1 Introduction

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1.1 THE BASICS

Food texture defines the eating experience and drives consumer liking or preference of food products. This has always been a fundamental aspect of the human (and perhaps animal) eating experience and has been known to food preparers as well as discerning consumers since the very beginning of food preparation. However, the development of technical and business expertise in food texture optimization and design using structured multidisciplinary tools is a more recent development. As culinary arts, food science, materials science, sensory science, and the study of consumer behavior have evolved in scope and complexity; it is now possible to develop a view of how the ability to study and optimize texture can drive consumer choice. The science and technology of designing and optimizing food texture have evolved significantly in recent years and continue to do so at a rapid pace.

The current volume is being compiled as a showcase for the current state of the art in this field. There have been several volumes that have been written as introductory texts or overviews (Bourne, 2002; Moskowitz, 1987; Rosenthal, 1999) or comprehensive references (McKenna, 2003; Kilcast, 2004) for those who would like to initiate study in the field. The scope of this volume is for those new to the field as well as for those who have experience but perhaps would like to gain deeper and wider insight on food texture and gain familiarity with the state of the art at the beginning of the twenty-first century. From the list of contributors in this volume, it should be clear to any reader that the scope of this work is both global and diverse. Enjoyment of food and how it impacts social and cultural aspects of anthropological evolution is a shared influence for every culture on this planet and despite regional and cultural variations there are strong similarities in ingredients and formulation considerations that make a particular food from a region more appealing than another. Indeed, there is scope for collaboration on a more global scale in the pursuit of greater understanding of the evolution and impact of food texture.

'The Ketchup Conundrum' is a widely quoted article by Malcolm Gladwell (2004) and brings to light a basic dilemma with the perception of food. There is inherent duality

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in the way humans treat food – each cultural sub-population has some food products that are ‘sacred’, that is, there are perceived requirements for ingredients, flavor, texture, and even preparation techniques. However, for all these products, if one is able to gather perspective over a long enough time-frame and over different population bases, it is clear that there has been significant evolution even in these products and preferences change gradually but surely across regions and over time. Mr. Gladwell’s article offers a sound perspective using experiments with condiments in the U.S. marketplace but once you expand scope to include Asian or other regional markets there is emergence of other factors that influence consumer choice.

The editors recently had the opportunity to be personally involved in a study of texture for ketchup and barbecue sauce and noted how this phenomenon is manifested in this category. Ketchup in different parts of the world, even for the same brand, can have marked differences in flavor and texture. Further, different populations use ketchup differently and hence it has led to an entire population of products that are tomato based sauces where any opportunity to differentiate flavor or texture leads to a new name for the product. In some regions (e.g. the United States), this is mandated by law due to standards of identity, but in others it is just a way of innovating in a marketplace that is constantly evolving. Ketchup products from different parts of the world have significant differences in thickness, cling, cohesiveness, and flavor aspects including sweetness vs. sourness vs. saltiness vs. spice content. The presence of such products over a long time in different marketplaces has driven consumer acceptance and familiarity with the local products and has evolved the definition for what is ‘traditional’. Regional taste preferences as well as differences in quality and type of raw materials also shape these effects.

The other side of this duality is that there are certain food products that populations love experimenting with and will constantly explore new and different flavors and textures. Certain categories of confectionary and snack foods are perhaps the best examples of this in many parts of the world. Not every exploration produces positive results and certain flavors or textures are more enduring than others. However, the main observation here is that the same people will not want to change certain types of food but will actively look to change others and that the types of food and the extent of change that is acceptable varies widely. Thus, if one takes Mr. Gladwell’s analysis of why ketchup does not have varieties, but extends that to barbecue sauce in the United States, the picture changes substantially. Barbecue sauce is made using similar basic ingredients and processes that are used for ketchup but is one of the most experimented with condiment category across the United States. There are hundreds of brands and strong preferences from state to state, sometimes even with states.

The other phenomenon that makes a global view of food texture somewhat complicated is that even for food products that are similar in evolution, and function, regional ingredients, supply quality, preparation methods, and storage methods/expectations vary so significantly that they can introduce substantial differences in product texture and quality.

A good example of ingredient variation is wheat flour – a basic ingredient that is perhaps used in almost every country in the world (Shewry and Khan, 2009) Despite the product being called wheat flour and labeling as such on the food product, there are significant variations in content and properties of protein, content/quality of starch, as well as other compositional differences that impact the processing and milling of these grains and ultimately the final texture of the wheat based products. Seasonal variations in wheat quality and properties add further complexity and all of these effects have led to a global industry that specializes in the standardization of grades of wheat flour to reduce the variation and uncertainty from region to region and year to year. This is especially relevant with the globalization of the food supply chain that leads to consumers who routinely eat food made with grains, fruits, vegetables, meat, and spices produced thousands of miles from where they live.

An interesting example of texture optimization from the last century is from Australia with the use of wheat gluten to optimize bread texture from the 1930s. (Technology in Australia, 2000) Fielder's Gluten Pty. Ltd was formed to commercialize the use of 'vital wheat gluten' to improve bread texture and allow bread of good quality to be made from grades of flour that were previously not used successfully. This is still a commonly used approach to optimize bread texture and counter seasonal or varietal variations in wheat flour.

The observation for wheat flour can be extended to other grains and tubers and is valid to different extents for meats, dairy products, fruits, vegetables, and other ingredients. Frequently, shortages in one region will require ingredient substitution from another. Government and trade regulations can limit the freedom of this exchange to some extent but the phenomenon has been growing in scope for many years. Produce and grains from agricultural economies are exported around the world and variations in trade and supply can lead to significant changes in ingredients.

