classification

[31] There are numerous methods that can be used to select the correct number of PCs. A plot of the cumulative proportion for each PC, which is known as a screeplot, would indicate that correct number from a tailing off of the curve.

[32] A 40% jitter is used to allow us to observe each point.

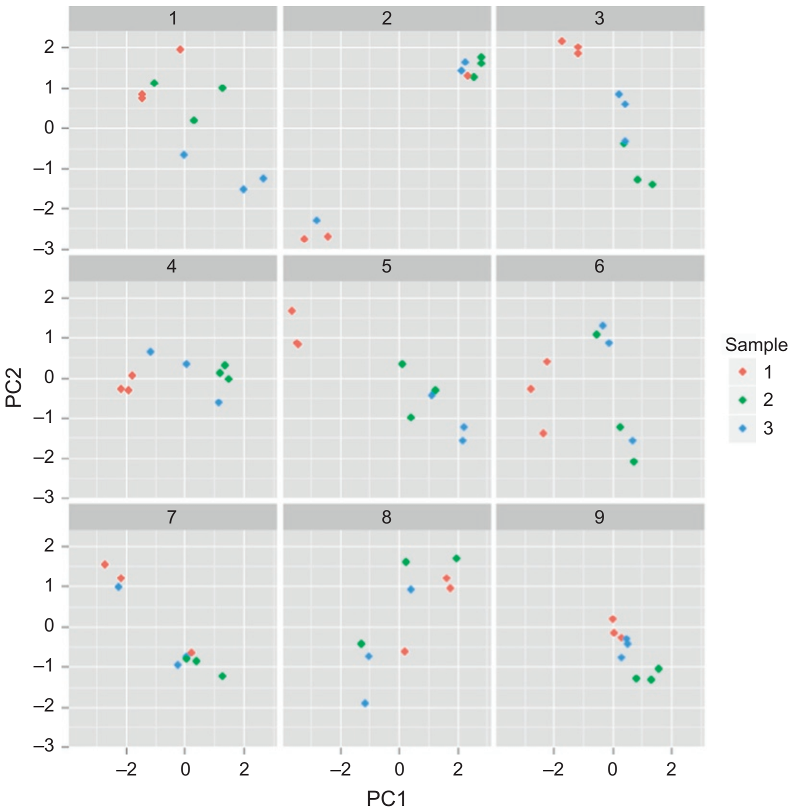

Figure 3.7 Results of a principal component analysis from a texture profile with descriptive analysis of three low-fat Cheddar cheese. Each subplot shows the results sample scores for each assessor on the first two PCs. 40% jitter is used to ensure that points do not overlap.

process. One such supervisory method is LDA, which can be done using the `lda()` function from the MASS package (Venables and Ripley, 2002). A plot of the first two linear discriminants (LDs) can be obtained after fitting the data with the `lda()` function shown in R output 3.17. Figure 3.8 indicates that sample 1 can be clearly differentiated from the other two samples. The results for LDA are somewhat similar to that of PCA. However, if we examine the results for each assessor separately using the `ggplot()` function, we can see that LDA gave a slightly better results in separating all three samples for some of the assessors (Figure 3.9).

```
> library(MASS)
> table3.10.lda <- with(table3.10, lda(Sample ~
Springiness+Hardness+Fracturability+
+ Cohesiveness+Stickiness+Chewiness))
> x11()
> plot(table3.10.lda)
>
```

R output 3.17 R script for a Linear discriminant analysis for data from table 3.10.

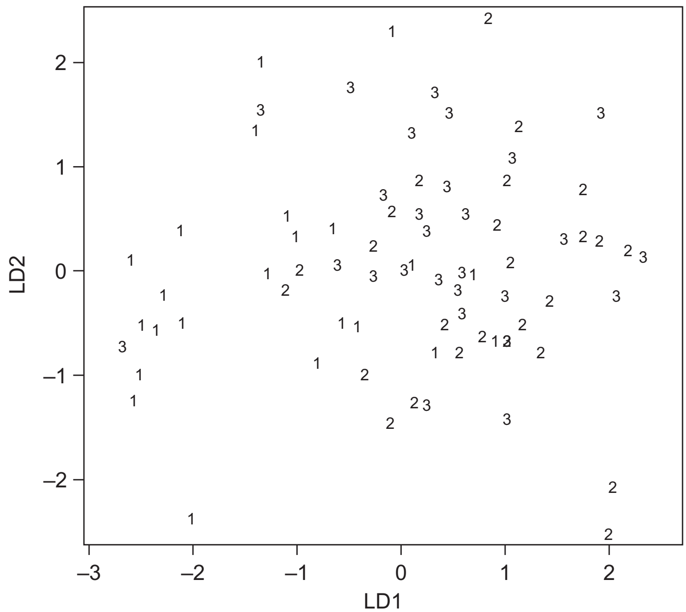

Figure 3.8 Results of a linear discriminant analysis from a texture profile with descriptive analysis of three low-fat Cheddar cheese.

The key to any statistical analysis of descriptive analysis data is to ensure that the assessors have good scoring reproducibility, discriminatory ability and that there is good agreement amongst assessors in terms of their use of the measurement scale. The panel of nine assessors were not all consistent between each other and the variability of assessments for the same sample varied between sessions. Statistical methods are aids in the interpretation of results and no amount of tweaking of parameter options can provide the desired results.

Appendix R basics

A.1 How to get started with R?

The basic installation of R comes with a set of pre-installed packages that contain different functions.[33] The basic structure of R consists of the R console, where instruction or code can be written and executed, and a drop-down menu for working with R files and packages (Figure 3.10). You can install new packages and update existing ones by going to the drop-down menu or by typing the appropriate functions in the R console.

[33] Detailed descriptions for each function can be found in html documentation by typing help.start() after the command prompt in the R console and searching for the name of the respective R package by accessing the linked named Packages.

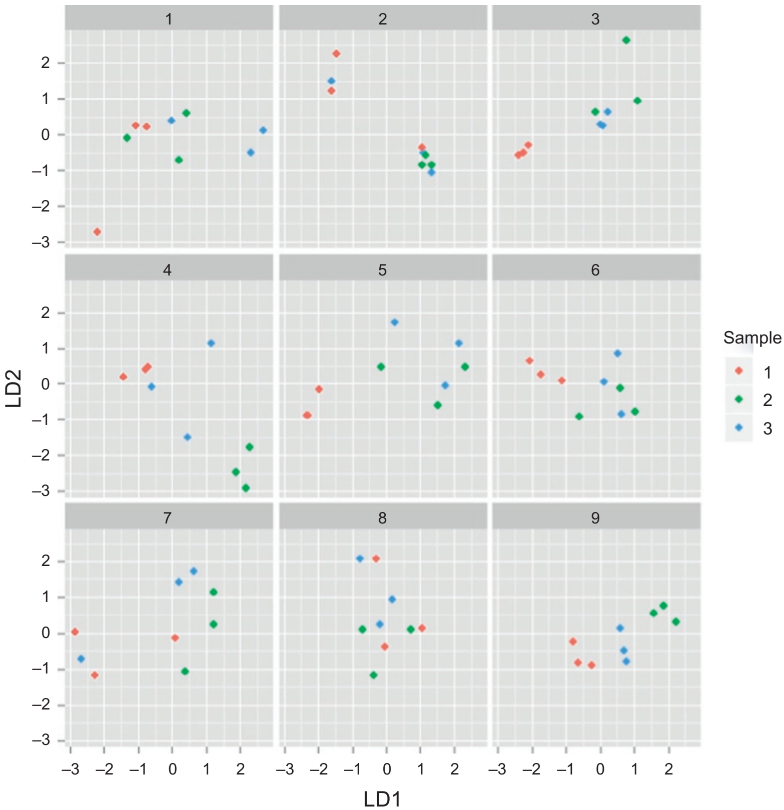

Figure 3.9 Results of a linear discriminant analysis from a texture profile with descriptive analysis of three low-fat Cheddar cheese. Each subplot shows the results of each assessor. Each subplot shows the results sample points for each assessor on the first two LDs. 40% jitter is used to ensure that points do not overlap.

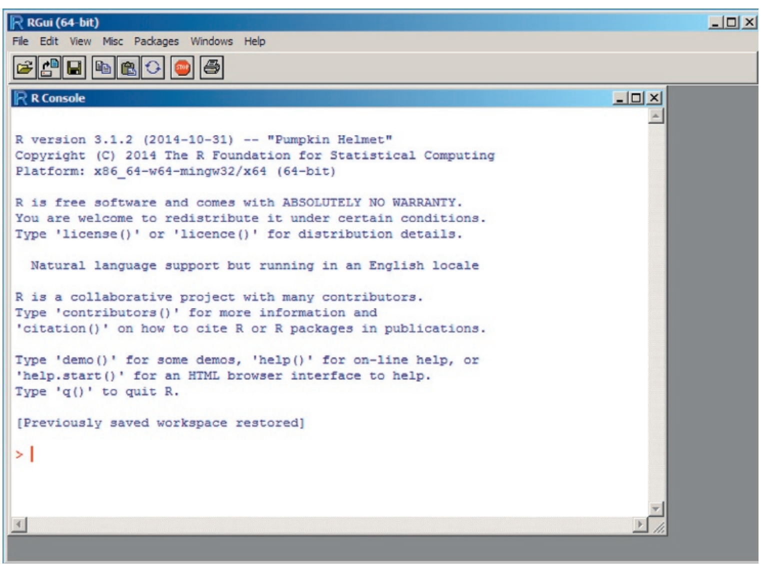

Figure 3.10 R console inside RGui.

A.1.1 My first R session[34]

When you open an R session and the R console window has appeared, the first thing you should do is to make sure that the working directory is set to where you have kept your .csv files, .R script files. Select the directory on your hard disc from the `Change dir...` from the `File` menu option. You will notice there aside from this option, there are also options to `Open Script..`, `Load Workspace...` and `Save Workspace...`, among others. Workspaces allow users to save an R session, which can then be opened again at another time. This is especially useful if you have a lot of data to analyse. When a workspace is saved that contains data that have been imported from external files and results of analyses that have been stored in R data objects, these R objects are made available for use when the workspace is loaded during another R session.

After you have set the working directory and opened the workspace or any R scripts you have, you are ready to start your session. If you need to do a quick analysis, you can type R scripts directly after the command prompt > symbol in the R console. However, it is better to open up a `New Script` window or `Open Script..` to open the R scripts that accompany this chapter. This allows you to copy and paste or `Run line or selection` (select the appropriate sections and click the right mouse button) different parts of the example R scripts. The complete R scripts for each data table can be downloaded from my Google+ community Stats@modifyingFoodtextureV2.

Table 3.13 shows a list of additional packages[35] that are used in the examples. Most of these packages should be available for installation for all OS platforms, although when a new version of R is updated it can take some time before packages for that version of the software are made available by the package maintainer. In those cases, an older version could be downloaded and installed. Make sure that you have the required packages installed before using any of the complete R scripts. R packages should be called at least once in a session and can be done by typing `library()` in the R console, with the name[36] of the package in the parentheses.

A.2 Creating data files

An R data object can be created by using a function such as `read.table()`, together with a set of options or parameters inside of the function. The name of the R object should be written first, followed by an assignment operator[37] and subsequently the function. If the line for creating Table 3.1 is copied to the R console and executed by pressing the enter key on your keyboard, you would have created your first data object. Although there are methods that can be used to create data files directly in R, you may find that your data might have been saved or created in a spreadsheet

[34] The explanation given here works in Windows OS. There are some differences when the user is using a Linux or Mac OS version of R.

[35] These packages should be installed after installing the base installation.

[36] Note that names of packages and R objects are case-sensitive.

[37] I have used the arrow symbol <– but the equal symbol = can also be used. The arrows indicate that the result of executing the `read.table()` function will be stored in the named data object.

Table 3.13 List of additional packages[a] and their functions required for conducting the analysis

Packages	Description	Functions used in examples
asbio	A collection of statistical tools for biologists	`pairw.anova();tukey.add.test()`
agricolae	Statistical procedures for agricultural research	`HSD.test();LSD.test`
car	Companion to applied regression	`qqPlot()`
coin	Conditional inference procedures in a permutation test framework	`symmetry_test()`
ggplot2	An implementation of the grammar of graphics	`ggplopt()`
MASS	Support functions and datasets for Venables and Ripley's MASS	`stdres();lda()`
moments	Moments, cumulants, skewness, kurtosis and related tests	`agostino.test()`
multcomp	Simultaneous inference in general parametric models	`glht()`
pgirmess	Data analysis in ecology	`friedmanmc()`

[a]Does not include packages and functions that are part of the base installation.

program such as Excel. It is for this reason that .csv files have been created in Excel, which can then be imported in R running on any OS.

The data that is created is in the form of a data frame, which is then called by other functions as and when needed. You can view the table in the R console by typing in the name of the data file after it has been created.

A.3 Using the complete R scripts

R scripts for all analyses for each data table in the chapter have been created.[38] These .R files contain instructions and comments on analysis. You will find any text written after a # symbol is considered commentary and will not be executed in the R console. All other text will be treated as part of a function. If you copy and paste an R script that is too long, you will notice that a + symbol appears that indicates the text is a continuation from a previous line. When the full script for a particular function has been executed, the R console will show either the common prompt or the result from executing the function. A + symbol is an indication that something is missing from the

[38] Table 3_1.R, Table 3_2.R, Table 3_5.R, Table 3_7.R, Table 3_10.R are available in its entirety online at http://dx.doi.org/10.1016/B978-1-78242-334-8.00003-1 (click the Resources tab at the bottom of the page).

script to complete the execution. In some cases, warning and error messages can also be displayed if there is an error in the written script. This can sometimes be something as simple as not having executed a previous script that is required. All scripts for the examples in this chapter have been tested in R running on a Windows and Mac PC and should work out of box.

You can follow all the analyses for each of the examples and tables by copying and pasting the relevant sections of the R scripts into the R console to view the results. Some of them have been shown in the chapter as R outputs and figures. A graphical window is opened, using the `x11()` function, before plotting each figure. This is to provide the user with the opportunity to compare more than one graph at a time. There is an option in the drop-down menu to save all graphs. R outputs can be copied directly to a text editor.

A.4 Where can I find more help?

A basic understanding of the R syntax and how functions are written is required in order to take full advantage of the R scripts provided in the examples. Many documents in different languages have been written that can be downloaded from http://cran.r-project.org/other-docs.html, which should provide the support necessary to get started with using R.

A.5 R GUIs

Some of the analyses, such as the paired *t*-test and two-factor ANOVA, can also be done using one of the graphical user interfaces (GUIs). The R commander (Rcmdr) is one such GUI that has been extended to include plugins for some of the R packages. This makes it easier for beginners to do many of the analyses in the example. However, no plugins have been made for some of the statistical tests and graphical methods used in the examples. In some cases, it is faster to use a previously written R script for doing a particular analysis. The user simply needs to change the name of the data file or make some minor adjustments to the original script. For example, all the scripts written in `table3_1.R` are the same as that for `table3_1.R` apart from the name of the data file. When there are a lot of analyses that need to be repeated, such as in the `table3_10.R` script for Example 4, it would be faster to execute a whole set of scripts than using the menu driven procedure in a GUI.

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Instrumental characterisation of textural properties of solid and semi-solid food

4

A.J. Rosenthal
Coventry University, Coventry, UK

4.1 Solidity in the context of time

The nature of solid materials is that when stressed they do not flow but deform—if only slightly—and when the stress is removed they then recover to their original shape. The archetypal solid can be imagined to behave as a spring, and the degree of deformation for a given stress is a measure of the so-called Elastic (or Young's) modulus.

Using mechanical analogies (such as a spring to represent elastic behaviour) can help people understand how materials behave when stressed or deformed. Figure 4.1 represents some mechanical analogues that are commonly used by rheologists to explain the deformation and flow of materials. In contrast to solids, liquids tend to flow when deformed and the ease with which they flow (or its opposite, the resistance to flow) can be visualised with a dashpot dampener (as found in vehicle suspension). Such a dashpot dampener consists of a cylinder containing a viscous liquid and a loosely fitting piston. If a force is applied to the piston it moves through the cylinder, being held back by the viscous flow of the liquid. When the force is terminated, there is no further movement. Rather than store energy as in an elastic spring, a dashpot dampener merely dissipates the force; however, there is an element of time as the liquid must flow through the annular gap for the force to diminish.

Of course all solids have an elastic limit, and applying stresses in excess of this limit, they rupture and break. The final mechanical analogue that needs to be considered is what happens at catastrophic mechanical failure when the material breaks into pieces. Such an event has been illustrated by a Saint-Venant slider, which consists of a calliper gripping a block, whereby the material is rigid until the frictional force between the callipers and the block is overcome, at which point the block is wrenched out of place and the material breaks.

The problem we have with foods is that few behave as these idealised materials, and in reality most exhibit both elastic and viscous properties; thus the classical concepts of solid and liquid start to become blurred. Moreover, while elastic changes to stress are virtually instantaneous, viscous behaviour is time dependent and consequently these hybrid—so-called viscoelastic—materials also seem to have a time dependency in their behaviour.

Modifying Food Texture, Volume 2. http://dx.doi.org/10.1016/B978-1-78242-334-8.00004-3

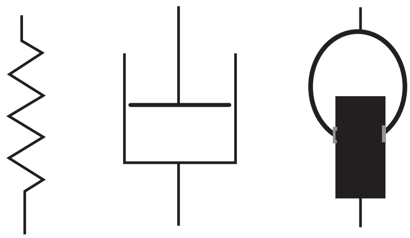


Figure 4.1 Mechanical analogues for an elastic body: a spring (left); viscosity: a dashpot (centre); and yield point: St Vennant Slider (right).

Elastic and viscous elements may be combined in series to produce a so-called Maxwell element or in parallel to produce a Kelvin-Voigt body. Figure 4.2 shows how these behave with time when a stress is applied. In the case of the Maxwell element, there is an initial instantaneous stretching of the spring, followed by gradual deformation as the liquid flows through the dashpot dampener, and when the stress is taken off the spring it contracts to its original length. Of course, the deformation of the dashpot dampener means that there will be a permanent deformation compared to the original material.

The convention with these mechanical analogues is to assume that items in parallel constrain each other and connectors remain parallel despite stresses being applied; thus when the Kelvin-Voigt model is stressed we observe the spring extending, but the rate of extension is limited by the dashpot dampener, and we see a retarded extension. Moreover when the stress is removed, the spring contracts back to its original length, but the rate of contraction is slowed by the viscous flow in the dashpot dampener, giving rise to a retarded relaxation. More complex models can be envisaged, such as the Burger body, which consists of a Maxwell and Kelvin-Voigt elements arranged in series. Clearly all these models have a time dependency, and if we do

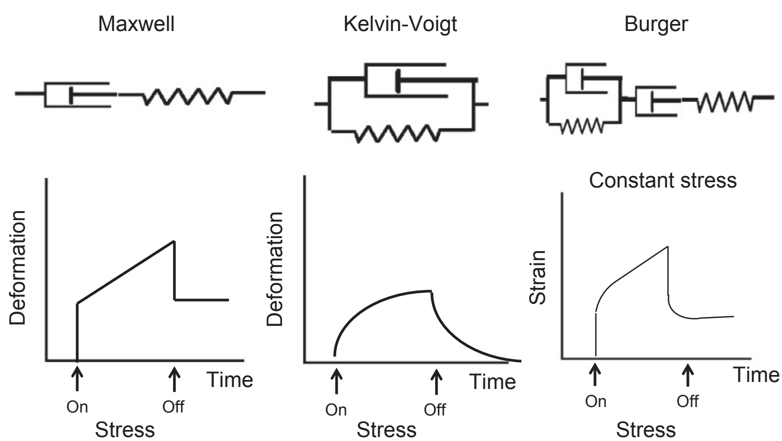


Figure 4.2 Derived mechanical analogues and their behaviour to a step change in stress. Maxwell element (left), Kelvin-Voigt body (centre), and Burger body (right).

not allow for the passage of time when testing the materials, we will gain a distorted view of their properties. For example, if a stress is applied for a very short duration, the dashpot dampener in a Maxwell body will have no time to extend and only the properties of the spring will be observed. Models of complete foods or intermediate products have been developed to explain their behaviour and help technologists to design processing and test equipment, such as Figure 4.3, which depicts bread dough (Shuey, 1974).

One of the test procedures employed by rheologists involves mechanically oscillating a sample between parallel plates. Consider the Kelvin-Voigt body: when a force is applied, there is a retarded elastic deformation; that is to say, it starts to stretch, but that stretching is slowed by the resistance to flow of the dashpot dampener to extend. If the frequency is high, the material has no time to relax to a steady state, and thus at very high frequencies, many materials behave as solids, while at low frequency oscillations, viscoelastic materials have time enough to relax and flow to an unstressed state. The relaxation time of some foods can be extremely long. Supercooled liquids,

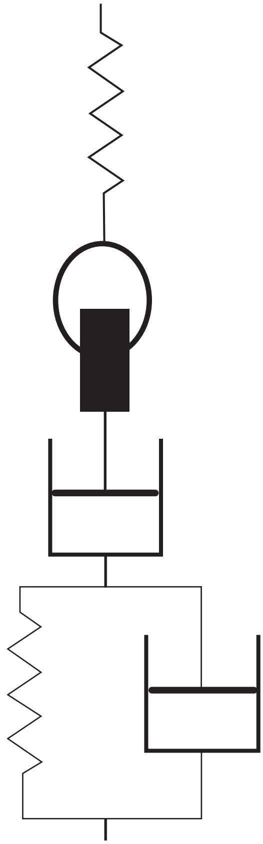


Figure 4.3 Mechanical analogue for bread dough.

which have been cooled to below their glass transition, appear in everyday terms to be solids, but they are in reality liquids whose viscosity is remarkably high. We are probably most familiar with window glass, yet many food glasses exist, such as boiled sweets (hard candy) and candy floss (cotton candy). Our everyday experience of glasses is that if we rapidly apply a large stress, they are unable to flow and dissipate that stress, resulting in catastrophic failure: the glass shatters.

In the light of this time dependency of food materials and the obvious blurring of differences between solid and liquid foods, the authors of this and the following chapters have tried not to be absolute about the classification of foods as solids or liquids. For just as many of the test methods are common to both liquid and solid foods, we observe that some food materials may appear solid in one set of conditions and liquid in another.

4.2 Consideration of testing machines

Before we look at the variety of tests, it is worth considering the basic instrumentation used to take measurements. To measure the rheological properties of a material we must either apply a force and measure the resulting deformation, or apply a deformation and measure the resulting force. Differences between test methods depend on the geometry of how the sample is held in the machine, and the nature of the force that is being applied.

Generally there are two types of machines used to measure the texture of solid foods: the texture analyser or universal testing machine, which has a motorised linear drive mechanism, and those devices that apply deformation via rotation.

Since measurement of food texture has become a science, a number of excellent textbooks have been written on the subject and the author would like to direct readers to a selection of these for more comprehensive coverage of the techniques that follow. While some of these are on the old side, there is much that can be gained from Sherman (1970), Sone (1972), Kramer and Szczesniak (1973), Mohsenin (1986), Vincent and Lillford (1991), Rosenthal (1999), Bourne (2002), and van Vliet (2013).

4.2.1 Texture analysers (universal testing machines)

Universal testing machines apply deformations in a linear manner, normally via a vertical drive mechanism. Typical machines have three key elements mounted in series with one another:

- A strain gauge to measure the stresses being applied. Some machines have the strain gauge below the specimen with the armature pressing down on the two, while other machines have the strain gauge mounted on the armature and the pair are then brought down onto the specimen.
- A motorized armature that compresses or stretches the specimen by defined amounts and at pre-set speed.
- A mount to contact the specimen. Depending on the type of test being undertaken these might be clamps for extensional measurements or plunger type probes for compression.

Food investigators have been particularly creative in their development of probes, such as the Kramer shear cell, back extrusion cells, Warner-Bratzler cells, Volodkevich Bite Jaws, extensional clamps, flat round-ended probes, ball-ended probes, cone-ended probes, and others. A selection of probes and attachments for a texturometer are illustrated in Figure 4.4. (Note that the front cover of this book includes a Stable Micro System TA. XT2 texture analyser with a three-point bending rig.)

Figure 4.4 Various Texturometer Test Cells: Top row: Flat-ended probe (left), compression platen (centre), cone-shaped probe (right); Middle row: Vlodokevich bite jaws (left), Shear blade (centre), tensile test jig (right); Bottom row: Wire-cutting tool (left), Kramer shear cell (centre), back extrusion cell (right).
With permission from Stable Micro Systems.

4.2.2 Rotational/oscillatory machines

Rather than squashing or stretching the specimen, it is twisted at a set speed or oscillated at a given frequency. As with the universal testing machines, there is a strain measuring device, which in this case measures angular strain. Specimens are held in a number of geometries such as "cone and plate", "parallel plate", "concentric cylinders", and so on.

Friction can be a limiting factor in commercial rheometers, for we are trying to measure resistance of the food material to very small stresses and resistance from the instrument limits the sensitivity. Consequently, research-quality rotational machines tend to employ an air bearing whereby the moving parts are supported on a cushion of compressed air with no contacting moving surfaces. Of course, sensitivity comes at a cost, and less sensitive mechanical-bearing-based machines may be perfectly adequate for quality assurance type work at a fraction of the cost.

4.3 Classification of test methods

The study of food deformation and flow has been driven by different needs. Generally these approaches divide into practical tests developed to show an aspect of food quality and fundamental tests developed to investigate physical properties of the food. In the past some scientists have derided the empirical test methods as being dimensionally unsound or theoretically weak, yet in many situations such tests provide insights into the behaviour of the foods when handled, processed or eaten. As such they mimic our interaction with foods in a practical hands-on way.

It is difficult to classify the variety of test procedures that exist for solid and semi-solid foods. Any classification scheme is arbitrary and no suggestion is intended as to a hierarchy or value to any particular method.

Before considering specific test methods, a few words of caution are appropriate. First, any material may be subjected to a test procedure and data will be obtained. The issue of what results mean is something quite different. Second, many of the test procedures have been adopted from physicists and material scientists. Such techniques were often developed to investigate homogeneous and isotropic materials. While some food ingredients such as hydrocolloid gels may fit these criteria, entire foods are often heterogeneous and anisotropic.

Scientifically rigorous test methods generally measure material characteristics such as moduli. In general these tests apply small deformations that allow material to recover when the stress is removed. In contrast, the empirical tests are designed to show a process, or a quality characteristic, or function in relation to an application. While not a requirement of an empirical test, they do in general involve the application of large forces, which take the test material beyond its elastic limit, thus leading to permanent and irreversible damage. Having said this, it is fair to say that empirical tests sometimes have a good scientific basis, but this is not a requirement because their purpose is to inform technologists who are applying the rheological behaviour to a useful end.

4.4 Scientifically rigorous test methods

4.4.1 Measurement of moduli

When a stress is applied to a solid, it tends to deform. The degree of deformation is often described as a strain (Figure 4.5), which is defined as the change in dimension as a proportion of the original (and is obviously dimensionless). In the case of a compression or an extension, the strain is in the direction of the normal stress. Young's (elastic) modulus is the ratio of the stress to the strain. In the case of a shearing force, the strain is tangential to applied stress and the shear modulus (or modulus of rigidity) is the ratio of the shear stress to the shear strain. Theoretically, it is possible to determine a bulk modulus where a hydrostatic force is applied and the change in volume is observed, though such a modulus is rarely determined and probably has little practical application. Furthermore, it can be calculated from other moduli (Sherman, 1970).

To undertake a determination of elastic modulus, it is necessary to have a sample of known initial dimension and to compress it under parallel plates. A clever alternative was proposed by Saunders and Ward (1954), who set a gel in a wide-diameter tube. A gas pressure was applied to one end and the deformation at the other end was measured by the displacement of a coloured drop of low-surface tension liquid within a narrow tube connected to the apparatus.

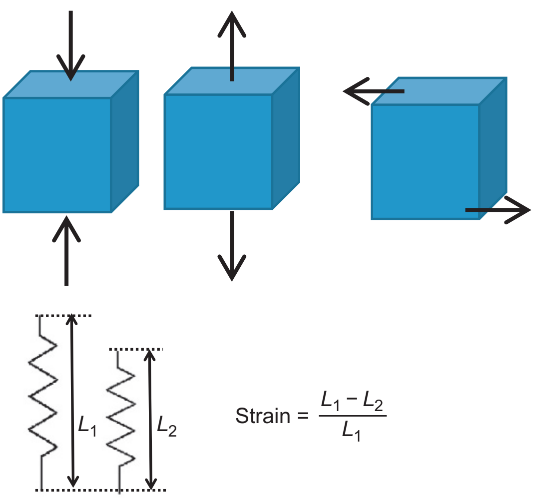
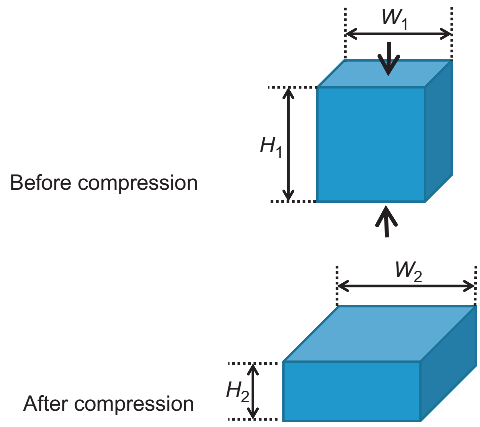


Figure 4.5 Compressive, tensile and shear strain.



$$\text{Poisson's ratio} = \frac{(W_2 - W_1)/W_1}{(H_1 - H_2)/H_1}\left(= \frac{\text{Elastic modulus}}{\text{Shear modulus}}\right)$$

Figure 4.6 Poisson's ratio, the lower block results from compressing upper one.

Poisson ratio, the proportion of transverse strain to axial strain (see Figure 4.6), has been determined for Hookean solids (i.e., those that behave as a spring); in the case of viscoelastic solids, the materials tend to barrel when compressed partly as a result of friction at the contact surfaces; of course, friction can be overcome to an extent by lubricating the contact surfaces with mineral oil or by using low-friction surfaces in contact with the food, such as Teflon. Clearly, even apparently simple actions like compressing a sample are fraught with complication, more so if one tries to measure foods in extension, for gripping the sample must hold it firmly without damaging the structure; if the material fails at the point of contact then it is likely that the failure is an artefact of how the material is clamped. While a variety of jaws exist, no single clamping device is suitable for all products. A novel approach with gels is to cast them as a ring and then stretch that ring between rounded hooks.

4.4.2 Dynamic oscillatory rheometry

The concept of both elastic and viscous components being present in a material at the same time is exploited in dynamic oscillatory rheometry. In this technique a layer of test material is mechanically oscillated and the transmitted force measured as a function of displacement. Figure 4.7a attempts to illustrate the key parameters that define a wave in an oscillation. The amplitude is a measure of the degree of deformation and the wavelength defines the duration of the wave. The frequency is the count of wavelengths per second and is a measure of speed of oscillation.

In the case of an ideal elastic material, there is no flow and the displacement and the transmitted force remain synchronized with each other, being in phase (Figure 4.7b). In contrast the force carried in a purely viscous material is out of phase with the displacement; as the amplitude of the oscillating displacement rises, it causes the liquid to flow.

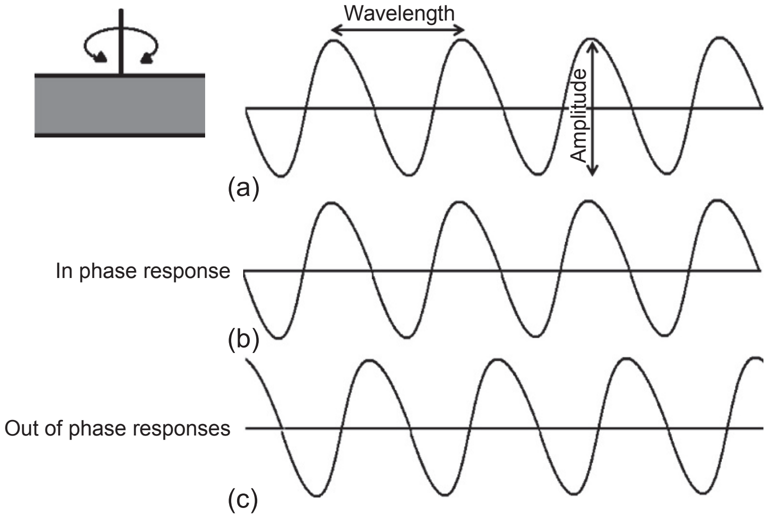


Figure 4.7 Oscillatory shear rheology: (a) is applied oscillation, (b) in phase shear, and (c) out of phase shear.

It is as though parallel layers of liquid slide past adjacent layers, dissipating some of the energy and motion to the next layer. As the amplitude of the displacement starts to fall at the end of the cycle, the momentum in the layers of liquid is still rising. The maximum flow in the liquid occurs when the amplitude of the displacement is virtually nothing (i.e., before the amplitude starts to increase in the opposite direction). Thus the technique allows us to gauge the degree of solidity and liquidity of viscoelastic materials.

With dynamic oscillatory rheometry, it is normal to initially explore the stability of a material over a range of amplitudes with an amplitude sweep. This allows us to identify the range over which the material behaves in a linear viscoelastic manner. At higher amplitudes the material is being deformed to beyond its elastic limit so all readings after the first oscillation are compromised in terms of whether the original material is still present! Following the amplitude sweep, researchers normally undertake a frequency sweep within the linear viscoelastic region. This identifies changes in the degree of solidity/ liquidity across the relaxation spectrum. As noted earlier, the behaviour of a material to a test is dependent on time to allow relaxation to occur. At high frequencies, where very short times are allowed for relaxation, most materials behave predominantly as solids, while at low frequencies viscous properties, if present, become exhibited. A useful measure of solidity versus liquidity is the ratio of elastic and viscous moduli or tan δ.

4.4.3 Creep tests

The creep test is the measurement of deformation at constant stress. In practice we see the deformation change as time passes. This change in deformation is normally described as a creep compliance (J), which is the strain at any particular time. While both universal testing machines and rotational rheometers can be used to undertake the measurements, it does not really need complex or sophisticated apparatus to be undertaken. Chang et al. (1986) reported a simple student experiment to determine creep on blocks of cheese using a vertical ruler and a weight. Their data, as with that of many other researchers who performed a creep test, resembles a Burger body (Figure 4.2) and as with other mechanical analogues, we are able to quantify the contributions of each component of the model:

- J_0 the initial vertical rise corresponds to an instantaneous elastic compliance and is equal to the reciprocal of the elastic modulus. This part of the Burger model is explained by the series spring and of course it re-manifests as an instantaneous vertical fall, when the load is removed.
- The retarded elastic creep compliance (J_R) corresponds to the Kelvin-Voigt element present in the Burger body. As with the instantaneous elastic compliance, when the load is removed the retarded elastic compliance can be seen to gradually reduce the deformation as the material recovers with time. Mathematically we can calculate this retarded elastic compliance by taking logarithms to linearize this exponential decay. In some materials after taking logs we might still observe further nonlinearity, suggesting that there are multiple Kelvin-Voigt elements needed to explain the behaviour.
- J_V is the viscous compliance and represents a non-recoverable deformation in the material, which is analogous to the dashpot dampener arranged in series. Unlike the other two creep compliances, when the load is removed there is a permanent and unrecoverable change in the material due to this element; moreover, the duration of the test will clearly afford more time for the element to deform.

4.4.4 Stress relaxation tests

The stress relaxation test applies a constant strain and measures changes in stress with time. Like the creep compliance, the stress relaxation test allows us to gain an understanding of some fundamental properties of a solid food material. A characteristic relaxation time can be calculated from the decline in the measured stress and is equivalent to the time for the initial stress to relax by 50%.

Stress relaxation can be modelled with a Maxwell model, though in practice several parallel Maxwell models are seen to exist, each with their own relaxation time, which in practice means that we measure a spectrum of relaxations.

As with the creep test, the measurements may be undertaken in a rotational rheometer or with a universal testing machine.

4.4.5 Three-point bending

In three-point bending, a strip of solid food is supported at each end and the force is applied from above midway through the span of the supports. Normally a ratio of 100:1 for the span to the thickness of the samples is necessary to gain useful results. The dimensions, force applied and degree of flex allows us to calculate fundamental characteristics like Young's modulus. Of course such tests are limited to homogeneous foods.

4.5 Empirical tests

As already stated, these tests are intended to inform technologists of a behaviour of the food that might affect interaction with other components, manufacture, shelf life, storage, oral breakdown, swallowing, and so on. The tests generally involve the application of forces large enough to overcome the material's elastic limits, resulting in permanent structural changes.

How are these tests established? Without doubt our experiences of life enable us to identify the quality of foods. Obvious characteristics like the colour of bananas guide our purchases. Even when visual cues are not available, we learn somehow that gentle pressing of avocados or listening to the sound made if we tap a watermelon are techniques to help us to select foods on the basis of ripeness. Such observations form the basis of many empirical tests. Obviously, there may be a variety of interactions that allow us to gauge what is considered to be a "good" or "poor" quality, and most mechanical tests tend to focus on just one attribute, yet these empirical tests are normally a good guide to the aspect of quality concerned.

4.5.1 Puncture tests

The puncture test involves pushing a flat ended probe into the food by a fixed depth, the characteristic measured is the force required to achieve the depth of penetration. Just as we may have pressed fruits to aid their selection, simple spring loaded plungers can be pressed into fruits and the force measured (Figure 4.8). Hand-held pressure testers are highly mobile for field work to test the maturity of agricultural produce.

For a puncture test, the probe should be no larger than one-third of the sample surface area. When such a probe makes contact with the surface, a combination of compression and shear forces act. The force acting on the food at the edge of a probe is predominantly a shear force, while the force towards the centre is predominantly

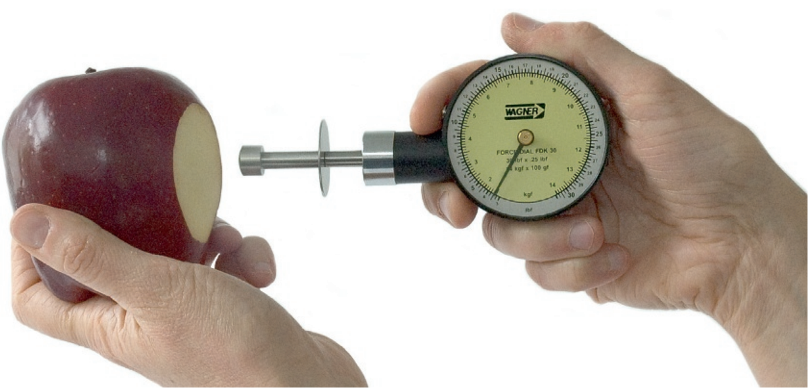


Figure 4.8 Wagner Instruments Dial Fruit Pressure Tester, Model FT 30. With permission from Wagner Instruments.

compressive. By selecting probes of different diameters, Bourne (1966) was able to separate out the shear and compressive components from the test.

4.5.1.1 Bloom gelometer

To all intents and purposes, the Bloom gelometer is a puncture test that follows a very specific test protocol. The preparation of the sample, its dimensions and the details of the test protocol are all specified in order that the procedure is standardized. The Bloom gelometer (and derived test apparatus) remain the standard to characterise the strength of gelatins. The Bloom gelometer utilizes a 12.7 mm diameter plunger being forced 4 mm deep into the gel. The weight required to achieve this penetration gives us the Bloom strength, which ranges from 50 to 300, whereby low Bloom gelatines ($\sim$100) are suitable to produce products like marshmallow, while high Bloom gelatines ($\sim$240) are more suitable for fruit gums.

While originally intended for gelatine, Bloom may be measured for other hydrocolloid gels. Today many of the commercial universal testing machines will have a Bloom probe and test protocols to allow Bloom to be determined.

4.5.1.2 Multiple-probe puncture tests

Several commercial devices have been developed to measure the texture of small food items such as peas by puncturing many at the same time, thus gaining a greater level of resistance and averaging that resistance across a number of individual items. Originally dedicated devices were created, such as the pea tenderometer. Over the years, test cells have been developed that attach to universal testing machines. The Kramer shear cell, for example, has multiple blades that cut through the sample and has been used for texture measurements of fresh produce such as peas or manufactured products like lasagne.

4.5.1.3 Texture Profile Analysis

Texture Profile Analysis (TPA) is a two-bite compression test that purports to mimic the first two bites of mastication. In its original form, a plunger compressed a wider sample by 75% in an arc-type motion at a rate of 42 bites per minute (Friedman et al., 1963). The arc-type motion was peculiar to the General Foods Texturometer and in 1968 Bourne modified the procedure to what is generally accepted to be the official test protocol. This consisted of a 75% deformation of the sample by a vertical motion of a platen (larger cross section than the sample) at a speed of 0.83 mm s^{-1}. Despite the conditions being “set”, scouring the literature reveals vast discrepancies such as the degree of deformation ranging from 20% to 80%, or the speed of deformation ranging from 0.083 to 6.667 mm s^{-1}. Rosenthal (2010) investigated the interplay of the different variables in relation to variation in the results. Working with a starch-glycerol gel that could withstand strains of 0.90 without failing, he looked at the compression speed, the % deformation (strain), the influence of lubrication, and the sample geometry (comparing Bourne’s platen with the narrow plunger acting on a wide sample as in the original paper). Generally caution is urged not to modify the test protocol from 75% deformation with parallel plates or to undertake the test at speeds of less than 2 mm s^{-1}.

Figure 4.9 is a schematic to illustrate the operation and output of the test. The upper image portrays an overview of the possible force curves through the two bites of the test. Initially contact is made and the resisting force is shown to rise, reaching a maximum at the full extent of compression. As the strain is reduced, the peak falls away, and when the instrument actually pulls away from the surface of the sample there is the possibility of a negative peak, indicating tack. The other sketches in Figure 4.9 illustrate the different attributes measured, such as the height of the first peak being an indication of the sample's hardness. Where two sketches appear alongside each other, they are normally alternatives for example brittle foods, which show multiple jagged peaks and are mutually exclusive from sticky foods, which exhibit a negative peak—the area of which is referred to as adhesiveness. The ratio of the areas of the first and second peaks is referred to as cohesiveness and is taken to be a measure of internal strength of the food material and its ability to recover structure in the time between the bites. As the cohesiveness is conceptually a measure of work necessary to compress the material in each of the two cycles, Peleg (1976) pointed out that in any one cycle work is only being applied during the compression stroke, thus giving rise to the corrected cohesiveness, which takes no account of the elastic forces pushing back on

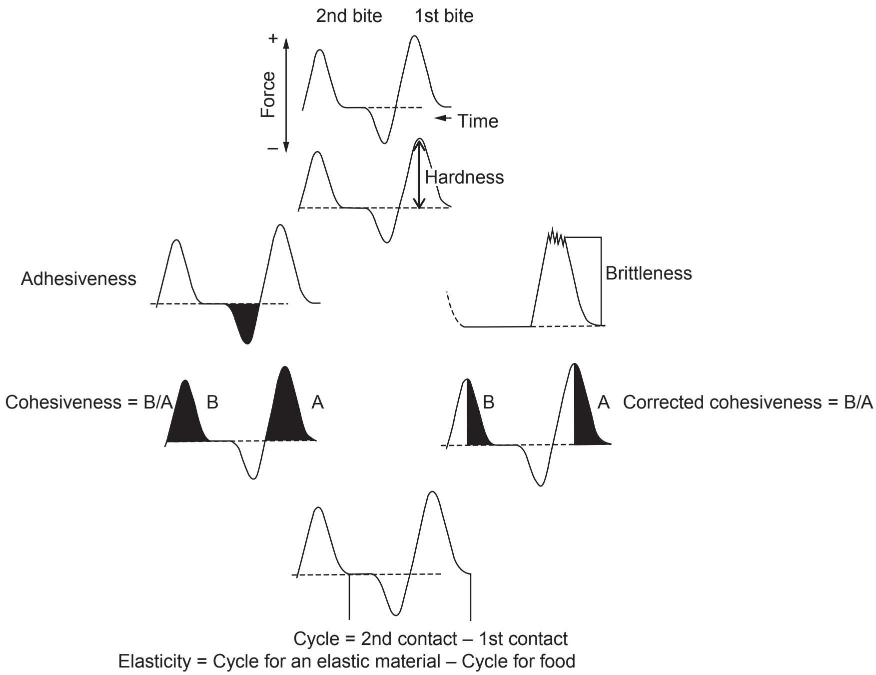


Figure 4.9 Schematic illustration of Texture Profile Analysis (TPA) and its derivative measurements.

the instrument during decompression. This idea of elasticity in the sample is actually measured in the final sketch, which shows the differences in contact time between the instrument on the food sample compared to the same test with a completely elastic material, which recovers all its structure between cycles.

