The tactile sensation of food, mouthfeel, is an important but often overlooked part of the total flavour experience of food. Mouthfeel is determined by the texture of the food, the texture being a multifaceted quality defined as that part of the food structure our sensory apparatus can detect. Texture often determines our food preferences, and modifying texture is therefore a key culinary exercise. An insight into the mechanics and molecular underpinnings of food structure and how it can be modified by various culinary transformations can be used to enhance the cooking experience and lead to new creations.

Preparing food and the culinary arts involve working with raw materials to produce food that is tasty, interesting, and nutritious. All of this necessarily involves finding ways to work with mouthfeel in the course of an often long series of transformations, first in the kitchen and then in the mouth. Many of the processes carried out in the kitchen are irreversible. Once a potato has been boiled, it is not possible to cool it and return it to its raw state. Similarly, a cooked egg that has set cannot easily become liquid again (This, 1996). In addition, subjecting a raw ingredient to a combination of processes will not necessarily lead to the same result if the processes are carried out in a different sequence.

Mouthfeel refers to sensory inputs from the so-called somatosensory system (Shepherd, 2011; Mouritsen and Styrbæk, 2017). This system is found not only in the mouth, but everywhere in the body. Physical stimuli, including pain, temperature, and tactile sensations, such as pressure, touch, stretching, and vibrations, are detected by the somatosensory system. Technically, mouthfeel is mediated by certain receptors in the epithelial cells of the oral cavity that are associated with four different types of somatosensory nerve endings that are sensitive to temperature, pain, touch, and pressure, respectively (Figure 88.1). The somatosensory system also detects the position and movements of the body and parts of the body (kinaesthesia), like the tongue. The motions of the tongue help us to explore and assess the size, shape, and texture of a piece of food while we are chewing. The nerve endings in the teeth also provide information about the structure of the food – its hardness, whether it is crunchy or elastic, and the size of the food particles.

![Figure 88.1](image-url)

*FIGURE 88.1* The sensory system in the skin, which registers heat, cold, pressure, and pain: (1) pain, (2) temperature, (3) touch or light pressure, and (4) pressure.
Transforming the properties of raw ingredients to achieve a desired texture and preserving it until the food is about to be eaten can be challenging. If prepared commercially, the food might need to be transported and may be kept on supermarket shelves for a long time. It is also necessary to take into account the changes that occur in the final stages of preparation. In all cases, it is crucial to make allowances for what happens when the food goes into the mouth and mouthfeel comes into play. There, the texture is affected by temperature, saliva, enzymes, and the way in which we chew.

The flow properties of liquids and soft solids, as can be measured by rheology experiments, are also important for mouthfeel. We can feel how the food flows in our oral cavity on its own or after we have worked on it with our tongue, palate, and teeth. We notice whether it is sticky (like syrup), slimy (like a thin jelly), or fatty (like oil). Liquid foods such as drinks flow into the mouth more or less quickly on the time scale of a second and fill it up. Semisolids, such as emulsions, on the other hand, flow more slowly and can behave in a viscoelastic manner. Solids do not flow at all, but sometimes they can be dissolved in saliva or melt, or can be reduced to very small bits by the action of tongue and teeth.

**Interplay between Mouthfeel and Other Sensory Perceptions**

A ‘taste sensation’ is the brain’s interpretation of a complex multimodal integration of all sensory inputs, not only taste proper: flavour is in the brain (Small, 2012). It is useful to know how mouthfeel interacts with the other sensory inputs. Whereas much is known about how sight, hearing, and somatosensory impressions are integrated, the understanding of the interplay between chemical sensory impressions (taste and smell) and mouthfeel is more limited (Saint-Eve et al., 2011). Most of the existing knowledge is rather phenomenological, with little understanding of its neurological basis. However, some of the knowledge can come in very handy in the kitchen. The following presentation is based on a series of research results compiled by Verhagen and Engelen (2006) and is adapted from a review by Mouritsen (2016).