The globalization of food brands from many corporations is another key trend that has led to additional complexity and challenge in addressing food texture related challenges. Important multi-national brands often have sales in billions of dollars and have signature texture and flavor profiles. The brand owners strive to maintain these profiles in different regions of the world. This leads to formulation challenges where locally sourced raw materials with differences in properties from other regions or legacy local processes with differences in temperature or shear profiles have to be optimized to provide consistent final product properties.

Supply and quality fluctuations have further impact on food and ingredient costs. This has a significant impact on food costs. The World Bank tracks food prices globally and the world is going through a series of crises as regards food inflation as shown in Figure 1.1. (World Bank Food Price Watch Report, November 2012). This has led to a constant search for approaches to maintain food quality while managing through changes in the prices of both raw and processed foods.

New developments in processing and packaging techniques have also had a significant impact in the study of food texture. New techniques that include using higher pressure and shear and consequently reliance on lower temperatures to achieve the desired food safety requirements lead to the ability to manufacture packaged foods with texture and flavor close to freshly prepared meals. The ability to use these new techniques while still achieving target food textures for packaged foods that were so far manufactured using traditional techniques often leads to reliance on formulation based approaches to optimize texture. High pressure processing (HPP) and pasteurization is one example of a recent technique that is leading to an evolution in how food is made safe for packaging and consumption (Doona and Feeherry, 2007). The use of very high pressures to achieve pasteurization allows foods to be processed at significantly lower temperatures, which can lead to large differences in texture when compared to traditional thermal pasteurization processes.

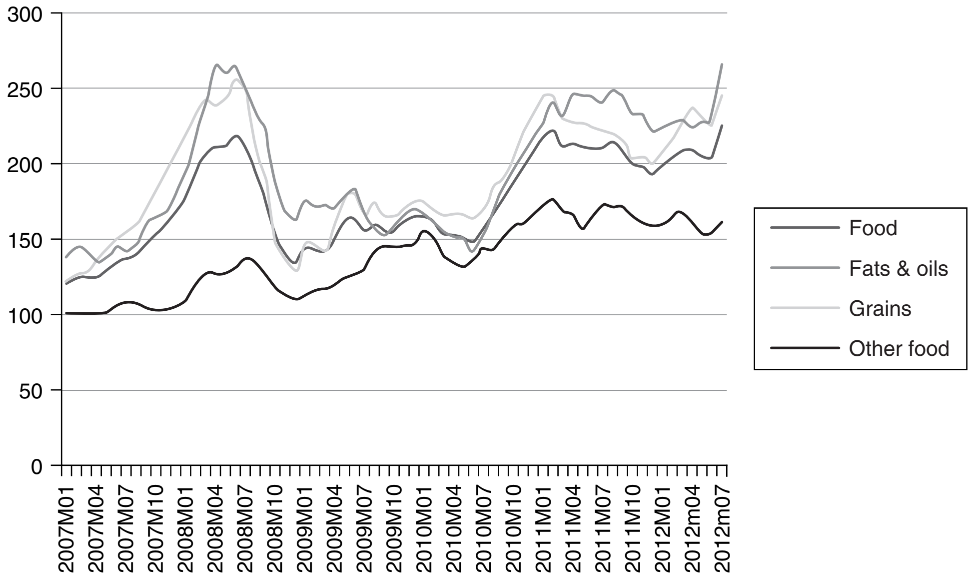

Figure 1.1 Food inflation (Food Price Index: 100 = 2005 Prices). (Source: World Bank Global Food Price Index. Reproduced with permission.)

Shelf life is a key concern for refrigerated, frozen, as well as shelf-stable packaged foods. Shelf life and stability criteria are different based on storage temperature for texture as well as microbiological stability. This has also led to the requirement for formulation based approaches that depend on functional ingredients to provide the desired texture and stability for the target product shelf life. Shelf life is a key consideration when considering the time taken from food production and distribution centers to local sales outlets and finally to consumers' homes or to restaurants and food service establishments.

What we know regarding texture today is that texture is a critical criterion in addressing food product design. The factors that make this important are summarized in Table 1.1. There is a strong penalty if food product developers are not able to hit the desired target texture. This is typically reflected in lower acceptance and consumption of the food product by the target consumers. This is true of a family consuming a home cooked meal, a customer ordering a favorite dish at a restaurant, as well as for an individual purchasing a packaged food product from the supermarket for a quick dinner.

Texture will continue to play a critical role for future food product development as the factors described in Table 1.1 as well as others will continue to evolve and impact how food texture preference and its impact on consumer choice will change. Texture needs to be addressed as part of the initial formulation before final flavor optimization and locking in the final recipe and formulation. This does not mean that flavor is less demanding but optimizing flavor before texture can lead to double work as changes in texture can lead to significant changes in flavor perception.

In order to understand and change texture, it is important to be able to measure it precisely. Measurement of texture is still evolving but there are two broad classes of techniques that are commonly used. Since texture is primarily a sensory concept and its perception is a combination of perceptions from several human senses, the ultimate measurement of

Table 1.1 Factors impacting texture choice or texture properties that impact choice.