Part of the enthusiasm with which the food science community has embraced this test protocol has to be due to its originators achieving good (though not always linear) correlations between TPA and sensory parameters (Szczesniak et al., 1963). It is an attractive idea that measures such as instrumental hardness should directly relate to sensory hardness and the like.

4.5.2 Penetrometer

The word "penetrometer" suggests a device that would do much the same as a puncture test; however, the equipment and test protocol are very different. A penetrometer allows a weighted cone in contact with the food material to penetrate the surface under its own weight. The distance that it penetrates in a given time is the characteristic measure that is recorded. The conical shape ensures an increased resistance as penetration ensues, causing the probe to achieve a characteristic depth for a particular material. Of course, the resistance to penetration of a cone increases in a non-linear way with depth of penetration. However, attempts have been taken to mathematically analyse the results from the technique (Hayakawa and Deman, 1982).

Originally developed for characterising tar- and bitumen-like materials, the test has been adopted to a limited extent for measuring the texture of fats. Of course, the texture of such materials is highly temperature sensitive and therefore careful thermostatic control are crucial for reproducible results.

4.5.3 Back extrusion

Back extrusion (annular pumping) involves pressing a loose-fitting plunger into a cylinder containing the food of interest. As the plunger squashes the food, any liquid (formed) or plastic material is forced through the annular gap as it becomes displaced. While such a technique could be used for liquids, potentially being a kind of viscometer, in the area of solid foods, it has been used to investigate the texture of berries or semi solid foods such as porridge or meat pastes. Thus the technique measures a combination of phenomena including: elastic properties, rupture strength, yield stress and the viscosity of any liquid present or liberated. A theoretical interpretation of data has been undertaken for a variety of materials (Steefe and Osorio, 1987).

4.5.4 Correlations

Textural changes in food products often reflect structural differences between materials and may result from interactions of food components under varying conditions. Bearing in mind that textural changes may be an outward manifestation of something far more fundamental, it may be that measuring more rudimentary properties is actually more useful than the texture itself. For example, the simple chemical estimation of alcohol insoluble solids (AIS) has been used as a measure of pectin content and indirectly fruit ripeness for many years, yet it is a reliable measure of the texture of many fruits and vegetables (see, for example De Vries et al., 1981).

4.5.4.1 Food sounds

An important aspect of food texture is the sound that is made when foods are handled and eaten. This is particularly important for crisp and brittle foods such as extruded snacks, many bakery goods and deep-fried potato products. When we eat, the sound travels both through the air and through the cranial bones to our ears, invoking sounds that seem different to what is heard when we listen closely to what other people eat (Dacremont et al., 1991).

A good deal of research has been undertaken into the sounds that food makes when fractured in both the mouth and with different geometries on universal testing machines (Arimi et al., 2010; Kim et al., 2012). A close correspondence between sound release and force elapse has been proved by Chen et al. (2005). The correspondence was almost peak-to-peak between sound and force curves.

4.5.4.2 Non-destructive testing

A number of non-destructive test (NDT) methods have been proposed to evaluate the texture and quality of a number of solid foods. Some of these techniques are based on automated, non-contacting visual inspection systems, while others rely on the transmission or attenuation of ultrasonic sound waves passing through a food. For a comprehensive reviews, readers are directed to Gunasekaran (2000) and Povey and Mason (1998), who focus on ultrasonic measurements. Other technologies, such as near infrared reflectance, have been used to correlate textural quality with a number of foods (e.g., Revilla et al., 2009). Of course, where correlations are involved it is necessary to justify the textural attribute with which it is being correlated.

4.6 Future trends

The subject of these volumes is texture modification and in that context we have to consider techniques that offer insights into our understanding of food structure, food component interactions and their contribution to texture from both an instrumental and a sensory point of view. From fundamental measurements on the properties of materials to increasingly sophisticated methodologies, the area of food texture measurement is expanding at a tremendous pace. However, the basic test procedures remain. What seems to change is the combining of different methods and protocols, along with ingenuity in the interpretation of data.

4.7 Sources of further information and advice

Lists in this section are in alphabetical order of manufacturer name and do not reflect any preference, quality, price or value for money. The lists are not intended to be comprehensive but should provide an interested reader with potential sources of equipment.

4.7.1 Texturometer manufacturers

Brookfield: www.brookfieldengineering.com
Instron: www.instron.com
Spectronic: www.spectronic-camspec.co.uk
Stable Microsystems: www.stablemicrosystems.com

4.7.2 Rheometer manufacturers

Anton Paar: www.anton-paar.com
Brookfield: www.brookfieldengineering.com
Göttfert: www.goettfert.com/
Malvern Rheometers (originating from Bohlin): www.malvern.com
TA Instruments: www.tainstruments.com
Thermo Fisher Scientific (originating from Haake): www.thermoscientific.com

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Instrumental characterisation of textural properties of fluid food

5

G. Sala, E. Scholten
Wageningen University and Research Centre, Wageningen, The Netherlands;
Top Institute Food & Nutrition, Wageningen, The Netherlands

Symbols and notations

A	surface area
d	thickness
$D_{3,2}$	surface mean diameter
$D_{4,3}$	volume mean diameter
E	elongational modulus
F_f	friction force
G	shear modulus
G'	storage modulus
G''	loss modulus
h_0	initial height
h_s	average height
k	constant
M	moment of force (torque)
R	radius
t	time
v	velocity
W	normal load
γ	strain (deformation)
$\dot{\gamma}$	shear rate
δ	phase angle
η	shear viscosity
η_c	viscosity of the continuous phase
η_E	elongational viscosity
μ	friction coefficient
σ	stress
υ	kinematic viscosity
ϕ	volume fraction
ϕ_{max}	maximum packing fraction
ω	angular velocity

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5.1 Introduction

Several definitions of texture have been formulated, and all agree on the fact that texture is a multi-factorial sensory attribute. The International Organisation for Standardization, for example, describes texture as 'all the mechanical (geometrical and surface) attributes of a food product perceptible by means of mechanical, tactile, and, where appropriate, visual, and auditory receptors' (ISO standard 5492:1992, 1992). Being a sensory attribute, texture can be measured by humans only. Nevertheless, scientists have long been trying to relate texture to instrumental measurements of some food properties, more specifically to their rheological and mechanical properties. The intention of explaining texture in terms of instrumental parameters derives from the necessity of understanding and describing the physical mechanisms behind the sensory perception of foods. Furthermore, scientists aim at understanding and cataloguing different textural properties to develop tools to better control the texture of existing products or to develop new ones. The goal of new product developers within the food industry is actually antithetic to that of food scientists. Product developers continuously aim at finding new textures with surprising/exciting sensations by inserting innovative structural features or novel ingredients in foods, making the task of scientists of exhaustively describing texture in terms of strict physical parameters more and more difficult.

Numerous challenges are involved when linking instrumental parameters to sensory attributes. To start, relevant instrumental attributes should be recognized with regard to the sensory attributes of interest. The sensory attributes should be described in a rigorous way. Furthermore, suitable instrumental techniques and measuring conditions should be selected.

The topic of this chapter is the description of physical properties of fluid foods that can be related to texture and measurable by instrumental techniques, as well as the relevant measuring methods. After the discussion of these issues, criteria to apply and combine the available methods and examples of applications from published studies will be presented. The focus is on products with a relative readiness to flow, ranging from thin emulsions like milk to semi-solid emulsions (e.g., mayonnaise) and polymer dispersions (e.g., Dutch custard). Consequently, the foods taken into consideration will comprehend both Newtonian and non-Newtonian fluids. The distinguishing texture characteristics of fluid foods include both mouthfeel properties such as thickness, creaminess, fattiness, slipperiness and sliminess, and after-feel properties such as coating, dryness and roughness.

5.2 Relation between textural and sensory properties

As already clearly formulated by van Vliet, 'establishing and understanding a relation between texture perception and instrumental parameters requires that the humans involved perceive texture of the food product in an unequivocal way, that relevant physical properties of the food can be determined, and that these can be measured by an instrument under relevant conditions. It requires people to work together who are trained in different scientific disciplines' (van Vliet, 2002).

Some specific textural properties of foods can be directly related to and/or fully explained by a single instrumental parameter. For example, sensorial thickness of fluid and semi-fluid foods can be related to viscosity. For other properties, like creaminess, combinations of available instrumental techniques or development of new techniques should be pursued. For systems with complex structural properties, even the combination of different rheological techniques might not be enough. In this case, also other physicochemical parameters should be included—for example, the wetting of surfaces with properties similar to those of the oral tissues by the food material, or the size of particles present in the product. The aspiration of texture researchers should be to achieve an exhaustive instrumental/sensory characterisation, but acceptable compromises should be sought.

The sensory perception of foods occurs during oral processing, which involves several stages, such as mastication and swallowing. For fluid foods, the teeth are not used, and the food is processed between the tongue and the palate. As soon as food is inserted in the mouth, its textural properties may change due to changes in its structure. Therefore, the perception of the food will be different at different stages. At the beginning of the permanence of food in the oral cavity, bulk-related sensory attributes such as thickness are perceived (de Wijk et al., 2011). In later stages, more surface-related attributes such as fattiness and after-feel properties are perceived (Selway and Stokes, 2013). The sensory perception at different stages during consumption will be much affected by processes that occur in the mouth, and by specific conditions, such as temperature changes and interactions between food and saliva (Chen, 2009). The first changes in the food will be affected by the increase in temperature, especially for chilled food products. In the mouth, the food is warmed up to body temperature, which may result in a decrease of the product viscosity. At the same time, the mixing with saliva dilutes the food to a certain extent and affects the lubrication properties. Saliva is a complex fluid that contains a variety of proteins, enzymes, electrolytes and mucus. Saliva itself provides coating and lubrication of the oral surfaces, which ease the movement of fluid foods through the mouth. These phenomena, together with the type of food, determine the regime of the lubrication, as will be discussed in more detail later. The interactions between saliva components and food lead to either structure breakdown or structure formation. Structure breakdown occurs because of the presence of different enzymes, which have the ability to degrade different food components. For instance, the enzyme amylase is able to hydrolyse starch into sugars. This breakdown will reduce the viscosity of the samples and therefore change the perception of the food over time, as shown in Dutch custards (Janssen et al., 2007). Structure formation can be seen in the case of emulsion systems, for example. For these types of products, the presence of saliva or mucins could induce aggregation of the emulsion droplets by depletion-flocculation and therefore increase the viscosity of the fluid (Vingerhoeds et al., 2005). Therefore, the sensory perception of fluids may depend on the composition of the food and may change over time during oral processing. To understand the properties of food and to link it to sensory perception, knowledge of multiple aspects of foods is necessary.

5.3 Physical properties

Since the defining characteristic of fluid foods is their readiness to flow, the most relevant physical properties for the description of their texture are related to their inherent flowing behaviour and to the flowing response upon application of a deformation. Different types of viscosity can be used to characterise fluid foods, and they will therefore represent the main part of this section. Starting with the investigations of Kokini (Kokini, 1987; Kokini and Cussler, 1983; Kokini and Dickie, 1981, 1982), which can be considered a real landmark in the field, the lubrication properties (usually called tribological properties) of foods have become an important feature in the characterisation of food texture. The physical basis for these properties and the related measuring techniques will be discussed here as well.

5.3.1 Viscosity of fluid food

The rheological behaviour of liquid foods depends to a large extent on the number and the type of components, and is often characterized by viscosity, which is a measure of the ease of flow and is related to the amount of force, often expressed as a stress σ, needed to deform the sample at a certain deformation rate. Fluid foods can be deformed in different ways. Deformation can be obtained by applying shear, which is a result of moving the sample along a surface, or applying compression, in which the sample is compressed or elongated in one direction, and becomes elongated or compressed in the other direction (as in compressing food between two fingers). The type of deformation determines the term used to describe the viscosity of the food. For fluids deformed by shear, the viscosity is often referred to as shear viscosity or dynamic viscosity. When the fluid is deformed by compression or extension, the viscosity is referred to as the extensional (or elongational) viscosity. Similar concepts are used to describe solid foods, in which the proportionality between the stress and strain is given by either the shear modulus, G, or the elongational modulus, E. An overview of the different deformations and the response of the materials can be found in Figure 5.1.

Shearing is the most common deformation applied for the measurement of viscosity. Fluids showing a linear relation between stress and the shear rate are called Newtonian. Most food materials, however, show a non-Newtonian behaviour, which is expressed as a deviation from the linear relation between stress and shear rate. The first main type of deviation is the shear thinning behaviour, in which the stress increases slower as the shear rate increases, and therefore the viscosity decreases with increasing shear rate. The shear thickening behaviour consists of the opposite: viscosity increases upon an increase in shear rate. For these different behaviours, we assume that the flow of the samples is initiated already when small forces are applied. However, in many food materials, a certain minimal force (stress) is needed in order for the material to flow, which is commonly known as the yield stress of the sample. An overview of the different behaviour of fluids can be found in Figure 5.2.

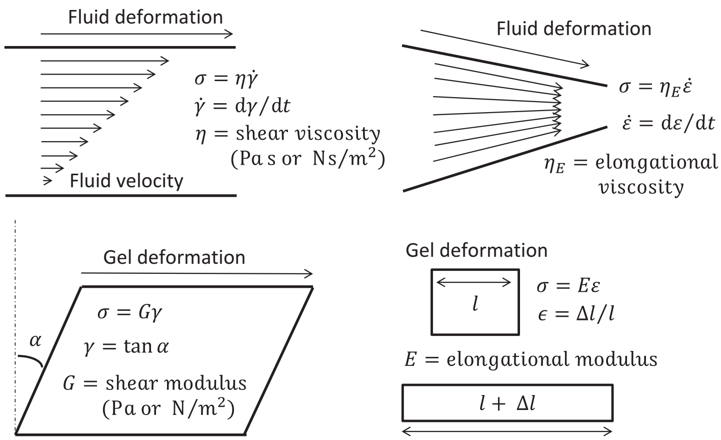

Figure 5.1 Simple deformations and the response of the materials.

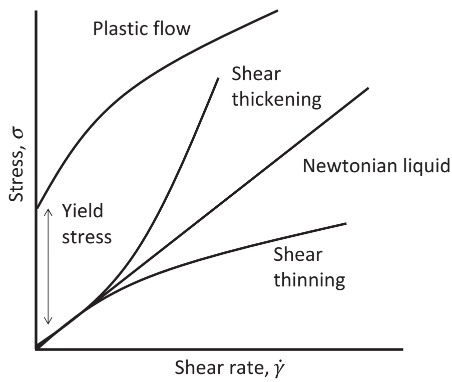

Figure 5.2 Rheological behaviour of liquid foods.

5.3.2 Dispersion viscosity

Most fluid foods can be categorized as solutions, dispersions or emulsions. A solution is characterized by a homogeneous distribution of small molecules in a liquid. A fluid is classified as a dispersion (or suspension) when solid particles (e.g., large proteins) are present, or as an emulsion when the dispersed particles are liquid. Milk can be regarded as a dispersion due to the presence of casein micelles (200 nm), and at room temperature, when fat is melted, as an emulsion due to dispersed fat droplets (1–10 μm). The viscosity of such fluids is dependent on the volume fraction (ϕ) and the type of particles or droplets present. The viscosity of a sample containing solid particles in the dilute regime ($\phi < 0.01$) was first described by Einstein as

$$\eta = \eta_c(1 + 2.5\phi) \tag{5.1}$$

where η_c is the viscosity of the continuous phase. For hard particles deviating from a spherical shape, this equation does not hold. For higher concentrations of particles, but still in the semi-dilute regime ($0.01 < \phi < 0.1$), interactions between the particles should be taken into account, and Equation (5.1) becomes the more extended version

$$\eta = \eta_c\left(1 + 2.5\phi + 6.2\phi^2\right) \tag{5.2}$$

as described by Batchelor (1977). For very concentrated dispersions ($\phi > 0.1$), the viscosity will tend to infinity at a volume fraction where the entire space is filled, and flow of the sample is arrested. This happens at the maximum packing fraction, $\phi_{\max}$, of the particles, the value of which can range from 0.52 for very open cubic packing to values up to 0.74 for more compact hexagonal packing of spherical particles. Taking this packing parameter into account, the viscosity of concentrated dispersions is often described by the Krieger and Dougherty model as (Krieger and Dougherty, 1959)

$$\eta = \eta_c\left(1 - \frac{\phi}{\phi_{\max}}\right)^{-2.5\phi_{\max}} \tag{5.3}$$

For emulsions, where the dispersed droplets are not hard and spherical but can be compressed into non-spherical shapes, these equations will not hold. When compressible droplets are incorporated, the maximum packing fraction can be increased to much larger values by formation of hexagonal droplets. This is the reason why in mayonnaise the volume fraction of oil droplets can exceed the maximum packing fraction of 0.74. Due to the fact that the droplets are deformable and their deformability depends on their size, the rheological behaviour of mayonnaise and the viscosity deviate from those of an ideal dispersion. A larger deformability of the droplets leads to a better flowability and therefore a decrease in the viscosity.

5.3.3 Viscoelastic materials

In the previous paragraph, we have assumed that considered systems behave as purely liquid materials. However, many food products cannot be considered pure liquids because they also show some properties of solids. For instance, desserts and dressings can better be described as semi-solids or soft gels. Such products show a so-called viscoelastic behaviour, indicating that they have both viscous (liquid-like) and elastic (solid-like) properties. These products are not fully characterized by a single parameter as the viscosity. Two parameters are required: the viscous modulus, describing the viscous behaviour, and the elastic modulus, describing the elastic behaviour. These parameters are related to the amount of energy that can be stored within the systems (solid elastic response) and the amount of energy spent to induce flow of the sample, defined as the lost energy or dissipated energy (viscous liquid response). Examples of foods that are able to store a lot of energy, thereby regaining their original shape after deformation, are products such as wine gums and cheese. Specific examples of fluids that are of viscoelastic nature are mayonnaise, salad dressing, yoghurt and ketchup.

5.3.4 Lubrication

A part of the textural properties of foods can be directly related to rheological properties that can be determined with the techniques described above. Other textural attributes are more complex than those cited in these examples, and cannot be directly related to simple rheological or mechanical parameters. It is now commonly accepted that textural attributes like fatty, creamy and smooth are related to the lubrication induced by the food products when tongue and palate are rubbed against each other. Starting from this assumption, it can be understood why fattiness, creaminess and smoothness can be related to compositional parameters like the fat content or the presence in the food of solid particles. Thin-film rheology, more commonly called tribology, is the discipline that studies the lubrication behaviour of (mostly) fluid materials. To be able to understand the application of tribology to food processing in the mouth, we are now going to introduce some basic tribological concepts.

Friction, expressed as friction force, occurs in all systems in which two surfaces in motion are in contact with each other (Chojnicka-Paszun, 2009). In presence of a lubricant, friction is determined by various factors like the roughness and mechanical properties of the surfaces taken into consideration, the viscosity of the lubricant, its entrainment speed, and the applied normal force. The friction force depends on the normal load between the rubbing surfaces:

$$F_f = \mu W \tag{5.4}$$

where F_f is the friction force, μ is a friction coefficient and W is the normal load. The speed at which the rubbing surfaces move along each other determines the speed at which the lubricants are entrained in the contact zone between the surfaces. Depending on the entrainment speed, the lubricants generate a pressure that provides some support to these surfaces. With increasing entrainment speed, a stronger support is developed by the lubricants and a lower friction is observed. The lubrication behaviour of a material is usually described by a curve, called Stribeck curve, relating the friction coefficient to the entrainment speed. In the Stribeck curve, three regimes can be distinguished depending on the degree of separation between the rubbing planes: the boundary, the mixed, and the hydrodynamic regimes (Figure 5.3). In the boundary regime the rubbing surfaces are in direct contact. The entrainment speed of the lubricant is too low to generate a pressure able to lift the upper surface. The asperities of the surfaces play a determinant role in the friction force, which is consequently relatively high. Larger surface irregularities extend the boundary regime to higher entrainment speeds. A similar effect is observed for compliant surfaces (e.g., rubber). Also in this case, adhesion between rubbing surfaces results in an extended boundary regime. The direct contact between rubbing surfaces induces wearing, which leads to degradation of the rubbing surfaces. Wearing can be prevented by the formation of a thin boundary lubricant film between surfaces. With increasing entrainment speed, additional

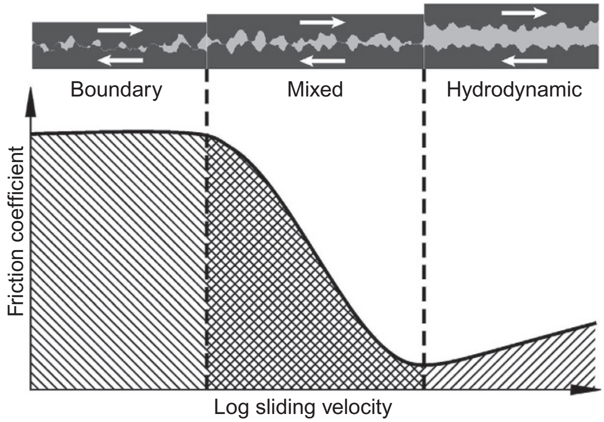

Figure 5.3 Stribeck curve with all three regimes of lubrication: boundary, mixed and hydrodynamic. The upper part of the figure shows a schematic representation of the asperities separation in each regime.
Reproduced with permission from Chojnicka-Paszun (2009).

pressure is developed by lubricant hydrodynamics, which results in a larger separation between surfaces. As a consequence, the friction force decreases with an increasing entrainment speed. However, the separation remains lower than the sum of the asperities of both surfaces. This is observed in the mixed regime, which is affected by both the bulk rheological properties of the lubricant and the properties of the surface. If the entrainment speed is high enough for the pressure to fully separate the two surfaces, the lubrication enters the hydrodynamic regime. In this regime the lubrication is mainly affected by the bulk properties of the lubricant, like viscosity. In the case of laminar flow of a Newtonian fluid, the friction force in the hydrodynamic regime is given by:

$$F_f = A/d\eta v \tag{5.5}$$

where A is the surface area of the two parallel surfaces, d is the thickness of the lubricating layer, η the viscosity of the lubricant, and v is the relative velocity of the surfaces. Commonly, the hydrodynamic lubrication regime is referred to as elasto-hydrodynamic regime if soft surfaces are investigated (e.g., to simulate oral environment).

5.3.5 Particle size and sensory perception

The size of the particles present in fluid dispersions has a large influence on sensory perception. When particles can be detected in the mouth, they could lead to a very grainy, gritty or sandy feeling. Examples are the sandy feeling of condensed milk when lactose crystals exceed a certain size, or the rough feeling of badly mixed sauce containing lumps. The sensory perception of such larger particles is a result of the detection of the particles mainly through friction between the food and the oral mucosa (de Wijk and Prinz, 2005). Sensory attributes such as grittiness, coarseness and roughness are associated with the perception of the particles between the tongue and the palate.

Although various food systems have been investigated, the role of particles in different media is still not completely clear. In general, we assume that the properties of the particles, the medium in which they are dispersed and the concentration at which they are present determine to a larger extent the sensory perception. For example, the particle size, shape and the hardness of the particles affect the detection limit of the particles; the larger, the more irregular and the harder the particles, the more easily they are perceived. Hard and irregular particles of a few micrometres may already be perceived at low concentrations and result in a rough and gritty mouthfeel, while smooth and soft particles in the millimetre range may be undetected, even at high concentration, which leads to a smoother perception.

This effect of particle size was confirmed by Engelen and co-workers, who investigated the effect of particles of different sizes in a polysaccharide suspension (Engelen et al., 2005). Relatively monodisperse particles with sizes between 2 and 230 μm were prepared, and different materials, such as SiO_2 and polystyrene, were used to compare soft and harder particles. The results show that people are able to perceive particles on a micrometre scale and are able to classify different sizes, as they were able to rate the different coarseness of the suspensions (Figure 5.4). Suspensions with harder SiO_2 particles were perceived as coarser, which confirms the hypothesis that harder particles are perceived more easily. They found that particles as small as 2 μm already resulted in an increase roughness perception (Engelen et al., 2005). This effect increased with sizes up to 80 μm and was found to be stronger for sharp particles than for rounded ones (de Wijk and Prinz, 2005). Besides an increased size of single particles, aggregation (and subsequent precipitation) may also lead to increased gritty feeling (de Wijk and Prinz, 2006). Both mechanisms will contribute to increased roughness. The effect of particle size was not observed, however, in a study where food-grade rye bran particles were used. The particles ranged in size between 20 and 180 μm and were dispersed in starch solutions with different viscosity

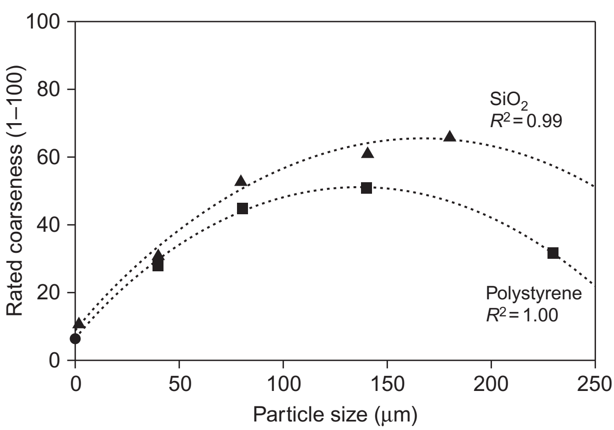

Figure 5.4 Rated coarseness as a function of particle size.
Reproduced with permission from Engelen et al. (2005).

(Petersson et al., 2013). The concentration detection limit of the particles was found to be similar for all sizes, and the viscosity of the medium did not show a significant effect.

In these studies, the perception of the particles was not influenced by the viscosity of the medium, although it is believed that the coarseness of the particles can be masked by a higher viscosity of the medium. However, the effect of differences in the medium of the dispersed particles was observed in another study by Chojnicka-Paszun et al. (2014). In this study, protein particles ranging from 8 to 56 μm were suspended in different polysaccharide solutions. Locust bean gum, pectin or xanthan were used. The hardness of the particles was adjusted by internal cross-linking of the proteins in the particles with transglutaminase. The results of this study show that not only the size or the hardness of the particles had an effect on several sensory attributes. Instead, the type of polysaccharides gave most differences in the perception. For example, xanthan showed lowest scores for attributes such stickiness, filmy and sliminess, but higher scores for slippery. Apparently, the lubrication properties of the medium also play a large role in the detection of particles and sensory perception.

5.4 Measurement techniques

5.4.1 Viscometers

The viscosity of fluid foods can be measured with a variety of techniques. The viscosity of thin liquid foods can be measured with capillary viscometry. The capillary viscometer, better known as the Ubbelohde (Figure 5.5a), measures the time needed for a liquid to flow through a capillary of a certain volume, from which the so-called kinematic viscosity, v, can be determined as

$$u = kt \tag{5.6}$$

in which k is the constant of the viscometer, and t is the flow time of the liquid. The kinematic viscosity can be used to express the dynamic viscosity as $\eta = u\rho$, where ρ is the density of the liquids. The constant k is determined using a suitable viscometer calibration liquid. As the applied deformation is of elongational nature, the viscosity measured is an elongational (or extensional) viscosity.

For more viscous fluids, the rotation viscometer is more often used. This measuring device usually consists of two concentric cylinders (the bob and the cup), one of which is driven by a motor, as given in Figure 5.5b. For low-viscosity samples, a double-gap geometry can be used. With this system the surface of the sample in contact with the device geometry is almost doubled as compared to the concentric cylinders. The viscometer measures the torque required to rotate the inner cylindrical probe within a fluid. For laminar flow, the shear viscosity of the fluid can be calculated as

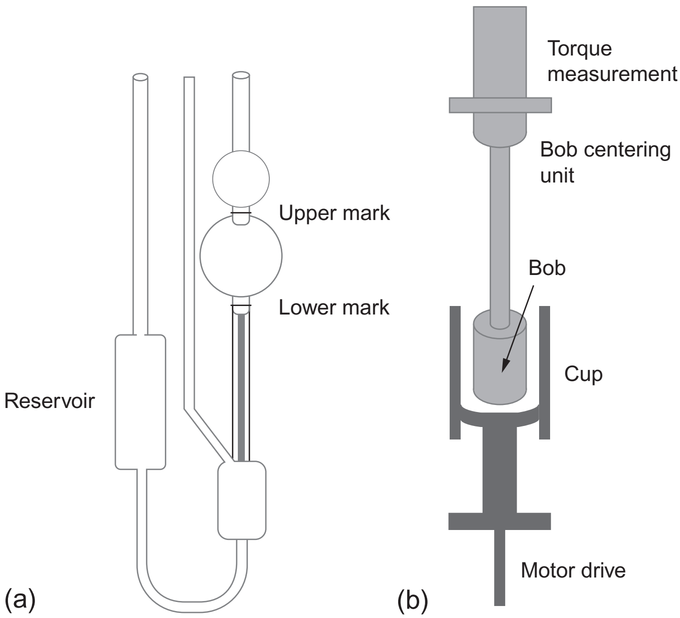

Figure 5.5 (a) Capillary viscometer and (b) bob-cup viscometer.

$$\eta = k\frac{M}{\omega} \tag{5.7}$$

where M is the moment of force (torque) and ω is the angular velocity. The constant k depends on the diameter of the bob and the cup used, and can be determined for each geometry with a calibration liquid. As previously discussed, the relation between the applied stress and shear is linear only for Newtonian liquids. For non-Newtonian liquids, the viscosity will change as a function of the shear rate, since shear-thinning or shear-thickening phenomena arise. In this case, the measured viscosity will thus depend on the shear rate or stress applied, and is defined as the apparent viscosity of the samples.

5.4.2 Rheometers

Similar to the viscometer, the rheometer is also able to measure the dynamic viscosity of fluids with a relatively high viscosity. In this case, the food material is often placed between two parallel plates, but other geometries can also be used (e.g., cone/plate). The gap between the two plates can be adjusted. The upper plate is rotated with a certain shear rate, while the lower plate remains stationary. As for the viscometer, the dynamic (shear) viscosity can be obtained from measuring the torque as a function of the applied shear rate. For viscoelastic materials, the plates are not rotated, but a oscillatory movement is applied to induce a sinusoidal shear deformation. The plate imposes a time dependent strain as $\gamma(t)=\gamma\ \sin(\omega t)$, where ω is the frequency of the oscillation. The stress response at the frequencies reveals the nature of the material. For purely elastic materials, the stress is proportional to the strain deformation (in phase), but for purely viscous material, a shift in the phase angle ($\delta=\pi/2$) is observed. For viscoelastic material, the phase angle is $0<\delta<\pi/2$, which can be used to define both the viscous and the elastic contribution to the rheological behaviour of the sample. The viscous contribution can be described by the loss (viscous) modulus, G'', which can be deduced from the shift in the phase angle as

$$G''=\sigma/\gamma\ \sin\delta \tag{5.8}$$

and the elastic contribution can be described by the storage (elastic) modulus, G', which can be deduced from

$$G'=\sigma/\gamma\ \cos\delta \tag{5.9}$$

In general, when the storage modulus (solid-like behaviour) is higher than the loss modulus (liquid-like behaviour), the material is considered a gel. The viscoelastic behaviour of a material is generally expressed with the parameter tan δ, which is equal to G''/G'. As these moduli are determined using a shear deformation, they are also referred to as shear moduli.

5.4.3 Tribometers

Tribometers are devices to measure friction forces between two surfaces in motion. The material for which the lubrication properties are being investigated is applied between the surfaces so its effect on friction can be determined. Different configurations can be used: pin-on-plate, ball-on-plate and flat-on-plate. The two elements of a configuration rotate or move at a specific speed, and the ratio between these speeds determines the entrainment speed of the lubricant into the contact zone between the surfaces. In the mentioned configurations, the pin, ball or flat are loaded onto the plate with a precisely known force. In a mini traction machine (MTM) the friction coefficient between a steel ball and a steel plate submerged in a lubricant moving at different speeds is measured (Figure 5.6a) (Chojnicka-Paszun, 2009). The geometry can be modified to allow the study of friction on compliant surfaces (Figure 5.6b). The steel ball can, for example, be replaced by a pin with a rubber O-ring, and rubber discs can be glued on top of the steel plate. These modifications lead to a decrease of the contact pressure between rubbing surfaces from GPa to kPa, allowing to perform measurements with pressures comparable to those present in the mouth.

Human mouth environment can also be mimicked in the optical tribological configuration setup, where specimens of rubber or pig oral tissue are rubbed against a glass plate under oscillatory movements (Dresselhuis et al., 2007).

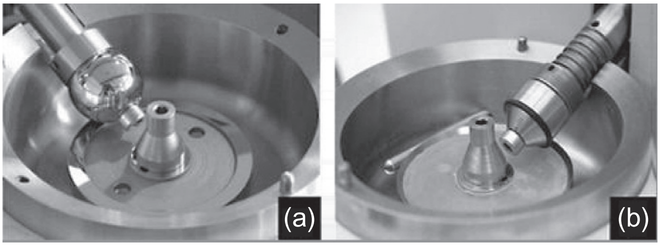

Figure 5.6 Measurement chamber with two rubbing surfaces for original MTM (a) and for modified setup used to simulate the oral environment (b).
Reproduced with permission from Chojnicka-Paszun (2009).

5.4.4 Light scattering

The particle size of spherical particles or agglomerates is usually measured with light scattering techniques, although also other techniques such as nuclear magnetic resonance could be used. The most common light scattering techniques are dynamic light scattering (DLS) and laser diffraction (LD). DLS makes use of the Brownian motion of the particles to calculate the particles size. By analysing the intensity of scattered light as a function of time, the diffusion coefficient is related to the particle size distribution (range of 0.002–2 μm). LD uses the fact that particles of different size scatter light at different angles, and from the light intensity, the particle size distribution is measured using the Mie theory (range of 100 nm–1 mm). The particle size can be expressed as a volume mean ($D_{4,3}$) or as a surface mean ($D_{3,2}$).

5.5 Mouthfeel: relating sensory attributes to physical parameters of food

5.5.1 Choice of instrumental techniques and measuring conditions

In order to exhaustively and correctly relate instrumental parameters to sensory attributes, several requirements should be fulfilled:

1. Relevant instrumental techniques and appropriate measuring conditions should be chosen.
2. The initial product structure should be known in order to explain the results of the instrumental measurements.
3. Changes occurring during oral processing (aggregation of particles as a result of interaction between food components and compounds present in the oral cavity, coalescence of droplets, formation of film on surfaces of the oral cavity, breakdown of ingredients sensitive to salivary enzymes, etc.) should be taken into consideration and consequent adjustments of the measuring techniques should be implemented.
4. Possible interactions between taste and odour components and perception of textural attributes should be investigated to explain the observed correlations.

The texture perceived by the consumer is the result of various textural characteristics of a food product and of their interactions. The literature mainly describes thickness and lubrication as relevant textural properties of fluid food, and most of the studies focussing on the link between sensory perception and instrumental measurements deal with these properties. The mouthfeel of fluid foods is affected by their inherent flow behaviour and the flow induced by movement of the tongue against the palate or other mouth surfaces. Furthermore, the structural elements of these foods will interact with the saliva, and this might affect the original flow behaviour. Interactions with oral surfaces will affect the friction between tongue and palate, and will also be responsible for after-feel sensations. Consequently, to investigate the link between product characteristics and sensory perception, consideration should be made not only of the rheology and lubrication behaviour of the products, but also their adhesion to oral surfaces, the interaction between foods and large charged macromolecules and the formation of coatings (van Vliet et al., 2009). The fact that certain textural sensory attributes are correlated with one another can represent a complicating factor, but can at the same time be exploited for the investigation of attributes with particular complexity.

When looking for mechanistic relations between instrumentally measured and sensory assessed thickness, the choice of the experimental set-up can largely affect the obtained results. Van Vliet (2002) extensively commented on the fact that while most researchers implicitly assume that the main type of deformation in the mouth during oral processing is shear flow, in reality elongational flow plays an important role, and that the flow will be intermittent over longer times. Squeezing flow between parallel plates, which corresponds to biaxial extensional deformation for lubricated plates, can be used to characterize the compression between tongue and palate of foods with yield stress larger than 50 Pa. Actually, the exact character of the elongational flow component in the mouth has not been unveiled yet. According to van Vliet, it will vary for different food products, just as the balance between shear flow and elongational flow (van Vliet, 2002). This makes the task of choosing relevant experimental conditions for the measurements of viscosity quite difficult. The difference between shear flow and elongational flow is that in the first case the velocity gradient (shear rate) is perpendicular to the direction of flow, while in the second one the velocity gradient (elongational strain rate) is in the same direction of flow. For Newtonian fluids (e.g., milk), the ratio of the elongational viscosity over the shear viscosity is three, but for non-Newtonian foods (e.g., yoghurt, custards) the ratio is substantially higher and will vary with product composition. The residence time of fluid foods in the mouth is usually of the order of seconds. For non-Newtonian food products, viscosity should be measured over times similar to the average residence time in the mouth. For these foods, every handling of a product before the loading in the mouth or an instrument will affect the viscosity/thickness observed (van Vliet, 2002).

Many studies have attempted to determine the shear rates occurring during oral processing between the tongue and the palate. It seems that the shear rate applied during oral processing varies between 1 and 1000 s^{-1}, depending on the flow behaviour of the specific food (Malone et al., 2003). The most common shear rate appeared to be around 50 s^{-1} (Cutler et al., 1983; Dickie and Kokini, 1983; Shama and Sherman,

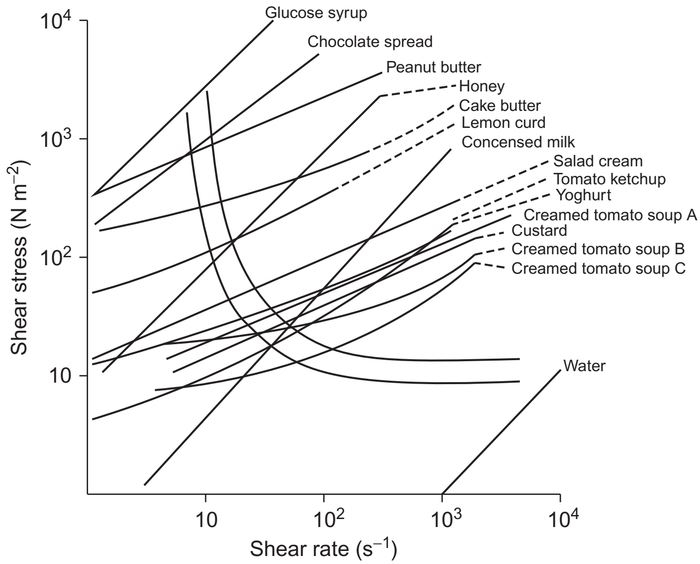

Figure 5.7 Shear stress–shear rate bounds in which fluid foods are likely to be orally evaluated. Reproduced with permission from Shama and Sherman (1973).

1973; Stanley and Taylor, 1993). Assuming that the oral evaluation of viscosity was purely linked to the shear stress brought about in the mouth by oral processing deformation, Shama and Sherman (1973) provided the shear stress–shear rate bounds in which fluid foods are likely to be orally evaluated (Figure 5.7).

According to these authors, the sensory evaluation of viscosity does not occur at a constant shear rate, but the effective shear rate applied in the mouth of the consumer strongly depends on the viscosity of the product. Low-viscosity liquids (viscosity roughly below 0.1 Pa s) are evaluated at a constant shear stress of about 10 Pa, while products with a viscosity above 10 Pa s are evaluated at a constant shear rate of 10 s^{-1}. This means that for thin fluids the oral evaluation of viscosity is likely based on the ease with which the material flows between the upper surface of the tongue and the palate. For thicker products, probably the stress required to produce significant flow in the mouth is used as assessment criterion. These findings are of paramount importance for establishing the experimental conditions applied for the instrumental characterisation of textural attributes related to viscosity.

The conditions required to link tribological measurements to sensory attributes have been recently the object of the attention of texture scientists. The boundary and mixed regime appear to dominate under the conditions observed during oral processing (Malone et al., 2003). The speeds at which tongue and palate move with respect to each other during oral processing were estimated to be in between 10 and 30 mm/s (de Wijk et al., 2006; De Wijk and Prinz, 2006; Malone et al., 2003).

Most of the surfaces in the oral cavity are soft, and upon application of a load the structures present on their outer part will deform, resulting in a modification of surface roughness. Tribological measurements are typically carried out with artificial materials that are also relatively hard. In a specific case in which pig's tongue and inside parts of pig's oesophagus were used, the friction coefficient between oral surfaces in the presence of food emulsions was found to decrease with increasing load, whereas it was constant for glass–metal surfaces (de Hoog et al., 2006). This also shows that the material with which the measurements are performed have to be taken into account. Also the effect of load on the contact area between surfaces is different for artificial materials used in tribometers and oral surfaces. For hard surfaces, the true contact area increases proportionally with the normal force, whereas for the tongue tissues a plateau is reached. As a result of this plateau formation, the coefficient of friction decreases with increasing normal force (de Hoog et al., 2006). The contact pressures applied in tribometers are in the order of GPa, whereas much lower values of about 30 kPa are typical for oral processing. Even variations in contact pressures can be observed in different parts of the tongue, which have been shown to be higher in the anterior part (19–36 kPa) and lower in the posterior part (11–24 kPa) (Heath, 2002; Prinz and Lucas, 1995). Measuring at too-high contact pressures would eliminate the effect of the characteristics of structural elements of foods, like the size and morphology of protein aggregates, on lubrication. Experimental conditions similar to those of oral processing indicated that larger aggregates give lower friction coefficients (Chojnicka et al., 2008). Furthermore, depending on the part of the tongue where a specific sensory attribute is sensed, different contact pressure can be used during tribological measurements to correlate sensory attributes to friction measurements.

The spreading of the food product on the surface of the materials used for tribological measurements will also affect the obtained friction coefficient. A dry tongue surface was observed to be relatively hydrophobic (Rohm, 1990), but the presence of saliva results in a more hydrophilic character (Bongaerts et al., 2007; Dresselhuis et al., 2008a; Ranc et al., 2006; van Aken et al., 2004).

5.5.2 Peculiarities of oral lubrication

There has been a lot of effort from texture scientists to explain the mechanisms relating food structure to lubrication properties. Knowledge of these mechanisms could be of importance in the investigation of the relation between lubrication properties and sensory perception. The composition of the food and the interactions between ingredients and compounds present in the oral cavity may affect lubrication properties to a large extent. Therefore, when relating sensory attributes to instrumental parameters the differences between the lubrication phenomena occurring in the mouth and the measuring conditions encountered in a relatively sterile environment like a tribometer should be kept in mind.

In protein-stabilized emulsions, the interactions between proteins present in the continuous phase, protein-covered droplets and the oral environment are shown to affect the perception or textural attributes related to lubrication. This effect seems to be particularly relevant for emulsions with low fat content. When emulsion droplets stabilised by protein get in contact with the oral mucosae, aggregation of the emulsion droplets occurs. This is due to interactions between the protein on the surface of the emulsion droplets and components of saliva present on oral tissues. This aggregation strongly affects the perception of the textural properties of the emulsions, mainly because of an increase of the effective viscosity of the emulsion in contact with the tongue, with consequent effects on lubrication between tongue and palate. When reversible aggregates are formed, like for emulsions stabilised by whey protein, a viscous coating is formed on the tongue, which positively affects the texture perception of the emulsions (experienced as velvety and creamy). However, when irreversible aggregates are formed, above all if they have a size larger than 10 μm and they precipitate on the oral surfaces, as in the case of emulsions stabilised by lysozyme, then the emulsions are perceived as dry, rough astringent (Dresselhuis et al., 2008c; Silletti et al., 2007a,b, 2008; van Aken et al., 2007; Vingerhoeds et al., 2005).

The retention of emulsion droplets and their coalescence on the surface of the tongue are phenomena with large effects on the perception of the textural properties of emulsions. Retention occurs because of adherence of the oil droplets on the viscous mucous layer at the tongue or entrapment between the papillae (Dresselhuis et al., 2008b,c). The presence of emulsion droplets on the tongue surface was visualised by confocal scanning laser microscopy. Retention of emulsion droplets seems to be higher for emulsions with a lower stability towards coalescence caused by a relatively low amount of protein adsorbed at the oil–water interface (Dresselhuis et al., 2008b,c) or by partial coalescence (Benjamins et al., 2009). Adherence of emulsion droplets on the tongue resulted in higher ratings for the attributes of thickness, creaminess and fattiness and lower ratings for roughness, dryness and astringency. The presence of coalesced emulsion droplets and of an oil layer on the tongue may cause a gradual transition from boundary lubrication to the mixed regime and the reduced boundary friction leads to a more smooth mouthfeel, which supports creaminess. The effect of the droplet size (size range 0.5–6 μm) on the perception of sensory attributes as thick, creamy and fatty was observed to be only minor for low-viscosity emulsions (Akhtar et al., 2005; Vingerhoeds et al., 2008). Nevertheless, droplet size will directly affect aggregation behaviour (Minor and Van Leeuwen, 2005), adhesion to oral surface, and coalescence stability (Walstra, 2005), with an indirect effect on sensory perception, as described above.