To stimulate the five basic tastes experimentally, certain classical taste stimulators are used: sweetness is derived from ordinary table sugar (sucrose), saltiness from sodium chloride, bitterness from quinine or caffeine, sourness from citric acid, and umami from monosodium glutamate (MSG). Irritation and pain are typically induced by capsaicin (from chili) or piperin (from black pepper). Mouthfeel can be evoked by changing the viscosity of the food, by direct contact with the food, or by the mechanical movements of the tongue in the mouth. In the following, ‘taste’ refers to chemical taste, i.e., proper taste perceived by the taste buds. ‘Touch’ refers to a mechanical stimulus, ‘impression’ is a somatosensory perception, and ‘irritation’ is the consequence of chemesthesia. For references to the original literature regarding the observations reviewed in the following, see Verhagen and Engelen (2006).

**Taste → Touch**

Taste can affect the way in which viscosity of a food is perceived. Sweetness enhances it, sourness lessens it, bitterness has no effect, and it is not clear whether salt has any effect.

**Touch → Taste**

The viscosity of a food raises the taste threshold for, and decreases the intensity of, sour, sweet, salty, and bitter tastes. The effect is also dependent on the medium in which the taste substances are embedded. For example, oil limits the access of the taste compounds to the taste buds. In contrast to other tastes, umami is intensified by the movement of the tongue.

**Temperature → Taste**

The taste thresholds for sour, sweet, salty, and bitter are lowest in the temperature range of 22–37 °C, which is, therefore, the range within we are most sensitive to the taste of food. It would appear that this is due to the temperature of the tongue rather than that of the food. Moreover, some experiments have shown that changing the temperature over a small area of the tongue can evoke different taste sensations. For example, warming a spot on a tongue that has been cooled brings out a sweet taste, and cooling the tongue to 10–15 °C can result in sour and salty tastes, but the effect varies from one person to another. Warming the tip of the tongue results in enhancement of sensitivity to sweetness from sucrose, but not to other tastes. This indicates that the perception of sweetness due to warming is less susceptible to adaptation.

**Taste → Irritation**

Sweetness (of sucrose) can reduce the burning sensation produced by piperin and capsaicin, whereas sourness (citric acid) and water have only a minor effect, and saltiness (NaCl) and bitterness (quinine) have no effect. Here, it should be noted that substances such as salt and quinine in large concentrations could in themselves lead to irritation.

**Irritation → Taste**

Irritation and pain caused by capsaicin and piperin reduce the taste intensity of sweet, bitter, and umami tastes, whereas sour and salty tastes have little or no effect. In the case of irritation caused by piperin, sour, sweet, salty, and bitter tastes are decreased; it would appear that its effect on umami has not yet been investigated. The special irritation and prickly sensation produced by carbonated drinks can reduce bitterness and enhance sourness. These results are complicated, given that some of the test subjects experienced capsaicin as a moderately intense bitter taste and that CO₂ forms carbonic acid, which is sour, in water.

**Smell → Touch**

The few results that are available indicate that smell can influence the experience of textural impressions such as creaminess, consistency, and melting qualities of a food. For example, a substance like vanilla, which releases intense odour substances and
is associated with creaminess, enhances the perception of creaminess of a vanilla pudding.

**Touch → Smell**

Increasing the viscosity of a food attenuates the intensity of the smell perception. In this experiment, the actual release of odour substances from the food is controlled so that it is not dependent on viscosity.

**Smell → Temperature**

Some odours are perceptually associated with temperature. This interaction is due to neural binding. For example, the retronasal aroma given off by many spices is associated with warmth.

**Temperature → Smell**

In general, the intensity of odours increases with temperature. This is most probably a purely physical-chemical effect, as the higher temperature leads to the vaporization of a greater quantity of volatile odour substances and makes the food less viscous, also facilitating the release of these substances. This sensory enhancement is independent of the neurological system.