Factor	Impact
Regional and cultural history	Individual preference toward familiar textures based on family and cultural history
Seasonal variation	Seasonal changes in grains, tubers, fruits, vegetables and other food products can change their composition and texture, and can in turn lead to changes in texture of the food products made with them
Regional variation	Different regions use the same names for products (e.g. wheat or rice) but varietal and other factors can lead to significant variation in texture
Supply constraints	Supply constraints for ingredients for formulated foods can lead to their substitution by others leading to changes in texture
Cost fluctuations	Cost increases in ingredients for formulated foods can lead to their substitution by lower cost ingredients leading to changes in texture
New processing techniques	Advances in processing techniques including the use of higher pressure or shear can lead to changes in texture
New packaging techniques	New packaging containers, equipment, and other factors can lead to changes in how the product is handled and how it changes over its shelf life leading to changes in texture
Regulatory developments	Regulatory changes can reduce or eliminate the use of certain ingredients requiring their substitution and changes in texture
Genetic makeup	Some genetic factors such as amount and potency of saliva or genetic predisposition to certain types of mouth behavior can lead to preference for particular textures

texture is through sensory measurements by humans. There are also several instrumental techniques that are used to measure physical properties that are either strongly correlated to or that strongly impact the sensory perception of texture. Having access to both types of techniques and being able to translate data into action to develop desired textures is a requirement for texture optimization.

1.2 DEFINING FOOD TEXTURE

Food texture has been defined by the International Standards Organization (ISO) in their standard vocabulary for sensory analysis as 'All the rheological and structure (geometrical and surface) attributes of a food product perceptible by means of mechanical, tactile, and where appropriate, visual and auditory receptors' (ISO 5492, 2008). The measurement of food texture using sensory and instrumental techniques has been the topic of considerable study over the last few decades (Rosenthal, 1999; Moskowitz, 1987). The entire process of food texture perception has been a topic of significant interest over the years. The overall process is illustrated in Figure 1.2. A more comprehensive description can be found in Sczezsniak (2002).

The overall perception of texture starts at first visual contact with the food product. The visual appearance includes color, shine, visual flow characteristics and other similar attributes. The next step in the perception of texture is the sense of touch. This is an opportunity to perceive surface properties like stickiness or roughness as well as bulk

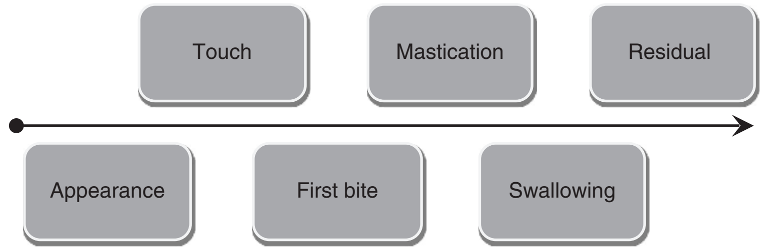

Figure 1.2 Eating experience: The perception of texture.

properties such as hardness or ease of flow. The next step in the consumption of food is the first sip, first bite or first compression of the food. This is a critical step where the senses of hearing and taste provide the first sensory input. The loudness as well as the frequency of sound has been shown to drive consumer interest and preference. The initial perception of hardness, flowability or other textural sensations in the mouth have a similar impact. This is also the first point where trigeminal sensations such as those related to temperature can be perceived.

The next stage in the perception of texture is the mastication or chewing of food. This stage provides perhaps the richest and most complex array of experiences in the textural perception of food products. The key texture attributes include resistance to chewing, the way the food product breaks down in the mouth, the extent to which it coats the palate, how the product sticks to the teeth or the tongue and eventually how long it takes to break down and dissolve in the mouth.

How the food feels as it is being swallowed is nearly the final stage in the perception of food texture. The characteristics can include the flow properties, roughness or smoothness, and how easy or difficult it is to swallow. Once the food has been swallowed, there is one final set of attributes related to texture. These are the residual textural effects of the food even after the consumer has swallowed it. These attributes include residual coatings of the mouth and the throat as well as any residual particulate elements left in the mouth.

As shown in Figure 1.2 and summarized above, the perception of food texture is a complex sensory process that involves the interplay of a variety of product characteristics and human senses. This is one of the reasons that it has taken so many years to measure and understand the texture of different food products and its impact on consumer perception and liking. The optimization of food texture requires the ability to measure it as well as the ability to make changes in the food formulation or preparation process to optimize the texture as well as the overall eating experience.

1.3 MEASURING FOOD TEXTURE

Food texture is primarily a collection of sensory properties and a variety of techniques have been developed to measure different sensory aspects of food texture. However, conducting sensory analysis can be time consuming and access to a suitable set of evaluators may not always be available. This has led to the utilization of a variety of instrumental techniques that can be used effectively to screen for certain critical properties that correlate strongly with sensory perceptions. In certain cases, the instrumental techniques can be used as a proxy for sensory analysis.

1.3.1 Sensory testing and analysis

The purpose of sensory testing and analysis is to employ humans to test food products and to use their perceptions to understand and optimize product texture. The techniques described here are used not only for texture but for flavor as well as overall evaluation of food products and the eating experience. Sensory tests can be used to determine differences in products as well as consumers' acceptance and/or preference for the food products being evaluated. The data generated through such analysis is typically used to address desired organoleptic characteristics to achieve business targets.

Amerine et al. (1965) still remains a good reference for sensory evaluation though many more recent references are available and used. A good recent reference is Moskowitz et al. (2006). Sensory evaluation is very commonly used in the food industry for new product development or reformulation, but is also used for a variety of other development activities. It can be used to compare products to a target and to qualify process changes to ensure that the final product meets expected organoleptic standards. It is used for quality assurance including the evaluation of storage stability and for shelf-life testing. A variety of different sensory tests are used based on the type of data that is required for decision making. These tests are summarized in Table 1.2.