Also, other type of interactions between different ingredients in the dispersion may influence lubrication properties. For example, interaction between astringent compounds in foods (tannins) and especially proline-rich proteins in saliva decrease lubrication properties because of an increase in size due to their precipitation (Prinz and Lucas, 2000).

5.6 Pivotal studies on complex sensory attributes

In literature, several studies can be found in which specific textural properties of fluid foods were successfully linked to instrumental parameters. Complex textural properties such as creaminess and fattiness can be partially related to the apparent viscosity of the product (Akhtar et al., 2005; Kokini, 1987; Moore et al., 1998). From a conceptual point of view, this can be ascribed to the direct relation in dispersion rheology between fat content and viscosity. However, the sensory properties of emulsions cannot be fully explained by bulk rheology. Furthermore, even products without fat can be recognised as creamy, indicating that fat-related sensory attributes are not determined solely by the presence of fat.

Kokini and co-workers investigated complex sensory attributes for a large variety of liquid and semi-solid food products, like different kinds of syrup, honey and solutions of specific polysaccharides. They determined that some sensory attributes, such as thick, gummy, heavy, thin, light, sticky, slippery, creamy, slimy and smooth are dependently related. All the attributes were shown to be derivable from the subset thick, smooth and slippery, using the relation:

$$\log(\text{attribute } k) = \alpha_1 k \log(\text{thick}) + \alpha_2 k \log(\text{smooth}) + \alpha_3 k \log(\text{slippery}) \quad (5.10)$$

The three attributes thick, smooth and slippery were further related by Kokini to rheological properties. In order to do so, Kokini simplified the processes that occur in the mouth by assuming that liquid perception takes place largely between the tongue and the roof of the mouth, which were modelled as two parallel plates (Figure 5.8). Kokini assumed that the two plates were squeezed together by a normal force W, which was constant during each assessment, and that the two plates moved steadily and relatively to each other at velocity v.

Based on the assumption that thickness is sensorially assessed when there is enough liquid between the tongue and the roof of the mouth to prevent their contact, this textural attribute was estimated by Kokini to be proportional to the shear stress developed on the tongue. For Newtonian fluids, the stress is given by:

$$\sigma = \eta\dot{\gamma} \quad (5.11)$$

For this kind of system, based on the geometry depicted in Figure 5.8, the thickness can be approximated by:

$$\text{Thickness} \propto \eta^{1/2} W^{1/2} v \left(\frac{4t}{3\pi R^4}\right)^{1/2} \quad (5.12)$$

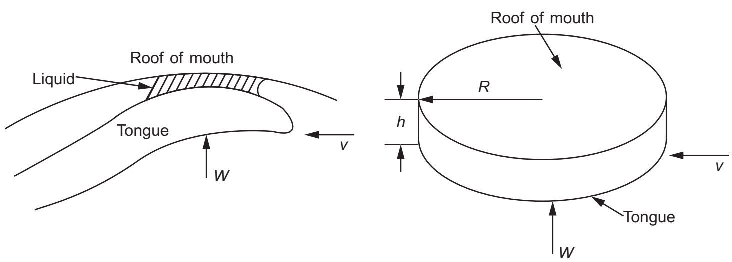

Figure 5.8 A model geometry of the mouth (v is the velocity with which the tongue moves from left to right; W is the normal force; h is the distance between tongue and the roof of the mouth.
Reproduced with permission from Dickie and Kokini (1983, slightly modified).

W, V and R are defined in Figure 5.8, and t is the time it takes to evaluate the thickness of a material. For non-Newtonian fluids, the stress is given by:

$$\sigma = \eta\dot{\gamma}^n \tag{5.13}$$

The resulting expression for thickness is:

$$\text{Thickness} \propto \eta v^n \left[\frac{1}{h_0^{(n+1)/n}} + \left(\frac{W(n+3)}{2\pi\eta R^{n+3}} \right)^{1/n} \frac{n+1}{2n+1} t \right]^{n^2/(n+1)} \tag{5.14}$$

Here h_0 is the initial height of the liquid at time $t=0$.

The attribute smoothness was related by Kokini to the boundary friction force between tongue and roof of the mouth. For this attribute, it was assumed that the sensorial assessment occurs when the liquid between the tongue and the roof of the mouth is reduced to a layer adsorbed to the tongue and the roof of the mouth. The proposed relationship between the smoothness and friction is:

$$\text{Smoothness} \propto \frac{1}{\mu W} \tag{5.15}$$

where, μ is the friction coefficient. Concerning the perception of slipperiness, Kokini and co-workers proposed that it results from the combination of both contributions of viscous and frictional forces. The oral assessment of slipperiness would take place when the liquid layer on the tongue is thinner than for the attribute thickness and thicker than for the attribute smoothness. The proposed relation is:

$$\begin{aligned} \text{Slipperiness} &\propto (\text{viscous force} + \text{friction force})^{-1} \\ &\propto \frac{1}{\eta (v/h_s)^n \pi R^2 + \mu W} \end{aligned} \tag{5.16}$$

Here h_s represents the average height of the asperities of the surface of the tongue.

Although the theory of Kokini was already developed in the 1980s, it is still regarded as a successful example of explanation of complex textural attributes in terms of instrumental parameters.

5.7 Modifying food: using ingredient interaction to control sensory perception

5.7.1 Fat replacers

Although already investigated for many years, it is still a great challenge to decrease the fat content while maintaining the original sensorial perception of fluid foods. Creaminess is especially difficult to mimic, as it is a combination of several sensory attributes such as thickness, mouthcoating, lubrication, smoothness and/or dairy flavour (Flett et al., 2010). Thickness may easily be changed by increasing or decreasing the concentration of viscosity enhancing ingredients, but lubrication related attributes are more difficult to mimic. Additionally, products often contain a lot of aromas (hydrophobic flavours) that are included in the fat, which contributes to the specific fatty perception. Removing fat would also remove these flavours, which would further alter the sensorial profile of the food. Therefore, fat replacement requires strategies to mimic a range of attributes at the same time. Depending on the type of the food, different fat replacers might be used. Different types of fat replacers have been developed in the last years (Akoh, 1998). In general, the following classes of fat replacers can be found:

- Lipid-based
- Protein-based
- Carbohydrate-based
- Fibre-based

Lipid-based substitutes are often referred to as fat substitutes and are made either from synthetic fatty acids or emulsifiers (esters). Examples of fat replacers in this category are Olestra (Olean®), a sucrose polyester, different sucrose fatty acid esters, polyol fatty acids esters, such as sorbitol and trehalose, or sorbitol polyesters, such as sorbestrin. The advantage of these fat replacers is that their nature is mainly hydrophobic, which may increase the lubrication properties and the ability to hold hydrophobic flavours. However, as some of them are indigestible, they may cause problems such as abdominal cramping. Protein-based fat replacers are referred to as fat mimetics, and are more hydrophilic than hydrophobic. Contrary to fat, these fat replacers absorb a lot of water and do not hold hydrophobic flavour molecules. Therefore, they may be able to replace some of the textural attributes of fat, but will not mimic a fatty flavour profile. Protein-based fat replacers can be made from different sources, including eggs, milk, whey, soy, gelatin or gluten, and they are often prepared through micro-particulation to obtain spherical particles with a certain size. Protein-based fat mimetics are often used in dairy products or salad dressings. Examples are Simplesse® and Dairy-Lo®, which are whey-protein-derived fat replacers, or Lita®, derived from corn gluten.

The category of carbohydrates is a much larger class of fat replacers. Many of these fat replacers are made from different polysaccharide sources, such as pectin, carrageenan, xanthan, locust bean gum and gum arabic. Similarly to proteins, these gums are also of hydrophilic origin and absorb large amounts of water (therefore classified as a fat mimetic). As their viscosity and the change in viscosity upon consumption (shear thinning behaviour) depends on their water absorption capacity, their molecular weight and network formation of the polysaccharide chains, the different gums will have different ability to mimic certain fat characteristics. In this category, we also find fat replacers as dextrins, maltodextrins and cellulose, all widely available under different brand names, such as Avicel®, Methocel®, MALTRIN®, Crystalean® and Lycadex®.

The last category refers to the fibre-based fat replacers, such as Inulin, Nu-Trim, Z-Trim and Oatrim. These fibres are extracted from different sources such as chicory, oat, barley, soybean, pea, rice hulls and a variety of fruits. Often, these fibres can be obtained in a digestible (soluble) and non-digestible (non-soluble) version and their size may be much larger than the ones of the other three categories.

The effect of fat replacers on textural properties varies in different foods. This means that the approach to characterise the texture of foods containing fat replacers should be modulated not only according to the type of fat replacer type, but to the kind of food.

5.7.2 Relevant interactions

As the functionality of fat depends on the type of product, there is no ultimate fat replacer that can compensate for the loss of fat. In the case of fluid foods, fat affects attributes such as thickness, creaminess and mouthcoating. Therefore, in these types of fluid foods the fat replacers need to fulfil the function of a thickener and a lubricant. However, how all these sensory attributes for the different types of fluid foods are related to the properties of the fluid, such as viscosity, friction and lubrication is not exactly known. The efficiency of the fat replacer depends largely on the type of the fat replacer and the interactions with the food matrix. For example, when proteins are used as a fat replacer in yoghurt, not only the size of the particles, but also the interactions with the matrix play an important role (Torres et al., 2011). When larger protein microparticles were used and incorporated into the network of the dairy product, the samples were perceived as less grainy than in the case of smaller particles that were not incorporated into the network. Therefore, the surface reactivity of such fat replacers is also of importance, as are the nature and the mechanical properties of particles used as fat replacers. Krzeminski et al. (2014) investigated the effect of aggregates consisting only of protein and of protein-polysaccharide aggregates in fat-reduced yoghurt. When whey protein aggregation was modulated to form protein particles, an increase in the gritty or grainy feeling was observed. However, when the proteins formed complexes with a polysaccharide (in the specific case, pectin), the graininess of the sample was reduced and a more creamy feeling was observed. In both cases, the viscosity of the sample was equal, indicating that viscosity alone is not related to the perception of creamy. The fact that viscosity cannot be directly related to the sensory attributes related to fat was also observed by Flett and co-workers (Flett et al., 2010). They investigated four types of beverages in which they used aggregates of casein micelles and κ-carrageenan with different sizes. Although the addition of these aggregates increased both the viscosity and the sense of creaminess, these beverages scored low for attributes as mouthcoating, which were observed in high-fat samples.

Also in the case of fibres, the interactions with the matrix play a large role. When inulin is used as a fat replacer, the viscosity can increase to a large extent as this ingredient has a large capacity to absorb water. In milk, the addition of inulin particles led to an increase in the perception of creaminess (Meyer et al., 2011). However, when used in starch-based systems such as sauces, inulin led to a change in the structure of the system from a starch-continuous to a inulin-continuous system, which lowered the viscosity (Guardeno et al., 2012). Even though the viscosity changed, no differences were observed in the sensory perception. The use of inulin as a fat replacer is thus very dependent on the composition of the system, and on the type of carbohydrates present.

Although a lot of research has been carried out in the field of designing fat replacers and understanding the relation between sensory attributes and food properties, a complete overview of the functionality of fat in fluid-like systems is still missing. Even though we are able to experimentally measure some properties, such as viscosity and lubrication, the obtained parameters often do not provide enough information to identify the characteristics a fat replacer should present. With this regard, next to knowledge on rheological and tribological properties, also information on flavour release and physiological attributes, such as receptor acceptance, would be required. In the search for the ideal fat replacer, new techniques and a wider range of scientific disciplines may be necessary.

5.8 Future challenges

The determination of the rheological and mechanical properties of foods by means of classical techniques is still an important task in the study of texture, as our knowledge on the structure and behaviour of foods advances. Nevertheless, in order to be able to link instrumentally measured material properties to sensory perception, relevant techniques and measuring conditions must be applied. To be able to do this, the dynamic processes occurring in the mouth should be better understood. This may require the use of multiple techniques, such as rheology, tribology, microscopy, magnetic resonance imaging and articulography.

Articulography, for example, allows us to spatially monitor and to resolve in time the movements of oral anatomic structures and surfaces during processing of foods. The application of this technique in the study of consumption of different kinds of foods will deliver important information on the deformation regimes occurring in the mouth, and on the applied tongue speeds and loads (Blissett et al., 2007). This will allow us to better tune the measurements of the instrumental properties of different kinds of foods within studies on specific textural attributes and will likely lead to the development of new measuring techniques and new combinations of existing techniques.

The continuous creation of products with innovative texture will demand the development of instrumental techniques suitable to catch textural features different from those that can be linked to viscosity or lubrication. An example of textural features that still need to be well characterised is the effect of air bubbles on sensory perception. Since aerated foods recall light and creamy sensations, but also within the context of strategies for the development of low-fat foods, the industry is applying a lot of effort in the production of aerated foods. Even though air bubbles affect the viscosity and the lubrication properties of the systems in which they are present, these two kinds of textural parameters do not exhaustively describe the effect of air bubbles on sensory perception. Techniques to instrumentally measure the effect of bubbles popping on sensory perception should be developed and will likely be included in the textural characterisation of aerated foods.

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Part Two

Modifying texture for specific consumer groups

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Texture-modified meals for hospital patients

6

J.A.Y. Cichero
University of Queensland, Brisbane, QLD, Australia

6.1 Introduction

All hospital patients need food and liquids that will fulfil their nutrition and hydration needs. Individuals with dysphagia are a special hospital population. They have unique needs for texture-modified foods that promote safe swallowing. 'Dysphagia' is a medical term that, at its most general, describes difficulty moving food, liquid, saliva and oral medication from the mouth to the stomach. 'Deglutition' is more expansive and describes the oral preparatory, oral, pharyngeal and oesophageal stages of swallowing (Kendall, 2008). Prevalence of dysphagia in acute care hospitals varies from 0.35% to 6.7% (Altman, 2011; Cichero et al., 2009). Differences in the prevalence rates are likely a result of data acquisition variation, with one study relying on hospital discharge coding, whilst the other identified patients using a screening tool on admission. Regardless, it is acknowledged that the prevalence of dysphagia is largely underestimated (Altman, 2011). Conservative estimates of annual hospital costs associated with dysphagia in the United States of America run to USD 547 million, with increased length of stay a noted finding (Cichero and Altman, 2012). Dysphagia is seen as a concomitant condition with neurological disorders (e.g., stroke, traumatic brain injury (TBI)), degenerative disorders (Parkinson's disease, Alzheimer's disease, Motor neurone disease), cancer (especially head and neck cancer and brain tumours) and a range of other conditions such as chronic obstructive pulmonary disease, burns and infectious diseases.

Johns et al. (2013, p. 46) describes hospital patients as 'unwilling customers... placed into an alien environment where meal times are imposed and choice of food is made well in advance of consumption'. Texture-modified foods are a diet of necessity, not a diet of choice. The two main reasons described in the literature for prescribing texture-modified foods are dysphagia (80%) and poor dental status (20%) (Wright et al., 2005). Individuals on texture-modified foods are frequently malnourished, and the reasons for this are complex, taking in nutrient dilution in the texture modification process through to transport and serving issues. This chapter will cover the needs and demands of hospital patients with dysphagia. It will address the eating risks and hazards of this population and the criteria of food supplied to individuals with dysphagia. The relevant texture classifications of foods supplied to this fragile population will be discussed along with international variations in the terminology of texture-modified food. Although it is acknowledged that dysphagia affects an individual's ability to safely swallow fluids, saliva and oral medications, this chapter will focus purely on food.

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6.2 Needs and demands of hospitalised patients with dysphagia

Individuals with dysphagia have difficulties associated with swallowing safety and/or swallowing efficiency (Cabre et al., 2010). Swallowing safety refers to the ability to orally process and then propel food, liquids, saliva or oral medications to the stomach, whilst simultaneously avoiding the airway. Dealing specifically with food, inadequate oral preparation increases risks associated with asphyxiation and choking. Unlike aspiration risks associated with liquids, choking on food is often sudden and can have fatal consequences.

Swallowing efficiency refers to timely preparation and swallowing of foods, and sufficient intake of food. Fatigue due to hemi-paresis associated with stroke, or even partial dentition can reduce chewing efficiency. Food that is inadequately chewed increases choking risks (Okamoto et al., 2012). Poor chewing efficiency may limit the amount of food consumed, thereby increasing the risk of malnutrition. Increased susceptibility to infection is a common consequence of malnutrition. The body's nutritional needs become higher again when dealing with infection. Food texture is modified for individuals with dysphagia to address the dual issues of swallowing safety and efficiency.

6.2.1 Swallowing safety: dysphagia and the bolus

In order to trigger a swallow reflex, the bolus needs to be moist and cohesive. Various authors have demonstrated that for healthy people, whilst there is individual variation in the number of chewing strokes to prepare a given food bolus for swallowing, the final 'swallow-ready' or 'swallow-safe' bolus has very homogenous characteristics (Prinz and Lucas, 1995; Mishellany et al., 2006; Loret et al., 2011; Peyron et al., 2011). Swallow-safe particles are small, averaging 1.4–2 mm each. This particle size threshold helps to avoid injury to the pharynx or oesophagus (Foster et al., 2011). Larger particles of food need to be soft enough to be swallowed whole (e.g., banana). Chewed particles are bound together by saliva with the swallow-ready bolus having a moisture content of about 50% (Loret et al., 2011). A combination of bolus cohesion and bolus pressure provides input to oral sensory receptors that the bolus is ready to be swallowed. Unlike liquids, solid foods are chewed and progressively moved to the posterior of the oral cavity and specifically the valleculae, prior to swallow reflex initiation (Dua et al., 1997; Saitoh et al., 2007). When sufficient material has been accumulated, a swallow reflex is generated. Material that dwells in the valleculae for longer than six seconds is seen to increase risks associated with accidentally inhaling material into the airway (Morton et al., 2002).

Individuals with dysphagia have varied requirements of the food bolus depending on their level of impairment and their stage of recovery or deterioration. Both sensory and motor impairments can affect oral preparation of a bolus. For example, following a stroke, individuals may have oral hemiplegia affecting their ability to contain and control the bolus. Their motor coordination may make it difficult to adequately reduce the particle size of the bolus to a 'swallow-safe' state and then safely move it to the posterior of the oral cavity for swallowing. Large pieces of poorly masticated food can become caught in the cheeks, adhere to the hard palate, become lodged in the airway or stuck in the oesophagus. Individuals with fewer than 13 remaining teeth have double the risk of dysphagia. Food textures are modified to be soft and then physically altered by chopping, mincing or pureeing to accommodate these needs. Although reduction in particle size and food softness is important, they are not the only parameters that require modification. Bolus moisture is critical to allow the swallow reflex to be activated. Individuals with complaints of oral dryness have an odds ratio of 2.16 for swallowing problems, meaning that they have double the risk of swallowing difficulties compared to those people without oral dryness (Okamoto et al., 2012). Texture-modified foods must be moist. Sauces and gravies are often added to help achieve this characteristic.

Sensory impairments may also occur post stroke, resulting in individuals being *unaware* of food pocketed in the cheeks (buccal cavity). Individuals with dementia may become distracted during eating or they may be impulsive, stuffing the mouth and inadequately chewing food before attempting to swallow it. These scenarios could result in damage to the pharynx or oesophagus and also pose a choking risk. Texture-modified foods are graded and provided depending on the level of oral preparatory impairment. There is a delicate balance between providing food textures that do not pose a choking risk, and allowing a diet of recognisable and 'normal' food textures.

Whilst oral phase impairments are a logical place to start when examining texture-modified foods, individuals with pharyngeal phase dysfunction may also benefit from altered food consistencies. Poor pharyngeal constriction to clear the tail of the bolus allows residue to remain in the pharynx post swallow. Very thick boluses require high tongue driving force and increased pharyngeal pressure to effectively clear the bolus from the pharynx (Raut et al., 2001). Residue remaining in the pharynx has an increased likelihood of being aspirated after the swallow, once the airway is reopened. Perlman et al. (2004) noted that dysphagic patients with impaired pharyngeal contraction were more at risk of aspirating pureed food than individuals with normal pharyngeal contractions. Impairment of pharyngeal function may arise post stroke, following head and neck surgery and for individuals with Motor neurone disease. Thin pureed textures may better suit the dual purpose of improving swallowing safety whilst minimising pharyngeal residue.

The oesophageal phase of swallowing may be affected by inadequate mastication and/or moistening of the food bolus. Dry foods such as meat and bread have been noted to cause oesophageal impaction resulting in pain, discomfort and heartburn. For some, the pain is sufficient enough to require emergency hospital admission (Lee and Anderson, 2005). The impacted material must be cleared in order for other food and liquids to reach the stomach. Emergency medical treatment includes the use of acidic effervescent drinks (e.g., Coca-Cola), and proteolytic enzymes (pineapple juice, papain) or endoscopic removal of the impacted bolus. Oesophageal impairments have also been implicated in near-fatal choking episodes (Ekberg and Feinberg, 1992).

6.2.2 Swallowing efficiency: dysphagia and nutrition needs

For some individuals with dysphagia, swallowing safety is managed at the cost of swallowing efficiency. The time and effort taken to consume a meal safely means that insufficient food is consumed to meet nutritional needs. A combination of approaches is used to manage this population. Using one approach, individuals who fatigue quickly while chewing and manipulating regular textured food may be provided with soft, chopped or minced foods. For individuals with very severe oral phase impairments, including poor tongue control, a pureed food texture may be prescribed. Hotaling (1992) reported that in long-term care, 15–20% of residents receive pureed food. Unfortunately the very process of pureeing food reduces the nutrient density of the product due to the addition of liquid in order that the food particles do not bind tightly to each other (Hotaling, 1992). In order to meet nutritional requirements, greater volumes of the energy-diluted food must be consumed. Recent studies demonstrate that hospitalised individuals requiring texture-modified foods have protein and energy intake levels 34–37% lower than those consuming a regular diet, placing them at risk of malnutrition (Wright et al., 2005).

Alternatively, it may be possible for individuals to continue to eat regular textured or soft-textured foods and supplement this with oral nutritional supplements to meet energy needs (Dunne and Dahl, 2007). However, the literature shows that some individuals actually reduce the amount of solid food taken in order to consume all of the oral nutritional supplements. Certainly thicker liquids and pudding-level consistency have been found to produce heightened feelings of satiety compared with thin liquids of the same energy content, energy density, volume and macronutrient composition (Zijlstra et al., 2008). The science behind the provision of oral nutritional supplements is also not convincing for long-term use, and particularly for those who are already malnourished (Dunne and Dahl, 2007). Focus needs to stay firmly on texture-modified foods.

6.2.3 Increased nutrition needs of specific populations

Dysphagia is an important risk factor for malnutrition. Following acute stroke, the prevalence of malnutrition rises from 16% on admission to 22–35% within the first two weeks (Finestone and Greene-Finestone, 2003). In a systematic review of the literature Foley et al. (2009) demonstrated that the odds of being malnourished were double for those with dysphagia post stroke compared to those without dysphagia. Due to the nature of certain other conditions, nutrient requirements may be exceptionally high. The ability to meet these needs using texture-modified foods is often a challenge.

Following TBI, approximately 61% of people present with dysphagia, wherein both swallowing safety and efficiency are affected (Cook et al., 2008). Fluctuating levels of consciousness in the early stages post TBI, and impulsivity with poor self-regulation for feeding during recovery, increase risks associated with swallowing safety. The events of TBI not only cause trauma to the body but also affect the brain's ability to maintain homeostasis. As a result, the body's metabolic needs increase.

These increased metabolic needs cause the body to break down skeletal muscle to use stored protein for fuel, risking losses of up to 1000 g of muscle per day (hypercatabolism) (Pepe and Barba, 1999). Together, these elements mean that the calorie and protein needs of patients with TBI can be double that of normal predicted levels (Pepe and Barba, 1999). An impaired swallowing system reduces the likelihood that the person will consume sufficient foods orally and increases the likelihood that material may enter the airway.

Burns patients are another group that present with high nutritional needs due to hyperrmetabolism and hypercatabolism (Prelack et al., 2007). Burns affecting the face and neck may result in impairment of the oral and pharyngeal phases of swallowing (Rumbach et al., 2011). McKinnon DuBose et al. (2005) found that 35% of patients with burn injuries required a texture-modified diet, whilst Ward et al. (2001) found that that on discharge only 3% of patients in their cohort required pureed foods and 6% needed soft food consistencies. Like the TBI population, the burns group requires texture-modified foods to manage swallowing safety and efficiency needs. Whilst these two groups are easy to identify, care must also be taken to meet the nutritional needs of less obvious groups, such as the frail elderly.

The natural ageing process contributes to a reduction in food intake. Changes to the senses of taste and smell, a natural reduction in hunger drive and psychological variables such as depression are associated with decreased food intake in the elderly (Kinney, 2004). Kinney (2004) reports that up to 50% of elderly hospitalised patients are malnourished. Protein energy malnutrition (PEM) is defined as an unintentional loss of 10% or more of body weight in a period of six months or less and/or serum albumin levels of less than 3.5 grams per decilitre (g/dl) (Hudson et al., 2000). When muscle is broken down and used as a fuel source, the muscle mass deteriorates and muscle remaining becomes weak. Malnutrition, therefore, starts to disassemble the muscle platform required for safe and efficient swallowing.

6.3 Eating risks and hazards of dysphagia patients

Eating risks and hazards for dysphagia patients fall into four primary groups: (a) patient-specific, (b) staff communication, (c) food texture and (d) food temperature.

6.3.1 Patient-specific hazards and eating risks

Patient-specific hazards can come about due to dental issues, oral motor deficits and impairments of sensation or cognition. Safe and efficient oral preparation of food requires a sophisticated system. Good dentition and strong masticatory muscles allow for safe and efficient breakdown of food particles. Absent teeth, ill-fitting dentures or dental disease are correlated on autopsy studies with sudden choking deaths (Berzlanovich et al., 2005; Wick et al., 2006). Okamoto et al. (2012) showed a dose-dependent relationship that fewer remaining teeth result in reduced bite force. Chen (2009) noted that bite force varies between ethnic groups and also as a factor of gender. Furthermore, individuals with removable dentures produce a coarser bolus than people with intact dentition, and achieve only 25% of the chewing effectiveness of dentate individuals (Okamoto et al., 2012; Pereira et al., 2006). Using a cohort study Berreton-Felix et al. (2009) demonstrated that the use of fixed-implant-supported mandibular prostheses resulted in improved masticatory efficiency, better bite force and thus fewer episodes of coughing and choking.

As previously noted, saliva is required to lubricate the bolus, and bind chewed particles together to form a cohesive bolus. In addition to infusing liquid into the bolus to make it moist, the mucins in saliva help to give to the bolus a slippery quality, which enhances bolus transport over oral and pharyngeal structures (Chen, 2009). Furthermore, tastants dissolve in saliva, enhancing taste perception. Saliva also has a role in equalising temperature of foods and liquids within the oral cavity. In a study that clearly demonstrated the effect of xerostomia on chewing and swallowing, Liedberg and Owall (1991) showed that a chemically induced lack of saliva in otherwise healthy individuals caused a lack of perception of food particles within the oral cavity, resulting in difficulty collecting the bolus to achieve a mass and initiating a swallow reflex. The provision of almonds to the chemically induced dry mouth environment further exacerbated difficulties with particle collection and transport to the pharynx. Liedberg and Owall (1991) noted that hydrophilic foods that particulate, such as biscuits and nuts, are likely to be particularly problematic for people with dry mouth conditions. Individuals with conditions that are associated with dry mouth (e.g., Sjogren's disease, multiple medications) may find dry food textures particularly challenging. Individuals with a diagnosis of diabetes mellitus commonly present with reduced saliva secretion and altered saliva composition. Okamoto (2012) noted that these individuals had one and a half times greater risk of swallowing problems compared to those without diabetes.

Muscle weakness and poor muscle coordination are features of oral phase dysphagia for a number of patient populations including stroke, TBI, many neurological disorders (motor neurone disease), degenerative diseases (Parkinson's disease, the dementias), and head and neck cancer patients. Conditions that impact the actual muscle strength (paralysis), the presence or absence of the muscle (surgery), or neurological control of the muscle (cranial nerve impairment) will impact on oral motor efficiency. Clinically this is seen as lengthened oral transit time often for both food preparation and time to swallow reflex initiation (Mann, 2002). As noted above, reduced oral sensation, such as that which occurs with some strokes, reduces the person's awareness of food within the oral cavity. Although the gag reflex is designed to eject insufficiently chewed boluses or large objects from the oral cavity, more than a third of healthy individuals have an absent gag reflex (Davies et al., 1995).

Whilst physical units such as teeth, muscles and nerves are integral to safe swallowing, the sophisticated system is governed by higher order brain function. Cognitive skills relating to attention and concentration, motor planning, and judgment can affect self-selection of appropriate bite size, bolus types, and result in bolus cramming and an eating rate that is often too fast to be safe (Samuels and Chadwick, 2006; Feinberg, 1993; Mackay et al., 1999). These types of cognitive deficits are seen following TBI, in the intellectually impaired and also in the dementia population. In order to manage these deficits, food texture is often modified to softer textures and even minced consistencies that are less likely to cause mucosal injury or catastrophic results if ingested quickly. In conjunction with texture-modified foods, provision of supervision at meal times is often a requirement.

6.3.2 Staff communication hazards

As patients are moved from ward to ward, care must be taken to ensure that diet requirements are clearly communicated. Thankfully, computerisation in hospitals now means that a patient moving from a general ward to a stroke ward, for example, will have their diet needs follow them. Texture-modified diets are unique, however, in the list of 'inclusion' and 'exclusion' items that accompany a diet heading. For example, whilst soft sandwiches with very moist fillings may be suitable for individuals on a 'soft diet', individuals requiring a 'minced and moist diet' may only have gelled bread (Atherton et al., 2007). A change in employment will see staff move between hospitals. Staff need to be cognizant of the names of diets at each hospital and also the specific inclusion and exclusion items associated with these. Multiple labels for texture-modified food have been documented in both the USA and Australia. Prior to standardisation, in the USA 40 different names were used to label solid foods, whist in Australia 95 different labels were used to describe texture-modified foods (Atherton et al., 2007; National Dysphagia Diet Task Force, 2002).

Problems with multiple names for texture-modified foods and lack of understanding of the importance of food texture qualities for each level have been shown to have sobering ramifications. A coronial inquest in 1997 found that a change in the label and the description of food within the texture category contributed to the choking death of an elderly nursing home resident (Coronial Inquest, 1997). The resident's diet was changed from 'vitamised' (puree), due to improvement in swallow function, to 'soft' by the speech pathologist. However, the nurse altered the resident's care plan to show 'soft/normal' and explained that by this she meant the resident could have "soft (i.e., minced meat) and normal (i.e., mashed) vegetables". The resident died of asphyxiation after being provided with a tray containing an 'assorted sandwich'. In order to address issues such as these, national standardised terminology and definitions for texture-modified foods and thickened liquids have been produced in a number of countries, with efforts underway to produce an international system (Cichero et al., 2013).

6.3.3 Food texture hazards

Certain food textures pose a choking risk. It is well known that children younger than three years of age are at increased risk of choking and significant efforts have been put into determining the characteristics of items that are a choking hazard. Rigid, solid, bulky, round and cylindrical items and conforming items (e.g., balloons) have been identified (Rimell et al., 1995). Food-specific items include hard lollies, hot dogs, meat, nuts, seeds, vegetables and fruit pieces (e.g., grapes) (Rimell et al., 1995; Congiou et al., 2005). However, the death rate from asphyxiation on food in older adults (>65 years) is seven times higher than for children aged one to four years of age (Kramarow et al., 2014). Increasing age is also associated with increased risk of choking on food. In a study examining food-choking deaths between 2007 and 2010 in the USA, a positive relationship was found between choking on food and a diagnosis of Parkinson's disease, dementia and pneumonitis (Kramarow et al., 2014). Curiously, in older adults asphyxiation on food is often misdiagnosed as myocardial infarction (Kramarow et al., 2014).

Many of the foods noted to be a choking risk for children are also noted as choking risks for older adults. For example, meat, poultry, popcorn, nuts and hard candy are also noted as choking risk items for adults (Ekberg and Feinberg, 1992). Meat accounts for the highest number of food items noted at autopsy (Irwin et al., 1977; Ekberg and Feinberg, 1992; Berzlanovich et al., 1999, 2005). Meat is particularly difficult to manage for denture wearers. Denture wearers tend to have lower bite strength and poor chewing efficiency. Loss of the periodontal ligament when teeth are removed means a loss in the provision of important information from the sensory feedback loop to help alert the person to food that has been inadequately masticated. Studies are in agreement that the meat bolus prepared by denture wearers is poorly fragmented (Veyrune and Mioche, 2000; Yven et al., 2006). Although one study has shown that denture wearers impregnate the bolus with the same amount of saliva as dentate individuals, other studies have shown that denture wearers swallow a less lubricated bolus (Yven et al., 2006; Veyrune and Mioche, 2000). Yven et al. (2006) refer to a hypothesis put forward by Hutchings and Lilliford (1988) that there is a critical level of moisture content that deems a food suitable for swallowing. This may explain why large pieces of soft and presumably slippery foods (e.g., banana) have been identified in autopsy studies. Edentulous people have a significantly greater risk of choking to death on food than people who are fully or partially dentate (Berzlanovich et al., 2005).

Although meat is the most common food choking item, in the older population the additional food textures of dry foods (bread, toast, cracker, donut), semi-solid foods (cereal, puree, mashed banana) and 'complex textures' (sausage on a bun, sandwiches, meatballs, meat and vegetables/noodles) have also been found to cause asphyxiation (Ekberg and Feinberg, 1992; Irwin et al, 1977; Berzlanovich et al., 2005). Berzlanovich et al. (2005) documented the consistency of asphyxiated food materials. Of concern, 61% of elders (>65 years) choked on semi-solid foods (puree, ground meat, mashed fruit) and 35% of elders choked on complex food items (Berzlanovich et al., 2005). Table 6.1 summarises the foods and textures most commonly implicated in choking deaths or near-fatal choking deaths for the adult population.

6.3.4 Food temperature hazards

Provision of food in hospitals that is of an acceptable eating temperature is challenging. To comply with occupational health and safety regulations, food needs to be served cooler than 5 °C or maintained at 60 °C or hotter to avoid food spoiling or harbouring food-poisoning bacteria (Food Standards Australia New Zealand, 2008). Whilst these methods help to ensure that food poisoning can be minimised, food

Table 6.1 Foods and characteristics of foods most often associated with fatal or near-fatal choking episodes in adults

Study	Foods found on autopsy (food most often found noted at top of list for each study)
Irwin et al. (1977)	Cheese Lima beans Peas Semi-solid cereal Bread Orange
Ekberg and Feinberg (1992)	Solid 40% (meat, poultry) Complex bolus 14% (hamburger, hot dog, sandwich, meat and potato, meatballs and spaghetti, chicken soup, pizza) Small, hard solid (peanut, popcorn, hard candy) Dry (bread, toast, cracker, donut, breadstick) Semi-solid (mashed banana) Cooked egg, ground meat
Wick et al. (2006)	Meat Banana, bread, pasta Scrambled egg, peanut butter sandwich Potato chips Grape
Berzlanovich et al. (1999)	Unchewed meat Sausage Fruit, vegetables Bread Cookies, pastries Cheese, egg
Berzlanovich et al. (2005)	Meat, fish Sausage Bread, pizza, cookies, pastry Puree, ground meat, mashed fruits Fruit, vegetables Noodles Cheese, egg
Food Safety Commission Japan (2010)	Sticky rice cake Steamed rice Bread Meat, fish, fruit Candy Konjac mini-cup jelly
Food characteristics that pose a choking risk	
Hard or dry foods	Require moistening and particle size reduction for safe swallowing (e.g., nuts, raw vegetables, apple, crackling, hard crust rolls or bread, seeds)

Continued

Table 6.1 Continued

Study	**Foods found on autopsy (food most often found noted at top of list for each study)**
Chewy or sticky	Adhere to the mucosa (e.g., lollies, cheese chunks, fruit roll-ups, gummy lollies, marshmallow, chewing gum, sticky)
Crunchy or crumbly	Require moistening and ability to gather particles to a cohesive mass for safe swallowing (e.g., popcorn, toast, dry biscuits, chips/crisps, dry cake, biscuits)
Floppy	Food that can conform to the mucosa and stick to the airway if aspirated (e.g., lettuce, cucumber, uncooked baby spinach leaves)
Fibrous or 'tough'	Requires bite strength and masticatory endurance for effective particle size reduction (e.g., steak, pineapple)
Husks	Require significant masticatory skills for effective particle size reduction; are dry and difficult to incorporate into bolus (e.g., corn, bran, shredded wheat)
Stringy	Requires significant masticatory skills to break and deform string (e.g., beans, rhubarb)
Round or long shapes	Round or long shapes may fit into the trachea or supraglottic space and occlude the airway (e.g., whole grapes, sausages, hot dogs)
Complex food consistencies including 'mixed' or 'dual' consistencies	Foods containing multiple textures for oral mastication and manipulation. Textures may be dry (e.g., hamburger, sandwich, pizza) or with a solid and liquid composition (e.g., watermelon, soup, breakfast cereal with milk)

consumed at these temperatures appreciably increases the likelihood of burns to the tongue and roof of mouth. Burns occur in less than one second for temperatures over 60 °C. For patients who have had a stroke, for example, oral processing delays are common and food may remain in the mouth for 10 s or more, increasing the likelihood of intra-oral injury from steaming hot food (Mann, 2002).

Oral burns from food most often affect the tongue and hard palate. However, the condition is not considered serious as it heals without medical intervention relatively quickly. As a result there is very little information regarding its prevalence. Consider, however, that some elderly individuals require feeding assistance. They rely on the feeder to ensure that the temperature of the food offered is of an acceptable temperature. Due to oral control impairments, patients may also not be able to remove food from the oral cavity if it is too hot, further increasing potential risks associated with thermal burns. As noted earlier, saliva has a role in reducing the temperature of hot foods. However, dry mouth is a condition that frequently accompanies old age and certain medical conditions. Food temperature considerations are particularly relevant for soups, purees and sauces containing cream and cheese that retain heat. In addition, more viscous foods have a slower rate of cooling, and therefore a greater thermal capacity (Chiu et al., 2007). This combination of factors is important when considering food service and feeding dependent patients with dysphagia.

6.4 Criteria of food supply to dysphagia patients

Food supplied to patients with dysphagia must meet a number of criteria. Food needs to be of appropriate texture to meet their physical needs for swallowing safety. Elements arising from these relating to food particle size, moisture content and softness require consideration. Textures that minimise choking risks must also be considered. In addition, the food offered should be nutrient dense to avoid issues associated with inadvertent PEM. Patient compliance is likely to be better with texture-modified foods that provide robust flavour and that are visually appealing. Efforts should be made to achieve these criteria.

6.4.1 Food texture criteria

A range of mechanical food texture characteristics requires consideration when designing texture-modified foods for patients with dysphagia. Chen (2009) discusses the evolution of food texture studies and nomenclature noting the following to be relevant: hardness, cohesiveness, viscosity, elasticity, adhesion, brittleness, chewiness and guminess. Table 6.2 provides adjectives associated with each of these textural characteristics utilising terminology from the International Standards Organisation on Sensory Analysis document (ISO 11036). In addition to mechanical properties, attributes relating to geometry, moisture and fat content are also relevant.

For individuals with dysphagia, the degree of food-texture modification prescribed following assessment of chewing and swallowing function will determine the food texture qualities and its relevant food inclusions and exclusions. From the information gleaned above, the bolus needs to be soft enough for those who are unable to chew it adequately, cohesive for those who have trouble manipulating and forming a bolus, and moist enough to facilitate transport through the oral cavity, pharynx and oesophagus. For individuals with poor dentition, ill-fitting dentures or mildly reduced bite/chewing strength, food textures are mechanically altered to be soft (e.g., avocado, banana, casseroles with tender cuts of meat), and/or for pieces to be cut to bite-sized pieces. Individuals who are able to chew soft foods but fatigue quickly, those who take a long time to chew and manipulate a bolus and those with dry mouth may benefit from minced and moist consistency diets. These diets require food to be chopped, or minced and/or cooked till soft. Additional sauces and gravies are added to provide moisture to food. For individuals

Table 6.2 Food texture characteristics, definitions and adjectives to describe their features

Food texture characteristics	Definition	Adjectives used to describe the food characteristic
Hardness	Force required to give a deformation or penetration of a product. Perceived in the mouth by compressing solids between the teeth and semi-solids between the tongue and hard palate.	Soft, firm, hard
Cohesiveness	Degree to which a substance can be deformed before it breaks. In the mouth this would be the amount of compression that can be applied before the substance ruptures	Fracturability: crumbly, crunchy, brittle, crispy, crusty); chewiness (tender, chewy, tough); gumminess (short, mealy, pasty, gummy)
Viscosity	Resistance to flow; for example, force required to draw a liquid from a spoon over the tongue	Fluid, thin, viscous
Elasticity or Springiness	Degree to and how quickly a substance returns to original condition after a force is applied	Plastic, malleable, elastic, springy
Adhesiveness	Force required to remove material that adheres to the mouth. Related to surface properties of the food.	Sticky, tacky, gluey, gooey
Brittleness[a]	Force necessary to break a product into crumbs or pieces	Crumbly, crunchy, brittle, crispy, crusty
Chewiness[a]	Length of time or number of chews to prepare a solid food to be 'swallow-ready' (timing and force are standardised in the international standards)	Tender, chewy, tough
Gumminess[a]	Effort required to disintegrate a 'tender' product to a 'swallow-ready' state. For example, the tongue and palate are used to manipulate the sample	Short, mealy, pasty, gummy
Granularity	Geometric attribute relating to size and shape of particles in a product	Smooth, chalky, grainy, gritty, coarse, lumpy, beady
Conformation	Geometrical attribute relating to the shape and orientation of the particles in a product	Fibrous, cellular (e.g., egg white foam), crystalline, flaky, pulpy, puffy, aerated

Table 6.2 **Continued**

Food texture characteristics	Definition	Adjectives used to describe the food characteristic
Moisture content	Perception of water absorbed by or produced from the product	Dry (biscuit), moist (apple), wet (mussels), juicy (orange)
Fat content	Surface texture attribute relating to the perception of the quality or quantity of fat in a product. Total amount of fat, its melting point in the mouth and mouthcoating attributes are important to this parameter	Oily (soaking, running fat like salad dressing), greasy (bacon, chips); fatty (lard, tallow).

[a]Related to cohesiveness.
Adapted from ISO 11036.

with significant reductions or efficiencies in bite strength and chewing ability, significant oral stage manipulation difficulties, and/or an inability to form a cohesive bolus may be provided with a pureed diet. These diets are uniform in texture and without lumps. Importantly, pureed food should be moist and cohesive without having adhesive (sticky) qualities. Individuals with significantly impaired tongue strength or those with very dry mouth will have difficulty overcoming apparent yield stresses to propel a sticky bolus to the posterior of the oral cavity for swallow initiation. The texture classification of dysphagia diets is discussed in detail below.

In the published literature, food particle size is one of the most noted attributes of texture-modified diets in North America, Australia and the United Kingdom (UK) (National Dysphagia Diet Task Force, 2002; Atherton et al., 2007; National Patient Safety Agency, 2011). Particle sizes suitable for 'soft' diets are classified as those less than 2.5 cm in North America, and 1.5 cm in Australia and the UK. Pre-mashed or minced and moist diets have a reduction in particle size varying from 0.2 cm (UK) to 0.5 or 0.6 cm (Australia and USA respectively). The rationale for observance of food particle size relates to choking risk and mucosal injury, with smaller particle sizes perceived to present less risk if accidentally swallowed whole or with minimal chewing (Atherton et al., 2007). Some of the autopsy studies have specifically mentioned that although food items were soft, that the size of the item relative to the airway contributed to the fatality (Berzlanovich et al., 1999; Wick et al., 2006). In Japan, the features of hardness, cohesiveness and adhesiveness of the food textures are stipulated (Ministry of Health, Japan, 2009). In the Australian and UK guidelines these features are described but not formally measured. The North American National Dysphagia Diet provides a food texture measurement scale with food examples at either end of a continuum for characteristics relating to cohesion, adhesiveness, firmness, springiness, biteability, hardness and yield stress (National Dysphagia Diet Task Force, 2002, p. 4).