**Smell → Irritation**

Normally, smells suppress the feeling of irritation. On the other hand, many smells can, in themselves, trigger irritation.

**Irritation → Smell**

Irritation, for example, as induced by capsaicin, depresses the intensity of smells such as those of oranges and vanilla. There are also indications that astringency in the nose contributes to the sense of smell.

**Touch → Temperature**

Experiments have shown that applying vibration to the lips raises the threshold for experiencing warmth or depresses sensitivity to temperature. Increasing the viscosity, for example, by increasing the fat content, increases the perceived temperature of a cold substance, even though the temperature remains constant. An explanation for this is that fat has an insulating effect. A further indication of this effect is that a food with a high fat content at a low temperature is sensed as being less cold than its low-fat counterpart. Conversely, a food with a high fat content at a high temperature is experienced as being less warm than one with a low fat content.

**Temperature → Touch**

Temperature has a marked influence on the mucous membranes and the tongue and on the physical properties of the food, especially its coarseness and texture. Hence, it is likely that the influence of temperature on mouthfeel is predominantly a physical-chemical effect rather than a neurological one.

**Touch → Astringency**

Astringency due to the tannins from grape seeds is decreased when the viscosity of the media in which they are dissolved is increased. This is in agreement with other studies showing that lubricants, for example, cooking oil, reduce the feeling of astringency. The reason for this effect is probably that the friction that accompanies astringency is reduced by the lubricant.

**Temperature → Irritation**

Heat increases irritation and pain, for example, from capsaicin, piperin, and alcohol, while cold does the opposite.

**Irritation → Temperature**

Irritation due to capsaicin is experienced as heat and subsequently suppresses the feeling of cold.

**Texture**

Alina Surmacka Szczesniak has studied texture and how it affects our choice of what to eat. She defines texture, and concomitantly, mouthfeel as follows (Szczesniak, 2002):

1. A sensory quality of food, and consequently, a quality that only a human (or another living being) can recognize and describe. Only certain properties of texture can be measured by physical means and the results of these measurements require a sensory interpretation;
2. A multifaceted quality that cannot be described by a single parameter, such as hard or creamy;
3. A quality that depends on the structure of the food at all levels, from the molecular to the microscopic;
4. A quality that is recognized by several senses, of which touch and pressure are the most important.

Bourne (2002) has condensed the definition of texture to: ‘The textural properties of a food are that group of physical characteristics that arise from the structural elements of the food, are sensed primarily by the feeling of touch, are related to the deformation, disintegration, and flow of the food under a force, and are measured objectively by functions of mass, time, and distance.’ In accordance with this definition, one ought to refer to ‘textural elements’ to acknowledge that texture is a set of sensory properties. Many different parameters may therefore be involved in the description of texture, and we use a large number of popular expressions to describe them. What has made it so difficult to define texture and, along with it, mouthfeel is that some textural elements have measurable physical dimensions, whereas others take on meaning only in connection with human sensory impressions and perceptions of the structure of the food. Hence, it is difficult to correlate the texture as it is experienced by the sensory apparatus of a human being with physical properties that can be defined accurately and measured quantitatively. Tables 88.1 and 88.2 provide lists of parameters and popular expressions for

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Texture: How Texture Makes Flavour

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## Texture and Food Culture

It is interesting to note that different countries and different food cultures have significantly different numbers of terms to describe texture (Mouritsen and Styrbæk, 2017). These differences most likely reflect different food cultures’ appreciation of mouthfeel as an important characteristic of food. The language with one of the richest vocabularies for texture appears to be Japanese, with more than 400 discrete terms, whereas most European and North American countries only have 100 or fewer. Drake (1989) has pointed out, from studying 22 languages, that 54 words for textural elements have an identical meaning. These words fall into six broad categories: viscous, plastic, elastic, compressible, cohesive, and adhesive. The most frequently used word regarding texture in the United States and in many European countries is ‘crisp’. In Japan, the word that occurs most often is ‘hard’. ‘Crisp’, ‘juicy’, ‘soft’, ‘creamy’, ‘crunchy’, and ‘hard’ are among the terms for textural most commonly used in the United States, Austria, and Japan.