The commonly used methods named in the last column of Table 1.2 are further described in Table 1.3. For consumer acceptance or preference tests, one of three common implementation methods is typically used. Central location testing involves recruiting consumers and bringing them to a specific location for testing. In-home placement involves recruiting target consumers and providing products to be used in their households for testing. Mall or store intercept involves stopping and interviewing consumers in shopping malls or stores. Each method has its own unique advantages as well as its own complexities.

Table 1.2 Commonly used methods for sensory analysis.

Test	Objective	Evaluators	Methods
Difference	To determine if differences exist between products	Experienced with test methodology	Triangle Duo-trio Directional
Acceptance	To determine the acceptability of the product	Target consumers	Monadic Paired
Preference	To determine if one product is preferred to another	Target consumers	Monadic Paired Ranking
Descriptive	To identify and quantify specific product characteristics of flavor and/or texture	Highly trained and calibrated to reference standards	Quantitative Descriptive Analysis Spectrum Descriptive Analysis

Table 1.3 Methods used for sample presentation and sensory testing.

Method	Description
Triangle	Two identical and one different sample are presented. Evaluators identify the different sample.
Duo-trio	Reference presented followed by one identical and one different sample. Evaluators identify the sample same as the reference.
Directional	Two different samples are presented. Evaluators are asked which one is stronger in specific sensory attributes (flavor or texture).
Monadic	One sample or series of single samples is presented for evaluation
Paired	Two samples are presented side-by-side or sequentially for evaluation
Ranking	Three or more samples are presented to be ranked for preference
Quantitative descriptive analysis	A panel of trained evaluators evaluates a set of samples for specified attributes to arrive at statistically derived product description of flavor and/or texture
Spectrum descriptive analysis	A panel of trained evaluators evaluates a set of samples using calibrated scales for specified sensory attributes to provide a complete and detailed descriptive characterization of the sensory attributes and their intensities

In order to obtain reliable and high quality sensory data, the facilities, setup, and training for sensory evaluation play a very important role. A good setup helps generate good quality data whereas inadequate attention to logistics and details can compromise the quality of the data and call into question the conclusions made from the data. The most common factor that impacts the quality of data is noise – changes in the factors being studied not caused by the parameters of interest. Noise can be random, as caused by random changes in the samples or environment or it can be systematic, as caused by factors other than those being studies influencing the outcome of the work. The recommendation below can significantly help reduce the impact of noise on the data.

The physical set-up for the analysis is important and can impact the outcome of the testing. Requirements for controlled testing include an area in which extraneous odors and distractions are minimized – individual booths are highly recommended. Laboratories or kitchens used for sample preparation should be equipped with a sink, food warmers, refrigerator/freezer, analytical balance, lab glassware, oven and stove. In addition any equipment needed to prepare and serve food products, such as blenders, mixers, and serving/sampling containers that are useful for the range of samples being evaluated.

Another area that needs to be taken into account is sample presentation. It is important to provide consistent sample sizes and portions for different samples and to different evaluators. The serving temperature needs to be regulated uniformly across samples and panelists. The samples should also be served in similar, preferably identical containers. Further, the samples should be coded so the evaluators cannot identify them by name and therefore will not be influenced by any prejudice towards the names or descriptions of samples. The serving order for the samples should also be changed using a suitable strategy for randomization to ensure that any effects due to order of presentation do not confound the data.

The selection of suitable evaluators is an area that requires significant expertise as well. For consumers being asked to evaluate a food product, it is important for most tests to use a selection or screening questionnaire to classify the consumers and eliminate any potential outliers. For example, for people evaluating yogurts to pick the most liked sample out of a set, it is important to identify people who consume yogurt regularly and actually have a liking for the product vs. those who do not like yogurt. If there are people in the set who are not frequent consumers and do not like yogurt at all, their views are not representative of mainstream yogurt consumers and will most likely need to be classified separately from people who like yogurt and consume it regularly. For trained panelists conducting difference of descriptive testing, it is important to recruit people to the panel who have the capability to differentiate between the attributes being evaluated. Certain people may not qualify based on their being overly sensitive to certain tastes or textures. In addition, food safety is a key factor to consider while conducting sensory analysis and testing. Proper safety guidelines for food preparation, storage, and serving need to be followed to ensure food safety and it is critical to ensure that people who are tasting food be informed about the ingredients used to ensure that there is no accidental exposure to any allergens for people who suffer from food allergies.

There is highly specialized training that is available and routinely conducted for expert evaluators for flavor and texture. There are three types of languages or terms commonly used to describe texture. These are basic/fundamental terms, integrated terms, and consumer terms. The ideal texture language used for sensory evaluation should be fundamental/basic and should translate integrated and consumer language into elements that can be measured and, if needed, altered through processing or formulation.

The basic/fundamental language terms constitute building blocks of a composite sensory perception and are developed from the basic elements of texture perception. They are discrete, concrete and clearly defined. Such elements can not only be measured reliably with high accuracy, but are also understood by a scientist or food formulator and are the fundamental elements of a texture experience. Examples of basic texture terms include thick, slippery, cohesive, firm, fracturable, loud and so on. Each term measures a fundamental property and though some of the terms may correlate to each other, each term measures a fundamental texture property of interest for the food.