6.4.2 Nutrient density

Food for individuals with dysphagia must have an emphasis on nutrient density. Previously cited literature demonstrates that individuals on texture-modified diets are at risk of malnutrition (Dunne and Dahl, 2007). Serving small frequent meals, although often recommended for individuals with dysphagia, has not been shown to increase energy intake (Taylor and Barr, 2006). Germain et al. (2006) used a combination of nutrient-enriched foods (e.g., adding cream, butter), and reforming of pureed and minced textures so that the food resembled the original unmodified food (e.g., carrot, vegetables, meat, cake). The authors found an increase in energy intake that extended to macro and micronutrient benefits to patients. However, there appear to be some differences in the procedure for the control and experimental groups such that the experimental group appeared to have had more choices available to them. This factor may also have influenced the results. In their review of the literature around improving nutrient intake for elderly individuals, Dunne and Dahl (2007) concluded that initial studies on food fortification suggest benefits to improved vitamin and mineral content; however, the challenge was the provision of fortified foods with the same flavour profile as their non-fortified counterparts.

6.4.3 Flavoursome

Texture and flavour have been quoted as the most important features for palatability of food (Foster et al., 2011). To meet the needs of individuals with very severe oropharyngeal dysphagia, significant food texture modification is required. Pureed foods are smooth and homogenous in texture. Food flavour appreciation comes from both taste, as sensed intra-orally, and aroma arising from food odours. Food odours are transmitted to the brain both from the nose (orthonasally) and aerosols that arise during chewing travel from the posterior of the oral cavity, up behind the soft palate (retronasally), superiorly to the cribriform plate and then to the frontal cortex for initial processing (de Araujo et al., 2003). Foster et al. (2011) noted that hard-textured foods result in more vigorous chewing and that intense chewing released more flavour volatiles. A pureed food does not require chewing; in fact, it is designed to require minimal oral manipulation. Chewing is found to release flavour volatiles throughout the oral phase, whereas foods that require little chewing and more tongue-to-palate shearing produce retronasal flavour appreciation that occurs *after* the swallow (Foster et al., 2011). Therefore, the more texture-modified the food, the greater the challenge in ensuring the food is flavoursome and motivating for patients to consume. Henry et al. (2003) found that using strong natural Oriental food flavours increased the mean food intake and energy intake of hospitalised elderly patients by 13–26%. Flavours with the most significant positive effect were oyster sauce, ginger and garlic.

Auditory information also plays a part in texture and flavour perception. Foods with a higher pitched sound on biting are more often described as 'crisp' than 'crunchy'. Inability to hear sounds associated with chewing have been shown to affect the moisture content of chewed pretzels. In other studies, loud background noise has been found to dampen the taste of salty and sweet foods (Spence, 2012). Although the literature in this area pertains to young healthy individuals, older individuals with hearing loss may lose the ability to discriminate sounds that alert them to the comminution of food into a well-moistened bolus.

6.4.4 Visual appeal

It is commonly understood in restaurant culture that 'we eat with our eyes'. Foods that are discoloured or atypical are regarded with suspicion (Delwiche, 2012). Food that does not look appealing is unlikely to be eaten. In fact, flavour intensity is also linked to colour. One of the methods of determining fruit and vegetable ripeness or whether a food is cooked is by the intensity of its expected visual appearance (Delwiche, 2012). Furthermore, the presentation of food on a plate in terms of its neatness is also important. Food that has been presented neatly is more likely to be found to be appealing with expectations that it will taste better than messy food presentation (Zellner et al., 2011). Texture-modified food again presents a conundrum in regard to visual appeal. Pureed or mashed foods do not have the same visual variation in height or texture as regular textured foods. Figure 6.1 shows a normal textured meal. Note the variations in height and the different food textures from the rice to the tempe to the meat moulded onto the lemongrass stalks. Pureed foods produced en masse are often presented side by side, akin to ice cream scoop balls on a plate, as seen in Figure 6.2. Without visual cues, a 'white scoop of puree' could be pureed potato or cauliflower; and 'orange scoops' could be pumpkin, carrot or sweet potato. Whilst restaurant connoisseurs might be excited by the prospect of being served the visual illusion of a 'fried egg' where the 'egg yolk' is mango puree and the 'egg white' is panna cotta (Delwiche, 2012), the hospital patient who requires a texture-modified diet would prefer to be able to identify their food. It is possible that creative serving and plating techniques from fields such as molecular gastronomy, including foaming, piping and gelling, could improve the visual appearance of texture-modified food. In fact, new Freeze-Thaw-Impregnate (FTI) patented technology from Japan (Hamamatsu City Rehabilitation Hospital and Hiroshima Prefectural Technology Research Institute, personal communication) allows for food to retain its typical structure, with impregnated enzymes and heating resulting in the internal structure softening to the point where the food melts in the mouth. Figure 6.3 shows visually appealing 'pureed' salmon and scallop sushi. Flavour, colour and nutrient density are all retained using FTI technology.

The time taken to create visually appealing meals is often a challenge in the delivery of 'institutional food'. 'Institutional food' is described as bland in taste, texture and temperature, with food delivered at times that are often not convenient for the recipient (Johns et al., 2013). Johns et al. (2013) investigated reasons why two institutionalised systems should have very different food and energy outcomes for their 'customers'. Prisoners are well fed, whilst hospital patients are at risk of malnutrition. Both institutions have to contend with budget demands, mass production and transport of food. Food waste from hospitals is much larger than that from prisons, with wastage rates increasing with decreased food acceptability. Plate waste from prisons was reported at 7%, whereas plate waste from hospitals was reported at

Figure 6.1 Normal textured meal example.

Figure 6.2 Pureed food, served as one would serve scoops of ice cream.

Figure 6.3 Visually appealing pureed food ('pureed' salmon and scallop sushi).

26% (Johns et al., 2013). When the authors looked at differences in the two systems, some striking features were revealed. In prison, meals were centrally prepared and then transported by trolley to cells or dining rooms. The transport and delivery process took no more than 20–30 min. Prisoners enjoyed meals at predictable times that were not interrupted by other activities. On the other hand, the transport and delivery process of hospital food took 45–95 min. Although the food remained in trolleys that were heated, delays in serving resulted in the food being dry, discoloured and altered in temperature (hot foods cool, cold foods tepid). Ward rounds, tests and treatments delayed service to hospital patients. Similar effects of reduced patient satisfaction with food temperature and texture of hospital food have been noted by other researchers (Hartwell et al., 2007). On careful consideration, Johns et al. (2013) concluded that in hospitals clinical considerations take precedence over meals, with the general perception that 'nutritional intake' is an afterthought (Johns et al., 2013). However, appropriate nutrition is required for healing, and inadequate nutrition can lengthen stay by 50% (Johns et al., 2013; Hartwell et al., 2007). Strategies such as 'protected mealtimes' where tests and interruptions are avoided at mealtimes have been implemented in some hospitals, but without significant improvement in food intake. Addressing issues relating to the coherence of food service and minimising delays that cause alteration in food temperature and visual appearance was advised (Johns et al., 2013).

6.5 Texture classifications of diets for dysphagia patients

Literature relating to the use of texture-modified foods for dysphagia patients dates back to the 1980s (Penman and Thomson, 1998). Literature reviews have been conducted and demonstrate that there are generally two to five different levels of texture modification distinct from regular foods that are reported in the literature, and used in clinical practice (Penman and Thomson, 1998; Finestone and Greene-Finestone, 2003; National Dysphagia Diet Task Force, 2002; Atherton et al., 2007; National

Patient Safety Agency, 2011; Cichero et al., 2013). Where only two levels of texture modification are described these are most often 'soft' or 'pureed' diets. In each category, the foods are described as moist, recognising the importance of this feature in dysphagia diets. The most common texture classifications from the literature and as used in clinical practice are described below.

6.5.1 Pureed food

Purees do not require chewing. They are cohesive, homogenous in texture, smooth and moist. Purees are described in the literature as 'smooth and lump free, with sufficient cohesion to hold its shape on a spoon; when plated it should not 'bleed' [seep liquid] onto the plate' (Atherton et al., 2007, p.s70). The North American guidelines describe puree as 'pureed, homogenous, cohesive and pudding-like, with no coarse textures, raw fruits, vegetables or nuts' (National Dysphagia Diet Task Force, 2002, p. 10). Purees can be eaten with a fork and the prongs of a fork make a clear pattern on the surface of a puree (National Patient Safety Agency, 2011).

Some countries have further divided the puree texture into 'thin or runny puree' and 'thick puree'. 'Thin purees cannot be piped, layered, moulded, scooped, or eaten with a fork; they are best poured' (National Patient Safety Agency, 2011; Atherton et al., 2007). From clinical experience, some palliative care patients and head and neck cancer patients find it easier and safer to manage thin purees than thick purees. Solid foods, coarsely mashed foods, fibrous particles, lumps, seeds, nuts, hard, dry and crumbly textures are excluded on a pureed diet. Sticky, adhesive textures such as peanut butter are also excluded.

6.5.2 Mashed or minced foods

From puree, the next level of food-texture modification on the continuum towards regular food textures in 'mashed or minced' foods. Foods in this category are moist, soft-textured and can be easily mashed with a fork. Minimal chewing is needed and, in fact, tongue-to-palate shearing can be used to break the food up. Meats are ground or minced. Some countries specify the particle sizes acceptable for this diet and they range from 0.2 cm to approximately 0.5 cm (National Dysphagia Diet Task Force, 2002; Atherton et al., 2007; National Patient Safety Agency, 2011). Smaller particle sizes are recommended for children younger than 5 years due to children's smaller-sized anatomy (0.2–0.5 cm, Atherton et al., 2007). Often a sauce, gravy or custard, depending on the meal, is recommended to increase the moisture content of the food and contribute to formation of a moist bolus. Bread, sandwiches, pastries, crackers and dry biscuits are excluded on this diet. Rice that 'holds together' may be suitable for this diet, with the underlying proviso that it is also moist rather than sticky.

6.5.3 Soft foods

Soft foods provide the level of texture modification one step lower than regular, unmodified food textures. Foods in this category may be naturally soft, or cooked or cut to alter the texture to a soft consistency. A larger variety of textures are included than in the other diets, whilst particulate foods that pose a choking risk should be avoided. It is expected that the soft food will need some chewing. Soft food should be easily broken up with a fork. Harder textures that require biting are not appropriate. Food should be moist or served with sauce or gravy as appropriate to increase moisture content. Food textures that display the following characteristics should be excluded: hard, tough, chewy, fibrous, sticky, stringy, floppy (conforming: like lettuce, cucumber, uncooked baby spinach leaves), dry, crispy, crunchy or crumbly. Pips, nuts, seeds, skins, fruit pith, husks and outer shells should be excluded. There are specific instructions regarding the size of meat pieces that are served on the plate. These vary from 1.5 cm $\times$ 1.5 cm in Australia and the UK, to 'bite-sized pieces' <2.5 cm in North America. The Australian standards further state that plated particle sizes should be equal to or less than 0.8 cm for infants and children younger than 5 years of age with this recommendation based on tracheal size and choking risk (Atherton et al., 2007). Plated pieces are specifically referred to, as raw meat pieces may be larger, given shrinkage that occurs during cooking. The inclusion of bread on this diet is contentious, and varies from country to country. Where bread is included, it is identified as 'well moistened' or 'soft', and excludes crusty, tough and hard breads (e.g., baguette).

6.5.4 Meat, bread and rice

In guides developed for the practical application of dysphagia diets, care is taken to make particular recommendations for different food categories, for each level of texture classification. For example, inclusion and exclusion items are often described for: bread, cereals, rice, pasta and noodles; vegetables, legumes; fruit; milk, yoghurt, cheese; meat, fish, poultry, eggs, nuts and legumes; desserts, and miscellaneous items (e.g., soup) (National Dysphagia Diet Task Force, 2002; Atherton et al., 2007; National Patient Safety Agency, 2011). The cut of meat and type and length of cooking time will affect the suitability of the final product for each level of food texture modification. There is also good reason to make recommendations regarding dry foods such as bread. For the same quantity of bread and pasta (3 g), five times the amount of saliva is needed to moisten bread as is required to moisten pasta in readiness for swallowing (Hoebler et al., 1998). Whilst bread is the common staple in Western diets, rice is the common staple in Asian diets. Information from the Food Safety Commission in Japan demonstrates that sticky rice is a food choking risk. The type of rice (short grain, long grain, brown, white) and the cooking method will have an impact on the final texture of the rice (fluffy, sticky, glutinous, creamy).

6.6 International variation in food terminology of dysphagia diets

A number of countries have developed national standardised terminology and definitions for texture-modified foods. A recent review of the published literature in English looked at international variations in texture-modified foods and thickened liquids for individuals with dysphagia (Cichero et al., 2013). It is possible that there are other countries that have standardised terminology that is not currently in English. Standardised terminology is seen to improve patient safety, providing a common language for all of those who care for people with dysphagia. Inconsistencies in terminology can have fatal consequences, as discussed above in Section 6.3.2.

Looking at published national standards, the fewest levels of food texture modification are noted in Denmark (two levels), whilst the largest number are noted in Japan (six levels). The Japanese system sets a level for 'test or training' foods before patients are placed on a diet. The training food is a gel consistency that specifically does not contain protein. The rationale is that if accidentally aspirated, a product that does not contain protein will cause least harm to the pulmonary tissue. The gel is also provided in a slice such that the piece is no wider than 0.5 cm and fits on a teaspoon.

In the international literature, most commonly there are three levels of food texture modification that fit with those described above in Section 6.5. A summary of international variation in terminology for texture-modified food is shown in Table 6.3. Problems with variations in national terminology can be seen in two countries that are geographically close. In the UK, Texture B denotes a Thin Puree Dysphagia Diet. However, in Ireland, Texture B denotes a Minced and Moist Diet. Similarly, Texture D in the UK is a Pre-Mashed Dysphagia Diet, whilst Texture D in Ireland denotes a Liquidised Diet. As noted in Section 6.5 for each example, these are very different textures that are essentially separated by two orders of magnitude of texture modification. Not only patients with dysphagia who might be travelling between the two countries, but also clinicians who may relocate for employment should be aware of this difference. Commercial companies that produce pre-packaged texture-modified foods would also need to be aware of the naming differences, and adjust their labelling accordingly. There is also much to be learned from other cultures. The Japanese Food Safety Commission report that was translated into English provides an insight into Asian food textures.

One way to resolve issues around terminology is by standardising at an international level. International standardisation in areas from food safety to texture analysis, computers, healthcare and engineering are seen on the International Standards Organisation website (ISO). ISO is the world's largest developer of voluntary international standards. ISO 11036 was noted in Section 6.4.1 as a reference for food texture terms. The International Dysphagia Diet Standardisation Initiative (IDDSI) is a volunteer not-for-profit group of motivated interdisciplinary individuals from around the world currently working towards developing standardised terminology and definitions for texture-modified foods and thickened liquids for individuals with dysphagia aiming to be relevant to all age groups, all care settings and all cultures (www.iddsi.org). IDDSI is aiming to have published standards developed by 2015 using a wide consultation process and collaborative decision making, with individuals being encouraged to make contact with the initiative through the website. In 2013, the group published a summary of the current literature available from published national diets (Cichero et al., 2013). At the time of writing IDDSI is in the process of publishing a systematic review of the literature for evidence to support texture modification as a treatment for dysphagia, and collating data from stakeholder surveys from around the world.

Table 6.3 An international perspective: texture classifications of diets for dysphagia patients (Cichero et al., 2013)

Level of modification	Food texture modification labels, including country of use
Most modified food texture	Thin puree (UK) Texture D liquidised (Ireland) High viscosity fluids (Sweden)
	Dysphagia pureed (USA) Texture C—Thick puree (UK) Texture C—Smooth puree (Australia, Ireland) Puree (Denmark) Mousse/Jelly products—homogenous texture (Japan, Sweden)
	Dysphagia mechanically altered (USA) Texture D—Pre-mashed dysphagia diet (UK) Texture B—Minced and moist (Australia, Ireland) Paste—heterogeneous texture (Japan) Timbales (Sweden)
Least modified food texture	Dysphagia advanced (USA) Texture E—Fork mashable dysphagia diet (UK) Texture A—Soft (Australia, Ireland) Soft (Japan, Denmark) Coarse pate (Sweden)
Unmodified food texture	Regular diet (USA, Australia, Sweden) Normal (Japan, Denmark)

A standardised international system is seen to have primary benefits to patient safety. Following from this, it is believed that in the process of standardisation of terminology that treatment research in the area of dysphagia will be advanced. Commercially there are benefits for industry and consumers in having a single nomenclature. It is envisaged that upon completion, IDDSI will also develop the equivalent of a 'currency converter', mapping existing national terminologies onto the new international standardised terminology.

6.7 Conclusions

Dysphagia is an under-recognised condition that particularly affects the elderly. Conditions such as stroke, TBI, degenerative diseases, head and neck cancer and others are associated with dysphagia. This chapter has addressed the challenges in providing texture-modified food for individuals with dysphagia. It has demonstrated that the 'swallow-safe' bolus is well masticated with small particle sizes, with a moisture content of about 50%, and held together in a cohesive fashion with saliva that both binds the particles together and lubricates the outside surface of the bolus for smooth passage through the oropharynx and oesophagus. Conditions that affect particle size reduction and production of saliva will increase the likelihood of choking risks. The energy requirements of the dysphagia population further complicate the provision of texture-modified food. Nutritional needs are often very high in the acute phase, due to factors such as catabolism. Traditional food texture modification practices often require that additional fluids are added to texture-modified foods to ensure they are moist. The additional fluids, however, result in nutrient dilution. Newer methods of food texture modification, such as freeze–thaw-impregnation technology, offer new advances in the field. Consideration must also be given to the process of providing hospital or 'institutional food' to improve efficiencies such that food colour and nutrient density is not lost as part of the serving process. Efficiencies in provision of texture-modified food should be prioritised to reduce malnutrition and concomitant increases in length of stay in hospital. Reviewing national terminologies, there are typically three levels of food texture modification offered to people with dysphagia, moving from soft as the least texture modified, through chopped and minced food, with pureed food the most modified food texture. Consistency in terminology advances patient safety through improved communication. The lessons learned from national terminologies are now being applied at a global level to develop standardised international terminologies for dysphagia diets. This process is best achieved with multi-disciplinary collaboration.

6.8 Further supporting information

The focus of this chapter has been on texture-modified food suitable for individuals with dysphagia. In addition to what has been discussed, there are two topics in the area of texture-modified foods that often result in robust discussion amongst health professionals that are beneficial for brief acknowledgement. Specially, these are (a) the defining boundaries between thickened liquids and semi-solids, and (b) whether patients who require texture-modified foods solely for dental purposes are truly part of the dysphagia diet framework. These will briefly be elaborated on below.

6.8.1 Semi-solid versus semi-liquid

Whilst texture-modified foods are used to manage foods, liquids are thickened for individuals with dysphagia to reduce risks associated with aspiration. Consulting the national terminologies, fluids are typically thickened to three or more levels of thickness (Cichero et al., 2013). At the thickest end of the continuum there are 'spoon-thick' (National Dysphagia Diet task Force, 2002) or 'extremely thick' liquids (Atherton et al., 2007; Cichero et al., 2013). The description of these fluids, regardless of country of origin, is that they are too thick to consume from a cup or through a straw, and that using a spoon is the best way to consume this level of thickened liquid. When lifted with a fork, the thickened liquid should sit on the fork and not drip through it (Atherton et al., 2007). Consider then, the definition provided above for the most modified textured food, pureed food (Section 6.5.1) where the food is cohesive, homogenous and holds its shape on a spoon. Looking at these definitions, the boundary between thickened liquids and pureed food is not clear. Typically there should be microstructural differences between solids and liquids. A typical liquid has a loose or amorphous molecular structure, allowing deformation when stress is applied, with the shape of the liquid determined by the shape of the container holding it. The introduction of thickening agents like modified food starch, xanthan gum and guar gum, however, introduces solids, and at high concentrations, such as that with extremely thick liquids, the boundary between liquid and solid is blurred. A typical solid has strong bonds between molecules, may be crystalline in structure and solids are more difficult to deform. Measures that provide information about the ratio between elasticity (G' or storage modulus) and viscosity (G'' or loss modulus) will provide information on whether a bolus has more solid-like characteristics ($G' > G''$) or liquid-like characteristics ($G'' > G'$) (Ishihara et al., 2011). Whilst such measures are available in laboratories, they are not available in hospitals. Decisions directed by trials in laboratories are required to provide some guidance on this topic and the development of dysphagia diets and terminologies.

Individuals who require thickened liquids for the management of dysphagia are frequently dehydrated (Whelan, 2001; Leibovitz et al., 2007). The dehydration is not due to water-binding characteristics of the thickeners (Sharpe et al., 2007). It is conceivable that extremely thick ‘liquids’ may in fact be better characterised as semi-solids, with additional measures put in place to optimise patient hydration. It is possible that thickened liquids may only be suitable for oral hydration if thickened to a level that can still be consumed from a cup or using a wide-bore straw. This is a topic for further debate.

6.8.2 ‘Dental soft’ diet

Whilst there is agreement that a ‘soft diet’ should be provided as one of the food texture modification levels for individuals with dysphagia, there is often debate about whether this level is the same as, or different to a ‘dental soft’ diet. A ‘dental soft’ diet is one that is often provided as a choice on the regular menu of hospitals for individuals with dentures or missing teeth. Doctors, nurses or dysphagia clinicians can prescribe ‘dental soft’ diets, whereas only a dysphagia clinician prescribes a ‘dysphagia soft’ diet. The difference then, appears to be in how ‘dysphagia’ is defined. From clinical experience, when poor chewing ability is complicated by impairment of tongue function resulting in poor bolus control, convention would typically dictate a ‘dysphagia’ diet. However, where tongue function is intact, with only dental status compromised, often a ‘dental soft’ diet is advocated. The discussions provided earlier at Section 6.3.1, however, detail that fewer than 13 teeth increases choking risks and that an inadequate number of teeth has a follow-on effect to reductions in bite force. Furthermore, reductions in mastication result in reductions in saliva output (Pereira et al., 2006). These factors will reduce the likelihood of adequate particle size reduction. Missing teeth are more commonly found in older individuals. Old age is also associated with multiple medications and their side effects of dry mouth. Also noted above in Section 6.3.1, reductions in oral wetness reduce the ability to form a moist and cohesive bolus. These factors suggest that dysphagia clinicians may need to consider that any individual who requires 'soft' food, even if the only indication is missing teeth, should still be considered to be part of the dysphagia continuum. Whilst the clinical time allocation to this population may not be as great as to individuals with severe or multiple phases of dysphagia involvement, the reductions in dental units, chewing strength and saliva production may be significant markers of imminent change to decline in oropharyngeal function.

6.9 Sources of further information and advice

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Texture modification of food for elderly people

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E. Rothenberg[1], K. Wendin[1,2,3]
[1]Kristianstad University, Kristianstad, Sweden, [2]SP Technical Research Institute of Sweden, Borås, Sweden, [3]University of Copenhagen, Copenhagen, Denmark

7.1 Introduction

Life expectancy at birth has risen rapidly in the last century due to economic growth worldwide manifested by reductions in infant mortality, improved living standards, better lifestyles and education, as well as increased quality and availability of health care (Key figures on Europe: 2013 digest of the online Eurostat yearbook, 2013; Turpin, 2014; Vaupel, 2010). At the beginning of 2012, the share of the population 65 years and above in the European Union (EU-27) was about 18% of the total population (Key figures on Europe: 2013 digest of the online Eurostat yearbook, 2013), and in 2060 this share of population is expected to account for about one third of the total population (Europe in figures: Eurostat yearbook, 2011, 2011). The share of those aged 80 years and above is projected to almost triple between 2011 and 2060. As a result of the demographic transition, the old-age dependency ratio is projected to more than double, from 27% in 2012 to 53% by 2060. An increased burden on those of working age to provide social and health care to elderly population will be a major demographic challenge for society (Europe in figures: Eurostat yearbook, 2011, 2011; Key figures on Europe: 2013 digest of the online Eurostat yearbook, 2013).

Life expectancy in the EU countries is generally higher than in most other regions of the world. Within the EU, variation exists between countries. For example, a female born in 2012 is expected to live between 77.9 years (Bulgaria) and 85.5 years (Spain), a difference of 7.6 years. A man born in 2012 can be expected to live between 68.4 years (Lithuania) and 79.9 years (Sweden), a variation of 11.5 years (Key figures on Europe: 2013 digest of the online Eurostat yearbook, 2013).

In response to demographic challenges, the EU has taken several actions to facilitate the creation of an active ageing culture in Europe, based on the principle of ‘a society for all ages’. Active ageing aims to create more opportunities for older people to continue working and to stay healthy longer.

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7.2 Ageing in different perspectives

7.2.1 Definition and classification of ageing

The definition of elderly may vary between different countries and different cultures. However, the general consensus is that the concept of elderly people covers a population range from newly retired to those 100 years and above. Those age 65 years or 60 years are often used as a convenient threshold in literature. The elderly population covers more than a generation and implies a great variation in living conditions and exposure to environmental factors, such as housing, health care, lifestyle and education. Older adults thereby constitute a heterogonous group in many different aspects, including mental, medical and functional abilities.

Ageing could be described as a continuous and gradual process characterized by great variability among individuals. Ageing could occur in different rates and ways, depending on factors such as environmental, cultural, genetic, as well as the presence or absence of pathological conditions. Normal ageing is characterized by declined capacity in all physiological systems as well as in cognitive function.

According to the science of gerontology, ageing may be characterized in four different categories:

Chronological ageing: years lived by an individual from birth
Biological ageing: the physical changes of an organ system as it ages
Psychological ageing: changes in sensory and perceptual processes, cognitive abilities, adaptive capacity, and personality
Social ageing: changing roles and relationships with family, friends, and society as one gets old.

A single individual could 'vary in ages' depending on which measure is used. Despite of the immediate convenience, chronological age is often a poor measure of the 'real' age of an individual. Individuals at the same chronological age could have very different physical, physiological, psychological, and mental performance, due to influences of genetic factors, life style, and disease or disability. Of outmost importance for individual conditions is the functional capacity.

According to Kirkwood (1996), it is important to distinguish the ageing process from ageing. The ageing process ('normal ageing') represents the universal biological changes that occur with age and are unaffected by disease and environmental influences. Not all of these age-related changes have adverse clinical impact.

By contrast, the process of ageing is strongly influenced by the effect of environmental, lifestyle and disease states that, in turn, are related to or change with ageing but are not due to ageing itself. Often what was once thought to be a consequence of normal ageing is now more appropriately attributed to ageing-associated factors (Kirkwood, 1996).

7.2.2 Physiology of ageing

With increasing age all physiological systems will decline in both capacity and function. However, the pace of decline will be different between different individuals and even between different organ systems within the same individual

(Aihie Sayer et al., 1999). To distinguish between a state of health and illness becomes more complicated as individuals get older. Symptoms of disease often vary and become less obvious for elderly people.

7.2.2.1 Nutritional status

Body composition gives important information about a person's nutritional status. It can be measured by different techniques where the most simple is anthropometry. However, more sophisticated techniques such as dual X-ray absorptiometry can give in-depth information on the amounts of compositions as well as relationships between body compartments (Kyle et al., 2004; Tengvall et al., 2009). Age-related body composition change starts in early middle age, signified by a continuous loss of body water, bone content, fat-free mass, skeleton muscle mass and function and an increase in body fat, mainly visceral. However, a great variation exists among individuals of the same chronological age. Body mass index (BMI), calculated based on one's body weight and height (kg/h^2), has been used as a useful indicator of body composition change. For most individuals both body weight and height decrease by age. However, regarding BMI a revised epidemiology is present, meaning that low BMI and weight loss are significant risk factors for all causes of mortality but elevated BMI and high proportion of body fat seem to have no harm but even a protective role on health and survival (Al Snih et al., 2007; Batsis et al., 2014; Flicker et al., 2010; Vischer et al., 2009). BMI is a proxy measure for energy stores and for older adults these stores seem to be beneficial. The cardiovascular risk by overweight appears to diminish by age. It has been shown that higher BMI (25–30) is associated with greater disability-free life expectancy compared to groups of lower and higher BMI (Al Snih et al., 2007). Skeletal muscle mass is of great importance for physical function but also for immune function. Some individuals preserve muscle mass up to very high ages but others develop a progressive and irreversible reduction of muscle mass and strength (Buffa et al., 2011), due to the reduction the number of motoneurones and atrophy of muscle fibers. This phenomenon is named as sarcopenia (Figure 7.1) (Cruz-Jentoft et al., 2010). To maintain muscle mass and physical function physical exercise is of outmost importance. Being sedentary has been shown to increase the risk of mortality.

7.2.2.2 Oral health and swallowing

There are several age-related changes in the oral cavity, pharynx and esophagus, but these changes during the normal ageing process do not affect the swallowing process. Generally, elderly swallowing during 'normal' conditions is not much different from that of younger people. But the potential of developing dysphagia is growing with advancing age because many older individuals are already using their swallowing function to the maximum capacity (Leder and Suiter, 2009). Age-related changes that could influence swallowing include changes in head and neck anatomy and physiology, in the central nervous system (e.g., decreased number of neurons affecting pharyngeal function), and the strength of mastication muscles. The forward movement of the

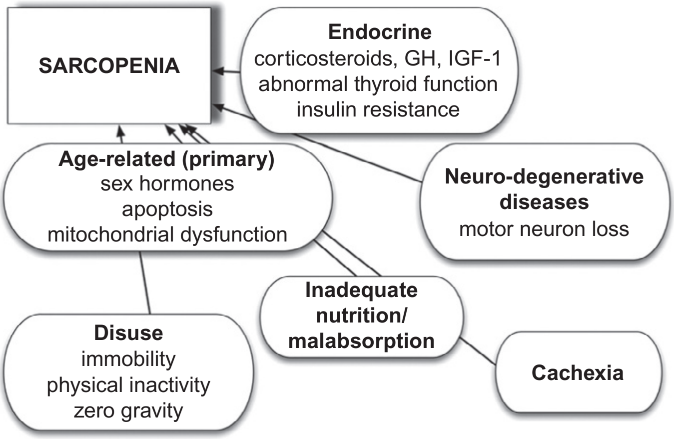

Figure 7.1 Mechanisms of sarcopenia.
Cruz-Jentoft et al. (2010).

larynx and the pharyngeal muscle contraction become less pronounced and slower. The pressure the tongue generates against soft and hard palate decreases. Swallowing becomes slower. As a result, risk of airway penetration increases and sensory capability and esophageal motility decrease (Ney et al., 2009). It is in the pharyngeal stage the swallowing disturbances often occur. When sensitivity in the oral cavity is reduced it can sometimes be seen that a person takes far too big a gulp and swallow in an uncontrolled manner. It is generally accepted that stressed coordination between the oral cavity, pharynx and breathing can result in swallowing disturbances.

Dental status of the general population has been improved over decades. However, edentulism is still prevalent among older adults all over the world and highly associated with socio-economic status. Persons with low income, with little or no education are more likely to be edentulous than those with high income and education. Poor oral hygiene or high levels of dental plaque are with the major causes of high prevalence rates and severity of periodontal disease. Low education, no dental check-ups, few teeth present and regular smoking have independent effects on the progression of periodontal diseases in older adults. A strong relation between tobacco and periodontitis has been shown (Petersen and Yamamoto, 2005).

A main function of food oral processing is to decompose the food into smaller particles by chewing and by saliva incorporation. Saliva is needed for lubricated food particle moving, bolus formation and swallowing. During chewing, salivary enzymes interact with some specific food components (e.g., starch, lipids) and lead to food oral digestion (Mese and Matsuo, 2007). Saliva also plays a role in taste and smell. Dispersion and saliva mixing in the oral cavity is voluntary, subjected to factors such as number of teeth, mucous membrane condition and possible morphological defects. Saliva layer that normally covers the mucous membranes of the mouth and throat are of great importance to the body's natural defenses against bacterial, viral and fungal infections. Many studies have confirmed that increasing age causes salivation decreases. A decrease in saliva secretion increases the risk of tooth decay and difficulties of eating and swallowing (Mese and Matsuo, 2007).

7.2.2.3 Senses

Humans' sensory systems deteriorate during ageing (Hummel et al., 2002). Increasing prevalence of sensory loss in higher ages will have a negative impact on food intake by these elderly (Schiffman, 1983, 1993, 1997; Doty et al., 1984; Stevens et al., 1995; Cain and Gent, 1991; Murphy, 1993). Decreased ability to identify odors and tastes makes food recognition and appreciation harder, thereby affecting appetite negatively (Edfors and Westergren, 2012).

7.2.2.4 Nutritional requirements

As long as older adults stay healthy, energy and nutrient intake should be adequate based on good food habits. With ageing, the need of energy decreases due to less physical activities. However, the need for micronutrients does not necessarily decrease. This implies that for elderly with reduced appetite there is a great need to increase nutrient density of the food they consume. For most micronutrients the scientific evidence for daily intake recommendations by elderly is still scarce. However, there have been many studies about protein and vitamin D supplements for older adults. Protein is necessary for synthesis of fat-free mass, metabolic processes and to offset inflammatory and catabolic conditions associated with chronic and acute diseases that occur commonly with ageing (Bauer et al., 2013). A recent systematic review suggests that the evidence for optimal protein intake relates to functional outcomes like maintenance of bone mass, muscle mass and strength, as well as morbidity. Results from particularly prospective cohort studies suggest a safe intake of 1.2–1.5 g protein/kg body weight/day or approximately 15–20 E% (Pedersen and Cederholm, 2014).

For vitamin D a level of 20 μg/day is recommended for those over 75 years old, 10 μg more than that for the young adult populations. Studies during the last 10–15 years show that insufficient vitamin D status is common especially in elderly living in institutions. There are several reasons: time spent outdoors may be limited; the amount of 7-dehydrocholesterol in the skin epidermis diminishes with age; and the conversion of this precursor into vitamin D becomes less effective. A recent literature review concluded that there is a convincing evidence of the protective effect of vitamin D against bone deficiency, total mortality and the risk of falling (Lamberg-Allardt et al., 2013). The effect was seen in persons with low basal serum 25OHD concentrations (<50 nmol/L). In intervention studies effects were seen for combined supplementation of vitamin D and calcium. There is, however, some epidemiological evidence that high concentrations are associated with increased total mortality (Lamberg-Allardt et al., 2013). Vitamin D also has important roles in many other physiological systems such as the immune system, the pancreatic beta-cells, cardiovascular, brain and muscles and in the biological responses in the related cells.

7.2.3 Pathophysiology of ageing

7.2.3.1 Illness and causes of death

Non-communicable diseases are fast becoming the leading causes of disability and mortality. More than 70% of elderly mortality occurs when people have been ill for several years, often in chronic condition. Diseases of the circulatory system account for nearly 50% of all deaths, with higher rates among men than women. Cancer is the second biggest cause of death, accounting for 20% of deaths in the EU region. Ageing is per se a great risk factor for disease and disability. Above 70 years of age, cancer diagnosis starts to decrease but circulatory diseases still increase. For those above 85 years old, about 70% of women and about 60% of men die from these diagnoses (World Health Organization Regional Office Europe, 2012). The main diseases of the circulatory system are ischaemic heart and cerebrovascular diseases, together accounting for 35% of all deaths in Europe, though rates vary between countries, different age groups and different genders.

7.2.3.2 Frailty, sarcopenia and cachexia

Frailty, sarcopeni and cachexia are three terms mutually related to each other within the frame of pathophysiology of ageing. Frailty is a common global health and social care challenge, meaning a state of decreased reserve and resistance to stressors (Fried et al., 2001). Frailty is both a physical and cognitive state. It is a result of cumulative decline across multiple physiological systems, causing vulnerability to different adverse health outcomes related to activity limitations, participation restrictions and co-morbidity. It stands for a dynamic progressive process from healthiness to functional decline, ultimately leading to death. Frail elderly fall frequently and suffer from immobility and confusion, increasing resource demand from community, hospital and long-term care institutions. Understanding the risk factors of frailty is a prerequisite to implement programs for early detection and management in order to improve outcomes and enhance vitality and quality of life and to reduce future demand.

Sarcopenia is defined as a syndrome characterized by progressive and generalized loss of skeletal muscle mass and strength with a risk of adverse outcomes such as physical disability, poor quality of life and death (Delmonico et al., 2007; Goodpaster et al., 2006). Sarcopenia is a threat to autonomy as well as physical and mental health. It increases the risk of malnutrition, disease and disability and thereby represents a cost burden to society (Buffa et al., 2011; Cruz-Jentoft et al., 2010). The factors behind this syndrome are multifactorial, including protein synthesis, proteolysis, neuro muscular integrity, muscle fat content and hormonal changes, caused by ageing, low physical activity and inadequate nutrition. Different individuals may be affected by different combinations of influencing factors, and even for the same individual the dominating factors may vary over time (Cruz-Jentoft et al., 2010). Frailty and sarcopenia often overlap. Most frail elderly are sarcopenic and some sarcopenia elderly are also frail. The third term of relevance is *cachexia*, a multifactorial syndrome characterized by severe loss of body weight, fat and muscle and increased protein catabolism due to underlying disease (Muscaritoli et al., 2010). Cachexia increases risk of morbidity and mortality. Contributory factors to the onset of cachexia are anorexia and metabolic alterations (i.e., increased inflammatory status, increased muscle proteolysis, impaired mechanisms of carbohydrates, proteins and lipids). Thus, most cachectic individuals are also sarcopenic, but most sarcopenic individuals are not considered cachectic.

7.2.3.3 Xerostomia

Xerostomia, a dry mouth symptom, has two different statuses. One is the subjective perception, while the other is an objectively measured decrease in the amount of produced saliva, hyposalivation. Often, the two coincide. Xerostomia greatly affects one's ability to chew and swallow, overall well-being and quality of life. It is one of the most common adverse drug reactions (Hopcraft and Tan, 2010; Nederfors et al., 1997). Also certain medical conditions, as well as oxygen and radiation therapy, can cause xerostomia. Overlooked as a cause is mouth breathing (Hopcraft and Tan, 2010). The combination of disease and drug treatment increases the risk of reduced saliva production. Drugs with pure anticholinergic effect, such as tri-and tetracyclic antidepressants and diuretics, have a negative impact on the amount of saliva secretion. Xerostomia increases the risk of poor oral health. Symptoms may be relieved by frequently drinking or rinsing the mouth in order to keep mucous membranes moistened. If necessary, saliva stimulants and saliva substitutes can also be given.

7.2.3.4 Dysphagia

Dysphagia is not primarily a medical or etiologic diagnosis but a symptom diagnosis, associated with a variety of diseases, with stroke as the single most common. Prevalence differs among studies, according to methods used for identification and the state of disease. More than 50% of all patients with acute stroke (within one week after the onset of illness) have been shown to have swallowing difficulties (Martino et al., 2005). Nearly every patient with Parkinson's disease and a third of patients with multiple sclerosis show impaired eating and swallowing ability (Kalf et al., 2012). The prevalence in hospitals and nursing homes has been estimated up to 50%. The incidence is much higher in very old elderly (i.e., over 85 years). On the other hand, neurological diseases such as stroke, dementia and Parkinson's are also very common in this high age group (Ekberg et al., 2002; Kumlien and Axelsson, 2002). Dementia is often associated with dysphagia. It has been shown that over 70% of dementia patients have oral dysfunction; and almost half of them have pharyngeal dysfunction (Easterling and Robbins, 2008). Investigation and treatment of patients with dementia and swallowing dysfunction is difficult because very often their cognitive functions are also impaired. Dysphagia is often a part of malnutrition problems in the elderly.

Swallowing difficulties could be of other origins than neurological disorder. Primary prebyphagia could be defined as changes of the swallowing function associated solely with changes according to ageing while swallowing changes due to disease in older adults is called secondary prebyphagia (Jahnke, 1991; Wakabayashi, 2014). Presbyphagia represents healthy swallowing in elderly individuals (Humbert and Robbins, 2008) and not dysphagia (Figure 7.2).

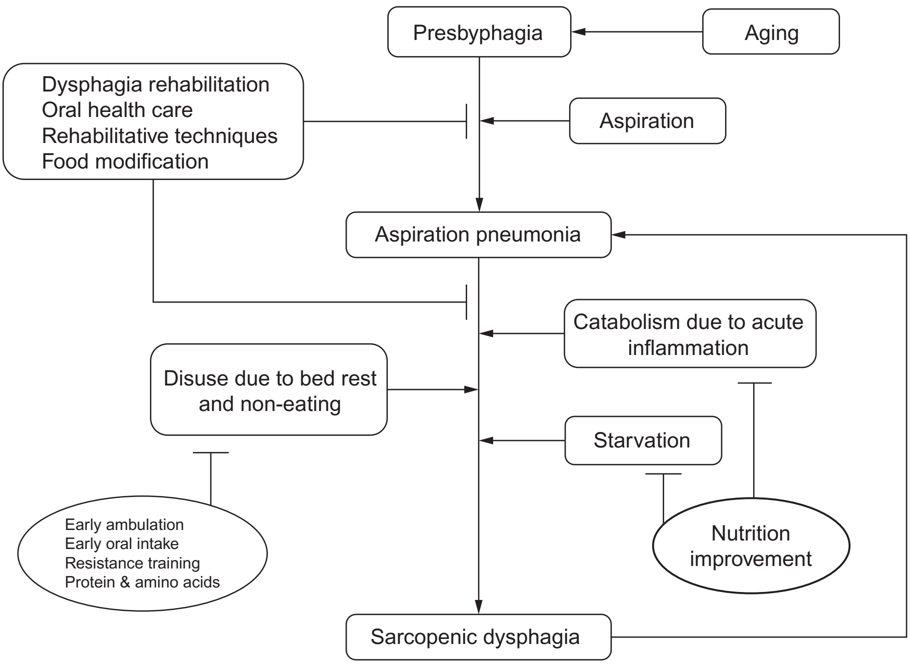

Figure 7.2 The relation between presbyphagia and sarcopenic dysphagia. Petersen and Yamamoto (2005).

Sarcopenic dysphagia refers to difficulty swallowing related to sarcopenia of the skeletal muscles mass, including swallowing muscles (Kuroda and Kuroda, 2012; Wakabayashi, 2014). In frail older adults suffering from oropharyngeal dysphagia, impaired safty of deglutition and aspiration are caused mainly by delayed closure of the laryngeal vestibule (Rofes et al., 2010).

Presbyphagia may present in several ways: as a lack of muscle strength complicating bolus propulsion; diminished lingual pressure; obstruction bolus driving; halting of the bolus whilst swallowing, leading to more difficult cleansing of; a decling residuals; a decline in taste and smell that makes it more difficult to initiate swallowing; difficulty in controlling the bolus from anticipatory phase; entry of the bolus into the airway; and finally, lack of teeth and wearing dentures or not wearing complete dentures, which influences chewing (Nogueira and Reis, 2013).

7.2.3.5 Diseases related to malnutrition

Disease related malnutrition. They are the key determinants of frailty, both as a cause and consequence. Similar to dysphagia, motoric dysfunctions lead to difficulties of eating. Elderly with motoric dysfunction will have problems manipulating food on the plate and transporting food to the mouth. These problems are frequently occurring in older ages and increase the risk of malnutrition (Jacobsson et al., 2000). Malnourished elderly people are at a higher risk of experiencing falls, prolonged hospitalization and institutionalization, postoperative complications and infections, pressure ulcers, delayed and complicated wound healing, reduced quality of life and increased risk of mortality (Elia et al., 2005; Guest et al., 2011; Martyn et al., 1998). Cachexia may be the strongest risk factor, but other factors such as sensory losses, side effects of medication, chewing or swallowing problems may also impair dietary intake, causing malnutrition-related diseases.

7.2.3.6 Routines for screening, assessment and treatment

In nursing homes and within health care it is important to establish routines for quick identification and assessment of the risks of nutritional problems. Nutritional screening is recommended for those at risk and several screening tools are available for this purpose (Kondrup et al., 2003). The most common and especially aimed for old adults is the Minimal Nutrition Assessment (MNA) (Kondrup et al., 2003; Rubenstein et al., 2001). After identification of individuals at risk, assessment should be made to probe problems. This is important for taking up a stand of proper treatment. Those found at risk need preventive actions to avoid malnutrition and those found malnourished need a proper treatment to diminish the negative impact of malnutrition on health. In the case of chewing and swallowing problems, the etiology varies dependent on the underlying disease or functional impairments. It is therefore important to assess the specific cause of chewing and swallowing problems, and to identify the symptoms in order to prescribe proper texture modification. For some individuals simply thickening beverages or avoiding specific food items could be enough, but for others a more specific texture is needed (Wendin et al., 2010). Utilization of texture modification is often used together with other actions, such as prescription of oral nutrition supplements and/or enteral nutrition. For those who need texture modification, it is important to pay special attention to oral hygiene. Normally the acidic environment lasts in the mouth for a short time (about 10–15 min) after eating. However, for those prescribed oral nutrition supplements, frequent and high-carbohydrate meals, thickened beverages and texture-modified foods, the time of acid environment will be greatly extended. Impaired oral motor skills leads to decreased sensibility and reduced ability of tongue movement, which makes it difficult to clean food particles from the mouth after a meal. Medications that are to be swallowed may remain in the oral cavity and cause burns to mucous membranes. These problems are common among those with functional impairments, causing a high risk of tooth decay.