Jurafsky (2014), using big-data techniques and data mining of information on the internet regarding food, recipes, menus, restaurant reviews, and people’s eating habits, has found, e.g., for desserts, that the reviewers’ descriptions of the desserts are full of expressions that can be interpreted as having thinly veiled sexual connotations. This connection manifests itself most prominently in the focus on mouthfeel, rather than those for aroma, taste, sound, or appearance. Some typical sensuously laden words that appear frequently include ‘silky’, ‘satiny’, ‘juicy’, ‘wet’, ‘creamy’, ‘sticky’, ‘smooth’, ‘oozing’, ‘spongy’, ‘melting’, and ‘hot’.

## Food Complaints Often Relate to Mouthfeel

When customers complain about products available in food stores or at the market, or when diners in a restaurant express dissatisfaction with a dish, it can very often be traced back to mouthfeel. Anecdotally, customers and restaurant guests seldom complain that something tastes ‘bad’. Instead, it is legitimate to say that the soufflé has collapsed, the meat is not tender, the French fries have gone soggy, the bread is dry, the coffee is tepid, and so on. It is much easier convincingly to describe an unfulfilled expectation related to texture than one that pertains to chemical sensations, such as taste and aroma. In addition, a certain texture is often associated with the freshness of the raw ingredients and their proper preparation.
Texture: How Texture Makes Flavour

### TABLE 88.3
Gelling Agents and Gums

<table>
<thead>
<tr>
<th>Gelling agent or gum</th>
<th>Properties</th>
<th>Uses</th>
<th>Mouthfeel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alginate (sodium alginate)</td>
<td>Soluble in cold water. Thermoreversible gel formation.</td>
<td>Thickener, stabilizer (for example, in ice cream and frozen desserts), and gelling agent (marmalade). Used for spherification.</td>
<td>Clean, lingering.</td>
</tr>
<tr>
<td>Carrageenan</td>
<td>Forms somewhat clear and fragile gels containing proteins. δ-carrageenan forms elastic gels in the presence of calcium ions.</td>
<td>Thickener, stabilizer, and gelling agent. Used, for example, in dairy products such as yogurt and chocolate milk.</td>
<td>Creamy, clean, lingering.</td>
</tr>
<tr>
<td>Locust bean gum</td>
<td>Forms cloudy, elastic gels in the presence of ions, especially when combined with xanthan gum.</td>
<td>Thickener and stabilizer. Improves freezing and thawing properties, for example, of ice cream. Adds softness and elasticity to bread dough.</td>
<td>Lingering, sticky.</td>
</tr>
<tr>
<td>Guar gum</td>
<td>Easily soluble in cold water. Forms opaque liquids that flow slowly.</td>
<td>Thickener (ketchup, dressings) and stabilizer (ice cream, dough).</td>
<td>Lingering, smooth.</td>
</tr>
<tr>
<td>Xanthan gum</td>
<td>Soluble in both cold and warm water. Forms clear gels (together with locust bean gum) and slowly flowing, complex liquids that exhibit shear thinning. Thermoreversible.</td>
<td>Versatile thickener (sauces, salad dressings) and stabilizer.</td>
<td>Lingering, smooth to sticky.</td>
</tr>
<tr>
<td>Gellan gum</td>
<td>Gelation properties resemble those of agar, carrageenan, and alginate. Stable at temperatures up to 120 °C.</td>
<td>Thickener and stabilizer.</td>
<td>Clean, creamy.</td>
</tr>
<tr>
<td>Pectin</td>
<td>Forms clear gels in sour foods with a high sugar content. Some types of pectin form strong gels in the presence of calcium ions.</td>
<td>Thickener (ice cream, desserts, ketchup) and gelling agent (marmalades, jams, candies). Stabilizer in emulsions and certain drinks.</td>
<td>Clean, lingering.</td>
</tr>
<tr>
<td>Methyl cellulose</td>
<td>Swells and thickens when heated. Clear.</td>
<td>Stabilizer, emulsifier, and thickener (ice cream).</td>
<td>Clean to lingering and sticky.</td>
</tr>
<tr>
<td>Gelatine</td>
<td>When cooled forms very clear, pliable, and elastic gels. Thermoreversible.</td>
<td>Gelling agent used in a wide range of food products.</td>
<td>Clean to lingering and sticky.</td>
</tr>
<tr>
<td>Starch</td>
<td>Swells up and dissolves in warm water.Opaque.</td>
<td>Thickener used in a wide range of food products.</td>
<td>Sticky and lingering.</td>
</tr>
</tbody>
</table>