Integrated language terms are so called because they are made of two or more fundamental terms. These are typically used by consumers or by experts when relating consumer terms to fundamental texture terms. These terms typically cannot be directly measured but have to be derived by either expert evaluation of the fundamental terms that comprise them or through consumer evaluation of the overall sensory impact. Examples include crispy, crunchy, creamy and chewy.

Consumer language terms are those typically used by non-expert consumers to describe the foods they eat. These are typically not well defined and can be difficult to translate into specific product characteristics. This is because these terms evolve from sensory, cultural, and even emotional responses to food. Even though the terms imply a consistent broad sense to most people, the same terms used by different people can often describe very different physical characteristics. A further complicating factor is that many consumers use similar terms to those used in fundamental or integrated languages to describe complex consumer experiences that convey meanings different from those conveyed by the same terms when used in the fundamental or integrated languages by expert evaluators. Examples include velvety, creamy, crunchy, chewy, and soupy.

A trained texture evaluation team needs to have the capability to be able to distinguish between the different terms and be able to conduct measurements and translate across the three different texture languages.

1.3.2 Instrumental measurements

Bourne (2002) provides a comprehensive overview of the history of texture measurement. One of the earliest documented examples of the systematic testing and optimization of food texture is from the mid-1800s in Germany where mechanical testing was used to measure the firmness of jellies or from the late 1800s in the United States where viscosity was measured to test the quality of milk or cream. Several key developments in Europe and the United States in the late 1800s and the early 1900s included systematic measurement and optimization of texture of dairy products, oil/butter, fruits, grains, and dough-based products.

There has been extensive research conducted in the use of instrumental measurements to measure physical properties of the food products that can be correlated to the sensory perception of texture. There is a large volume of information available on the use of these techniques in Rosenthal (1999) and Bourne (2002). These tests can be divided into three types of measurements.

The first type is the measurement of primary physical characteristics including size, shape, volume, porosity, and color. These properties are relatively straightforward to measure and provide data that is easy to compare between products and can sometimes be directly related to sensory perception. These characteristics can also be routinely measured during quality control and basic physical attribute testing.

The second type of measurements are based on mechanical deformation or flow behavior and are typically based on relating the rate or scale of deformation in the instrument to that in the mouth or in a processing unit. These measurements are related to rheological testing for liquids or semi-solids or to compressive or tensile testing for solids. A typical test involves preparation of samples of defined shape or geometry and deforming them using carefully measured forces. The test can be conducted by controlling the force and measuring the deformation or by controlling the deformation and measuring the required force. The force is measured as a function of deformation and/or temperature and/or rate of deformation. The magnitude of the force and deformation as well as the shape of the curve including shape and size of the peaks and valleys are related to different fundamental properties and in some cases can be directly related to sensory perception. The so-called texturometer was an instrument used for this type of measurement (Szezsniak, 2002) and there are a variety of instruments routinely used for liquid as well as semi-solid foods. Many examples are provided in McKenna (2003) and Kilcast (2004).

Rheology for semi-solid as well as solid foods is an important tool for texture evaluation. It requires significant expertise and training to generate as well as interpret reliable data and can be time as well as effort consuming. However, rheology enables precise evaluation of food texture in a way that few other techniques can. Rheological properties broadly correlate to sensory properties in the range where both types of evaluation provide reliable results. However, rheological testing can have advantages over sensory testing for samples or conditions where sensory testing is difficult to conduct. Examples could be samples that are too hot or too cold and the extreme temperatures can impact a normal trained panel's ability to conduct objective evaluation across samples. Another example is samples that are too spicy, for example, hot pepper sauces that some panelists would find difficult to taste and different panelists would have different degrees of sensitivities to the level of spiciness. Such trigeminal sensations can introduce significant noise and variation in the evaluation of other texture attributes. Another area where rheology excels is the ability to pick out small differences in the flow behavior of samples. These may or may not be important for the immediate eating experience but do play a role in influencing the stability of texture over time and ultimately play a role in influencing the product texture.

For these reasons, rheological testing finds frequent use in determining ingredient functionality in product development, intermediate or final product quality control, shelf life testing, as well as process engineering calculations for scale-up of processing operations.

The third type of measurements are custom fabricated to detect physical attributes that are specific to the human perception of texture. These attributes include devices that track jaw movement or measure the neurological activity of jaw muscles and relate them to properties of the food and the response of consumers. Some good examples are described in Cakir (2011).

1.3.3 The ultimate texture language

Research and product development efforts from different parts of the world have evolved the measurement and understanding of texture using a variety of approaches. Though these approaches are all useful in their own way, small yet significant differences make it difficult to translate work conducted across groups or locations and even the same samples and terms measured by different groups can lead to different results.

This is true for sensory and, to a lesser extent, for instrumental measurement and is due to the fact that texture measurement is inherently a complex undertaking. Our understanding of what comprises fundamental texture and how to best measure it is still evolving for several food products. The ultimate texture language would perhaps be more universal in its applicability and understanding and pull together the different groups working on solving similar problems in different parts of the world.