Prescribed therapies should be documented in the medical record and evaluated. To handle nutritional problems successfully it is a great advantage to establish a multiprofessional nutrition support team, including doctors, nurses and dieticians, and in cases of dysphagia also dentists and speech therapists. It is also important to involve kitchen staff or food technologists when texture modification is needed.

7.2.3.7 Anorexia of ageing

Dysphagia is a serious risk factor for *anorexia in ageing* (Donini et al., 2003; Hays and Roberts, 2006), which is defined as an unintentional decline in food intake, resulting in loss of body weight. This often occurs near the end of life. It represents a sign of failure to preserve steady levels of body weight and energy stores (Donini et al., 2003).

7.3 Food and ageing in a broader perspective

7.3.1 Meal situation

The experience of a meal is an important part of the quality of life, but the scientific evidence regarding optimal conditions for an appetite stimulating meal is quite limited. Having a meal should engage all the senses and should be something to look forward to. The mental and physical environment, as well as social and cultural aspects, affect one's appetite. A broader view on the meal is needed where nutritional aspects, taste aspects and physical as well as social aspects are taken into account. The elderly person herself or himself should be allowed to be active in the choice of where, when, what and how to eat. Older persons wish to live independently and appreciate to keep on preparing and cooking foods by themselves (Amella and Aselage, 2011; Bülow et al., 2007; Edfors and Westergren, 2012; Gustafsson et al., 2006). Taking these factors into account lays the groundwork for preventive actions against malnutrition already occurring in the homes of the elderly.

In nursing homes it has been shown that family-style meals stimulate daily energy intake and protect against malnourishment (Nijs et al., 2006). An important explanation is that social facilitation promotes the feeling of having the meal in the company of others with stimulating conversations, extension of meal duration and extra attention from the staff (Nijs et al., 2006).

7.3.1.2 Five aspects meal model as a tool to optimize meal consumption

The five aspects meal model was originally developed for planning service delivery to enhance customers' satisfaction in restaurants (Gustafsson et al., 2006). It is now also used as a tool to understand and handle different aspects involved in a meal in care settings for elderly people and to optimize their meal consumption. The meal optimization includes following aspects.

The room setting: The physical environment is important for meal consumption. It should be harmonious and functional. Elderly people have a great need of good lighting. They may have weakened color perception and therefore using warm colors can facilitate locating objects. Exploiting the contrast effect between colors and the selection of tableware may help food items to stand out on the table. People with impaired vision need instruction on where glasses, cups and cutlery are placed and where on the plate various food components are located. The acoustic environment is also an important factor, because most elderly prefer a quiet eating environment. Curtains are often very effective to suppress sound and echoes. Selection of tables and chairs must be carefully considered for their suitability for elderly with disabilities and for those who may be in a wheelchair. Several smaller tables instead of a long one in common dining room increase the feeling of harmonic experiences of a meal. Of course, respect must be shown if individuals wish to eat separately.

The meeting: Staff eating together with the elderly creates conditions for a pleasant and positive dining experience (Nijs et al., 2006). Joint eating promotes social interactions and helps to create a calm atmosphere around the meal. Keeping the day's menu visible in the dining room and having staff inform what is served facilitate preparation for everyone to understand what the meal consists of. This is even more important when texture-modified food is served.

The product: The food must be adapted to meet elderly need and preference in terms of type of cuisine, texture and seasoning. Capable individuals should be encouraged to remain independent by utilizing self-service. For those who are not able to serve themselves, it is important to serve a moderate portion. A portion that is too large can be perceived as overwhelming and unappealing.

The atmosphere: Older people are sensible to stress. Therefore, meals should be served in a peaceful atmosphere to create conditions for a good appetite. Disturbing sounds (e.g., television or dishwasher) should be avoided. Those suffering from handicaps and impairments may eat slowly and should be allowed to take extra time to complete their meals. Those who are unable to continue eating because of fatigue may need assistance to complete their meals. Eating assistance should be individualized and be given with sensitivity and respect.

The management control system: The organization around the meal is important. The management control system comprises administration, economic and legal aspects and leadership. Rules for food handling must be followed in every stage of meal service. Texture-modified foods often consist of mixed and minced ingredients and therefore are at extremel risk for bacterial contamination. The risk of food poisoning increases among elderly both as a result of the contamination risk and their diminished sensory functions. Both in their own homes and in care settings, it is profoundly important to be careful about food hygiene procedures and food safety because the elderly are especially vulnerable to foodborne infections (Wendin et al., 2014).

7.4 Food solutions

7.4.1 Texture modification

There is a large variation in dysphagic symptoms, from mouth dryness to the inability to swallow. Individuals who have difficulties ingesting food and liquids are in need of texture modified foods and liquids to facilitate oral intake of energy and nutrients (Ekberg and Feinberg, 1991; Ekberg et al., 2002; Hall and Wendin, 2008; Rothenberg et al., 2007). It has been shown that institutionalized elderly people suffering from dysphagia increased their oral intake and also their body weight when served texture-modified food (Germain et al., 2006a; Stefanovic-Andersson and Bülow, 2006).

To reach a successful treatment outcome with texture-modified food it is of greatest importance that everyone involved in the management of the patient use the same terminology when recommending a texture-modified diet. Holmer (2009) as well as Pennman and Thomson (2008) found a broad variation in descriptions of texture-modified foods. These descriptions vary between two and five categories for food in solid form and between one and six categories for liquid foods. No objective measurement was involved in the classification of these categories. Specific terms such as soft, smooth, thin, minced and the like are often used, but so far no clear definition has been given for these terms.

The effectiveness of the dysphagia therapies is dependent on the recommended viscosity (sometimes called thickness or consistency). Rheological properties of food play a key role in affecting bolus swallowing and transportation (Meng et al., 2005). Objective measurements of liquids differing in thickness are not always simple. However, precise definitions and objective rheology measurements are necessary for a texture-modified diet, because influences of composition, serving temperature and time effect (storage) are much more complicated for this type of food (Adeleye and Rachal, 2007; Budke et al., 2008; Dewar and Joyce, 2006; Garcia et al., 2005; Garcia et al., 2008; Germain et al., 2006b; Mark and Robbins, 2007). Steele et al. (2003) compared subjective viscosity assessed by clinicians with results obtained from objective rheological measurements for different foods. They showed that rheological standards are needed within the area of texture-modified food and liquids for dysphagia management. Funami (2011) also concluded that understanding and quantifying the dynamic changes of food is essential to get an objective description of food texture. Rheological measurements analyze physical properties of food items but sensory analysis evaluates texture attributes perceived by human senses. A trained analytical sensory panel can develop objective descriptions of perceived sensory attributes and is capable of identifying texture differences between different foods in a qualitative manner or even in quantitative manner (Lawless and Heymann, 2010). Nakauma et al. (2011) even recommended inclusion of acoustic analysis in order to optimize the swallow-ability assessment of liquid foods.

A guide for texture-modified food has been developed in a Swedish research project (Rothenberg et al., 2007; VINNOVA, 2007), a large collaborative work with the expert participation of dietitians, speech therapists, food technologists specialized in rheology and sensory science, and radiologists. The purpose of the guide was to define distinctive food texture terms and was influenced on what was already available in the literature (Jones et al., 2003; Socialstyrelsen, 2000). In the guide, some specific categories are proposed for the description of texture-modified food, including 'Regular or cut', 'Coarse pates', 'Timbales', 'Jellied products', 'Liquids', and 'Thickened liquids'. These terms are now recommended by the Swedish government to be used in the management of dysphagia. To further elucidate the physical and sensory meaning of these terms, objective rheological as well as objective analytical sensory measurements have been conducted. Results are shown in Table 7.1, and explanation of the rheological measurements is shown in Table 7.2 (Wendin et al., 2010).

Classifications and specific textural terms are greatly helpful for food texture-modification for dysphagia management. However, most such classifications so far

Table 7.1 Definitions of textures: summary of sensory and rheological analyses

Category	Objective sensory description	Texture measurement
Patés	Higher degree of chewing resistance and larger particles compared to timbales and jellied products.	Maximum load: 0.6–2.4 N Strain at max load: 16–34% G′: 11 000–20 000 Pa △: 7.4–7.9°
Timbales	Moderate degree of chewing resistance, creaminess and wobbling. More porous, wobbly, creamy and melting than patés.	Maximum load: 0.5–0.8 N Strain at max load: 25–33% G′: 15 000–17 000 Pa △: 6.6–7.2°
Jellied products	Wobbly, homogenized and creamy. Lower degree of chewing resistance and firmness but higher degree of melting and creaminess compared to timbales and patés.	Maximum load: 0.1–0.3 N Strain at max load: 18–28% G′: 800–16 000 Pa △: 4.4–8.4°
Low viscosity fluids (soups)	Lower degree of chewing resistance, firmness, porosity and wobbling compared to high-viscosity fluids.	Consistence index in shear: 1.0–3.3 Pas^n In tension 120-520 Pas^{next} Shear thinning exponent: 0.4–0.5 Tension thinning exponent: 0.1–0.3
High viscosity fluids (thickened soups)	More melting, easier to swallow and creamy compared to low-viscosity fluids	Consistence index in shear: 7.6–12.0 Pas^n In tension 410–1260 Pas^{next} Shear thinning exponent: 0.3–0.4 Tension thinning exponent: 0.2–0.4

Wendin et al. (2010).

available are empirically based rather than objectively measured. It is therefore extremely important to develop a valid quantitative scaling system for the assessment of texture-modified food. A corresponding clinical scale should also be developed for the assessment of dysphagia patients. A match between the food texture scale and the dysphagia scale will be most helpful in selecting the most appropriately modified food for safe consumption by these patients.

Table 7.2 **Rheology—methods, parameters and descriptions**

Method	Parameter	Description
Solid products		
Penetration test	Maximum load	The maximum force reached when pushing a probe through the sample
Penetration test	Strain at maximum load	Percentage of the sample penetrated when the maximum force is reached
Penetration test	Young's modulus	A measure of the stiffness of the sample derived from the penetration test
Oscillatory test	G' (storage modulus)/G'' (loss modulus)	G' represents the elastic behavior of the sample. G'' represents the viscous behavior of the sample. A higher value means more resistance to deformation
Oscillatory test		
Oscillatory test	△ (phase angel)	Relation between G' and G''. 0° is a completely elastic material and 90° a completely viscous material
Liquid products		
Shear viscosity		K and n are derived from model adaptation to viscosity measurements at several different shear rates. This allows the behavior of a fluid over a range of shear rates to be described with two parameters
Shear viscosity	K (Consistence index)	K is a measure of the fluid thickness. K is equal to the viscosity at the shear rate 1s–1
Shear viscosity	n (Shear thinning exponent)	Describes a fluid's behavior depending on shear rates. 1, Newtonian; <1, shear thinning (i.e. the samples had a lower viscosity at higher rate); >1, shear thickening (i.e. samples have a higher viscosity at higher rate)
Extensional viscosity		K_{ext} and next are derived from model adaptation to extensional viscosity measurements at several different extension rates. This allows the behavior of a fluid over a range of extension rates to be described with two parameters
Extensional viscosity	K_{ext}	K_{ext} is a measure of the fluid thickness. K_{ext} is equal to the extensional viscosity at the extension rate 1s–1
Extensional viscosity	n_{ext} (Tension thinning exponent)	Describes a fluid's behavior depending on extension rates. 1, Newtonian; <1, tension thinning (i.e. the samples had a lower viscosity at higher rate); >1, tension thickening (i.e. samples have a higher viscosity at higher rate)

Wendin et al. (2010).

A further matter for the management and treatment of dysphagia is the consistent implementation of these texture terms. To be able to provide dysphagia patients with food of appropriate texture, the same textural terms must be communicated between health care personnel and food providers. To avoid any misunderstanding, it is of utmost importance that objectively defined texture terms such as shown in the table are used throughout the whole communication chain (Wendin et al., 2010).

7.4.2 Energy and nutrient content

Elderly people in need of texture-modified foods are often at risk for malnutrition due to a combination of impaired appetite and eating difficulties. In order to maintain body weight, it is important that diets for the elderly should have increased energy density (kcal/g). High-energy foods will have a high nutrient content; examples include high-fat dairy products, eggs, fish and meat. For elderly with low appetites, small portion sizes should be served. It is therefore important in care settings to offer snacks between breakfast, lunch and dinner.

The feeling of thirst diminishes with age. Because of this, elderly people are especially vulnerable to dehydration. Beverages should be offered with and between meals. To improve energy and nutrient intake, milk or other nutritious beverages can be served with meals.

Familiar, good-tasting, appetizing food with nutritional composition that meets the requirements of elderly people is essential for their well-being. Provision of such food is also critically important to optimize the capability of the elderly to respond to medical treatments, to minimize anxiety and to enhance the quality of life.

7.4.3 Perception of food

Sensory dysfunction is a common problem among elderly people, affecting their perception and enjoyment of food (Bengtzon, 2003). Moreover the sensory loss increases with age; however, it has been shown that odor sensitivity decreased more than the abilities of discrimination and identification of odors (Duffy et al., 1995; Hummel et al., 2007). Foods contain a complex mixture of elements that stimulate different senses. The perceived sensations from different senses are then integrated into one impression that forms the basis of one's attitude towards the food (like or dislike). In this process, each sense makes a unique contribution. Loss of any of the sensory inputs will alter the sensory profile and result in a change in the overall perception of the food (Murphy, 1993). Thus, food intake will be reduced and eventually lead to consequences such as malnutrition (Donini et al., 2003). The greater the changes in sensory perception, the larger influences on the appetite (Westergren and Edfors, 2012).

Normal eating is usually carried out without the eater's reflection upon what is happening inside the mouth. The food is chewed and blended with saliva until it gets to a proper consistency and particles are small enough to swallow (Hutchings and Lillford, 1998). During chewing the sensory attributes of the food are perceived and sensory signals help to determine when the time is right to swallow (Chen, 2009). Dental dysfunction, declined muscle strength and other physiological or psychological changes lead to impaired capabilities of chewing and swallowing (Moynihan and Bradbury, 2001; Smith Hammond et al., 2004). This has a great impact upon the type and the amount of food that can consumed and how it can be swallowed. The amount of saliva produced is important in the chewing and swallowing processes for properly lubricated food particle movement inside the mouth. For this reason, xerostomia has huge influences on the type and amount of food that can be safely consumed by elderly people (Schiffman et al., 2004). Good understanding of the dynamics of food oral processing may allow new ways to develop food that can meet both sensory and nutritional needs among the elderly (Hutchings et al., 2011).

7.4.4 Sensory aspects on food manufacturing

Eating is normally a pleasurable process for those who have no chewing and swallowing problems. The time it takes before a bite or a sip is swallowed depends on the rheological properties of the food (Hutchings and Lillford, 1998). During chewing and swallowing, texture-related sensations are perceived, together with sensory stimuli from taste and flavor (Buettner et al., 2002; Weel et al., 2004; Chen and Engelen, 2012). For those suffering from dysphagia, impairment of sensory perception and saliva production would indicate that many elderly people lose their enjoyment of eating (Ekberg et al., 2002; Schiffman et al., 2004; Sreebny, 2000).

A common strategy for dysphagia treatment is to modify the texture of foods (Atherton et al., 2007; Bülow, 2003). Texture-modified foods should be specially designed to give preferred experiences as well as safe consumption to those for whom they are intended. Since it is a challenge to design texture-modified foods with attractive sensory properties, a strategy called creative design (Naes and Nyvold, 2004) might be applied. This strategy allows a more creative approach than an experimental design does (Box et al., 2005). The main steps of creative design can be described as follows:

1. Combination of main and ideas and methodologies
2. Production of prototypes and evaluation of these
3. Sample selection for consumer testing

The first thing to do is to identify the main attributes given by the original product concept. The product developer can then use these attributes to develop concrete prototype products to be tested by the intended consumers. In this way systematic aspects are taken care of, but an open space has been left for the product developer to fill in. The main attributes of a texture-modified food can be, for example, 'texture', a specific 'nutrient' and a specific 'taste' or 'flavor'. In a classic experimental design a number of main factors are chosen and then the design is built upon the variation of these factors. In creative design the idea is to use experimental design in product development in order to ensure efficient utilization of both creativity and experience, while at the same time addressing a systematic exploration of the space of possible products. In the statistic evaluation it is recommended to use multivariate statistics to find the most optimal combination of ingredients and manufacturing processes. It is recommended to include both objective analytical sensory science and consumer tests during the development process (Naes and Nyvold, 2004).

The texture of food has a high impact upon how the food is perceived. This is due not only to the sensation and perception of texture itself, but also to the texture-dependent release of taste and flavor components. Texture modification can be performed either by the use of different ingredients or the application of innovative processing techniques. Varying fat content, changing the size of fat droplets, adding thickeners and using emulsifying agents are common approaches used in industry for food texture modification (Wendin, 2001). As an example, the manufacturing procedure of texture-modified meat- and carrot-based products according to an experimental design obtained samples that varied significantly in sensory characteristics. The manufactured samples were evaluated by product experts in order to select the most appropriate samples for persons suffering from chewing and swallowing difficulties. The selected samples were then tested by older respondents in a consumer test that could confirm whether the selected samples were accepted and easy to chew and swallow (Hall and Wendin, 2008). Careful analysis of factors used in the manufacturing design showed that increased oil content gave coarser and juicer meat products. A high proportion of added egg yolk gave soft, coarse and fatty carrot products. Compared to puréed products, a milling degree of 2 mm gave a juicier and softer meat product. A coarser texture of meat products was obtained by using cold-swelling starch instead of warm-swelling. Increased amount of starch increased the amount of detectable particles in the carrot products (Hall and Wendin, 2008).

7.5 Conclusions

Elderly individuals suffering from disease and functional and mental impairments are vulnerable to malnutrition, resulting in several negative health outcomes, including decreased quality of life. For these individuals food must be regarded as a part of the medical treatment. Proper identification and assessment of nutrition-related problems are needed in order to establish proper treatment for these elderly people. When dysphagia is present, texture-modified foods become a critical part of any treatment. Many factors need to be considered when designing texture-modified foods, including energy and nutrient content, palatability, texture, food services and food packaging. Creativity, experience, a systematic approach and the involvement dysphagia consumers are important for the development of new texture-modified foods. The meal situation per se must also be carefully arranged in order to make meal consumption a pleasurable experience, even if dysfunctions are present. Even though some major developments in the food for elderly consumption have been made in the past decade, further research is still needed both on fundamental understanding of ageing and impaired eating capability, and on the innovative approaches of food texture modification to suit the needs of these disadvantaged consumers.

7.6 Short commentary on future trends

It is a given that the elderly population will continue to grow worldwide, along with the number of individuals suffering from dysphagia and dysphagia-related symptoms. A major difference is that in the future, the elderly will be much more skilled in the use of computers and other technical devices. They are expected to be more demanding regarding service and care.

Existing and new technologies will enable innovations in healthcare and elderly care. Screening and automated diagnosis will be made at much shorter intervals than before. Research within the area of dysphagia will strive for deeper understanding of the neuro and muscular mechanisms behind the symptom of dysphagia and how textures can be manipulated in different ways for safe swallowing. Tailor-made nutritious and palatable texture-modified foods can then be developed for individual purposes and needs. With higher accessibility, for example in food stores, the texture-modified food may reach more people and can be used in the prevention of malnutrition, for convenience and improved quality of life.

Social innovation is another great area for full exploration in future. Modern techniques, in particular use of the internet, will be adapted to peoples' needs and demands. For example, internet technology could be used to change meal situations. It will be easy to join friends and family for a meal together via internet connections with possibilities for both video and audio communications. The aim of these achievements is to preserve autonomy and a feeling of independence among elderly people for as long as possible, even if the need of various types of assistance may occur. That should add healthy years to lives.

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Modifying the texture of foods for infants and young children

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S. Nicklaus[1,2,3], L. Demonteil[1,2,3], C. Tournier[1,2,3]
[1]CNRS, UMR6265 Centre des Sciences du Goût et de l'Alimentation, F-21000 Dijon, France, [2]INRA, UMR1324 Centre des Sciences du Goût et de l'Alimentation, F-21000 Dijon, France, [3]Université de Bourgogne, UMR Centre des Sciences du Goût et de l'Alimentation, F-21000 Dijon, France

8.1 Introduction

This chapter will provide an overview of the development of oral abilities in infants and young children, and of its implication for food texture modification. We will focus here on infants (1–23 months) and young children up to the age of 3 years, in accordance with the European regulation regarding infant food (The Commission of the European Communities, 2006). This period is characterized by important transitions in oral abilities (Delaney and Arvedson, 2008; Le Reverend et al., 2014), in mode of feeding with the transition from milk feeding to complementary feeding (Nicklaus, 2011) and in acceptance of food texture (Schwartz et al., 2011). Thus, it appears particularly relevant to analyze the need for texture modification of foods to be fed to children in this age range.

Section 8.2 of this chapter will describe the evolutions in oral physiology in healthy infants and young children born at-term, more specifically regarding anatomical motor components, oral motor skills and feeding skills. Section 8.3 will first describe how each type of texture is accepted at each stage of development of oral physiology, and second, how exposure to food textures impacts the development of oral physiology and acceptability of food with different textures. Based on these two sections, the need for texture modification of infant foods will be demonstrated. Section 8.4 will draw a picture of how the need to modify the texture of infant foods is addressed, whether through national regulations regarding foods for young children, or through recommendations regarding the introduction of complementary foods from public health bodies. After noting the necessity to modify food texture, the absence of evidence-based regulation and the lack of consensus in guidelines from public health bodies about this topic, we will describe some practices of texture modification of foods for infants and young children, based on national surveys and case reports; this will open the discussion of baby-led weaning (BLW). The chapter will be closed by a commentary on future trends and by a description of sources of further information and advice.

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8.2 Oral development in infants and young children

8.2.1 Development of anatomical oral motor components

An infant's oral physiology undergoes important changes during the first year of life, as a result of anatomical changes, neurological maturation and feeding experience, which are summarized in Figure 8.1. Readers are invited to read recent comprehensive reviews for additional information (Delaney and Arvedson, 2008; Le Reverend et al., 2014).

8.2.1.1 Oral anatomy

Compared to the adult mouth, the newborn mouth is small, narrow and devoid of teeth. The tongue is voluminous and contacts all surfaces, leaving little space around it (Delaney and Arvedson, 2008; Gaspard, 2001a). The oral cavity size is further reduced by the presence of fatty tissue on the cheeks (sucking fat pads). The larynx and the hyoid bone are high in the neck. The epiglottis touches the back of the soft palate. This position of the epiglottis helps diverting the sucked liquid around the laryngeal opening (Stevenson and Allaire, 1991). As the infant grows, an anatomic reorganization takes place (Figure 8.1). The sucking fat pads disappear (Stevenson and Allaire, 1991). As the neck gets longer, the pharynx elongates, the larynx moves to a lower

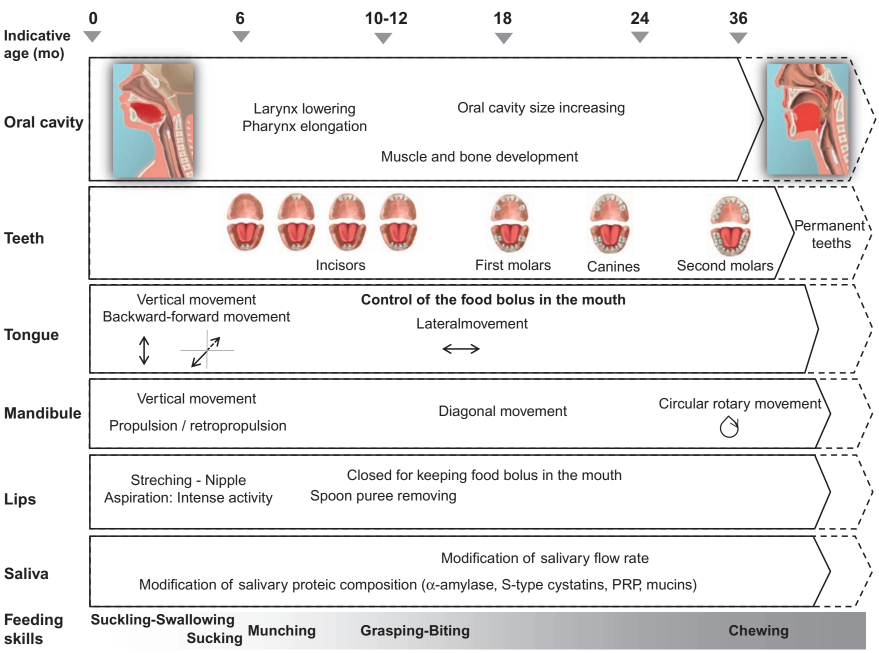

Figure 8.1 Chronological progression of infant's oral motor skills from birth to 36 months.

position in the neck and the distance between the epiglottis and the soft palate increases (Matsuo and Palmer, 2008; Stevenson and Allaire, 1991), while the posterior third of the tongue moves down into the pharynx (Delaney and Arvedson, 2008). Vorperian et al. (2005) used magnetic resonance imaging (MRI) to measure the growth pattern of soft tissue vocal tract structure in 63 children from 2 weeks to 6 years, 9 months and in adults. They observed an ongoing growth of all oral and pharyngeal structures from 2 weeks to 6.7 years, which is more rapid during the first 18 months. The naso-oro-pharyngeal length varies from 5 to 7 cm at 3 years (representing 70% of adult size), the laryngeal descent varies from 3 cm at 2 weeks to 4.8 cm at 3 years (60% of adult size) and hard and soft palate length varies from 5.2 to 6.8 cm at 3 years (80% of adult size).

Along with the development of the oral anatomy, the lips and the tongue also grow. The thickness of the mandibular and maxillary lips changes from 6 to 8 mm and from 7.2 to 9.5 mm at 2 weeks and 3 years, respectively. The tongue length increases from 6 cm at 2 weeks to 7.5 cm at 3 years (65% of adult size) (Vorperian et al., 2005).

These anatomic changes induce an increase in the size of the oral cavity, which is reinforced by the growth of the bony structures: the maxilla (upper jaw) and the mandible (lower jaw). The maxilla is vertically short at birth, but by 3 years it has completed one third of its eventual growth (Ranly, 1998). This growth induces a modification of the palatal arch dimension. During the first year, the palatal width increases from 26 to 32 mm, and the palatal height from 6.5 to 11.5 mm (Le Reverend et al., 2014). At birth, the mandible is small compared to the skull but increases in size and changes in shape along with the development of the primary dentition. According to Ranly, by the age of 3 years, the mandible has achieved approximatively one third of its growth and one half of its eventual size (Ranly, 1998). This change has been monitored by MRI (Vorperian et al., 2005). A growth in mandible length from 30 to 47.5 mm (60% of adult size) and a growth in depth from 45 to 60 mm (78% of adult size) were reported between 2 weeks and 3 years. Hutchinson et al. (2012) observed that the mandible morphology changed from the 31st gestational week to the age of 36 months from a round, smooth contour anteriorly to a sharper and narrow adult shape. These changes were suggested to be synchronized with the development of the tongue, the eruption of deciduous teeth and the development of mastication.

8.2.1.2 Teeth eruption

The eruption of teeth is an important anatomical change in infancy that is usually described by the emergence of temporary central incisors (around 6–12 months), then the lateral incisors (8–14 months), the molars (13–19 months), the canines (16–20 months) and finally the second molars (23–33 months, Figure 8.1). Nevertheless, high inter-individual differences in the eruption sequence can be observed (Ranly, 1998). These different teeth provide children with different oral skills with regard to food manipulation: incisor, canine and molar functions are respectively cutting; tearing and crushing; and grinding. The emergence of the first molars is critical as it provides stability to the jaw by fixing the occlusion position of the mandible against the maxilla (Limme, 2002). By 3 years, children dentition is complete and composed of 20 primary teeth, which will be progressively replaced by permanent teeth around 6 years. An adult dentition is composed of 32 teeth.

8.2.1.3 Oral muscle activity during feeding

The muscles involved in sucking milk from a nipple are the same muscles that will later carry out mastication (Pires et al., 2012). The main masticatory muscles are the jaw elevators (masseter, temporalis and medial pterygoid) and the jaw depressors (lateral pterygoid and suprahyoid muscles: mylohyoid, geniohyoid and digastric).

As the infant grows, the masticatory muscles develop and their coordination optimizes. According to Le Reverend et al. (2014), there is no literature data concerning their growth (in terms of mass or thickness) in children younger than 59 months. The activity of some masticatory muscles was studied transversally by surface electromyography (sEMG, recording of electrical signals produced during muscle contraction) during breastfeeding when breast milk is delivered from the breast or from a bottle at birth up to 6 months (Franca et al., 2014; Gomes et al., 2006; Inoue et al., 1995; Sakashita et al., 1996), during sucking and chewing at 9 months (Steeve et al., 2008) and 15 months (Moore and Ruark, 1996); and during the development of mastication from 12 to 48 months (Green et al., 1997). Follow-up studies of masticatory muscle activity during feeding are scare. Tamura et al. (1998) showed an increase in the suprahyoid muscle activity but no changes in jaw elevator activity between 1 and 5 months. At 9 months, infants display a basic coordinative capability, or coordinative organization as referred by Steeve et al. (2008), of mandibular muscles for both sucking and chewing. Skills of muscle coordination refine over time. From 12 to 48 months, activities of jaw elevators (masseters and temporalis) gain in synchrony, whereas co-activation between antagonist jaw elevator (masseter/temporalis) and depressor muscles (digastric) decreases from an overlap of 290 to 100 ms (Green et al., 1997).

8.2.1.4 Salivary flow rate and saliva composition

Few studies investigated the role of saliva in the context of eating behaviour in infants, whereas it is well admitted that saliva flow and composition contribute to food bolus formation (Engelen et al., 2005; Hutchings and Lillford, 1988; van der Bilt, 2002), flavour and taste compound release (Salles et al., 2011) and sensory perception (Dsamou et al., 2012; Neyraud et al., 2012; Poette et al., 2014) in adult populations.

Data on the evolution of salivary flow rate during infancy are limited. Dezan et al. (2002) reported an increase of salivary flow rate (collected via slight suction through a catheter) from 0.47 to 0.63 and 0.66 ml/min for infants aged 18, 30 and 42 months, respectively. Moreover, salivary flow rate may vary as a function of teeth eruption. Increased salivation is in fact a symptom associated to teething (Gaspard, 2001a; Ramos-Jorge et al., 2011).

Infant saliva composition has been studied for electrolytes (Ben-Aryeh et al., 1984, 1990), peptides (Morzel et al., 2012) and proteins (Inzitari et al., 2007; Morzel et al., 2011; Tenovuo et al., 1986; Weemaes et al., 2003).

Altogether, the data suggest a change in the relative composition with age. Some electrolytes such as Na^+, K^+ and Cl^- decrease between the ages of 3–30 days and 7–12 months (Ben-Aryeh et al., 1984). Sialic acid tends to decrease between 18 and 42 months (Dezan et al., 2002). On the contrary, Ca^{2+} and Mg^{2+} are constant across age groups (Ben-Aryeh et al., 1984). So was salivary protein concentration through the first year (Ruhl et al., 2005) and up to 42 months (Dezan et al., 2002). An increase in serum albumin during the first year was reported (Morzel et al., 2011; Ruhl et al., 2005) and was associated with teeth eruption (Ruhl et al., 2005). Finally the level of some proteins such as β-2 microglobulin and S-type cystatins increases from 3 to 6 months (Morzel et al., 2011). The salivary protein composition may alter the acceptance of a bitter solution (of urea) over water in infants (Morzel et al., 2014).

The functional consequences of salivary composition modification with age on feeding skills during infancy has received little attention. The salivary α-amylase concentration increases with age during the first year (Ben-Aryeh et al., 1984; Morzel et al., 2011; Ruhl et al., 2005), and up to 2.5 years (Ben-Aryeh et al., 1990; Dezan et al., 2002), and so does its activity between 3 and 6 months (Morzel et al., 2011). Sevenhuysen et al. (1984) reported a low amylase activity at birth to approximatively 66% of adult values at 3 months and 85% at 5 months; they concluded that starchy food should preferably be introduced at 4 months, as 3-month-old infants or younger would probably produce not enough amylase to digest even small amount of starch. Salivary mucins are also potentially playing a role in bolus formation and texture perception as they bind food particles into a cohesive bolus that can easily slide through the oesophagus without damaging the mucosa (Pedersen et al., 2002). In infants, salivary mucins are differentially expressed: MUC7 expression decreases between 1 and 12 months, whereas MUC5B becomes more predominant toward the end of this period (Ruhl et al., 2005). Other proteins, so-called proline-rich proteins (PRP), are known to be involved in astringency perception (Gibbins and Carpenter, 2013). In infant basic PRP expression increase between 3 and 6 months (Morzel et al., 2012) and at puberty reach levels comparable to that of adult (Cabras et al., 2009).

8.2.2 Progression of oral motor and feeding skills with age

The development of oral motor (from both anatomical and physiological perspectives), feeding skills and mastication in healthy infants was well described from a theoretical point of view (Gaspard, 2001a,b; Limme, 2010; Stevenson and Allaire, 1991) but limited data-based studies are currently available (Delaney and Arvedson, 2008).

Oral feeding is a complex developmental process that begins prenatally (Delaney and Arvedson, 2008). From birth on, the development of feeding skills is a gradual process, evolving as a consequence of changes in anatomical structure, neurological maturation, types of foods eaten and food preparation method, as well as relationships with caregiver. Neonates are only able to process liquids. Introduction to complementary foods is the process of expanding the diet from milk to solids but also a transition from suckling to sucking, biting and munching and finally chewing. This goes along with different feeding behaviours towards independent feeding by the child: breast-feeding or bottle-feeding, eating from a spoon, drinking from a cup, biting and chewing (van den Engel-Hoek et al., 2014).

The gradual transition from suckling to chewing in term of assessment of oral motor skills will now be described mainly through observations of lip, jaw and tongue movements, which undergo transformation from synergistic and undifferentiated movements to independent and coordinated movements (Meyer, 2008). In this section we will provide age ranges for the acquisition of each oral motor skill (Figure 8.1) but it should be kept in mind that these ranges may vary among studies and between infants (Carruth and Skinner, 2002; Carruth et al., 2004).

Milk (breast milk or formula) is the only food consumed by infants during the first few months of life and suckling is the first oral motor action involved in milk feeding. Newborns have a biological suckle reflex, which disappears progressively around 4 months (Bosma et al., 1986). Suckling is performed together with swallowing and breathing in a well-coordinated manner. During breastfeeding, the newborn compresses the breast between the back of the tongue and the palate (Gaspard, 2001a). The lips help in locating the nipple and assist in forming a seal around it (Lau and Hurst, 1999). The tongue makes backward–forward movements to extract the milk, lateral and vertical movements being limited due to the lack of room in the oral cavity (Gaspard, 2001a). In parallel, the jaws perform downward movements creating negative pressure (Lau and Hurst, 1999). At 2 months, sucking action starts to take place (Torola et al., 2012). In contrast to suckling, sucking is a volitional action (Torola et al., 2012), described by vertical movements of the tongue accompanied by small vertical movements of the mandible and a more tightly closure of lips around the nipple to extract the milk (Delaney and Arvedson, 2008; Stevenson and Allaire, 1991) (Figure 8.1). The infant triggers or stops the sucking when he or she wants. Around 5–6 months, the infant can keep the bolus in the mouth before swallowing it. Suckling and sucking work together around 6 months, then suckling wanes because it is less efficient for milk and food intake (Stevenson and Allaire, 1991).

At about 5–6 months, infants are able to maintain an upright posture when placed in a seating position, they are ready for complementary foods generally introduced with a spoon (Delaney and Arvedson, 2008). The lips play a critical role in removing the food from the spoon and maintaining the bolus inside the oral cavity. According to Stolovitz and Gisel (1991), this skill varies both with age and food texture. Most 6-month-old infants are able to remove puréed food from a spoon, but they succeed at doing so with solid food in only four trials out of 10. At 8 months, this success was observed for 8 out of 10 trials (Stolovitz and Gisel, 1991). An interview of 98 mothers revealed that infants were able to bring the upper lip down on a spoon to remove food at ~7.5 months (Carruth and Skinner, 2002). A larger survey ($n = 3022$ mothers) reported that 88% of infants were able to remove food from a spoon with the lips between 9 and 11 months (Carruth et al., 2004). Lip closing pressure on spoon actually increases with age, from ~25 g/cm^2 (ca. 2.45 kPa) at 5 months to ~80 g/cm^2 (ca. 7.84 kPa) at 36 months, as measured by a strain gauge transducer embedded in a spoon (Chigira et al., 1994).

With the introduction to complementary foods, infants have to handle semi-solid food. Because they are only experienced with sucking liquid, they manage semi-solids by sucking (Torola et al., 2012). Sucking is obviously adapted to a limited range of textures; therefore munching will develop. Munching is defined by vertical movements of the jaws together with vertical movements of the tongue (Stevenson and Allaire, 1991). At the beginning munching and sucking can alternatively be used, depending on the texture of the food. Texture-related eating strategies have been reported to vary among infants (Gisel, 1991). Some 6-month-old infants let Cheerios® cereal be softened by saliva, then swallowed using sucking motions, whereas other infants attempted to munch on them. Munching was observed as early as 5 months (ranging from 4 to 8 months) (Torola et al., 2012) and is firmly established at 8 months (Gisel, 1991). At 10 months, infants adopt a sucking strategy for applesauce but a munching strategy for cereals. From 10 months on, munching is more frequent than sucking (Stolovitz and Gisel, 1991). During this period, with the eruption of the first temporary incisors, the infant discovers the possibility of biting with the first teeth. This requires a protrusive movement of the mandible, allowing the phasing between the teeth (Gaspard, 2001b; Limme, 2002). According to Torola et al. (2012), the phasic bite-and-release first appears as a reflex before infants are able to take a bite of food in a controlled manner, which may happen around 1 year for food with a soft texture like banana.

With repeated exposure to different foods, infants gain in feeding skills. For example, 6-month-old infants require, on average, 42 s and 30 vertical jaw cycles to eat Cheerios®, whereas 24-month-old infants require only 16 s and 14 cycles; however, the duration of a cycle remains constant (Gisel, 1991). This maturation in feeding skills is texture-dependent. The number of cycles and processing time were similar for applesauce between age groups (6–24 months); thus the maturity for semi-solid food was supposed to be achieved between 6 and 8 months. On the contrary, age-related changes observed for the cereals led to the conclusion that the maturity for solid food was still in development at 24 months (Gisel, 1991). The increase in feeding skills is also showed by the fact that jaw closing speed observed at 18 months is dependent on food consistency. This supports the idea that infants have learned to adapt their bite force to the texture of food products (Wilson and Green, 2009).

These changes in efficiency in feeding skills are paralleled by a transition from munching to chewing (Figure 8.1). Up and down movements of the jaw during munching transition through diagonal and lateral movements to finally reach a circular rotary movement (Torola et al., 2012). Tongue movements also increase in complexity, through shifting and rolling movements to lateral movements, allowing the transfer of the food to the surface of the molars (Stevenson and Allaire, 1991). The emergence of the jaw rotary movements together with the lateralization of the tongue, allowing the transfer of the food to the surface of the molar, are the signs that chewing is mastered (Figure 8.1). Chewing development is also accompanied by more actions of the lips. Closing the mouth was found to increase as infants get older (Stolovitz and Gisel, 1991). The age at which chewing is fully mature is unclear from the literature. According to Stevenson and Allaire (1991) these movements appear at around 1 year and controlled rotary jaw movements are seen by 2 years. Other authors mentioned that the transition from munching to chewing starts around 18 months, with the eruption of the molars, which brings the possibility for infants to crush food (Limme, 2002). Parents reported that infants chew softer food around 9.5 months and firm food around 12 months (Carruth and Skinner, 2002) and that 95% of infants between 12 and 14 months eat food that requires chewing (Carruth et al., 2004). Gisel (1991) investigated feeding behaviours in 143 infants between 6 and 24 months for purée, viscous gel and Cheerios® cereals and did not observe any rotary component. This is in agreement with a more recent investigation of 3D jaw movements by kinematics with the same products, which did not show any rotary movements of the jaws at 30 months (Wilson and Green, 2009). However, for both studies, the cereals used as reference for solid texture (Cheerios) might have not been tough enough to induce chewing behaviour (Gisel, 1991), especially because this product can be easily softened by saliva. A study of circum-oral movements of infants showed that tongue lateralization for solid food increases between 6 and 24 months but it was observed for only 2 out of 10 trials for the whole age range (Stolovitz and Gisel, 1991).

After 2 years, the development of chewing continues: for solid foods, the duration and the number of chewing cycle decreases strongly from 2 to 3 years, then more slowly between 3 and 4 years and onwards; for mixed and viscous foods, these parameters regularly decrease between 2 and 8 years (Gisel, 1988).

8.3 The mutual relationships between development of oral physiology, exposure to food textures and acceptance of foods with different textures in infants and young children

This section will first describe how each type of texture is accepted at each stage of oral physiology development, and second, the impact of exposure to food textures on the development of oral physiology and of acceptance of foods with different textures.

As described in the previous section, oral physiology evolves greatly during the first few months, leading to evolving feeding skills (Carruth and Skinner, 2002), which will ultimately determine whether or not a food with a given texture is acceptable (Lundy et al., 1998); that is, whether it can be swallowed. According to Szczesniak (1972), the impact of texture on food preferences is more important in children than in adults. It is therefore essential to take into consideration the texture of the foods introduced during the early stages of discovery of solid foods in infancy.

8.3.1 Acceptance of food texture at different stages of oral development

The consequence of the stages of development of feeding skills is the substantial evolution of acceptance of food texture during this period (Szczesniak, 1972). In children even more clearly than in adults, food texture may strongly influence rejection, since food textures that cannot be dealt with (i.e., swallowed) are rejected. Briefly, at birth, the only accepted texture is liquid. Around 4 months, the acceptance of semi-solid foods develops. At 8 months, solid foods start to be dealt with, and are well accepted at 10–12 months. At about 2 years, children more easily accept foods that require chewing in order to be swallowed. Between 2 and 4 years, with the development of lateral movements involved in chewing, foods that are either soft/moist or crispy/crunchy start to be accepted. So preferences are progressively oriented toward textures that can be processed.

Few experimental studies support these general statements. Offering applesauce with different textures (puréed, lumpy and diced) to infants from 6 to 12 months showed that they react negatively to the most complex textures, whereas infants aged 13–22 months show positive face and body movements for the same textures (Lundy et al., 1998). Alternatively, comparing different textures of carrot (puréed and chopped) in 12-month-old infants showed that the acceptance of the chopped carrots was more variable than acceptance of puréed carrots (Blossfeld et al., 2007). Moreover, the infants who were introduced to mashed foods earlier, and had a greater experience with chopped foods, consumed more chopped carrots than the infants who were introduced to solid foods later. Additionally, infants who had more teeth ate more of both textures (puréed and chopped) of carrots (Blossfeld et al., 2007).

In Japan Sakashita et al. (2003) studied which type of foods could be eaten by children of ages varying between 2 and 46 months. This work usefully reported the median age at which each type of food could be accepted by children, though unfortunately textural properties were not precisely described.

8.3.2 Impact of exposure to food textures on the development of oral physiology and food acceptance

Eating behaviour is essentially learned through experience. In particular, learning how to chew is developed by experience with food textures. In other sensory domains, it has been clearly shown that the exposures as early as the first oral stimulations will contribute to developing competences and food acceptance. Many studies regarding early food exposure were focused on the role of flavour (taste and odours) on the development of food acceptance (Nicklaus, 2011; Schwartz et al., 2011), but much less is known about the specific role of experience with food textures. However, exposing the child to foods with different textures seems essential for the development of oral physiology and also of acceptance of foods with varied textures (Coulthard et al., 2010).

Several factors related to early feeding experience may impact the acceptance of food texture: the mode of milk feeding (breast vs. bottle), and the timing and progression of introduction to solid foods, in particular the texture experience of the first non-milk feeding. The impact of these factors will be discussed below.

8.3.2.1 Impact of the mode of milk feeding

Breastfeeding and bottle-feeding differ in different aspects, in particular because the flavour of breast and formula milk differ (Cooke and Fildes, 2011). During the last 20 years, the role of breastfeeding in the promotion of the acceptance of new flavours and foods has been extensively discussed (Hausner et al., 2010; Lange et al., 2013; Maier et al., 2007b; Mennella and Beauchamp, 1993; Mennella et al., 2001; Schwartz et al., 2013a; Sullivan and Birch, 1994). Breastfeeding also impacts feeding skills, as will be described.