Source: Barham et al., 2010; Myhrvold et al., 2010; Mouritsen and Styrbæk, 2017.

### Modifying Texture

A common goal of the culinary arts is to alter the textural properties of the food, e.g., so that a dish fractures when chewed to the extent that it breaks up into appropriate pieces, thereby enhancing its taste and maximizing its nutritional value; or the food deforms, flows, and coats the oral cavity in a pleasant way and releases the taste and odorant compounds in a desired fashion.

A prominent example is cooking (heat-treating) raw ingredients so that they are easier to chew. In the case of both vegetables and meat, the cellular structure in the connective tissue is ruptured, but paradoxically, this is not why they are easier to chew. Cooked vegetables deform more readily when chewed because the cooking process has softened the cellulose in the plant fibres, making them less stiff. In contrast, meat that has been heated becomes stiffer due to actin and myosin coagulation, and at the same time, the connective tissue loosens when collagen denatures. Enzymes and various methods of fermentation are other ways to modify the texture of food. Moreover, temperature, acidity, and the presence of specific minerals (salts) can be absolutely crucial for the texture.

Common ways of modifying the mouthfeel of food involve various natural or artificial agents that change the texture of liquid foods, e.g., egg, bread, dairy products, emulsifiers, gelling agents, thickeners, and stabilizers. A list of some of these is provided in Table 88.3.

Once the desired texture of a foodstuff has been achieved, it may change over the course of time by a variety of natural physico-chemical, chemical, and enzymatic processes, as illustrated in Table 88.4 (Bourne, 2002). Some of these changes can be remedied; others cannot.

### The Challenge in Designing Texture

In principle, one can classify food into three levels. The top level contains the biological organisms we eat (e.g., animals, plants, insects, algae, fungi, bacteria, etc.). Below that is the level of
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so-called formulated food, that is, highly processed food (e.g., bread, dairy products, sauces, fermented food and beverages, etc.), whose biological origin is difficult to recognize without some preconceived knowledge. Below that level is still another more basic level, which could be called the 'elementary particles' of food, that is, pure proteins, carbohydrates, nucleic acids, fats and oils, minerals, water, vitamins, etc. Since all kinds of food are built of these elementary particles, many of which are macro-molecular entities or assemblies, it is in principle possible from these particles to build and construct foodstuffs on the two higher levels. Whereas this is a feasible and in some cases manageable task for, e.g., bread, some dairy products, and sauces, it would be very difficult, if not impossible, to construct a chicken or a mushroom. One of the major problems is to build the foodstuff in the hierarchical way living organisms are built by nature (Mouritsen and Styrbæk, 2017). A main challenge here is to get the texture right. This is exactly the challenge many companies are now facing when attempting to grow artificial meat. Whereas it may be possible to get the flavour right (as well as the nutritional content), it is much more difficult to provide a proper mouthfeel.