Figure 1.3 shows an example graphic illustrating the TEXICON™ or texture lexicon used by Ingredion Incorporated. This is an example graphic illustrating how fundamental instrumental measurements (outermost layer) could be related to fundamental sensory terms (next two layers) and ultimately to integrated consumer terms (innermost layer). The ability to understand this relationship and use it to change food texture by design can lead to the perfect texture (as illustrated at the core of the graphic). Another way to look at this interconnection is that understanding this relationship can help translate the eating experience (at the center of the graphic) into measureable and, ultimately, controllable attributes that can be optimized to design the perfect texture. This graphic and the concept of the TEXICON™ is used here as a tool to illustrate the importance of

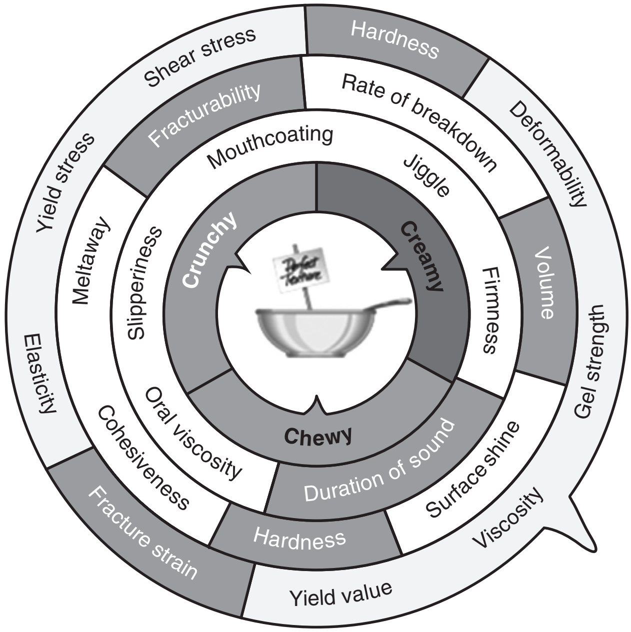

Figure 1.3 TEXICON: The Texture Lexicon. (Source: Copyright © 2013 Ingredion Incorporated. Reproduced with permission.)

understanding these relationships but the fundamental concept and approach here is broadly applicable to any team and any organization that endeavors to understand and optimize texture as well as the overall eating experience.

1.4 THE OPTIMIZATION OF FOOD TEXTURE

A variety of tools and techniques are used to develop optimum food textures. This is true for a person preparing a home cooked pasta dinner where a combination of the right cooking time and type of pasta is needed to get the desired *al dente* texture. It is also true for a food scientist designing the next popular meal choice for consumers in the food aisle in a grocery store. A skilled chef truly understands the synergy between food ingredients, flavor dynamics as well as manipulating cooking conditions to achieve highly desirable, even sensational food textures and taste. From a texture perspective, the tools available to optimize food texture can be divided into two sets: formulation and process optimization.

1.4.1 Formulation

Food formulation has traditionally been looked upon as an art as it had its roots in highly skilled chefs using experience and creativity to gain mastery of texture, and ultimately taste. As food science knowledge has increased and many research teams have developed and documented this knowledge, food formulation has evolved into a much more scientific tool to develop and optimize food texture. Different ingredients have traditionally been used to impart a variety of textural experiences. Traditional uses of ingredients include the use of fats to provide lubricity or mouthcoating, starch based ingredients to provide viscosity, or protein based ingredients to provide gel or set characteristics. Significant developments and advances have been made in the ingredients available that provide food formulators with a versatile toolbox to design and optimize texture. The advances made include a variety of ingredients based on carbohydrates, proteins and fats. Carbohydrate ingredients include starches, gums, fibers and a variety of derivative ingredients. Fat based ingredients from different sources with different levels of unsaturation, and refining can influence a variety of textures. Protein based ingredients from animal and vegetable sources including concentrates and isolates can also provide a range of texture and nutrition benefits. Functional ingredients provide a variety of texture properties including viscosity, gelling, and other textural attributes in many applications. For example, carbohydrate based ingredients can now be used to provide attributes related to indulgence and lubricity as well as gelation that were only previously possible using fat or protein based ingredients.

In addition to functional ingredients, a variety of computer-based applications and tools have evolved to enable formulation development and optimization. These tools include the ability to generate and optimize nutritional information, conduct design of experiments and optimize formulations based on driving preferred texture attributes as well as the ability to routinely review and statistically analyze multivariate texture data.

1.4.2 Process Optimization

The impact of processing including temperature, level of shear and pressure has been a topic of considerable study by food scientists and engineers for more than a hundred years. The time spent at a particular temperature, shear level, or pressure also plays a significant role in determining the texture of the food product. The changes induced by processing are due to changes in the physical characteristics of the ingredients due to the cooking process. From a texture perspective, this can include changes in viscosity as well as in the hardness of ingredients. The actual changes are strongly impacted by the physical breakdown of the native ingredients added to the recipe as they interact with each other and water. The actual changes can be quite complex and the order of ingredient addition plays an important role.

The primary impact of processing is based on temperature, shear, pressure and the length of time the product is subject to these parameters. Not only are the specific conditions important but the scale of the process as well as the type of apparatus used can have a significant impact. The intensity of cooking depends directly on time at an elevated temperature. Higher levels of shear or pressure typically accelerate the cooking process. Shear also independently acts to change texture through imparting mechanical force that can help with mixing as well as with breaking down certain ingredients.

The choice of equipment used is important in several ways. The application of heat plays a strong role in developing ideal texture. Whether the heat is applied through uniform exposure to moderately high temperature or through short exposure to very high temperature or through long exposure to a range of temperatures can lead to very different textures for the same substrate. For example, chicken that is boiled, fried or grilled has very different textural attributes that are primarily related to the cooking process and how that changes the texture of the food differently. Another factor that has strong impact is how the heat is transmitted to the food being cooked. Whether it is through being immersed in hot water, hot oil, or steam or being cooked in a shallow layer of water or oil can all lead to different textures.