Breastfeeding, grasping-biting and chewing cycles progressively induce continuous stimulation of the growth of the maxillaries and dento-alveolar structures (Limme, 2010). The feeding skills develop together with the types of foods eaten and the food preparation method (Stevenson and Allaire, 1991). Feeding provides the stimuli for craniofacial growth, through oral muscle activity: muscles are stretching the bones, resulting in bone growth (Gomes et al., 2006).

Sucking from the breast starts the process of stimulation of oro-facial muscles, which will be taken over by mastication. Children who were breastfed for longer period (at least 12 months) had higher masticatory functions scores (which consisted in an evaluation of cutting with incisors, lip closure during mastication, bilateral and alternating masticatory movements, rotational mandibular motion and no excessive use of perioral muscles during mastication) at 3–5 years (correlation coefficient: $r = 0.47$) (Pires et al., 2012). The milk feeding mode can affect the development of oral musculature (Limme, 2010). Sucking from the breast induces a strong aspiration and intra-buccal depression, requiring a strong activity of the lips and propulsion/retro-propulsion movements of the mandible. When sucking from a bottle, the required intra-buccal depression is less important, and the lip, tongue and jaw activities are reduced (Lau and Hurst, 1999). Moreover, horizontal movements of mandible are limited and vertical movements are more important (Limme, 2010). Few studies evaluated the impact of mode of milk feeding (breast, bottle and cup) on oral muscles activities. A reduction in masseter activity was observed during bottle-feeding compared to breastfeeding (Gomes et al., 2006, 2009; Inoue et al., 1995; Sakashita et al., 1996). Muscle activity was also shown to change with mode of milk feeding because sucking from the bottle results in a hypo activity of the masseter and temporalis muscles and a hyper activity of the buccinator muscle (the muscle forming the anterior part of the cheek), compared to sucking from the breast (Gomes et al., 2006). This different organization may produce different functional stimuli, which may affect craniofacial growth and ultimately oral functions (Limme, 2010; Pires et al., 2012). Based on sEMG measurements, some authors showed that cup feeding as of the first weeks or months (Franca et al., 2014; Gomes et al., 2006) or bottle-feeding with a chewing-like bottle teat (Sakashita et al., 1996) could be an alternative method if the infant cannot be breastfed, because these methods provide muscle activity similar to breastfeeding.

The impact of breastfeeding on the time and number of chewing cycles required to eat solid, viscous and puréed food in infants aged between 6 and 24 months has not been systematically examined (Gisel, 1991). However, in a review on the effects of the mode of milk feeding on oral motor development, Neiva et al. (2003) concluded that starting with breastfeeding may promote a proper oral motor development and may help preventing speech-language disorders related to oral motor system.

8.3.2.2 Impact of timing and progression of introduction to complementary (solid) foods

Few studies have investigated the importance of the timing of introduction of foods with different textures during infancy on feeding skills (Nicklaus, 2011). Some studies have highlighted the impact of repeated exposure (Maier et al., 2007a; Remy et al., 2013; Sullivan and Birch, 1994) or of the introduction of a variety of complementary foods on the acceptance of new foods (Coulthard et al., 2014; Gerrish and Mennella, 2001; Lange et al., 2013; Maier et al., 2008); however, they did not directly address the impact of the introduction of a variety of textures on feeding skills and texture preferences.

It has been proposed that there is a sensitive period of introduction of foods with different textures (Harris, 1993), at about the moment following the disappearance of tongue protrusion reflex (Illingworth and Lister, 1964). This reflex results in pushing the food out of the mouth when it is placed on the anterior tongue. Moreover, introduction to complementary foods should not take place before infants are able to maintain their head in an upright position while seated (Delaney and Arvedson, 2008).

In order to understand the impact of food texture on the masticatory ability in infants, it is useful to remember that in adults, the rheological properties of the food products induce an adaptation of the chewing behaviour (Woda et al., 2006). Thus, proposing a variety of food textures to infants will provide different stimuli and will trigger adaptation in term of muscle activity and mandibular movements. Since the infant is in a developing phase, this stimulation will affect the growth of the masticatory apparatus. During the phasing bite stage (at about 1 year), infants start to bite with the incisors. This action requires movements of propulsion of the mandible, similar to movements during breastfeeding, which will contribute to the growth of the mandible and the development of the maxilla (Limme, 2010). It therefore seems important at this stage to propose foods resistant to biting.

The introduction of complementary food was reported to impact peptide and protein salivary composition (Morzel et al., 2011, 2012) but not electrolyte content (Na^+, K^+, Ca^{2+}, Mg^{2+} and Cl^-) (Ben-Aryeh et al., 1984). An increase in S-type cystatins in saliva has been observed with diet transition. According to Morzel et al. (2011), this increase may constitute a regulatory mechanism in order to protect against excessive proteolysis by cysteine proteases brought by fruit and vegetables, which constitute an important part of the complementary diet.

Longitudinal studies help to understand the functional impact of timing of solid food introduction on eating behaviour. A follow-up study of the same group of infants between 6 and 15 months showed that infants who received lumpy solids before 6 months had less feeding difficulties (32%) than those who received it after 10 months (52%) (Northstone et al., 2001). These results were complemented by a more recent follow-up of the same cohort of children, when they reached 7 years, which showed that the children who had received their first complementary foods after 10 months consumed fewer vegetables at 7 years than children who received solid foods before 6 months (Coulthard et al., 2009).

8.4 Modification of food texture for infants and children: Need and practices

At around the age of 6 months, milk is no longer sufficient to provide the nutrients the infant needs for growth, so the introduction of solid foods to complement (breast) milk feeding is recommended (Pan American Health Organization, 2003; World Health Organization, 2003). Some paediatrician and dietician organizations recommend starting complementary feeding after the 4th month; that is, when the infant starts to be physiologically ready to learn to process semi-solid and solid foods (Agostoni et al., 2008; Butte et al., 2004). However, the timing of complementary feeding is debated. There is even less consensus on the way to introduce solid foods (Schwartz et al., 2011), probably because of the relative lack of knowledge in this area.

However, to ensure and promote children's health and nutritional status, some governmental public health bodies established guidelines about infants' complementary feeding, which can be categorized according to the 'when, what, how' framework (Butte et al., 2004; Pac et al., 2004; Schwartz et al., 2011). Such guidelines take the scientific rationale into account, but also the cultural traditions. As a result, complementary feeding practices vary a lot among different cultures.

This section will give an overview of the existing regulations and recommendations regarding food texture introduction at the beginning of complementary feeding, from both a public health body and a scientific perspective (Table 8.1). Some practices of texture modification for infants and toddlers foods will also be described (Table 8.2).

8.4.1 Regulations regarding texture of complementary foods

We tried to locate national regulation regarding the texture of the first complementary foods, but were not able to identify such regulation. In Europe the Directive 2006 125/CE is focused on the nutritional quality of preparations made from cereals and baby foods for infants and toddlers (The Commission of the European Communities, 2006). It does not address the topic of texture.

8.4.2 Recommendations from public health bodies

There is a lack of consensus among countries regarding the age for the introduction to complementary foods and how parents should manage the variety and infants' exposure to these foods (Schwartz et al., 2011).

In the WHO guidelines (World Health Organization, 2003), experts recommended exclusive breastfeeding for 6 months, followed by a gradual introduction of complementary foods (Table 8.1). Puréed, mashed and semi-solid foods are recommended at 6 months followed at 8–12 months by finger and family foods (Pan American Health Organization, 2003). Similar timing was advised by the American Academy of Pediatrics (AAP) (2012), the National Health and Medical Research Council of Australia (NHMRC) (2012), the European Network for Public Health Nutrition (2006) and the French Institute for Health Prevention and Education

Table 8.1 Selected guidelines from public health bodies with highlights on recommendations regarding the introduction to solid foods

Guideline	Year	Country	Recommendation
Pan American Health Organization (PAHO): *Guiding principles for complementary feeding of the breastfed child (pp. 18–20)*	2003	International	Complementary feeding at 6 months of age with small amounts of food. Gradually increase food consistency and variety as the infant gets older, adapting to the infant's requirements and abilities. At 6 months, infants can eat pureed, mashed and semi-solid foods. By 8 months most infants can also eat 'finger foods'. By 12 months, most children can eat the same types of foods as consumed by the rest of the family. Avoid foods that may cause choking.
World Health Organization (WHO): *Complementary feeding* *Report of the global consultation. Summary of guiding principles (pp. 3–12)*	2003	International	Appropriate complementary feeding around 6 months with continued BF up to 2 years or beyond. Complementary foods should be varied and include adequate quantities of meat, poultry, fish or eggs, as well as vitamin A-rich fruit and vegetables every day.
American Academy of Pediatrics (AAP)	2000	USA	Exclusive BF until 4–6 months of age; introduction of solid foods at 4–6 months of age, continued BF to the first birthday and beyond if possible. Use infant formula for the first year of life when BF is not possible. The Academy cautions against the feeding of hard, small particulate food during the 2–3 years of life and recommends introducing single-ingredient complementary foods one at a time for a several day trial.
	2012		Exclusive BF for about 6 months, followed by continued BF as complementary foods are introduced, with continuation of BF for 1 year or longer as mutually desired by mother and infant.

Continued

Table 8.1 Continued

Guideline	Year	Country	Recommendation
Maternal Child Health Division	2001	Japan	Solid food (smoothly mashed or puréed) can be introduced at 5 or 6 months. The best sort of nutrition for a baby before weaning is milk (breast milk or formula). Juice is not recognized as a meaningful form of nutrition before the start of introducing solids.
National Health and Medical Research Council of Australia (NHMRC) (pp. 10–12)	2012	Australia	Introduction of solid foods at around 6 months to meet the infant's increasing nutritional and developmental needs and iron-containing nutritious foods are recommended to be the first foods. Ensuring appropriate food texture with developmental stage: from puréed to lumpy to normal textures during the 6- to 12-month period. Avoid whole nuts and other hard foods to reduce the risk of choking.
European Food Safety Authority (EFSA)	2009	Europe	In agreement with the WHO recommendations and other authoritative national and international bodies: breast milk is the preferred food for infants. The Panel considers that the appropriate age for starting complementary feeding is determined by the nutritional adequacy of exclusive BF at different ages, by potential health benefits related to continued exclusive BF (effects on development of motor, cognitive and social functions) and by the impact of early feeding on risk of diseases in later life (obesity, cardiovascular disease, diabetes mellitus, etc.).
European Society for Pediatric Gastroenterology, Hepatology and Nutrition (ESPGHAN)	2008	Europe	Introducing solid food not before 17 weeks (4 months) and not later than 26 weeks. FF and BF should receive solid food at the same time.

Table 8.1 Continued

Guideline	Year	Country	Recommendation
European Network For Public Health Nutrition (EUNUNET) (p. 17)	2006	Europe	Infants should be started on complementary foods at or shortly after six months of age. Between 6 and 8 months foods should be given 2–3 times a day, increasing to 3–4 times daily after 9 months of age, with additional snacks offered 1–2 times per day, as desired, after 12 months. Breast milk should remain the primary source of nutrition for the whole of the first year of life. During the second year of life, family foods should be the primary source of nutrition.
French Institute for Health Prevention and Education (INPES) (pp. 25–43)	2005	France	Complementary feeding not before 6 months. Accustoming the infant to different textures and introducing one change at a time (new taste or texture; bottle or spoon). From 6 months: mixed, pureed, mashed fruit, vegetables, meat and fish. From 8 to 12 months: starchy foods and food texture should evolve with the infant's maturity and desire.
Department of Health and Children	2003	Ireland	BF mothers are now being encouraged to delay the introduction of any food or drink, other than breast milk, until their babies are 6 months old. They are also being encouraged to continue BF after that in combination with appropriate complementary foods (solids) up until the age of 2 years or beyond.
Food Standard Agency (p. 27)	2008	UK	Starting complementary feeding at around 6 months. At 6 months: smooth purée and mashed food; From 6 to 9 months: soft finger foods, mashed food with lumpy pieces. From 9 to 12 months: chopped, minced food and hard finger foods.

Continued

Table 8.1 Continued

Guideline	Year	Country	Recommendation
Department of Health (Start4life)	2011	UK	Introducing solid foods to babies at around 6 months old. Recommends homemade food from simple ingredients with no added sugar or salt. Baby food in jars or packets can be handy but portion sizes are often too big and much of it has the same texture. First food from 6 months: mashed or soft cooked sticks of fruit and vegetables all cooled before eating, and baby rice mixed with the baby's usual milk. Cup introduction from around 6 months and offering sips of water with meals. From 8 to 9 months: mixture of finger foods, mashed and chopped foods. From 12 months: chopped food, maternal milk or cow's milk and healthier snacks (e.g., fruit, vegetables sticks or toast, rice cakes).

BF, breastfed/breastfeeding; FF, formula fed.

(INPES, 2005). In 2000, the AAP recommended introducing single-ingredient complementary food one at a time for several day trials (American Academy of Pediatrics, 2000). Between 6 to 8 months complementary foods should be given 2–3 times a day and then increasing to 3–4 times daily after 9 months, with additional snacks; during the second year, family foods should gradually become the primary source of nutrition (European Network for Public Health Nutrition, 2006).

Other groups, such as the Nutrition Committee of the European Society for Pediatric Gastroenterology, Hepatology and Nutrition (ESPGHAN), suggested that around 4–6 months, infants are able to adapt to different foods varying in texture, and that complementary feeding may start after 17 weeks, and not later than 26 weeks (Agostoni et al., 2008). The European Food Safety Authority (EFSA) (2009) added that between 4 and 6 months it is safe to introduce complementary foods. In France, during the transition phase from milk to complementary feeding, it is recommended to accustom infants to different food textures, but one at a time (INPES, 2005). From 6 months, mixed, puréed, mashed fruit, vegetables, meat and fish are recommended, then from 8 to 12 months on, the texture should evolve with the infant's maturity and desire. In Ireland, recommendations from the reference of Section 8.7: http://www.dohc.ie/press/releases/2003/20030805.html?lang=en are aligned with those from the ESPGHAN (Agostoni et al., 2008). More recently, the UK Department of Health (Start4life, 2011) recommended that solid food should be introduced at around 6 months for both breastfed and formula-fed infants. The UK Food Standard Agency (2008) specified that new textures should be introduced at different stages: from 6 months on, mashed, soft fruits/vegetables (parsnip, potato, apple, etc.) and baby rice mixed with milk were advised. From 8 to 9 months, mashed foods with lumpy pieces and soft finger foods are advised. From 12 months on, a diet similar to that of the family (e.g., chopped, minced forms, hard finger foods) could be followed.

In the Asia Pacific region, the recommended timeframe for the introduction of complementary foods also varies between countries. In China, the Ministry of Health used to recommend the introduction of solid foods to infants after 4 months, but more recently this was changed to 6 months (Inoue and Binns, 2014). In Japan, the Maternal Child Health Division of the Ministry of Health recommended in 2001 the introduction of solid food such as smoothly mashed or puréed foods at 5–6 months. In 2012, The Australian NHMRC recommended puréed foods, rice cereal, yoghurt and egg-yolk as first foods introduced at 6–7 months, followed by vegetables, fruit and cooked soft meat around 8–12 months. The WHO, the EUNUNET, the UK Food Standard Agency and the Australian NHMRC agree in their recommendation concerning the age for the transition from baby to family food, 12 months.

8.4.3 Description of infant feeding practices

Results from contemporary research evidenced that, in most countries around the world, caregivers give complementary foods before the recommended age, as described in Table 8.2.

Mothers in the USA introduce solid food earlier than the recommended age, which is 4 months (Butte et al., 2004). Fein et al. (2008) highlighted that 21% of US mothers introduced solid food before 4 months and 7% waited until 6 months; and that 10% of mothers introduced new foods faster than recommended (no more than 3 new foods per week) when infants were 5 months, 16% when infants were 9 months and 13% after 10 months. Single-grain cereals are generally introduced first, mixed with breast milk, formula or water. Between 3 and 4 months the proportion of infants consuming cereals increased from 18% to 40% (Grummer-Strawn et al., 2008). American mothers often use commercial baby foods between 5 and 10.5 months, especially for fruits and vegetables; after this age they prefer homemade products (Fein et al., 2008). In another study, before 4 months, 44% of infants had received cereals and, for 71% of them, it was given in the bottle (Crocetti et al., 2004). Infant cereal persists as the main food in the diet until 8 months. The median age for the introduction to meat was at around 8 months and at 1 year 97% infants consumed meat or substitute (Grummer-Strawn et al., 2008). From 9 months on, infants consume all food categories. At 1 year, 50% consumed French fries, candies and cookies.

In Asia, the earliest age of complementary feeding was 3.8 months in urban areas in China, while it was closest to the WHO recommendation (5.6 months) in Japan and the

Table 8.2 **Examples of complementary feeding practices (e.g., regarding texture modification) in different parts of the world, from national surveys (longitudinal, cross sectional and transversal surveys)**

Authors, year	Country	When: age of complementary feeding	What	Other information
Fein et al., 2008	USA	Before 4 months: 21%		Between 5 and 10.5 months, 29% of the mothers introduced more than three new foods per week.
		After 6 months: 7%		Between 6 and 9 months, 42% of mothers used commercial baby food (fruit and vegetables), by the end of the first year mothers used it less.
		Before 6 months	Juice (20%)	Among infants aged 10.5 months: 48% had eaten restaurant food at a restaurant at least once in the previous 7 days, 22% had eaten take away food from a restaurant at least once, and 28% had eaten either type of restaurant food at least twice.
		Before 10.5 months	Cow's milk (26%)	
		9, 10.5, or 12 months	<1 daily serving of fruit or vegetables (15%)	
Crocetti et al., 2004	USA	Before 4 months	Cereals (44%)	Exclusive or partially BF infant were less likely to have been introduced to solid food before 4 months.
			Jar food (17%)	71% of infants who received cereals had it in bottle for feeding.
			Table food (3%)	

Grummer-Strawn et al., 2008	USA	3 and 4 months	Cereals (18% and 40%, respectively)	
		5–6 months	Fruit and vegetables	At 4–5 months, most of infants received solid food as daily basis.
		7.5 months	Fruit and vegetables (>90%)	From 6 months, 80% of the infants consumed solid foods on a daily basis. At 6 months, the majority of infants consumed at least 1 serving per day of solid foods only from two food groups, by 9 months, most of them consumed at least 1 serving per day from all three food groups (protein products, fruit and vegetables and cereals).
		10.5 months	Cow's milk (17%) and products based on milk	
		1 year	Meat (97%), milk (81%), French fries, candies and cookies (50%)	
Inoue and Binns, 2014	Asia Pacific region	4 months (mean age)	Rice, rice products	In Vietnam, farmer and educated mothers introduced solid food later, at 24 weeks.
	China	3.8 months (urban area)		
	Vietnam	4 months (median age)		In Japan: 100 days after birth, traditional ceremony: introduction of vegetables soup. First priority for mothers is to continue exclusive breastfeeding for the first 6 months and then introduce nutritious complementary foods. In Australia, mean age of introduction of CF changed over the decade separing the two cohort studies (PIFS I and PIFS II) from 4.0 to 4.4 months.

Continued

Table 8.2 Continued

Authors, year	Country	When: age of complementary feeding	What	Other information
	Malaysia	5.5 months	Traditional food: wheat flour and fish	
	Japan	~5.5 months		
	Australia	4.4 months		
Jackson et al., 1992	Northern Thailand	4 weeks (median age)	Rice-based foods	In most cases, rice-based foods is softened to a semi-solid by pounding or mastication. In rural northern, glutinous rice preferred to ordinary one.
		3 months	Mashed rice and banana + fresh fruit, fruit juice and commercial infant cereal	Throughout the first year, foods softened by pre-mastication.
		6 months	Soft meat and rice mixtures, fresh fruit	
		9–12 months	Pre-masticated pieces of meat and snacks (rice-based dish with coconut milk or agar–agar jelly or wheat products)	First reasons for starting complementary feeding: 'time to stop breastfeeding' or 'baby old enough' (37% of mothers).
Sakashita et al., 2004	Japan	Before 6 months, >50% of infants	Rice gruel	Complementary feeding evolves faster for mothers who follow family and friend advices than for those who follow books or magazine information.

		At 6 months, 83% of infants	Rice gruel, noodles, boiled rice, boiled minced meat, sliced apple, bread, ham easily accepted	
		From 12 months	Cucumber sticks, leaf vegetables, boiled Japanese leek, shredded raw cabbage, sliced meat, or beef steak not easily accepted	Preparation from family table seems to promote eating progress.
Duong et al., 2005	Vietnam	The CF rate increasing from 16.4% at week 1 to 56.5% at week 16 and to nearly 100% at week 24	Fruit juice (15% and 19% at weeks 16 and 24), homemade rice solution (nuoc chao) (5% and 24%, respectively)	Home cooked preparation. Infants, whom solid food was introduced to, were fed more than twice per day.
			Home cooked solid foods (rice, meat and egg) (4.8% at week 1; 40.9% and 74.3% at weeks 16 and 24)	Reasons for changing the feeding pattern: 'do not have sufficient milk', 'for better health of infants', 'returning to work' and 'complementary food is good for health'.
				Infants were likely to be fed with solid food when their parents had higher income and lived independently.
Schiess et al., 2010	Europe (Belgium, Italy, Spain, Poland, Germany)	Among FF infants: 6% at 3 months, 37.2% at 4 months, 96.2% at 6 months and 99.3% at 7 months	Solid food (meat, fish, cereals, bread, egg, fruit, vegetables, milk products, nuts, soy products, potatoes and fat)	FF: early introduction of solid food in Belgium (15.8% at 3 months and 55.6% at 4 months), while in Italy and Poland the proportion were the lowest at 3 months (2.4% and 3.1%, respectively)
		Among BF infants: 0.6% at 3 months, 17.3% at 4 months,		BF: at 4 and 5 months Belgium had the highest proportion of infants receiving solid food (43.2% and 84.8%,

Continued

Table 8.2 Continued

Authors, year	Country	When: age of complementary feeding	What	Other information
		87.1% at 6 months and 97.7% at 7 months		respectively), while Germany and Poland had the lowest percentage (4.9% and 25%; 6.7% and 36.2%, respectively).
Giovannini et al., 2004	Italy	4.3 months (median age)	First solid foods: fruit (73.1%) and cereals (63.9%; gluten free (52.2%), with gluten 11.7%), vegetables (40.3%), meat/poultry (13.7%) and milk products (9.2%)	All infants received solid foods by 9 months. In BF and FF infants, solids were introduced before 3 months in 5.1% and 10.1%, respectively.
Mesch et al., 2014	Germany	From 5 months	Commercial and homemade baby food: vegetables–potato/rice/pasta/pasta–meat meal	From 6 to 9 months the total number of vegetables increased in homemade meals and decreased slightly at 12 months. The number of different vegetables consumed with a vegetables–potato–meat meal did not differ between homemade and commercial meal between 6 and 9 months, but at the age of 12 months higher values were observed for the commercial meal (2.7 ± 1.4 vs. 3.7 ± 1.5). Most often poultry and beef were used in homemade and commercial meal. No puree vegetables meals were offered in junior age (8–12 months).

Lande et al., 2003	Norway	Before 4 months: 21%	Porridge of iron-fortified commercial baby cereal, meat and vegetables/potatoes	Positive shift towards delayed introduction of solids among Norwegian infants over the past two decades.
		At 4 months: 47%	Banana most consumed, fruit and berries (54%) almost once a day	
		Before 6 months: 91%	Yoghurt (9% of infants)	
Schwartz et al., 2013a,b	France	Before the recommended age of 6 months	First food given: pureed carrot and apple puree	Mothers added vegetables to the bottle of milk to create a smooth transition to purees. They preferred the introduction of solids using a spoon rather than a bottle.
				For mothers, texture should evolve gradually from smooth puree to lumpier foods alongside the oro-motor skills development.
				Potatoes used as binder to adapt the texture of the meal.
				Shared practices concerning the use of ready-to-eat baby food and homemade food.
Lange et al., 2013	France	Around 5 months	Fruit (45%) and vegetables (40%)	The variety was particularly high for vegetables (mean = 38; sd = 23), meats (mean = 35; sd = 22) and dairy products (mean = 24; sd = 14). The variety was lower for biscuits and starchy foods (mean = 6; sd = 5 for both).
		Before 4 months: 7% of the infants		The number of new food introduced increased significantly between the ages of 4–5 months and 5–6 months (5–13 in average).

Continued

Table 8.2 **Continued**

Authors, year	Country	When: age of complementary feeding	What	Other information
		Between 4 and 6 months: 74% After 6 months: 26%	Dairy products, cereals, meat, starchy foods, fish and biscuits	Positive reactions to new food (91% of the cases), but differ according to food category: fruit and vegetables were the least positively accepted foods at the beginning of weaning (mean reaction = 2.3 on a scale from −3 to +3).
Brown and Lee, 2011	UK	BLW: later complementary feeding (~22.3 weeks) compared to SW (~20 weeks) but earlier introduction of foods in solid form (23 weeks) compared to SW (26 weeks)	First food introduced: fruit or vegetables (~78%)	BLW-mothers were more likely to offer their infant fresh, homemade foods.
Cameron et al., 2013	New Zealand	After 6 months: 65% of the 'adherent BLW', 33% of the 'self-identified', 34% of the 'parent-led feeding'	Within BLW infants: baby rice cereal (5.9%), fruit (58.8%) and vegetables (35.3%) Within parent-led weaning: baby rice cereal (53.6%), fruit (34.3%) and vegetables (12.1%)	BLW infants were more likely to be offered family foods and less likely to be offered commercial baby foods.
Cameron et al., 2012a,b	New Zealand	Start of BLW: 5.5–6 months (exclusively BF infants)	Vegetables (steamed or boiled pumpkin, potato, sweet potato, broccoli and carrot; $n = 13/20$) and fruit (avocado, banana; $n = 11/20$)	According to mothers and health professionals, BLW promotes shared family meals, reduces mealtime battles and is more convenient than spoon feeding purees, encourages healthier eating patterns (child control of feeding)

CF, complementary feeding; FF, formula fed; BF, breastfed; BLW, baby-led-weaning; SW, standard weaning.

Maldives (Inoue and Binns, 2014). From 3 to 4 months rice in the form of paste, gruel or porridge is the main food introduced, with an exception in Malaysia, where a traditional dish based on wheat flour and fish was first introduced (Inoue and Binns, 2014). In Thailand, rice-based foods are introduced in the first days or week after birth and in some regions such as the north of the country, glutinous rice is preferred to ordinary rice (Jackson et al., 1992). At 3 months, mashed bananas complement the rice diet. At 6 months soft meat is added to rice; fruit are also introduced. At 9–12 months, soft meat, rice and mashed banana are gradually removed from the infant's diet and snacks (e.g., biscuits, crackers) are offered instead (Inoue and Binns, 2014; Jackson et al., 1992). Some mothers soften rice and meat by pre-mastication before feeding their infants (Jackson et al., 1992). In Japan, rice is also commonly introduced first, but 100 days after birth, a traditional ceremony includes the introduction of fruit juice and vegetable soup (Inoue and Binns, 2014; Sakashita et al., 2004). More than 50% of Japanese infants received rice before 6 months, and 83% at 6 months (Sakashita et al., 2004). This is in accordance with a national survey (Maternal and Child Health Division the Ministry of Health Labour and Welfare, 2001).

Significant variations also exist among European countries in the timing of complementary feeding. In Italy, mothers introduced solids before the age of 3 and 4 months, for 5.6% and 34.2% of infants respectively (Giovannini et al., 2004). During this period, the first foods introduced were principally fruit, vegetables and cereals. In a recent work studying the complementary feeding practices in five European countries, authors reported an early introduction to solid foods in Belgium among formula-fed infants (FF) (15.8% at 3 months and 55.6% at 4 months), while in Italy and Poland the proportion was lower at 3 months (2.4% and 3.1%, respectively) (Schiess et al., 2010). Among breastfed infants (BF), Belgium had the highest proportion of infants receiving solid foods at 4 and 5 months (43.2% and 84.8%, respectively), while Germany and Poland had the lowest percentage (4.9% and 25%; and 6.7% and 36.2%, respectively). Among the five countries, 97.7% of BF and 99.3% of FF had been introduced to solid food at around 7 months (Schiess et al., 2010). In Norway, 21% of infants were given complementary foods before 4 months and 91% at 6 months (Lande et al., 2003). Porridge-based baby cereal was the most common first food (39% at 3 months) and meat with vegetables/potatoes was the most common dinner. From 6 months on, fruit and berries were consumed by 54% of infants. In France, vegetables, fruit and cereal are introduced to child's diet almost at the same moment, at about 5.5 months (Lange et al., 2013). However, from 5 to 15 months, the variety was particularly high for vegetables, meats and dairy products, but was lower for biscuits and starchy foods (Lange et al., 2013). Fruit and vegetables in the form of purée or soup are mainly introduced at around 5 months (Fantino and Gourmet, 2008). During the second year, family food consumption gradually increases from ~3% of energy intake at 5 months to ~72% at 31–36 months (Fantino and Gourmet, 2008). An investigation of practices, attitudes and experiences of introducing vegetables among French mothers revealed that the first foods given to infants were puréed carrot and apple (Schwartz et al., 2013b). French mothers agreed on the fact that texture should evolve gradually from smooth purées to lumpier food, and they adjust the texture of foods by adding potatoes to other vegetables. According to the interviews, it is difficult for mothers to choose between ready-to-eat baby food and homemade food. Preparing food is seen as a healthy investment for infants, whereas commercial foods are considered as good backup option when mothers are busy. However, French mothers found the texture and taste of commercial baby foods different from their own preparation.

Altogether, timing of complementary feeding and texture modifications may vary to a large extent between and within countries, in particular in relation to the use of commercial or homemade foods.

We will now describe examples of texture variations in commercial foods, and on the other end of the spectrum, practices related to BLW, which involves the presentation of pieces of food, with no modification of their texture.

8.4.4 The texture of commercial baby foods

Presently, ready-to-eat commercial foods represent an important part of complementary foods (Caton et al., 2011; Fein et al., 2008; Mesch et al., 2014; Schwartz et al., 2013b). These commercial preparations are designed so that recipes meet nutritional needs at different ages. If nutritional values are well described, little information is available on the texture of these commercial preparations as a function of age. In the literature, the flow and/or viscoelastic properties were determined for various baby foods composed of vegetables (Ahmed and Ramaswamy, 2006a,b), vegetables and meat (Alvarez and Canet, 2013), meat (Ahmed and Ramaswamy, 2007b), fish (Alonso and Zapico, 1996) and fruit (Ahmed and Ramaswamy, 2007a; Juszczak and Fortuna, 2005). The evolution of the flow during storage at different temperatures was studied for 4 different groups (vegetables, meat, fish and fruit) (Alonso and Zapico, 1996). Finally, several authors characterized the rheological properties of new recipes for developing baby food product with added nutritional values (Kechinski et al., 2011; Ramamoorthi et al., 2009; Wadud et al., 2004; Wan et al., 2011). In all these studies, the foods were puréed, corresponding to the early transition foods.

To the best of our knowledge, limited information is available concerning food products proposed for older infants and, more generally, on how the textural properties of commercial baby foods change as a function of age. Therefore we recently ran experiments in order to characterize the structural properties of baby foods available on the French market and to describe how these properties change according to the suggested age for consumption. Twenty-five baby food products (7 fruits and 18 vegetables or vegetables–meat), commercialized in plastic containers, plates or glass jars, were randomly selected in a local supermarket. Products were selected based on the suggested age (as mentioned on the packaging), from 4/6 to 24 months, and represented 3 main baby food manufacturers.

Fruit products available on the market were only puréed and the suggested ages were 4/6, 6 or 8 months. Their flow behaviour was determined by steady flow measurement (ambient temperature, shear rate varying from 0 to 100 s^{-1}). Flow consistency and flow index behaviours varied significantly among recipes but the differences were not related to suggested age.

Vegetables and vegetables/meat products suggested for 4/6 and 6 months were puréed. They included particles in all studied samples from 8 to 24 months. Particles were collected via filtration (1 mm) and further analyzed for their relative quantity (ratio between particle weight/total product weight), size (image analysis after filtration) and global hardness (20 g of particles, compression test at 50%, TAXT-Plus, retro-extrusion geometry). Particles filtered in all tested recipes were mainly pasta and vegetable pieces (mainly carrot), as illustrated in Figure 8.2.

Differences in particle hardness were not related to suggested age. For all the samples, particles represented 8.8–48.3% of product total weight and measured between 3.9 and 15.4 mm for vegetables pieces (carrot, corn, peas, pepper and leek) and 3.2 and 22.2 mm for starchy particles (pasta, rice and potato) (Figure 8.3). The quantity and the size of the particles tend to increase with suggested age; however, important

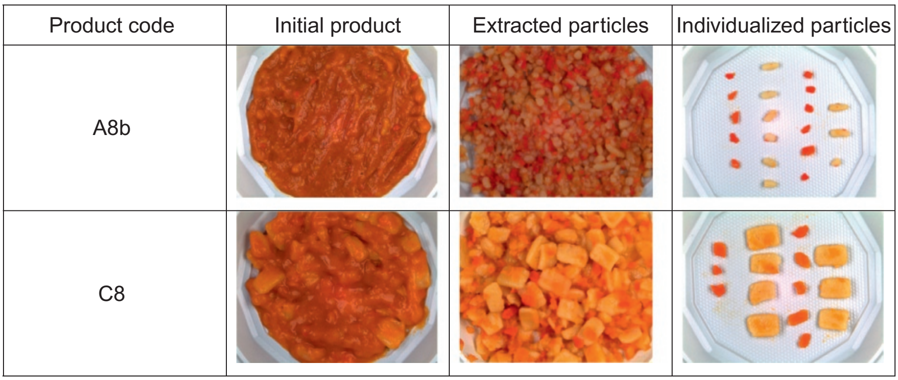

Figure 8.2 Examples of two baby food products prepared with vegetables aimed for 8-month-old infants.

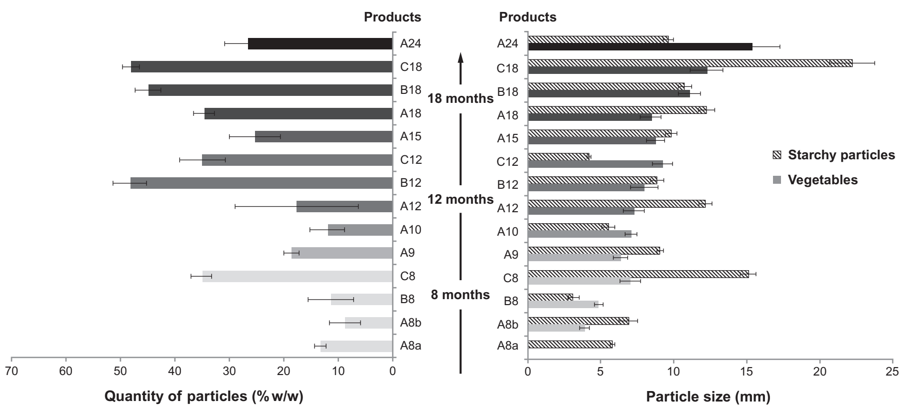

Figure 8.3 Evolution of particle size and quantity of particles with age in baby food products. Products: A, B and C represent different baby food manufacturer; 8, 9, 10, 12, 15, 18 and 24 represent the advised age. The intensity of the grey/black shading is proportional to the age of the infants.

variations were observed across brands and recipes, as highlighted in Figure 8.2 where textural and (micro-) structural differences are illustrated for two recipes recommended for the same age.

The number of different particle types also seemed to increase with age: products for 8–10 months ($n=6$) contained 1–4 different types of particles and products for 12–24 months ($n=8$) 3–5 types. The differences were mainly due to an increased variety of vegetable particles.

Over the products studied, changes in structural properties between baby food products for different suggested ages were observed. With ready-to-eat foods, infant oral functions may be mainly challenged by the management of particles of increasing size, content and variety with time. Nevertheless, in the present sampling, large variations were observed between brands and between recipes. These results are in line with the absence of regulation regarding the texture of baby food products. It is important to keep in mind that this study was exploratory and only a limited number of products were studied for a given age. Therefore these results do not necessarily represent the full diversity of commercial products offered on the French market and even less around the world.

8.4.5 Baby-led weaning: consequences for texture modification

Recently, a practice known as BLW has emerged and has become quite popular among parents in New Zealand and the UK (Cameron et al., 2012b; Rapley, 2011). BLW is an alternative method for introducing complementary foods to infants in which infants feeds themselves hand-held foods instead of being spoon-fed by an adult. Generally it takes place at 6 months and the first foods offered are vegetables and fruit (Cameron et al., 2012b; Rapley, 2011). In order to allow self-feeding, only pieces of whole foods are offered to infants. The knowledge, attitudes and experiences of parents and healthcare professionals regarding BLW were studied recently (Cameron et al., 2012a, 2013). According to interviews and questionnaires, both parents and healthcare professionals recognized several advantages to BLW. Firstly, it facilitates the mealtime preparation because the infant eats the same foods as the rest of the family. Secondly, this method allows the child to control the amount of food eaten. However, despite the enthusiasm for BLW, some disadvantages are noted. Professionals were skeptical about the beginning of BLW at 6 months, knowing the immaturity of the oral motor processing at this stage. Parents also acknowledged that food waste increases with infant autonomy. In addition, professionals and mothers were not sure if children who fed themselves ate enough to ensure appropriate caloric and iron intake.

A comparison between mothers who used BLW and those who used standard weaning (SW) showed that BLW-mothers introduced complementary foods later than SW-mothers, but introduced finger foods earlier (Brown and Lee, 2011). BLW-mothers were more likely to give fruit or vegetables as first food (~78%). This comparison was not focused on texture, despite the expected impact of BLW on acceptance of texture.

8.5 Conclusions

The reasons and benefits of the introduction of new textures during the process of complementary feeding have been detailed. Despite of the benefits of introducing a variety of new textures during this period, advice on this topic has not been systematic and universal. Many parents have difficulties introducing new textures and dread the introduction of small pieces of foods. Currently there is no regulation in this area and recommendations are mostly limited to the timing of the onset of complementary feeding. Few recommendations establish a food texture evolution as a function of the infant's age and emphasize the importance of exposing the child to varied textures. Clearly, more experimental studies are needed regarding this topic to provide a scientific rationale to improve recommendations.

8.6 Future trends

Despite the recognized importance of the topic, very few studies have characterized infant's acceptance of foods according to their texture. In particular, infants' eating behaviours toward foods with important contrasts of texture (like pieces in a purée) has not been revealed. Moreover, rheological properties of the foods offered to infants have not been properly described. The consequences of infant's oral processing of foods on bolus formation have also not been shown. In particular, how saliva may incorporate in food and change its texture deserves attention in future studies. Studies reporting complementary feeding practices rarely drive attention toward the texture of complementary foods.

The consequence of being exposed to food with soft texture (such as complementary foods) or hard texture (such as the case in BLW) on the development of children's feeding skills is still an open question. A better knowledge of the influence of the timing of complementary feeding on the development of feeding skills is also required. All these aspects are very important to producing more evidence to support appropriate guidelines for health professionals and the food industry, concerning timing of introduction to different textures. Ultimately, this will contribute to support parents' efforts in developing their infant's healthy eating habits.

8.7 Sources of further information and advice

International conference on Food Oral Processing, organized every other year (First edition, 2010, organized by University of Leeds, Leeds, UK; Second Edition, 2012, organized by Centre des Sciences du Goût et de l'Alimentation, Dijon, France; Third Edition, 2014, organized by Wageningen UR, Division of Human Nutrition, Wageningen, The Netherlands).

The following websites from public health bodies may have useful information (all websites consulted in July 2014):

The World Health Organization: http://www.who.int/publications/guidelines/child_health/en/.
The American Academy of Pediatrics: http://www.aap.org/en-us/Pages/Default.aspx.
The Japanese Ministry of Health Labour and Welfare: http://www.mhlw.go.jp/english/.
National Health and Medical Research Council of Australia: https://www.nhmrc.gov.au/guidelines-publications.
The European Food Safety Authority: http://www.efsa.europa.eu/.
The European Commission's Directorate for Public Health and Risk assessment: http://ec.europa.eu/health/nutrition_physical_activity/projects/index_fr.htm.
UK National Health Service Start4life: http://www.nhs.uk/start4life/Pages/healthy-baby-advice.aspx.
The Food Standard Agency: http://www.food.gov.uk/.
The Department of Health of Ireland: http://www.dohc.ie/press/releases/2003/20030805.html?lang=en.
The French 'Programme National Nutrition Santé' from the Ministry of Health: http://www.mangerbouger.fr/pro/le-pnns/pnns-en-detail/documents-pour-le-grand-public/le-catalogue-des-outils-du-pnns.html.

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Legislation and practices for texture-modified food for institutional food

9

D. Johnson
National Association of Care Catering, West Sussex, UK

9.1 Introduction

The main theme of the chapter will focus in brief on the current legislation, industry guidance standards and recommendations for care establishments and services, schools and hospital food provision. This work is based on the service provision in the United Kingdom; depending on where the reader is, there may be different providers, but ultimately a person in care in the UK requires the same level of good nutritional care as does a person in care in the Americas. The scale and influence of public sector catering is not to be underestimated: An excess of three billion meals are served annually in the United Kingdom, and half of these are to young people in the education sector. This chapter will investigate the challenges faced in delivering these standards and guidance, often non-regulatory. The information will endeavour to elucidate how these services handle identified eating problems, and the pressures this type of dietary requirement is placing on services to support and meet these specific needs, which often occurs as a result of associated work being undertaken to raise awareness of eating issues in health and social care settings, in particular.

The sections will contain the current regulations and guidance; identify potential regulations in consultation or being considered by government; the awareness and pressures of the modified texture dietary need; future trends and developments in the industry to support services in addressing this increasing requirement to meet this specific need; further support and information currently available; and options for keeping abreast of market developments and accessing the reports, legislation and guidance relevant to your own setting.

This chapter will be useful for those commissioning, managing or operating food services for healthcare settings, social care or schools. This includes but is not limited to service commissioners, senior managers and catering professionals.

9.2 Regulations and guidance

On April 1, 2010, for the first time there was a reference to a food and drink provision in health and social care settings. The legislation for governing food and fluids in these settings was made under Regulation 14 of the Health and Social Care Act 2008 (Regulated Activities) Regulations 2010 (Health and Social Care Act, 2008).

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The extract from regulation 14 reads
"Meeting nutritional needs:

14—(1) Where food and hydration are provided to service users as a component of the carrying on of the regulated activity, the registered person must ensure that service users are protected from the risks of inadequate nutrition and dehydration, by means of the provision of:
- **(a)** a choice of suitable and nutritious food and hydration, in sufficient quantities to meet service users' needs;
- **(b)** food and hydration that meet any reasonable requirements arising from a service user's religious or cultural background;
- **(c)** support, where necessary, for the purposes of enabling service users to eat and drink sufficient amounts for their needs.

(2) For the purposes of this regulation, "food and hydration" includes, where applicable, parenteral nutrition and the administration of dietary supplements where prescribed."

Usually referred to by those operating in the industry as "Outcome 5 Meeting Nutritional Needs", it provides the provider with a requirement to meet the needs of a person who is prescribed a texture-modified diet as this is determined under (a) and (c) of the regulation; to ensure the person receives sufficient amounts of food and the support required for them to consume it. In practice many people on a modified diet do require extra support to eat the meal provided, either due to the cause of the requirement through dementia or Alzheimer's disease or as a result of an illness (i.e., stroke) restricting movement and the need to reacquire the skills where possible to enable them to feed themselves.

Every health and care service with a catering provision should understand the importance of getting nutrition and hydration right and strive to improve the quality of their nutritional care in an environment that also respects their service users' dignity.

The National Association of Care Catering (NACC) and Care England worked together to produce guidance, *How to Comply with Care Quality Commission's (CQC) Outcome 5: Meeting Nutritional Needs,* which embeds nutritional well-being into good practice and enables all regulated social care providers to meet Outcome 5 and Care Quality Commission (CQC's) fundamental standards.

The guidance highlights the evidence required and links this evidence to what inspectors will be looking for when they inspect. The guidance document provides useful implementation packs to help providers meet the standards without having to reinvent the wheel, as many will have no formal training or expertise in catering or nutritional care. Guidance such as this helps embed good practice in the care sector. If mealtimes are to be enjoyable then they will have been provided in a person-centred, dignified manner and this guidance will help achieve that.

There is a now call by industry, led by the Cost Sector Catering PS100 group, to turn some of the guidance outlined below into regulated standards that can be monitored and effectively introduced in all the relevant settings. (See the section on Future Trends for further details.) As the reader will see, guidance and regulation apply to different parts of the process for health and education settings, yet besides meeting nutritional needs there is no defined regulation for the care sector in either residential and day care or community settings.