A mode of cooking has been coined note-by-note cuisine by This (2014). This is an ultimate strategy to build dishes and a meal from the elementary particles of food, i.e., pure components of carbohydrates, proteins, and fats together with water, minerals, etc. (see examples in the application/cooking section of this book). The challenge here is less one of imparting a desired flavour to the food and more of how to create a particular mouthfeel. Whereas it is reasonably straightforward to construct a jelly, a cheese-like structure, and a bread from the elementary particles of food, it is much more complicated to build more intricate structures, e.g., those of meat and vegetables, whose texture is multifaceted and often determined by a hierarchical architecture.

**Acknowledgements**

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**TABLE 88.4**

<table>
<thead>
<tr>
<th>Food</th>
<th>Texture change</th>
<th>Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bread crumbs</td>
<td>Firmness increases, springiness decreases</td>
<td>Starch retrogradation, moisture transfer from starch to gluten</td>
</tr>
<tr>
<td>Bread crust</td>
<td>Firmness decreases, toughness increases</td>
<td>Moisture migrates from crumb to crust</td>
</tr>
<tr>
<td>Butter and margarine</td>
<td>Firmness and graininess increase, spreadability decreases</td>
<td>Growth of fat crystals, change in crystal form, strengthening of network bonds</td>
</tr>
<tr>
<td>Cheese, ripe</td>
<td>Firmness and fracturability increase, elasticity decreases</td>
<td>Enzymatic changes</td>
</tr>
<tr>
<td>Chocolate</td>
<td>Graininess develops</td>
<td>Change of the crystal structure of the cocoa butter</td>
</tr>
<tr>
<td>Crackers</td>
<td>Loss of crispness</td>
<td>Sugars and fats crystallize on surface</td>
</tr>
<tr>
<td>Fruit, fresh</td>
<td>Softening, wilting, loss of crispness, loss of juiciness</td>
<td>Pectin degradation, respiration, bruising, loss of moisture and turgor, weakening of middle lamella</td>
</tr>
<tr>
<td>Ice cream</td>
<td>Coarseness increases</td>
<td>Ice crystals enlarge</td>
</tr>
<tr>
<td>Butteriness</td>
<td>Clumping of fat globules</td>
<td></td>
</tr>
<tr>
<td>Mayonnaise</td>
<td>Emulsion breaks</td>
<td>Crystallization of lactose</td>
</tr>
<tr>
<td>Meat, fresh</td>
<td>Toughness increases at first</td>
<td>Rigor mortis</td>
</tr>
<tr>
<td>Meat, frozen</td>
<td>Toughness decreases later</td>
<td>Autolysis</td>
</tr>
<tr>
<td>Mustard, prepared</td>
<td>Leakage of water (syneresis)</td>
<td>Surface desiccation, reduced water-holding capacity</td>
</tr>
<tr>
<td>Pickles</td>
<td>Softening</td>
<td>Aggregation of particles</td>
</tr>
<tr>
<td>Pies</td>
<td>Crust loses crispness, filling becomes dry</td>
<td>Moisture migrates from filling to crust</td>
</tr>
<tr>
<td>Shellfish</td>
<td>Softening and mushiness</td>
<td>Leakage of water from the gelling agent (syneresis)</td>
</tr>
<tr>
<td>Sugar confections</td>
<td>Crystallinity, stickiness</td>
<td>Enzymatic breakdown</td>
</tr>
<tr>
<td>Vegetables, fresh</td>
<td>Toughening</td>
<td>Sugars change from amorphous to crystalline state</td>
</tr>
<tr>
<td>Pitting</td>
<td>Softening</td>
<td>Conversion of sugar to starch, e.g., green beans, sweet corn</td>
</tr>
<tr>
<td></td>
<td>Loss of crispness</td>
<td>Moisture loss and turgor loss, e.g., lettuce, celery</td>
</tr>
</tbody>
</table>

*Source: Adapted from Bourne (2002).*
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