For home cooking, there is specific equipment used for these different types of processes ranging from stove-tops, ovens, convection ovens, grills based on a variety of different fuels, and more recently microwaves. A variety of cooking utensils including pans, steamers, stock-pots, griddles, and pressure cookers further help in developing optimal textures. In a commercial production environment, there is a variety of equipment that is commonly used to get the same target textures at a larger scale, with greater reliability, and faster speed. The type of equipment can vary significantly by scale, source of heat, food safety regulations, and economic as well as cultural considerations. The choice of equipment has a strong influence on texture and changing equipment scale as well as type typically needs to be compensated with a change in processing parameters or formulation or both to maintain or optimize texture. Trained food formulators and applications scientists typically have the expertise to deliver target textures as well as overall taste while navigating the complexities of process development and optimization.

1.5 A HOLISTIC APPROACH TO INTEGRATED FOOD TEXTURE DESIGN

The optimization of food texture can be a complex undertaking as illustrated by the different aspects that can lead to changes in texture perception as well as the many different tools and techniques that are required. A systematic and data driven approach to food texture design can help lead to robust solutions faster. A good example based on the editors' experience is the DIAL-IN® Texture Technology, which is Ingredion's integrated approach to food texture design and optimization. This approach is unique to Ingredion in that it uniquely uses the knowledge and experience of the Ingredion team to provide robust and reliable texture solutions. However, most of the elements in this approach are based on a general framework that is applicable for anyone who seeks to develop strong capability in designing food texture, or for that matter, other aspects of food product design and optimization.

This approach is a rapid, robust, data-driven methodology that combines the art and science of food formulation and translates consumer needs and sensory preferences into food products that provide a superior eating experience. The approach has five steps as shown in Figure 1.4.

1. Define business and technical goals: This is perhaps one of the most critical steps in addressing any product development issue. It is critical to not only define the goals and objectives but also to define how to address these through the project being planned. This includes relevant cultural insights, label or nutritional requirements, desired package claims, the relevance of any benchmarks, as well as the desired timeline and measures of success.

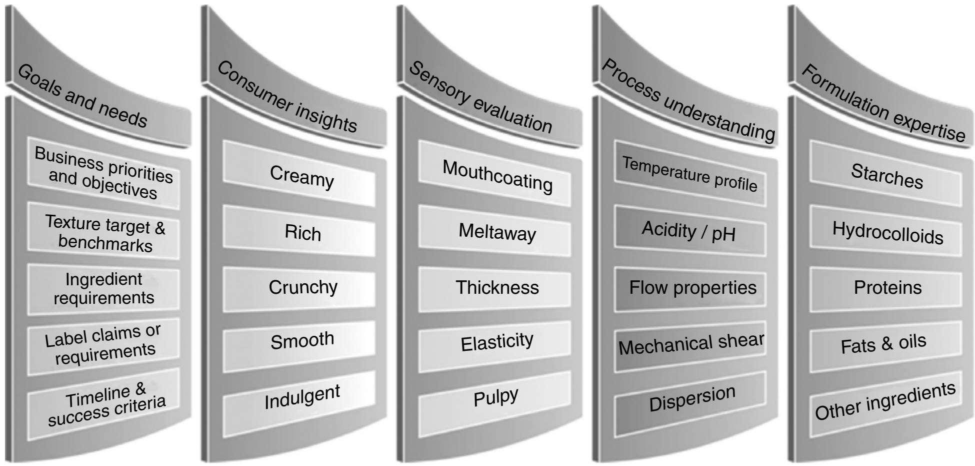

Figure 1.4 The systematic approach used for DIAL-IN® Texture Technology. (Source: Copyright © 2013 Ingredion Incorporated. Reproduced with permission.)

2. Gather consumer as well as market insights: Define consumer expectations for the product being designed and to define the requirements to gain consumer acceptance and liking. This step requires access to capabilities and expertise to be able to develop and utilize consumer insights.
3. Evaluate sensory attributes and set texture target: Ensure that there is adequate understanding of the sensory texture attributes that need to be measured to define the eating experience of the food product being developed or optimized. This may include characterization (e.g. descriptive sensory analysis) of a number of commercial products in the market that represent a range of textural diversity. This information is then used to set a texture target including a definition of the fundamental sensory texture terms that need to be optimized and the sensory and instrumental measurements that need to be conducted. It is important to have access to a capable sensory program with the capabilities summarized in Table 1.2.
4. Understand impact of process equipment and constraints on texture: The specific process equipment, process times and temperature, pH and the amount of shear need to be set and their impact on texture needs to be considered. Food processing expertise and compliance with current food regulations are critical to ensure success in this step.
5. Formulate to optimize texture: The final step is to use a scientific structured process to optimize formulations using the best functional and basic ingredients to develop the target texture. In order to be successful in this step, it is important to have expertise in formulation science. This includes several key capabilities including intimate knowledge of ingredients and their impact on texture, expertise in tools to rapidly design and test food formulations, as well as the ability to use measurements to detect gaps and address these gaps through formulation know-how. Use of capabilities including experimental design, statistical analysis and optimization as well as multivariate data visualization are all helpful in providing rigor and robustness to this step to optimize texture.

1.6 CURRENT MARKET TRENDS AND FUTURE CHALLENGES IN FOOD TEXTURE DESIGN AND OPTIMIZATION

Food texture has been one of the fundamental characteristics that consumers look for in their food products and drives consumer liking and purchase intent. This has always been important but as science and technology have developed, it is increasingly possible to optimize texture and to target new product texture by design. There are three main categories of texture related product development initiatives that are commonly encountered in the food industry.