To make it clearer for the reader, I have indicated the sector that the guidance applies to at the head of each section.

Care—This sector covers nursing homes and residential homes, sometimes known in other countries as long-term care facilities; day care where there are no health professionals involved in supporting the care service; and community-based services (i.e., meals on wheels or lunch clubs).
Health—This sector covers food provided in all healthcare settings for both inpatients and outpatients where applicable.
Education—For the purposes of this information, this covers children and young people from entry into education until the age of 18 if attending a school. Colleges and universities are not addressed, because the person accessing these services has freedom of choice of where they access food to meet their own individual needs.

9.2.1 Care

9.2.1.1 A Recommended Standard for Community Meals (National Association of Care Catering, 1992)

First published in 1992 by the NACC and updated regularly since, this guidance provides constructive and informative advice about operating and specifying a community meals service. Local authorities and leading manufacturers have adopted it as the industry standard for community meal provision. The last review includes the latest thinking on nutritional needs for the elderly, with practical advice on achieving these requirements. The guidance includes specifications for breakfast and tea as well as main meals delivered in the community. There is a section on training and development that incorporates guidance on induction, development and the training for food safety and implementing National Vocational Qualifications. Transportation for the meals to ensure quality and safety is key. With details on refrigerated temperature-controlled vehicles and mobile regeneration vehicles, it provides guidance on best practices. Dietary needs are also addressed in the guidance with reference to meeting cultural needs (i.e., Greek, Mediterranean, Chinese and Polish diets, amongst others). Medical diets and meeting these requirements are addressed, as are texture-modified meals. The latter is a growing area of provision for community meals services.

9.2.1.2 NACC Minimum Standards for Residential and Community Care Settings (National Association of Care Catering, 2012)

In the absence of any specific standards for the care sector, the NACC through its commitment to providing recipients of community meal with tasty and appealing food that is appropriate to meet a complex range of individual tastes and nutritional requirements extended their work in the community meals sector to include residential settings. Thus there was an updated reference point for nutritional guidance for a residential setting, following on from the 1995 Caroline Walker Trust Eat Well for Older People (Anne Dillon Roberts et al., 1995) report of the expert working group, which set out nutritional guidelines for older people in residential or nursing homes and community meals. A further report on nutritional support for people with dementia was published in the 2011 (Crawley and Hocking, 2011).

The NACC nutritional guidance requires nutritional analysis of meals, and asks for the nutritional content of each meal and snack to be provided. A task for many of the smaller care homes without a specialist resource, and no legislation to require adherence means it is the larger groups and local authorities' provision that can adhere to this guidance fully.

The minimum standard requires that each meal such served at lunch, tea or suppertime consists of a main course (e.g., the entrée, starch, vegetables and gravy/sauce or sandwiches and their fillings) plus side salad must provide a minimum of 300 kcals of energy, provide a minimum of 15 g of protein and include a good source of protein and a starch, and a minimum of 80 g serving of vegetables. The dessert, unless fruit, must provide a minimum of 200 kcal.

For those providing other meals, breakfast must provide each a minimum of 380 kcal and 8 g of protein; 5 portions of fruits and vegetables per day should be available, some as snacks with these providing at least 400 kcal. Where fluids are provided: a minimum of 7 beverages per day (1500 ml) including the use of a minimum of 400 ml milk (see Table 9.1).

Table 9.1 Nutrient recommendation per day for older persons

Breakfasts, main meals, snacks and beverages	Total energy (approx.)	Protein (approx.)
Breakfast (Assuming a choice of fruit juice, cereal and milk, bread and spread, preserves)	380 kcal	8 g
Main meals Two per day, each providing 500 kcal	1000 kcal	30 g
Higher-energy snacks, including a supper snack Total of at least three daily (If fruit is served, this will provide fewer calories but is a good option for fibre and for those who need to control their energy intake)	400 kcal	4 g
Milk for drinks 400 ml Minimum of 7 beverages, including milky drinks	264 kcal full fat variety	13 g full fat variety

For practical purposes, the total provided from these can be rounded to 2050 kcal and 50 g protein.
from NACC Minimum Standards for Residential and Community Care Settings.

The minimum standard is for a varied menu available to suit a variety of clients' needs including ethnic, cultural and religious requirements; medical/health conditions (e.g., healthier eating, gluten free, modified texture, etc.). For the latter, soft may also be useful for identifying which dishes are easier to eat. Local and regional customs and traditional practices (e.g., fish on Fridays) should be reflected, even though this is in direct contradiction of the CQC guidance on the same dish not appearing on the menu in a four-week period.

The standard also describes requirements for dietary codings, and just two years later the first one, Healthier Eating to embrace tolerances for salt, saturated fat, sugar and total fat, thus making it suitable for people with diabetes, and those managing their weight, cholesterol levels and/or blood pressure is changing in industry terms to Eating for Health to avoid confusion with the wider concept of health eating.

Higher energy for those with conditions that require extra calories and allergen content of meals must be available in accordance with UK Food Labelling Regulations and Amendments. The latter is a challenge for the smaller providers.

The hydration standard is now widely accepted as the requirement in the UK, with the requirement for drinks to be available at all times and with 1.5 l per day provided.

The NACC nutritional standards were launched in October 2010, with the aim to be in place by end of December 2012. The NACC have indicated the nutrition standard will be updated every 5 years.

The standards address the minimum acceptable level. Many providers of meals for the care sector already provide high standards of meals with nutritional content commendably in excess of the standards outlined here.

9.2.1.3 Menu Planning and Special Diets in Care Homes Manual (National Association of Care Catering, 2006)

This manual was produced in 2006 (see National Association of Care Catering, 2006 and in references) to assist care home staff in meeting the nutritional needs of adults under their care. The manual was developed from work-based practices by Val Conway, a community dietitian from the Bexhill & Rother Primary Care Trust. The manual's primary aim is to guide care homes into meeting or even exceeding the National Minimum Standards for Care Homes, as set at the time by the Department of Health. The manual still continues to provide solutions to common menu planning problems and dietary issues, and its easy-to-follow format enables a balanced diet to be served. The manual provides a reference point that could be utilised to help unit managers, care staff and catering staff understand the myriad of special diets, whether they are medical, cultural or religious, to enable the provision of nutritional and wholesome meals to all. The guidance includes specific reference to texture-modified foods and includes examples of menus for the provision of texture-modified meals and finger foods. The day to day provision of nourishing food to care home residents can be a challenging task, taking into account that every resident has individual dietary needs. This manual explains what special and healthy eating diets are. It gives practical advice on how to prepare and plan menus to meet residents' requirements. It is best used as a reference, where the appropriate section can be turned to and read.

9.2.2 Care and health

9.2.2.1 Healthier and More Sustainable Catering: a toolkit for serving food to adults (Levy et al., 2014)

This guidance published by Public Health England in 2014 (see Levy et al., 2014 and in references) focuses on the Government Buying Standards for Food and Catering Services (GBSF) to ensure food sold to consumers is produced to higher sustainability and nutritional standards, and with a more sustainable catering service provision. It also includes information to help those buying, preparing and serving food, with a range of support tools and case studies to assist with the aim of achieving a healthier, sustainable provision. The nutrition standards included are nutrient based and for a healthy 19–74-year-old, as detailed in the Healthier and More Sustainable Catering: Nutrition Principles (Nutrition Advice Team, 2014). This guidance is good for healthy under 74 years old. However the majority of those in Long Term care and in some hospital wards are over 74 years and with their health is deteriorating they require significantly more nutritional intake than recommended in this guidance.

9.2.3 Health

9.2.3.1 Health and Social Care (amended) (Food Standards) Bill 2013

This is a private members bill introduced to the House of Lords on 14 May 2013 by Baroness Cumberledge, who is the President of the Hospital Caterers Association. The explanatory notes for the bill state, "The Bill seeks to improve hospital food in England by requiring the Secretary of State of Health to: (a) convene a body of experts to draft standards for hospital food, and (b) apply these standards to all hospital food in England by including them in Care Quality Commission inspections. If it is found that hospitals are not compliant with the standards, they will risk having their registration with CQC suspended."

The bill has reached the stage in Parliament when it has had its third reading in the House of Lords and is being passed to the House of Commons for consideration. If it is passed on to the Statute Book, it will then ensure there is a minimum regulatory standard for nutrition in all healthcare settings in the England.

9.2.3.2 Observation prompts and guidance for monitoring compliance Guidance for CQC inspectors Outcome 5: Meeting nutritional needs (Care Quality Commission and the Royal College of Nursing, 2010)

The guidance was published by the Care Quality Commission and the Royal College of Nursing with assistance from the National Patient Safety Agency and the Department of Health in October 2010. The generic guidance was developed to ensure that those inspecting and monitoring health and social care settings are able to act effectively during their visit through a series of observations and prompts. The document does help the person inspecting or monitoring to focus on the day-to-day food and drink provision, ensuring it is person centred.

9.2.3.3 10 Key Characteristics of Good Nutritional Care

The '10 Key Characteristics for Nutritional Care' are based on recommendations made by the Council of Europe. These encourage member states to:

1. Implement national recommendations in food and nutritional care in health and social care
2. Promote implementation both in public and private sectors
3. Ensure widest possible dissemination of recommendations

Since their launch the '10 Key Characteristics for Nutritional Care' (National Association of Care Catering, 2011; National Patient Safety Agency et al., 2009), have helped to raise the standard of care catering for hospital patients and those in social care settings. The characteristics set out the criteria that should be used as a standard measure of care for all those working in the care sector. There are two versions of the 10 Key Characteristics, one for hospital settings and the other for care settings; both have the same guiding principles but are written so the characteristics apply to the setting in which the nutritional care is delivered. The characteristics are endorsed by the leading professional organisations operating in the respective settings and this assists to further encourage their embedding in frontline practices.

9.2.3.4 Dysphagia diet food texture descriptors (National Patient Safety Agency et al., 2011)

The descriptors detail the types and textures of foods needed by individuals who have swallowing difficulties and who are at risk of choking or aspiration (food or liquid going into their airway). The aim of these descriptors is to provide standard terminology to be used by all health professionals and food providers when communicating about an individual's requirements for a texture-modified diet. The food textures are:

B = Thin Purée Dysphagia Diet
C = Thick Purée Dysphagia Diet
D = Pre-mashed Dysphagia Diet
E = Fork Mashable Dysphagia Diet

After development by the National Patient Safety Agency (NPSA) Dysphagia Expert Reference Group in association with Cardiff and Vale University Health Board, the descriptors were launched in May 2011, and initially reviewed in April 2012. The descriptors are supported by the key professional associations: National Patient Safety Agency, Hospital Caterers Association, National Association of Care Catering, National Nurses Nutrition Group, the British Dietetic Association and the Royal College of Speech and Language Therapists (SLT).

9.2.3.5 The Education (Nutritional Standards and Requirements for School Food) (England) Regulations 2007 (The Education (Nutritional Standards, 2007))

These regulations introduced a nutrient-based food standard over a three-year period to ensure by 2009 that it was in place in all state schools. The interim position utilised a food-based food standard prior to the nutrient-based food standard being introduced. The future for education catering is the School Food Plan (Dimbleby et al., 2014), which advocates a food-based plan and takes into account all food served in schools. This is important to include as much as possible, as unlike the health and social care settings where often the food and drink served is the only food and drink the person can access, in a school environment the nutrient-based standard was covered by legislation but for only one meal per day. The change means more of the food provision the child can access is covered by the standard. It needs to be remembered that the rest of the day, during the weekend and holiday periods, the child's food experience is usually family centred.

9.2.4 Education

9.2.4.1 The School Food Plan

The consultation phase is now complete and the new standards will be confirmed in the summer of 2014 and come into effect in January 2015, with 16 key actions aimed to transform the way children eat and learn about food in the school setting, including the introduction of food-based standards again. The food-based standards cover any food served in school, including breakfast clubs, break-time snacks, any food served in after-school clubs, as well as the main lunchtime meal; the previous nutrient-based standards covered only this meal. The standards will set requirements for minimum servings of fruit, vegetables and oily fish, meat content for meat products; and ban categories of foods including confectionary, snacks and sweetened soft drinks, and limit the number of times less healthful foods can be served.

Education: In addition to the School Food Plan, Universal Infant Free School Meals are to be introduced in England from September 2014. Similar arrangements will apply in Scotland from January 2015. Wales has decided to concentrate on its existing School Breakfast initiative. Northern Ireland has extended the criteria for free school meals and is considering their position on the universal option. This highlights the challenges the school caterers face across the four home countries, with differing approaches to feeding young school-age children a balanced diet.

Prison food: The main source of nutritional intake for those incarcerated is provided to a generally healthy population unlike health and social care, where those in receipt of the core services are nutritionally vulnerable due to other longer-term conditions. The current guidance document Prison Service Order 5000 is being phased out; this was based upon the Food Standards Agency nutritional information and the eatwell plate (Your Guide to the Eatwell Plate—Helping You Eat a Healthier Diet, 2013). It does include guidance on portions sizes and meal entitlement for prisoners. Prisons already cater for a range of cultural and religious diets, and these special diets can achieve these nutrition principles.

9.3 Awareness and pressures

The main pressure on the provision of food in any of the public sector settings is the food budget and the allowance per head. There is little guidance on recommended minimum allowances; the Caroline Walker Trust (CWT) were recommending approximately £18 per head per week for a residential care home on page 18 of the second edition of Eating Well for Older People (Anne Dillon Roberts et al., 1995), published in 2004, but they have accepted it was not calculated in a very scientific way. The average amount spent in a hospital is less than in a prison setting, and more than a care setting, and within the education sector there is constant pressure to reduce the cost of food on the plate. The big pressure on the budget is the general increase of food costs up 5.8% in the last two years, based on the Office of National Statistics information, yet many public sector organisations have held or reduced budget allowance to reflect wider financial pressures in this sector. It is worth reflecting that the price allowed per day would barely buy a coffee on the high street; the challenge is for the provider of the catering services—whether they are internal or external—to supply a meal and more for this cost. Fortunately or unfortunately, depending how it is viewed, we are now in a period when food and drink are being seen a fundamental part of the care of a person in hospital or social care; the development and growth of a child in school, and even in prisons food is seen a vital part of ensuring a calmer and more stable environment.

In an age when integrated working, particularly in health and social care, is the in vogue terminology, there is no formal recognition of the role food and drink plays in helping to prevent illness or demand for other more costly interventions; how food and drink can aid recovery more effectively in healthcare settings, often reducing pressure on beds space (reducing cost) or more costly clinical interventions using costly medication. The food budget spent effectively in one sector or department can result in reduced costs in others, but the transfer of appropriate funding to the internal food and drink budget or the external provider to achieve this or further develop the services and support does not take place.

Constant questions and pressures are asked of the caterer (can you reduce this meal by x pence?), but the key dilemma facing the caterer is how these financial demands are met without compromising the nutritional integrity of the food and drink provided.

When the identification of a person requiring a texture-modified diet is made, this often increases the pressure on the food budget. An external food source may have to be utilised to provide food to meet this need, where the catering staff in the care facility do not have the skills, knowledge or equipment to safely produce food to enable the modification to take place on site. There is also the requirement to fortify the meals if they can be produced on site, as a person with modified texture requirements will in practice eat smaller portions. This can be due to several factors, including not being able to feed themselves, or to the fact that despite the taste of the food being familiar, the change in texture removes the enjoyment from eating the meal. This may be due to the change in appearance, affecting the swallow, to the feel of the food itself in the mouth being unfamiliar. All this increases the cost to the caterer, but it actually is a clinical intervention that has been made, yet the cost is from the catering budget and not the medical or pharmacy budget. After all, texture-modified food and drink are the medication in this scenario.

The skills and knowledge to safely and appropriately texture-modify food in a care setting are more problematic than in a hospital setting. This is often due to the care home cook/chef being the only person in the kitchen, whereas on hospital catering teams there are usually specialist dietary sections, and training and instruction can be more easily accessed from the on-site Speech and Language Department. The core skills training for cooks and chefs does not include training in texture modification, and for those who have received instruction from the Speech and Language Specialist, accessing the equipment to achieve the requirement may also be restricted. With increasing numbers of cases of dysphagia being identified in residential care settings, there is a growing requirement for suitable training in this area. In many cases initial training is carried out by the provider of food or drink modification products rather than the local health care professionals.

The training and support from the producers of thickening products varies, as does the accessing of this support from service managers. Many users of these products do not realise if there are changes from gum based to starch based, and vice versa; the method of use changes, as does the food/drinks appearance. There is the challenge for staff or carers to support the appropriate use of these products, as they often have a view on its suitability, appearance or taste for the person they are caring for, despite it being prescribed by the General Practitioner/Doctor or Speech and language Specialist (SLT).

Increased awareness in wider health and social care professionals has led to earlier identification of potential dysphagia illnesses. Through the development of training and awareness sessions and initiatives, this has enabled these professionals to spot the signs of swallowing issues earlier. This in turn has led to more referrals for specialist intervention to further investigate. This awareness means there has been a reduction in local ‘prescribing’ of soft/pureed food, with service managers waiting for the medical specialist to identify the appropriate texture modification required.

As with every good initiative, raising the awareness of dysphagia, there is an impact, the wait for speech and language assessment increased sometimes up to three months after initial identification. In a residential care setting this places pressure on the registered managers to develop a care plan for the person’s food preferences as carefully as possible so as not to compromise the person’s rights whilst maintaining a duty of care. In many areas this has been recognised and new teams of SLT are being redeployed and placed in community settings. In healthcare settings this has been recognised with SLT intervention to occur within five days of admission as required.

Early identification and intervention is key; if this risk/illness fails to be recognised, it can put someone at risk of under-nutrition. This failure to identify and intervene is often a cause for the onset of under-nutritional illness in institutional settings.

Terminology is a huge hurdle to overcome, until everyone adopts the same terminology for food and fluid descriptors at least nationally, if not internationally. Because many of the producers of product for this market place are multi-nationals, it would make sense for there to be one agreed set of descriptors globally. Every day in the realm of health and social care, terms such as soft, mashed, mushed, liquidised, blitzed, porridge-like, rice-pudding-like and blended still are heard. Everyone has slightly differing interpretations of those terms. 'How do you like your rice pudding?' Thick or milky, two very different textures, yet if that's how someone's dietary need is described, it would be easy to get it wrong. The introduction of the Dyspahgia Diet Food Texture Descriptors in May 2011 (National Patient Safety Agency et al., 2011) was a huge leap in the right direction, because not only is the terminology standard, but there is supporting information on how to produce meals to meet the specific diet type, which are very useful for the caterer. The challenge is to make everyone involved in the care and health sector aware of them.

9.4 Conclusions

The identification of people requiring texture-modified diets in the sector is increasing faster than the education or services to meet these specific dietary needs. The sector's service users will become more reliant on texture-modified diets and their safe delivery to aid recovery and improve quality of life, so it is imperative that everyone working in the sector is aware of this particular type of dietary need.

To compound this issue further, the recognition of good nutrition and hydration as a means of aiding recovery and improving quality of life is still a long way from being universally recognised by all involved in the person's care. From senior executive levels to the frontline workers, both clinical and support services, this key aspect of care needs to be further embedded within the service and various organisations that provide nutrition and hydration.

9.5 Future trends

The industry has seen developments in recent years in the production of texture-modified meals.

The Canadian company Prophagia's Epikura Foods range led the early development and this continues today. Prophagia's development work was reported as early 2006, as a way to improve nutritional intake in a report in the *Journal of the American Dietetic Association* (Germain et al., 2006). Their unique process used in the production provides normal-looking foods that remain appetising to the recipient. The process developed enables the food to be safe and easy to swallow, and has led the way for other food producers to make foods suitable for the various texture-modified diets. These products take the reliance off the caterer and place them into the hands of a specialist producer, but the effect is an increase in the cost of the meal, the benefit to the caterer is a reduction in the choking risk and often a perceived improvement in the food for the person on the specific modified diet (www.prophagia.com).

In the UK, Apetito, a major manufacture of prepared meals for the care and health care sectors, have won many industry awards for their development work in producing texture-modified meals to the industry descriptors (www.apetito.co.uk). Producers and distributors of food to the care and healthcare sectors are now investing time and research and development into products that are suitable for the dysphagia diet. Premier Foods are carrying out research and development in this area for products that will provide the caterer with wider opportunities to deliver an in house meal that meets the dietary need (http://www.premierfoods.co.uk).

There have been recent reports on development work in producing laser-printed foods that would be suitable for those in need of a texture-modified diet. These are in the early stages of development.

There are always new food companies, suppliers of food or services entering the marketplace. To do this does require perseverance on the part of the new service provider because the market is often sceptical about the reliability of the provider to remain in the marketplace. Once this is passed the sector does see key providers gain a high brand loyalty and often market dominance. If a new supplier is looking to test the market with a new service or product, I would suggest they exhibit at the professional association exhibitions, as well as maintain contact through area/regional meetings, and take the opportunity to attend the various events to find out the latest trends in the respective sectors.

The work being initiated by the International Dysphagia Diet Standardisation Initiative (DDSI) in developing global standardised terminology and definitions for texture-modified foods and thickened liquids for individuals with dysphagia of all ages, in all care settings and all cultures will hopefully come to fruition. The interest around the world in achieving this aim is huge, with over 2000 health care professionals, food service, industry partners, patients, careers and patient organisations all expressing an interest and responding to a survey to move this initiative forward. If achieved, this will mean reducing risk even further and the food provision to those with swallowing issues will improve as national boundaries will no longer prevent the dissemination of best practices in this form of nutritional care.

In the UK there is a movement of professionals who through the Cost Sector Catering PS100 are increasing pressure for legislative nutrition standards based around the eatwell plate. The PS100 are calling for government to take three decisive actions for food served in or funded by the public sector:

- Protected mealtimes, currently only a good practice intervention. If this was a legislative require then mealtime would truly become everyone's business to ensure good nutrition is delivered; they could no longer be interrupted except in an emergency.
- A lifetime nutrition plan to ensure all the service in the public sector or promoting the same levels of good nutrition.
- Create a national lead for Food, Health & Nutrition. The appointment of the latter will be key to driving this agenda forward; whoever undertakes this role must have a passion to drive change and to promote good food across the public sector.

9.6 Support and information

National Association of Care Catering (NACC) The professional body for those involved in care catering in UK. A useful point of accessing further information on care home guidance, the community meals recommended standard and the 10 Key Characteristics for Good Nutritional Care in care settings (www.thenacc.co.uk).

Hospital Caterers Association (HCA) are the professional body for caterers in hospitals in UK, a useful contact for further information on hospital catering in the UK (www.hospitalcaterers.org).

National Patient Safety Agency Link to the 10 Key Characteristics for Good Nutritional Care and supporting fact sheets for hospitals (www.npsa.nhs.uk).

Malnutrition Task Force An independent group on working on preventable malnutrition and hydration (www.malnutritiontaskforce.org.uk).

International Dysphagia Diet Standardisation Initiative (IDDSI) aims to develop global standardised terminology and definitions for texture-modified foods and thickened liquids for individuals with dysphagia of all ages, in all care settings, and all cultures (www.iddsi.org).

Local Authorities Caterers Association (LACA) The professional body for school meal providers in the UK; a useful contact for further information on school meals catering in the UK (www.laca.co.uk).

Care Quality Commission (CQC) Regulatory body for health & social care, issued guidance about compliance, essential standards of quality and safety, March 2010. This guide is designed to help providers of health and adult social care to comply with the Health and Social Care Act 2008 (Regulated Activities) Regulations 2010 (www.cqc.org.uk).

Nutrition and Hydration Week An international focus week held in every year in March to raise and share good practices in health and social care settings worldwide; this does include modified texture foods and practices (www.nutritionandhydrationweek.co.uk).

9.7 Glossary of worldwide terms used in food service

The information below demonstrates what diverse terminology is used in the delivery of food in institutional settings across the world, and this does not include the numerous terms used in each nation for texture-modified food.

UK & Ireland—Hygiene
US & Canada—Sanitation
Australia—Hygiene
All measures necessary to ensure the safety of food during preparation, processing, manufacturing, packaging, storing, distribution and handling and so on.
NB: In Australia, sanitation refers to a final cleaning process of sanitising food preparation equipment and surfaces as bacteria free.
UK & Ireland—Catering Manager
US—Dietary Manager
Canada—Nutrition Manager or Food Service Supervisor
Australia—Food Services Manager or Catering Manager
An individual who is responsible for the food service operation, including menu compliance, cost control, customer satisfaction, staff hours and hygiene/sanitation will normally hold a managerial qualification.

UK & Ireland—Home for Older People
US—Nursing Home or Assisted Living or Senior Apartments
Canada—Long-Term Care Facility
Australia—Nursing Homes or Aged Care Homes
An establishment where over-65-year-olds live; here meals are served in dining areas. Staff are in attendance 24/7 to look after residents' care needs.
UK & Ireland—Nursing Home
US—Long Term Care Facility
Canada—Long Term Care Facility
An establishment where those in need of nursing care live; here meals are predominantly served in dining areas. Registered Nursing staff are in attendance 24/7 to look after residents' care needs.
UK—Day Centre
Canada—Adult Day Centre
Australia—Day Centre or Community Centre
Normally an establishment where over-65-year-olds are referred after an assessment of needs; meals are served in a communal dining area.
For other age groups, the type of group is specified in the title (i.e., Day Centre for Adults with a Physical Disability).
UK—Lunch Club
US—Congregate Dining
Canada—Lunch Club
Australia—Senior Citizens Club
A voluntary group who organise a weekly or twice-weekly event in a community setting (i.e., a church hall) where a meal is served to elderly living in the community.
UK—Meals on Wheels/Community Meals Service
US—Meals on Wheels Program
Canada—Meals on Wheels
Australia—Meals on Wheels
The organisation that delivers meals to a person who is living at home in the community. These can either be served hot or frozen.
UK—Sheltered Housing Complex
US—Assisted Living
Canada—Assisted Living Facility
Australia—Aged Care Residential Living or Aged Care Retirement Village
A group of living units overseen by a *warden*, where the elderly live in their own environment. The complex may include a communal area. (A warden is a paid member of staff who lives on site and checks on the residents daily.)
Australia - Other organisations include Women's Crisis Centre, Men's Welfare Club, Drug and Alcohol Centre, and Social Outreach Services.
UK & Ireland—Dietitian
US—Registered Dietitian
Canada—Dietitian
Australia—Dietitian
A registered person with a dietetic qualification.
UK—Catering
Ireland—Catering
US—Foodservice

Canada—Foodservice
Australia—Foodservice
An area of the hospitality industry we are employed in, or the core activity we provide at our place of work.
UK—I.T. (Information Technology)
US—Automation
Canada—Automation
The use of computers and software packages in the workplace.
UK—Rubbish
US—Trash
Canada—Garbage
In a world where waste management and recycling of waste is becoming an issue, these are the local terms we use for the products and food stuffs we no longer require.

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Texture design of 'free-from' foods—The case of gluten-free

10

M. Papageorgiou, A. Skendi
Alexander Technological Educational Institute of Thessaloniki (ATEITh), Thessaloniki, Greece

10.1 Introduction

A 'free-from' claim could be seen as an absolute claim that consumers perceive as complete absence of the substance in question. On the other hand, the best that can be scientifically demonstrated at present is that samples of the food are shown to be below the analytical limit of detection of a testing method for the particular substance. In the case of a general scientific consensus, appropriate limits for claiming that a product is free from, for example, a particular allergen can be set, on the condition that adverse reactions to human health are unlikely to be triggered.

A popular 'free-from' case is gluten-free cereal products intended primarily for consumption by celiac patients. In the western culture gluten is a traditional ingredient in baked goods, but nowadays it is used in different applications due to its unique structural and functional properties. Excluding gluten from the recipe imparts substantial changes in the texture of the final product since gluten has important functions in foods such as texture enhancer, leavening agent, thickener and flavouring agent. Therefore, gluten-free formulas require a number of other ingredients to substitute wheat gluten and to mimic its texture in the food matrix.

Market availability of products made from naturally gluten-free flours such as rice, corn, pseudocereals and other alternative sources in combination with additives such as non-gluten proteins, hydrocolloids and emulsifiers is increasing, aiming at maintaining the desired textural properties on one hand and enhancing the nutritional value on the other. Joint research by food manufacturers and academia/research institutes is necessary to fully capitalize on the use of these ingredients and novel processing techniques for the production of tasty and healthy gluten-free products in order to match the needs of gluten-free consumers.

10.2 'Free-from' food: definition and classification

10.2.1 Allergen-free

A food allergy is an abnormal reaction of the immune system to certain proteins in food, known as 'allergens', whereas a food intolerance is an adverse reaction to a protein or non-protein constituent of a food that does not involve the immune system.

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It was estimated that around 1–3% of adults and 4–6% of children from the European population are affected with conditions ranging from very mild to potentially fatal from food allergies (EFSA, 2004). This data is reflected by the renewed consumer interest in free-from allergenic foods (European Union, 2007) such as cereals containing gluten, crustaceans, eggs, fish, peanuts, soybeans, milk, nuts, celery, mustard, sesame seeds, sulphur dioxide, lupin and molluscs during the past few decades.

‘Free from’ in the product label, in the consumer’s perception, means that the allergen is NOT a part of the product as it is delivered by the supplier. Although food manufacturers and retailers are providing foods made without adding a certain common allergenic, these foods should not be assumed to be ‘free from’. Consumers should seek further information about particular ingredients that may contain allergens and have the guaranty that rigorous controls have been in place by manufacturers and retailers to ensure the validity of the claims.

On the other hand, care should be taken by the manufacturers when guaranteeing the absence of allergens in the final product. This is because the allergens present in the samples of the food could be below the analytical limit of detection of a testing method. Only using reliable detection and quantification methods for food allergens can provide the desired compliance with food labelling and guaranteed consumer protection (Besler, 2001; Poms et al., 2004). It was observed that the amount of some allergens and their allergenicity will depend on plant variety and growing conditions (Codina et al., 2003) as well as the way of processing and preparing food (Maleki et al., 2000; Beyer et al., 2001).

For consumers who are susceptible to allergens, it is vitally important that food products have accurate, complete and informative labels. The use of the term ‘allergenic-free’ must follow some strict rules. Regulations and laws on food labelling have evolved noticeably during the last two decades and this trend is expected to continue in order to protect consumers from potential allergens. In the European Union significant progress has been made in providing consumers with valid information related to the safety of the food they consume. The key requirements of European Union Directive 2000/13 for pre-packed food among others relate to the ingredients, including allergens (European Union, 2000). The Directive 2003/89/EC amended Directive 2000/13/EC and abolished the exception that ingredients comprising less than 25% of the food were excluded from declaration. In addition, in the same directive various allergenic foods are listed that must be properly declared on the label when used as ingredients including any product derived from such foods (European Union, 2003). The European Food Safety Authority (EFSA) gives information about detection of relevant food allergens listed in the Directive 2003/89/EC as well as the threshold doses below which sensitized consumers are not at risk of developing allergic reactions (EFSA, 2004).

Commission Directive 2006/142/EC extends the list of specific allergens (including lupin and molluscs) whereas Commission Directive 2007/68/EC provides a new list of allergens which gives permanent exemption to some ingredients (European Union, 2006, 2007). Commission Regulation (EU) No. 1266/2010 further extends the allergen labelling exemption to wines (European Union, 2010). Regulation 1169/2011 introduces new requirements that allergens must be highlighted specifically in the ingredients lists (European Union, 2011). Moreover, the obligation to provide before the purchase information on allergens was expanded even further to non-pre-packed foods, including restaurants, as well as in the case of foods offered for sale by means of distance communication (distance selling). Entering into force on December 2011, this regulation gives food companies the possibility to comply with its provisions until December 2014. Currently, EFSA is reviewing the request for advice from the Food Safety Authority of Ireland about allergen risk assessment and recommendations for threshold concentrations of each listed allergen, with expected outcome in November 2014.

10.2.2 The case of gluten

Gluten, a protein composite of prolamin (in wheat named gliadin) and glutelin (in wheat named glutenin), is found in the endosperm of various cereal grain such as wheat, triticale, rye, oat and barley and is one of the listed allergenic ingredients. Intolerance to gluten is referred to as celiac disease (CD). CD is not a true allergy, it is an inherited, autoimmune disorder where the proteins from cereals (wheat, rye, barley and oats) damage the small intestine, causing diarrhoea, weight loss, malnutrition, and if not treated, significant morbidity and increased risk of mortality (Fasano, 2003a; Corrao et al., 2001; Dewar et al., 2004). The severity of the symptoms generally reflects the degree of intestinal malabsorption. It was observed that gluten induced a diversity of conditions, indicating that the immune system handles gliadin in different ways (Sapone et al., 2010). Moreover, the peptides present in the proline- and glutamine-rich protein fractions of the cereals will affect individuals who have genetic predisposition to CD (Dewar et al., 2004).

Research found that CD is only one part of disorders related to gluten. Latent CD, cereal allergy and non-celiac gluten sensitivity present more or less the same symptoms as CD does (Kaukinen et al., 2000). It was reported that CD can develop at any age and is hereditary with first-degree relatives having up to 11.5% higher risk of developing the disease (Castro-Antunes et al., 2010).

CD is a lifelong condition with no existing cure except for the strict avoidance of potentially harmful concentrations of gluten in the diet for life, in order to prevent the clinical and pathological complications of the disease as well as the associated risk of diseases such as Type I diabetes mellitus, and intestinal cancers (Fasano and Catassi, 2001; Farrell and Kelly, 2002; Peters et al., 2003; Catassi et al., 2002).

All products (foods and food additives) or medications containing gluten from wheat, triticale, rye, oats and barley or their derivatives can be harmful if taken even in small quantities. In Western cultures there exist many common foods that contain enough gluten to aggravate the health conditions of people with CD. Common sources of gluten are bread, many breakfast cereals, crackers, muffins, pasta, noodles, pizza, cakes, pies, biscuits, beer, energy bars, chocolate bars and more. Moreover, gluten may also be used as an additive for other food products such as sauces and salad dressings, prepared meat (sausages, hamburgers patties, etc.), bouillon cubes and soups. In addition, cross-contamination could be a source of gluten (e.g., preparation of food with the same tools handling gluten-containing products). Since people can be sensitive to minute trace amounts of gluten, the Association of European Coeliac Societies (AOECS) recommends utilization of separate storage/working-production area/equipment/transport (AOECS, 2013).

Oats were found to be toxic to less than 5% of patients with CD (Pulido et al., 2009). It was recommended that oats can be gradually introduced in a gluten-free diet whilst monitoring for adverse effects since only a small number of gluten-sensitive patients have an immune response to oat peptides (Ellis and Ciclitira, 2008). Products containing oat in the market today are not considered as gluten-free mainly because of the cross-contamination with wheat, rye or barley (Pulido et al., 2009). In one study it was reported that 68% of commercial oat samples from Europe, Canada and the United States are contaminated with gluten-containing cereals (Hernando et al., 2008). Moreover, 32% of inherently gluten-free millet grains, seeds and flours were found to contain more than the set limit of 20 parts per million (ppm) gluten (Thompson et al., 2010).

10.2.3 Labelling gluten-free

Even though a crossed grain logo has been universally accepted as a mark of gluten-free, labelling of gluten-free products varies around the globe. So far there is no consensus on the acceptable levels of gluten in order for a product to be categorized as gluten-free. In addition, the massive use of cereals or their ingredients that may be allergenic for individuals having CD makes it difficult for these consumers to choose the right food.

10.2.3.1 European Union

Commission regulation (EC) No. 41/2009 concerning the composition and labelling of foodstuffs suitable for people intolerant to gluten foresees that the legal definition for the claims of 'very low gluten' and 'gluten-free' in labelling is the content of gluten not exceeding 100 mg/kg and 20 mg/kg respectively (European Union, 2009). If gluten is found at lower levels (e.g., as a result of cross-contamination in a food), there is no specifically required declaration. Coming into force on 13 December 2014, the EU Regulation 1169/2011 will have a huge effect on both manufacturers and retailers and consequently on the individuals with CD (European Union, 2011). It applies to food business operators at all stages of the food chain by making mandatory labelling for cereals containing gluten (i.e., wheat, rye, barley, oats, spelt, kamut or their hybridized strains) and products thereof, including those carried over in processing aids, additives and solvents.

Due to those recent regulatory developments the choice of the right food for CD individuals has been further facilitated and the fear for hidden gluten has been eliminated.

10.2.3.2 Australia and New Zealand

The legislation for labelling of products in Australia is set out in the Australia New Zealand Food Standards Code, Standard 1.2.8, administered by Food Standards Australia New Zealand (FSANZ) (Food Standards Australia New Zealand, 2011).

In the Code, 'gluten' was determined as the main protein in wheat, rye, oats, barley, triticale and spelt relevant to the medical conditions, coeliac disease and dermatitis herpetiformis. The Code determines that claims in relation to gluten content of food are prohibited unless expressly permitted by the Code. The Code states that foods labelled as 'gluten-free' must not be used unless the food contains 'no detectable gluten', and no oats or their products, or cereals or their products containing gluten that have been malted. In addition, a 'low gluten' claim must not be made in relation to a food unless the food contains no more than 20 mg gluten per 100 g of the food. Moreover the Code specifies that a claim that a food contains gluten or is high in gluten may be made to a food product. The Code applies to all food sold or prepared for sale in Australia and New Zealand as well as the food imported into Australia and New Zealand.

10.2.3.3 Canada

In Canada, a 'gluten-free' claim can be used if the food meets the health and safety intent of B.24.018 of the Food and Drug Regulations (FDR) from Health Canada (Health Canada, 2011). This regulation on food labelling came into force in August 2012. The definition 'gluten' in the regulation comprises any gluten protein (as well as any modified gluten protein, including any gluten protein fraction) from the grain cereals such as barley, oats, rye, triticale, wheat, kamut or spelt or the grain of a hybridized strain created from at least one of the above mentioned cereals. According to Heath Canada, the food with levels of gluten not exceeding 20 ppm as a result of cross-contamination meets the requirements and the gluten-free claim can be made.

10.2.3.4 United States

Beginning August 2013, the US applies the final FDA, rule which specifies that items labelled as 'gluten-free' must meet a defined standard for gluten content (Food and Drug Administration and Department of Health and Human Services, 2013). This rule states that for voluntary use, a food labelled as 'gluten-free' must meet the following criteria:

- It inherently does not contain gluten and any unavoidable presence of gluten in the food is below 20 mg gluten per kg of food.
- It does not contain a gluten-containing grain and is not derived from a gluten-containing grain, or is not processed in order to remove gluten, if gluten presence at 20 mg or more per kg of food.

10.2.3.5 Argentina

The regulation in force of the Ministry of Health, Disposición 2574/2013 substituted the Article No. 1383 of the Argentinean Food Code. It specifies that the 'gluten-free' claim should be made only if the products contain ingredients that, naturally or after purification, are free of protein from wheat, from all Triticum species, oats, barley and rye, and from their crossed species (Ministerio de Salud, 2013). This regulation specifies that the gluten content in 'gluten-free' foods must not exceed 10 mg/kg as determined by all analytical methodologies evaluated and accepted by the National Administration. Moreover, the oral dose of pharmaceutical products must comply with the above regulation in order to make a 'gluten-free' claim. In addition, these products should include in their labels and leaflets in characters that allow easy identification the legend 'This drug is Gluten Free' and in addition print out perfectly distinguishable the same symbol used to categorize foods as 'gluten-free' as identified under Article 1383 bis of the Argentinean Food Code. A national logo was created to mark gluten-free food: *Sin T.A.C.C.*, which means NO wheat, oat, barley and rye.

10.3 Choice of alternative ingredients

10.3.1 Naturally gluten-free ingredients

As mentioned in previous sections, gluten responsible for inducing CD is limited only to certain cereal grains such as wheat, rye, oat, barley, kamut and triticale. Other cereal such as rice (*Oryza sativa* L.), maize (*Zea mais* L.), sorghum (*Sorghum bicolour* L.) and millet (*Panicum miliaceum*) lack gluten, and consequently can be used to produce gluten-free products. Although occasionally called glutens, the proteins of maize and rice differ from that of wheat since they lack gliadin. Rice, corn and potatoes were the most widely used substitutes for gluten-containing cereals, but nowadays a number of other grains, seeds, legumes and nut flours are becoming widely used.

Corn and rice flours, although commonly used, have lower nutritive value when compared to gluten-containing cereals. On the other hand, pseudocereals are considered as a good source of fibre, minerals, proteins and bioactive compounds (e.g., vitamins, antioxidant capacity and total phenols) (Valcárcel-Yamani and da Silva Lannes, 2012; Ruales and Nair, 1993; Alvarez-Jubete et al., 2009; Steadman et al., 2001; Zielinski and Kozlowska, 2000; Kozioł, 1992). Moreover, pseudocereal proteins contain a high amount and high bioavailability of essential amino acids, superior to that of common cereals and close to the quality of animal proteins (Kozioł, 1992; Ruales and Nair, 1992; Gamel et al., 2004).

Pseudocereals are ancient crops cultivated in different countries in Africa, Asia, Central and South America and fall in the category of starchy food grains. In pseudocereals, the proteins are composed mainly of globulins and albumins, and contain very little or no storage prolamin proteins, responsible for the toxicity in CD (Alvarez-Jubete et al., 2009; Grobelnik Mlakar et al., 2009). Among them, amaranth (*Amaranthus* sp.), quinoa (*Chenopodium quinoa*) and buckwheat (*Fagopyrum esculentum*) have gained increased importance. Their use is considered a valuable alternative for the production of gluten-free bakery products because they offer high nutritional quality contributing to a balanced gluten-free diet (Kupper, 2005). During the last years, a growing number of studies have investigated the application of pseudocereals in the production of nutrient-rich gluten-free foods such as bread, pasta and confectionary products (Renzetti et al., 2008; Alvarez-Jubete et al., 2010; Caperuto et al., 2001; Kaur et al., 2015; Gambuś et al., 2009; Hozova et al., 1997; Torbica et al., 2010).

Other grains that are used as gluten-free ingredients are those falling in the category of minor cereals such as fonio, teff, millet, teosinte and Job's tears. Teff (*Eragrostis tef*) was used for the production of several types of traditional flat bread (Tatham et al., 1996). Moreover, gluten-free bread was produced from sorghum (Schober et al., 2005) and carob flour (Tsatsaragkou et al., 2012, 2014).

Meals from other plant seeds were also used as alternative for the production of gluten-free products. The use of flaxseed meal (Rodrigues et al., 2012) and linseed meal (Gambuś et al., 2009) for production of cookies and cakes were also studied. Yam (*Dioscorea japonica*) flour that was traditionally used in Japanese cakes was successfully used to produce a new gluten-free bread (Seguchi et al., 2012). Acorn meal is another attractive ingredient to use in the preparation of gluten-free breads (personal unpublished data).

10.3.2 Use of additives in gluten-free products

Gluten-free formulas require a number of other ingredients to substitute the functional role of wheat gluten since gluten is a fundamental component that contributes to the overall quality and the microstructure formation of the baked products. The use of starchy flours instead of wheat flour in gluten-free products could not give the desired quality appreciated by the consumers. The most common additives used in gluten-free products include a protein source, hydrocolloids/gums and emulsifiers as well as their combinations.

10.3.2.1 Non-gluten proteins

Addition of non-gluten proteins in the recipes that include gluten-free flours was made to modify the functionality of their proteins in order to promote protein networks and improve baking characteristics of final products. In an early study, addition of different dairy powders at different concentrations in the gluten-free bread recipe was investigated (Gallagher et al., 2003). The non-gluten proteins commonly used in different recent studies are albumin (Storck et al., 2013; Schoenlechner et al., 2010; Ziobro et al., 2013; Phimolsiripol et al., 2012), casein (Storck et al., 2013; Matos et al., 2014), dry egg (Lorenzo et al., 2009) or egg white powder (Onyango et al., 2009; Matos et al., 2014), whey protein (Lorenzo et al., 2009; van Riemsdijk et al., 2011), collagen (Ziobro et al., 2013), as well as pea (Ziobro et al., 2013; Miñarro et al., 2012; Matos et al., 2014), lupine (Levent and Bilgiçli, 2011; Ziobro et al., 2013) and soy protein (Miñarro et al., 2012; Ziobro et al., 2013; Matos et al., 2014).

Ziobro et al. (2013) studied the effect of adding different proteins to a gluten-free bread recipe. They observed that replacement with albumin, collagen, pea, lupine and soy protein of 10% of the starch in a gluten-free bread formulation altered the water-binding capacity of mixtures and affected the rheological properties of the resulting dough. In the case of albumin and lupine, an increase in the specific volume of bread was reported, whereas soy protein and collagen reduced it. Generally, these proteins reduced the hardness of the bread crumb and the enthalpy of retrograded amylopectin, suggesting a valuable anti-staling effect (Ziobro et al., 2013). In their study, Miñarro et al. (2012) reported that the bread with added chickpea flour and pea protein isolate exhibited the best physicochemical characteristics and, in general, good sensory behaviour, indicating that they could be a promising alternative to soya flour.