1. Developing a new food product with a desired target for texture as part of the overall eating experience.
2. Building back the texture of an existing food product after changing some key ingredients, for example, reducing fat in a sauce/dressing or adding whole grains to a bread loaf. In either case, it is desirable to maintain texture and the eating experience while creating a more healthy and desirable nutritional profile.
3. Transforming the texture of an existing product to one that is more highly desirable for the target consumers.

One of the best ways to assess the attention on food texture is to look for texture claims on food products introduced to the marketplace. It is possible to do this using many different approaches. In recent years, front of package texture claims have risen so that almost 1 in 2 products launched has a front of package texture claim. It is possible to review these claims through using any suitable market insight tool. Figure 1.5 provides examples of texture claims on bakery and snack products manufactured in the United States from 2009–2011. Over 3000 products, more than 50% of all product launched, had texture claims on the front of their packages. The top texture terms are shown in Figure 1.5 broken down by category.

Based on current and emerging market trends, texture will continue to be a key factor in food product design and optimization for the foreseeable future. A key area of focus where texture will need to be addressed is cost optimization and affordability initiatives as fluctuations in price of food ingredients necessitate initiatives to optimize the cost of food formulations while maintaining a desirable eating experience. This could include replacement of costly sources of carbohydrates, fats or proteins with more cost-effective ones while minimizing undesirable changes in the eating experience.

Another area of focus continues to be the reduction of ingredients that could be harmful if consumed in excess. Current initiatives in different parts of the world include reduction of different types of fats, salt, and sugar. These ingredients have an impact on texture and flavor but can also have impact on other factors including shelf stability and food safety. The impact of reducing or eliminating the undesirable ingredients from the food formulations needs to be compensated for by using a combination of ingredients and processing.

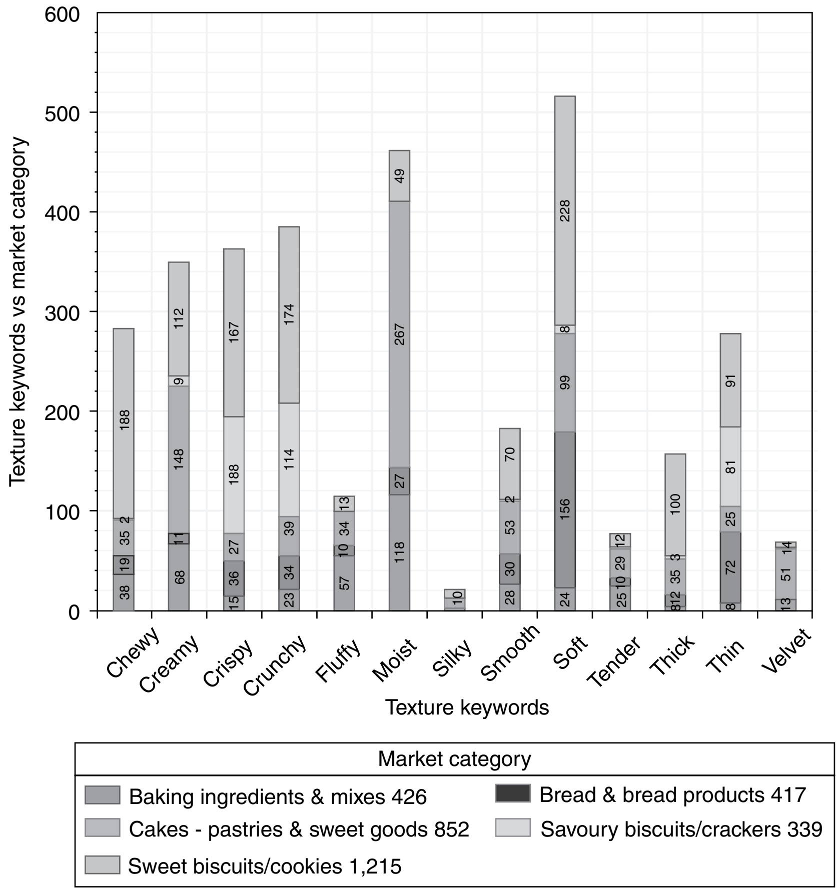

Figure 1.5 Top texture terms featured in texture claims on bakery and snack product launched between 2009–2011. (Source: Image generated using Innova Market Insights by S. Mutz-Darwell, Ingredion Incorporated. Reproduced with permission.)

The addition of healthy ingredients to food product to promote personal health and well-being will also continue to lead to texture challenges. The addition of wholegrain or multi-grain flours, soluble and insoluble fibers, and proteins lead to texture challenges due to the unique and sometimes undesirable texture attributes introduced by these ingredients in a variety of food products.

The need for allergen free foods for populations suffering from different food allergies will also continue to generate texture challenges that will need to be addressed. As an example, the development of gluten free baked goods have seen significant interest and advancement over the last 10 years but several challenges still remain to be addressed.

Processing and shelf-life optimization are also important challenges that will continue to provide new food texture challenges. New processing techniques such as high pressure processing (HPP) (Doona and Feeherry, 2007) provide new avenues to develop food products with desirable attributes. However, these techniques lead to texture related challenges as the difference in processing conditions lead to changes in texture from ingredients as compared to traditional cooking methods. High quality microwavable products still continue to be a challenge. Evolution in shelf life and food safety requirements can also lead to changes in formulation and processing and consequently changes in texture.

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