10.3.2.2 Hydrocolloids and gums

Guar (Arendt et al., 2002; Lorenzo et al., 2009) and xanthan gum (Sciarini et al., 2010; Lazaridou et al., 2007; Lorenzo et al., 2009; Hager and Arendt, 2013) are the commonly used hydrocolloids as additives in gluten-free breads because of their ability to mimic the viscoelastic properties of gluten. They increase the viscosity and moisture retention, as well as improve the mixing ability and extend the shelf-life of the final product. Other hydrocolloids such as carrageenan (Sciarini et al., 2010), alginate (Sciarini et al., 2010), hydroxypropylmethylcellulose (HPMC) (Lorenzo et al., 2009; Andersson et al., 2011; Hager and Arendt, 2013; Onyango et al., 2009; Phimolsiripol et al., 2012), carboxymethylcellulose (CMC) (Sciarini et al., 2010; Lazaridou et al., 2007; Onyango et al., 2009), pectin and agarose (Lazaridou et al., 2007) are also used. Moreover, maltodextrins are also included in gluten-free recipes but their effect depend on the DE (dextrose equivalent) (Witczak et al., 2010). Addition of low DE (3.6) decreased loaf volume and deteriorated the quality of bread whereas addition of high DE (18.0 and 21.8) increased bread volume and decreased crumb hardening during storage.

10.3.2.3 Lipids and emulsifiers

Fat is another ingredient commonly used in the preparation of gluten-free bread. Although present in low levels, lipids exhibit significant functional properties during processing and storage in bread making. A natural lipid source is found in the gluten-free meals and flours used to produce gluten-free products. The amount of fat content and its structure depends on the origin of flour and type of processing used to produce it.

Shortenings such as margarine and butter lubricate dough or impart a tenderising effect to the products to which they are added. Although in a bread formula shortenings are added at a level of 2–5% on flour basis, in a gluten-free formulation the levels are higher (10%) (Pongjaruvat et al., 2014). Levels of vegetable fat powder to 4% were reported not to produce changes to textural characteristics of gluten-free bread containing amaranth, whereas the combined effect of fat with albumen increased the acceptance in overall sensory evaluation (Schoenlechner et al., 2010).

Schober et al. (2003) observed that instead of using palm oil to produce gluten-free biscuits of good quality, one can add in the biscuit recipe cream powder, microencapsulated high fat powder and low fat dairy powders.

Emulsifiers are widely used in the cake baking industry to help dispersion of ingredients, incorporate air and provide stability to batter. Sodium stearoyl-2-lactylate (SSL) and diacetyl tartaric acid esters of monoglycerides (DATEMs) are two emulsifiers commonly used in traditional bread making. DATEM are anionic oil-in-water emulsifiers that enhance bread quality by improving mixing tolerance, gas retention and the resistance of dough (Aamodt et al., 2005). Moreover, SSL is a surfactant known to promote emulsifying and air incorporation into dough (Stauffer, 1990) whereas in bread making it improves texture and prevents water loss and staling of bread (Eliasson, 1983). Both of them were used in recent studies to improve gluten-free bread quality (Sciarini et al., 2012; Demirkesen et al., 2010a; Onyango et al., 2009). Moreover, other emulsifiers such as glycerol monostearate (Onyango et al., 2009; Rodríguez-García et al., 2014), calcium stearoyl-2-lactylate (Onyango et al., 2009), esters of mono and diglycerides of fatty acids (Miñarro et al., 2012) and polyglycerol esters of fatty acids (Rodríguez-García et al., 2014) have also been tested for suitability for the production of gluten-free breads.

10.4 Methods of texture design of 'gluten-free' food

Generally, many people consider texture to be the key property of food, even more significant than taste. Food texture is a function of the components and ingredients that a food contains, as well as the processes it undergoes. Sensory evaluation of texture represents the evaluation process that uses human senses such as fingers, tongue, palate and teeth to perceive different food textures (i.e., crispiness, crunchiness, hardness, tenderness, chewiness, creaminess, etc.). In addition to sensory evaluation, the texture of food is measured in a scientific way by standardized assessment methods using different equipment that try to mimic the human senses.

10.4.1 Sensory evaluation of gluten-free products

The increasing occurrence of CD and wheat allergy has amplified the demand for gluten-free foods with suitable sensory acceptance. Sensory evaluation is an important evaluation process in the food industry. Sensory evaluation requires careful training and selection of panellists as well as the control of the surrounding environment. Generally, in sensory analysis of bread samples, freshly baked breads are submitted for an acceptance test, usually applying a nine-point hedonic scale to trained panellists. In the hedonic scale the 0 means (dislike extremely) unacceptable whereas the highest value means (like extremely) very acceptable. The chosen panellists are familiar with sensory analysis techniques. A recent study draws attention to the importance of involving celiac individuals who are regular consumers of gluten-free products (Laureati et al., 2012).

Bread is one of the most consumed products among baked foods and the sensory properties usually taken into consideration during the development of new gluten-free products are taste, appearance, softness, colour, texture, flavour and overall acceptability (Torbica et al., 2010; Lazaridou et al., 2007), whereas for biscuits the order tends to be colour, appearance, flavour, texture, taste and overall acceptability (Kaur et al., in press).

Panellists assess the breads for each sensory property and rate each sample based on the hedonic scale. Despite the technological development, gluten-free products are generally considered of low sensory quality. Optimized rice starch bread with added

HPMC, yeast, β-glucan, and whey protein received lower scores for texture, taste and overall acceptability than the reference wheat flour bread (Kittisuban et al., 2014). Addition of hydrocolloids increased the overall acceptability of rice breads (Lazaridou et al., 2007). Among the hydrocolloids, CMC and egg albumen are the major determinants in improving rice bread sensory quality making it comparable to wheat bread. Moreover, gluten-free breads containing rice flour with husked and unhusked buckwheat flour were judged as acceptable following sensory evaluation (Torbica et al., 2010). In another study it was observed that the sensory acceptance was increased for rice bread after rice bran addition (Phimolsiripol et al., 2012).

The sensory test performed on the quality of biscuits showed that panellists valued the biscuits prepared from refined wheat flour with the highest scores whereas those prepared from gluten-free flour (buckwheat flour) with the lowest sensorial scores. Hydrocolloid incorporation in the recipe (guar gum, gum acacia, xanthan and gum tragacanth) improved the sensory scores of the prepared biscuits (Kaur et al., 2015).

10.4.2 Instrumental methods of texture measurements in gluten-free products

The trend of food industry is directed towards production of new food products that are safe, convenient, affordable, pleasurable and healthy. However, in order to design new foods one must understand fundamental structure–function relationships of food components.

10.4.2.1 Pasting properties of flours

Generally, pasting properties of the flours and starches are evaluated using a Rapid Visco Analyser (RVA). Peak viscosity differed significantly among the rice and pseudocereals (Figure 10.1) and decreased in the order: rice > buckwheat > quinoa > amaranth using RVA (Alvarez-Jubete et al., 2010). Compared to rice, pseudocereals resist heating and shear stress as shown by significantly lower breakdown. Moreover, rice and buckwheat exhibited the highest final viscosity among samples. This behaviour was related with the high amylose content found in rice and buckwheat starch compared to amaranth and quinoa starches.

10.4.2.2 Farinograph measurements

Farinograph and Extensograph are generally used to determine the quality of wheat flour. In their article Sivaramakrishnan et al. (2004) showed that the farinogram curve of pure rice flour dough differs from that of wheat dough (Figure 10.2a). Although rice dough absorbed the same water quantity with wheat dough it reached the 500 BU consistency at longer time and contrary to the wheat dough the consistency continued to increase with time. This was due to the moving of the rice flour particles inside the gap between mixing bowl and mixer blade of the farinograph, resulting in an increased torque towards the end of the measurement. This was poor dough for baking that exhibits handling problems on mixing.

Similarly, Lazaridou et al. (2007) reported that the signal of the curve of pure rice flour was noisy and the consistency increased with measuring time, showing a poor

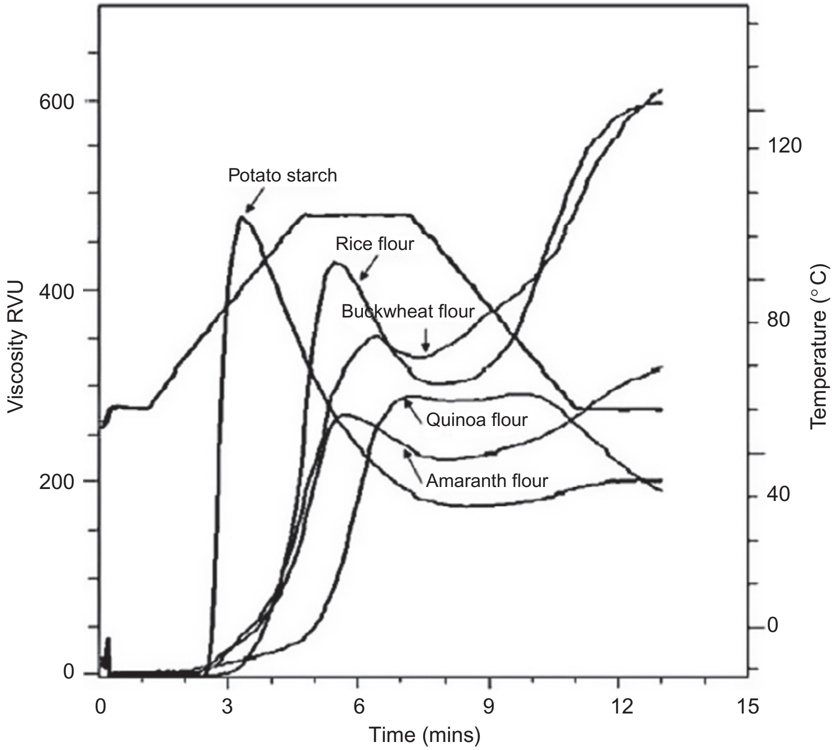

Figure 10.1 Pasting profile of amaranth, quinoa, buckwheat and rice flour, and potato starch (Alvarez-Jubete et al., 2010).

dough for baking. Additives such as DATEM and/or CMC at 1% addition level or a combination of 40% corn starch and 60% rice flour with 1% DATEM increased significantly the consistency of rice dough in the presence of 5% sodium caseinate (Figure 10.2b). DATEM entailed greater increase in the consistency of the dough than CMC, however it was not possible to reach 500 BU for the studied formulations within a reasonable timeframe (personal unpublished data).

10.4.2.3 Rheometer measurements

The viscoelastic behaviour of gluten-free dough can be determined using small deformation measurements such as strain sweep/yield stress, dynamic oscillation and creep tests performed in a rheometer. When doughs are tested in their linear range, their measured strain response will be proportional to the applied stress or strain. Oscillatory and creep measurements are performed within the region of linear viscoelasticity as determined by the strain sweep test, a test showing the modulus responses to increasing strain deformation. When the elastic modulus (G') starts to decrease, it shows microstructure break down within dough network and marks the strain limit of the linear region. Figure 10.3a clearly shows that the linear region for the

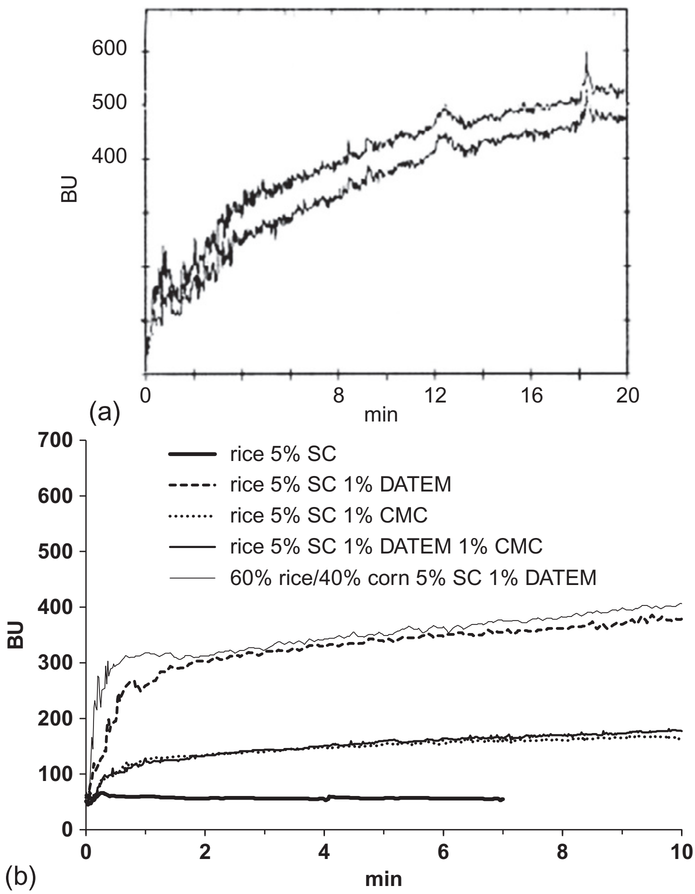

Figure 10.2 The standard farinogram for (a) pure rice flour (adapted from Sivaramakrishnan et al., 2004) and (b) rice flour and rice flour with corn starch with different additives (up to total 300 g dry weight) (personal unpublished data) (SC—sodium caseinate; DATEM—diacetyl tartaric acid esters of monoglycerides; CMC—carboxymethylcellulose).

gluten-free dough samples was under 1% strain. Strain values of 0.1% can be applied for linear regime oscillatory tests.

Yields stress represents the minimum stress required to initiate material flow thus these measurements are performed in order to measure the strength of the material structure.

Generally, mechanical spectra of gluten-free doughs made with rice flour exhibited more elastic than viscous behaviour ($G' > G''$) (Sivaramakrishnan et al., 2004). Moreover, G' values were higher than those of pure wheat dough during the frequency range applied (Figure 10.3b).

Creep-recovery tests are performed by applying a sudden stress to the dough sample (creep-phase). In the recovery phase the stress is quickly removed and the sample

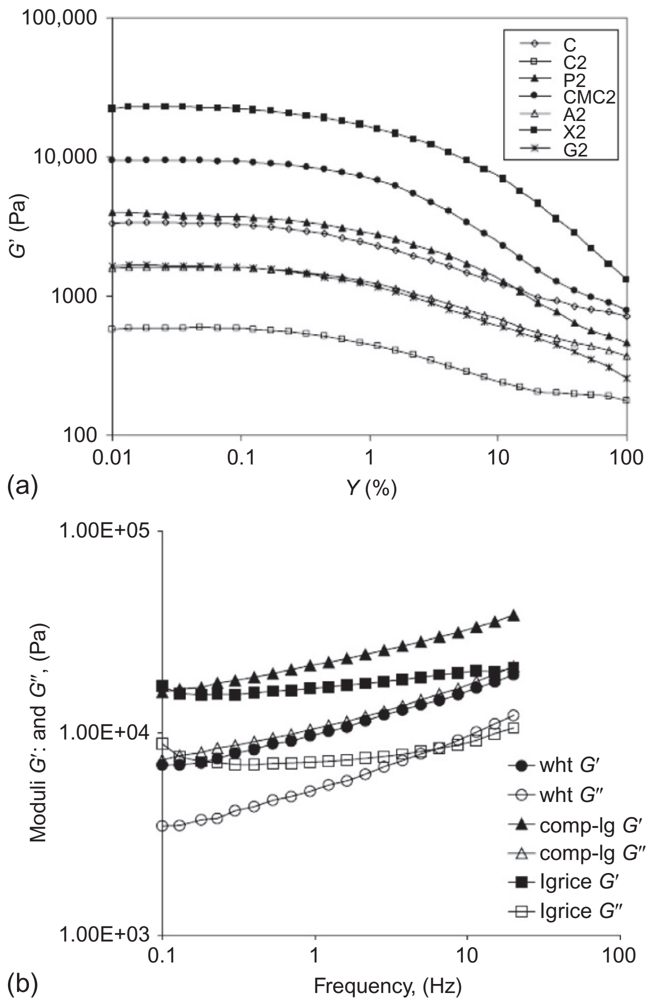

Figure 10.3 (a) Strain sweep curves of gluten-free dough formulations (1 Hz frequency, 25 °C); curves are means of duplicates for each bread formulation (C—control rice flour + 130 ml H_2O; C2—control rice flour + 150 ml H_2O; P2—control rice flour + pectin 2% + 150 ml H_2O; CMC2—control rice flour + carboxymethylcellulose 2% + 150 ml H_2O; A2—control rice flour + agarose 2% + 150 ml H_2O; X2—control rice flour + xanthan 2% + 150 ml H_2O; B2—control rice flour + β-glucan + 150 ml H_2O) (Lazaridou et al., 2007); (b) the variation of moduli with frequency for pure wheat (wht), pure long-grain rice flour (lgrice) and composite flours with 50% addition of long-grain rice and wheat flours (comp-lg) (Sivaramakrishnan et al., 2004);

(Continued)

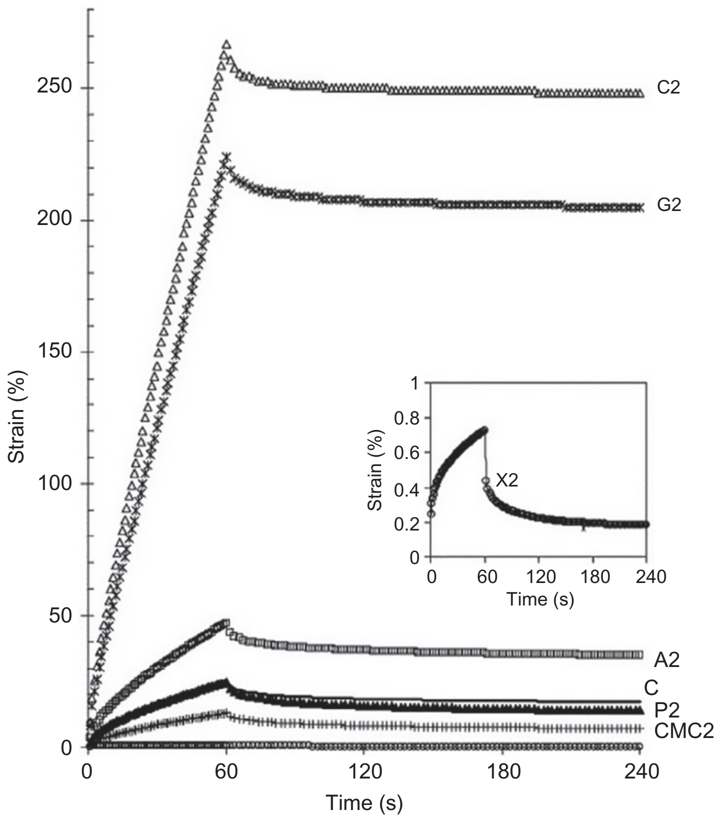

Figure 10.3, cont'd (c) effect of hydrocolloid addition on creep test curves of gluten-free dough; inset shows the creep-recovery data for xanthan (X2) at a larger scale (legend, see (a)) (Lazaridou et al., 2007).

is allowed to recover the elastic part of the deformation. Lazaridou et al. (2007) showed (Figure 10.3c) that xanthan exhibited the lowest creep compliance values and the highest zero shear viscosity compared to CMC, pectin, agarose and β-glucan. Due to its weak gelling properties and high viscosity values at low shear rates, xanthan is probably the most efficient hydrocolloid in enhancing elastic properties of gluten-free dough.

10.4.2.4 Large deformation measurements

Large deformation measurement in dough may be performed using a Kieffer dough extensibility ring where dough strips are elongated using a constant deformation rate. Such a test can be performed only for semi-solid materials that allow proper moulding and stretching. Gluten-free doughs are often problematic for large deformation test because they are too flowable and cannot form a coherent mass. Van Riemsdijk et al. (2011) referred in their study that whey protein structured into a mesoscopic particle suspension as a gluten alternative showed a similar strain hardening behaviour to wheat dough.

Firmness, gumminess, cohesiveness, springiness and resilience are usually measured on doughs using the Texture Profile Analysis method (double compression cycle). Effects of freezing and frozen storage conditions on the above empirical rheological parameters revealed that wheat dough is more affected by freezing during the first days of storage whereas the gluten-free dough is more affected at longer storage time (Leray et al., 2010).

Firmness or hardness of the bread crumbs are also evaluated by using the Texture Analyser. One of the most undesirable characteristics of the gluten-free rice breads is their firm and brittle texture due to the lack of gluten. In wheat-containing breads gluten slows down the movement of water, whereas the absence of gluten increases water migration from bread crumb to crust, thereby resulting in a firmer crumb.

Moisture significantly affects the structure of crumb and crust of gluten-free breads. The effect of water was greater than that of hydrocolloids on the quality of gluten-free bread; higher water levels significantly increased loaf specific volume and decreased crumb firmness whereas the opposite was observed for hydrocolloids (McCarthy et al., 2005). Type and level of hydrocolloid used and water level can exhibit very complex interactions; up to a certain level, high water addition and limited amounts of hydrocolloid can lead to a soft crumb and crust consistency. Similarly, addition of powders with a high protein content gave breads with an increased crumb and crust hardness but addition of extra water resulted in breads with a much softer crust and crumb texture (Gallagher et al., 2003). Hydrocolloids and non-gluten proteins have a high water-binding capacity, so addition of extra water in the recipe becomes necessity in order to avoid negative effect on the texture of breads. Figure 10.4 shows the variation of the crumb hardness of gluten-free bread made from rice and pseudocereals (Alvarez-Jubete et al., 2010). Pseudocereal-containing gluten-free breads exhibited a softer crumb and higher cohesiveness and springiness crumb than the gluten-free control, an effect attributed to the presence of natural emulsifiers present in the pseudocereal flours.

10.4.2.5 DSC (differential scanning calorimetry) and XRD (X-ray diffraction) measurements

Texture of bread is affected by the degree of starch retrogradation. Usually DSC endotherms or/and XRD spectra are evaluated to obtain starch recrystallization data.

Rice bread exhibited melting enthalpy (ΔH) values about three times the value of whole-wheat bread, suggesting a strong tendency to retrograde (Kadan et al., 2001). Melting enthalpy was increased by hydrocolloid addition, indicating higher amylopectin recrystallization during storage. Higher ΔH values in the DSC studies were found for gluten-free breads made with hydrocolloids and higher water content

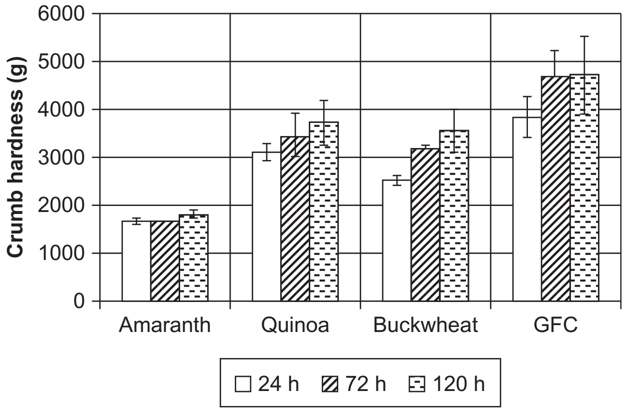

Figure 10.4 Crumb hardness of the breads after 24, 72 and 120 h post-baking. Mean value of three replicates ± SD (GFC—gluten-free control rice 50%:potato starch 50%; Amaranth—rice 50%:amaranth 50%; Quinoa—rice 50%:quinoa 50%; Buckwheat—rice 50%: buckwheat 50%) (Alvarez-Jubete et al., 2010).

(Sciarini et al., 2012). A drop in melting enthalpy of recrystallized amylopectin indicated that proteins of different origins (albumin, collagen, as well as pea, lupine and soy protein) acted as an effective anti-staling agent when incorporated in a gluten-free recipe (Ziobro et al., 2013).

Generally, the degree of crystallinity increases during storage as evidenced by the intensity increase in the X-ray diffraction peaks. Kadan et al. (2001) attributed to retrograded rice starch the development of 2θ peaks between 16.7° and 17.0° in rice bread stored for 7 days. Moreover, the amount of water and its redistribution during bread storage affects the kind of starch crystallites formed in gluten-free breads (Osella et al., 2005). Optimization of a gluten-free recipe by incorporation of chestnut flour, xanthan gum, guar gum and DATEM decreased peak intensities (Demirkesen et al., 2014).

10.4.2.6 Structure of the bread crumb at macro and micro scale

Generally the microstructure of gluten-free bread was studied using instruments such as a scanning electron microscopy, a confocal laser scanning microscope and image analysis.

Scanning electron microscopy was used to determine the size of the flour particles as well as the size and shape of the starch granules. Alvarez-Jubete et al. (2010) reported that smallest flour particle size was observed for potato starch, followed by rice, buckwheat, amaranth and quinoa flours. Moreover, they reported that the size of the starch granules in amaranth and quinoa flours was significantly smaller (<2 μm) whereas potato starch granules were significantly larger than the rest of the flours. Buckwheat, amaranth and quinoa starch granules are polygonal in shape, rice starch granules are irregular in shape whereas potato starch granules are in oval shape.

Confocal laser scanning microscopy of the gluten-free bread samples made from rice and pseudocereals such as amaranth, quinoa and buckwheat revealed significant variation in the microstructure among these breads. Contrary to the control bread made from rice flour where starch granules fused together and lost their original structure, the pseudocereal-containing gluten-free breads have a greater number of starch granules which still retain their integrity due to partial gelatinisation. In addition, the formation of fat globules-starch granules complexes was prevalent in the pseudocereal-containing gluten-free breads in comparison with the gluten-free control, resulting in a more homogenous matrix with fewer gas voids and a more even distribution of fat, protein and starch (Alvarez-Jubete et al., 2010).

Image analysis is a useful technique for the studies of the crumb microstructure. The technique is capable of giving quantitative analysis of various structural and physical parameters such as cell to total area ratio, total number of cells, mean cell area and number of cells with area less than 4 mm^2. Crumb grain analysis showed that the mean cell area (1.05 mm^2) of an optimized gluten-free bread was comparable to that of wheat bread (1.01 mm^2). Moreover, gas cell walls of the optimized bread appeared to be thicker than those in wheat bread exhibiting lower cells/cm^2 (22 vs 32 cells/cm^2 respectively) (McCarthy et al., 2005). Incorporation of low protein-containing powders in the gluten-free bread recipe produced the largest gas cells to total area ratio (Gallagher et al., 2003).

10.5 World market investigation

10.5.1 Behaviour of gluten-free consumers: current trends

Gluten-free products are purchased by different groups of consumers. The main group comprises the persons diagnosed with CD, for whom a strict gluten-free diet is the only option. Gluten-free products are also purchased by those with a wide variety of other conditions, such as non-celiac gluten sensitivity, wheat allergy, autistic spectrum disorders, multiple sclerosis, irritable bowel syndrome and so on. A third group consists of people who wish to avoid gluten consumption not for medical reasons but as a 'healthy' choice in their diet, triggered by marketing strategies and disputable scientific evidence. These consumers seem to embrace gluten-free diets to lose weight and to improve health (Cross, 2013). Despite the lack of any scientific research confirming the validity of this theory, this new trend made gluten-free one of the top restaurant menu health claims in 2010, according to the National Restaurant Association and American Culinary Federation.

On the other hand, the 'healthiness' of gluten-free products is questionable. Besides being low in fibre and short of beneficial compounds, gluten-free products tend to have more calories because they contain more fat and sugar to make up for the lack of gluten. Moreover, gluten-free flours that are commonly used for the production of gluten-free products (i.e., rice, tapioca, potato and sorghum) have a higher glycemic index than wheat. Therefore, enriching gluten-free products with dietary fibres and nutrients (i.e., folic acid, calcium and vitamins of B complex) is highly desirable in the development of gluten-free products.

The prevalence of CD is about 1% of the total Western population (Europe and North America) (Fasano, 2003b), but it is estimated that for each diagnosed case of CD, an average of 5–10 cases remain undiagnosed (Fasano and Catassi, 2001). Moreover, the prevalence around the world varies widely because of genetic and environmental factors (Lohi et al., 2007). The total prevalence of CD seems to increase over time possibly due to the environmental factors. Reports underline that the prevalence of the CD for the period 1978–1980 to 2000–2001 was doubled in Finland (Lohi et al., 2007), whereas in Scotland was increased 6.4-fold from 1990 to 2009 (White et al., 2013). On the other hand, the efforts to raise public awareness of CD may increase further the diagnosing rate. The interest in buying gluten-free products grows as more people learn about gluten intolerance.

It was observed that 55% of gluten-free consumers spend 30% or more on their grocery budget for gluten-free foods and the majority (71%) agreed it is hard to find good-tasting gluten-free foods. More than half (57%) of gluten-free consumers try a variety of 10 or more new gluten-free products (Case, 2009). Moreover, for gluten-free consumers, product selection is the most important factor, followed by low price, convenience, good service, close to where they live, knowledgeable staff available to help, friendliness of staff and/or close to where they work.

The economic environment may have a significant impact on the choice by low-income consumers to eat gluten-free foods, as both the availability and price of healthier food items may limit their purchase. A strict gluten-free diet results in higher feeding costs that impose limitation in the budget of celiac patients. Lee et al. (2007) evaluated the economic burden of a gluten-free diet. They demonstrated that gluten-free foods have poor availability and are more expensive than their wheat-based counterparts. They also noticed that cost was affected more by shopping spot than geographic location. In another study it was underlined that a strict gluten-free diet is an expensive diet since on average, gluten-free products were 242% more expensive than regular products (Stevens and Rashid, 2008). Singh and Whelan (2011) also showed that gluten-free versions of everyday foods were 2–124% more costly than standard counterparts. The analysis of the cost of basic food basket compared to a basket especially designed for celiac patients in Chile showed that these patients spend in food 89% more than normal consumers (Castillo and Rivas, 2008).

10.5.2 Gluten-free existing market: forecasts

The report on Gluten-Free Foods of Datamonitor, published in November 2013, underlines that gluten-free products are becoming more sophisticated and more than 9500 new gluten-free products have been launched since 2008 (Datamonitor Nov 19, 2013). According to Datamonitor, the U.S. is the number one country for new product launches whereas the UK is the most productive region of Europe. Nowadays, a growing variety of gluten-free grains, flours, starches, seeds and vegetables are being used to create a wide array of gluten-free baked products such as muffins, bagels, cookies, cakes and doughnuts not just bread and flour. The gluten-free market is expanding, with an increasing number of new products such as baking mixtures, cereals, pastas, pizza, entrees, side dishes, soups, snack foods and even alcoholic beverages designed to appeal to consumers on a sensory level.

Gluten-free markets continue to grow as a result of more people being diagnosed with CD. It was reported that in 2010 gluten-free sales reached more than $2.6 billion in U.S. and the figure is expected to continue to grow (Packaged Facts 1 Feb, 2011). In Canada the gluten-free market had an annual growth rate of 26.6% between 2008 and 2012, reached over $450 million in 2012 (Packaged Facts 30 Aug, 2013). The most notable was the growing of gluten-free items in Canadian restaurants (Neshevich, 2013). Growth rate and retail sales are expected to grow to reach $811.5 million in 2017. In addition, it was estimated that the North American trend will spread worldwide and the global gluten-free market will reach $6.2 billion by 2018 (Neshevich, 2013). Major growth in the gluten-free market in the near future is anticipated to come from countries such as the U.K., Italy, the U.S., Spain, Germany, Australia, Brazil, Canada, India and more.

The largest volume share in the sector are gluten-free bakery and confectionery products, which accounted for about 46%, followed by gluten-free snacks with about 20% in the gluten-free market.

The highest consumption of gluten-free product in the global market was through conventional sales channels. There is a notable shift in the retail distribution of gluten-free products from specialty stores to mass chains making chain stores a preferred retail channel for gluten-free products (Packaged Facts 1 Feb, 2011).

Despite the progress made in the area of gluten-free products, a more recent study revealed limited availability of gluten-free foods (Singh and Whelan, 2011). It was reported that, on average, 41% of foods are available in a gluten-free version per store. Regular supermarkets have a greater availability of gluten-free foods when compared to small stores (budget supermarkets and corner shops).

10.6 Future direction

10.6.1 Novel gluten-free ingredients

Other ingredients than rice and corn flour can be included in the formulation of gluten-free products in order to improve their nutritional value. In addition to the pesudocereals, flours or meals of other origin have also been explored.

In the literature, the possibility of developing gluten-free products with green banana flour has been investigated. Green bananas are considered a subproduct of low commercial value with little industrial use that can contribute to a more diverse diet (Zandonadi et al., 2012). Utilization of chestnut flour in gluten-free bread formulations was also suggested (Demirkesen et al., 2010b).

In our laboratory, we explored the possibility of producing gluten-free breads using leached acorn flour and obtained promising results (personal unpublished data). A variety of different vegetable flours such as artichoke, asparagus, pumpkin, zucchini, tomato, yellow pepper, red pepper, green pepper, carrot, broccoli, spinach, eggplant and fennel were used in addition to maize flour to produce gluten-free spaghetti (Padalino et al., 2013). Introduction of leguminous flours in the recipe of gluten-free products has also been attempted to improve their biological value. Broad bean (*Vicia faba*) flour was used to produce corn–broad bean spaghetti-type pasta with high protein and dietary fibre content and adequate quality (Giménez et al., 2013).

Dietary fibre preparations are becoming another attractive source to use as additive in order to improve physiological characteristics of gluten-free breads. Dietary fibres are mainly non-starch polysaccharides including cellulose, hemicellulose (i.e., arabinoxylans), β-glucans and pectins that are not absorbed and digested in the small intestine. Resistant starch is another major component of plants that physiologically behaves as dietary fibre. Resistant starch (tapioca and corn resistant starch), in addition to the increase in dietary fibre content, increased the elastic character of corn starch dough and decreased the hardness of the bread crumb (Korus et al., 2009).

The possibility to incorporate in the gluten-free recipe dietary fibre from rice in the form of fractions of rice bran (Phimolsiripol et al., 2012) and oat (Gularte et al., 2012), pentosans (Mansberger et al., 2014), β-glucans from different sources (Lazaridou et al., 2007; Andersson et al., 2011; Heo et al., 2014; Ronda et al., 2013) as well as resistant starch (Korus et al., 2009) has been proved in recent studies. The use of whole buckwheat flour produced gluten-free crackers with higher tocopherol and phenolic content, as well as increased antioxidant activity compared to the crackers made with refined buckwheat flour (Sedej et al., 2011).

Inulin is part of the dietary fibre complex that resists digestion in the upper gastrointestinal tract, but is almost quantitatively fermented by the microflora of the colon. Prebiotics are nutritional compounds recognized for their ability to promote the growth of specific beneficial gut bacteria. Although inulin, oligofructose and frutooligosaccharides are recognized as dietary fibres, they exhibit some prebiotic activity and are generally associated with health and well-being. Prebiotics have recently been used to improve the physiological characteristics of gluten-free products (Rodríguez-García et al., 2014; Gularte et al., 2012).

10.6.2 New processing techniques and technology

Treatment methods such as enzymic, sourdough preparations, freezing, milling, sieving, extrusion and high pressure (HP) processing technology have been used to improve the quality as well as nutritional attributes of gluten-free cereal products developed for patients suffering CD.

Enzymes were added in gluten-free formula in order to modify the functionality of proteins from gluten-free flours. Although, it was shown that enzymes improved the structure of gluten-free bread, they exhibited diverse interactions with the various gluten-free flours.

Among the enzymes used in the food industry, transglutaminase was successfully implemented in order to promote protein networks (crosslinking) and improve baking characteristics of flours. Renzetti et al. (2008) reported that transglutaminase addition (up to 10 U/g of proteins) can be applied to gluten-free recipes with brown rice, buckwheat or corn and result in significant positive effects on the specific volume and hardness of gluten-free breads while no such effects were noted in the case of oat, sorghum or teff flours. Moreover, transglutaminase was reported to reinforce protein-enriched composite blends in an optimized gluten-free formulation suitable for bread making

(Storck et al., 2013). The level of transglutaminase addition was of great importance for bread making (Pongjaruvat et al., 2014). Addition of transglutaminase at a level of 0.1–1% (flour weight basis) increased the bread volume and decreased crumb hardness whereas higher levels decreased bread loaf volume and increased crumb hardness. Similar results were also reported by Smerdel et al. (2012).

Other enzymes used in the preparation of the gluten-free breads are glucose oxidase and α-amylase (Sciarini et al., 2012), protease (Kawamura-Konishi et al., 2013) (Hamada et al., 2013; Martínez et al., 2013) and lipase (Rodríguez-García et al., 2014).

It was observed that the addition of α-amylase slightly increased the specific volume of bread whereas the presence of glucose oxidase produced no significant changes in bread specific volume despite the observed protein polymerization. Moreover, addition of glucose oxidase or α-amylase in the recipe decreased the crumb firmness of gluten-free bread but glucose oxidase on the other hand increased the firming rate (Sciarini et al., 2012). Bread treated with protease was of higher quality (i.e., good crumb appearance, high volume and soft texture), depending on the amount of enzyme added (Kawamura-Konishi et al., 2013). Moreover, cakes with lipase displayed a better texture profile during storage (Rodríguez-García et al., 2014).

Sourdough fermentations are used in conventional baked products. They use metabolic potential of lactic acid bacteria (LAB) in order to improve flavour, texture and shelf-life properties of baked products. Different studies have used a diversity of lactic cultures and yeast during dough processing in order to improve the flavour of the product (Moroni et al., 2011). However, this procedure was not widely applied in the production of gluten-free bread. The literature specifies that the flavour, texture and shelf-life of gluten-free bread was improved as for conventional baking (Schober et al., 2007; Arendt et al., 2007). Several gluten-free cereal fermentations have been characterized on the microbial and biochemical levels (Nout and Sarkar, 1999; Hammes et al., 2005). In addition, LAB with special properties such as antifungal activity, exopolysaccharide production and enzyme production can be of great interest for the industry.

The freezing process was widely used at different steps of bread-making procedure to make available fresh breads in retail stores or to make available to consumers a frozen product ready to bake at home. The research on the effect of a freezing step on gluten-free dough and breads was rather limited. One study reported that freezing process lowered specific volumes and produced harder gluten-free crumbs but with more homogeneous distribution of gas cells (Mezaize et al., 2010).

Moreover, new methods in the preparation of the non-gluten flours can produce changes in the quality of gluten-free products. A dry milling technique of dried rice grain after soaking for at least 6 h claimed to increase water absorption of rice flour during dough making, to have similar particle size distributions as wheat flour (Shin et al., 2010). In addition to milling process, the particle size range of rice flour is an important factor to consider for rice processing since it affects the quality of gluten-free products. Rice flour that passed through 80, 120, 160 and 200 (<180, <125, <95 and <75 μm) mesh sieves will have different quality of batters and rice cupcakes (Kim and Shin, 2014). The specific volume of cupcakes was highest when rice flour passed through 95 μm mesh while the hardness, springiness and air cell sizes decreased as the particle size of rice flour decreased.

The use of HP processing, was also introduced in order to produce foods with novel textures, since HP affects the structure of macromolecules such as proteins and starch. Treatment of buckwheat, white rice and teff batters for 10 min at 200, 400 or 600 MPa produced changes in the microstructure of the batters, induced starch gelatinization and increased viscoelastic properties (Figure 10.5) (Vallons et al., 2011). In addition, in white rice and teff batters, protein polymerisation by thiol/disulphide-interchange reactions was observed whereas in buckwheat proteins no such crosslinking mechanism was detected.

Extrusion cooking represents an alternative processing method for the production of gluten-free pasta-like products. It was found that by applying extrusion process corn/broad bean blend loses approximately 20% of total crystallinity, enough to confer adequate cooking quality to the pasta-like spaghetti type (see Figure 10.6)

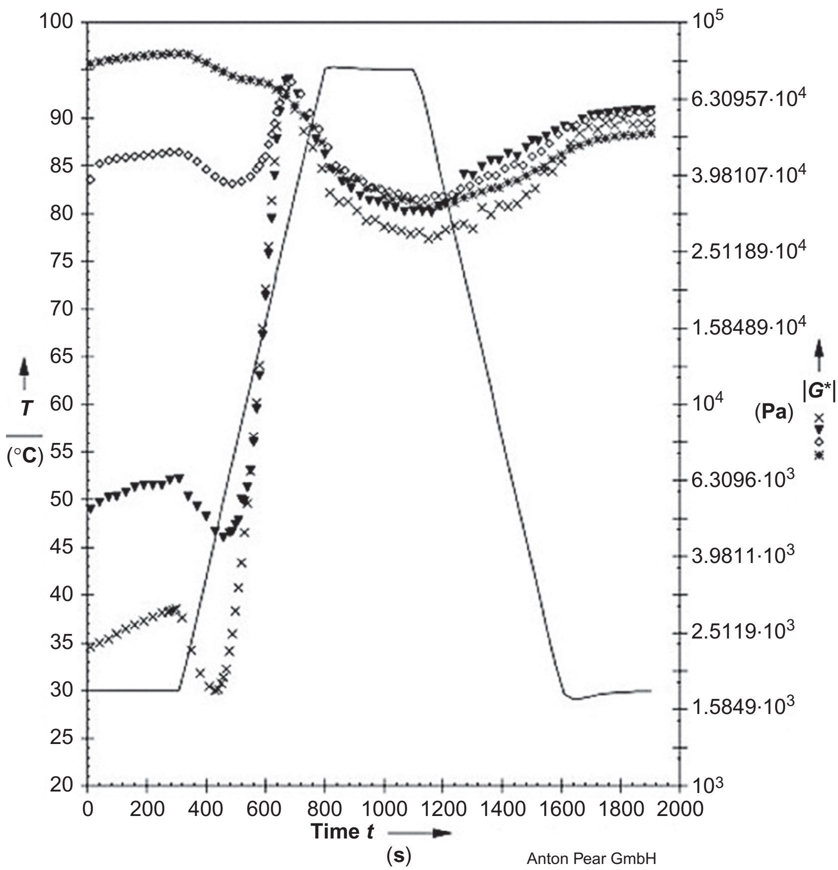

Figure 10.5 Pasting profile of control batters (×) and white rice batters treated at 200 MPa (▼), 400 MPa (◇) and 600 MPa (*) with the temperature (full line) and complex modulus (G^*) given as function of time (Vallons et al., 2011).

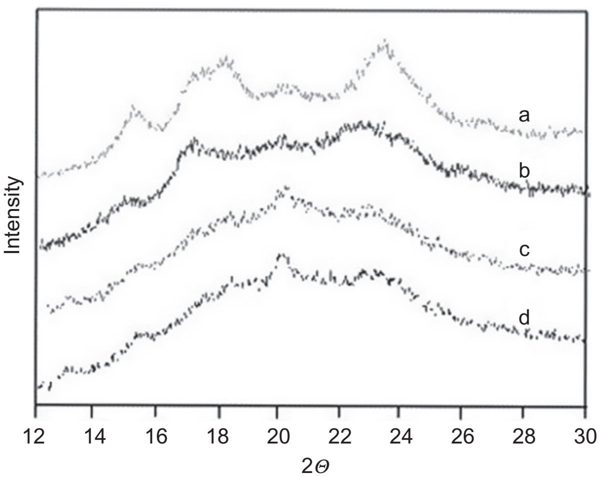

Figure 10.6 X-ray diffraction patterns of corn flour (a), broad bean flour (b), corn spaghetti-type pasta (c) and corn–broad bean spaghetti-type pasta (d) extruded at $T = 100$ °C and $M = 28\%$ (Giménez et al., 2013).

(Giménez et al., 2013). Moreover, in order to avoid unnecessary loss of nutrients such as carotenoids, due to the high temperature over the drying process, optimized dehydration at a lower temperature was found feasible for pasta production from the flour of yellow pepper (Padalino et al., 2013).

10.7 Conclusions

In recent years, a great improvement on a global basis is observed with regard to gluten-free food labelling. The market for gluten-free products is increasing and becoming more attractive for food industries around the world because of the increasing incidence and risk of CD, the increasing number of individuals avoiding gluten for health benefits and the high market price of these products.

Production of gluten-free baked goods is primarily based on the utilization of various types of starches, and flours from gluten-free plants such as maize and rice. Nowadays, the range of the gluten-free products has been expanded notably with the introduction of new ingredients from alternative sources and their quality was been improved.

This chapter was focused on different instrumental methods used to measure and evaluate the texture of gluten-free food, revealing the effect of additives, new natural ingredients and processing technologies in the quality of the gluten-free products. Moreover, it underlined the importance of the sensory evaluation of the product as an estimator of consumer's acceptance.

The challenge to improve the texture of gluten-free products is major and the field of research vast. It is up to the food scientists' community worldwide to collaborate with the industry and come up with tasty, nutritious and affordable gluten-free food for anybody who needs or wishes to consume these products.

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