Cheese: Hot Culinary Uses of Cheese

Sébastien Roustel1 and John A. Hannon2
1 Chr-Hansen, Cheese application, Boge Allé 10–12, 2970 Horsholm, Denmark
2 Glanbia Ireland DAC, Ballyragget, Co. Kilkenny, R95 W3KD, Ireland

Globally, cheese is mainly consumed in two forms (Roche, 2018, Guinee, 2016): as a table cheese that does not require any special preparation, such as in a cheese platter consumed at the end of the meal or as cheese slices consumed at breakfast, and as an ingredient cheese that is used in culinary applications (Figure 18.1). Currently, the use of cheese as an ingredient represents the majority of cheese use, and this trajectory is set to continue (Kerjean, 2018).

For example, the use of cheese as a pizza topping represents more than 50% of the culinary use of pasta filata cheese (Mintel, 2017). Culinary applications cover its use both as a cold ingredient (in salads and sandwiches) and in hot applications (e.g., pizzas, gratins, pasta, ready meals and toasted sandwiches) (Guinee, 2016; Roustel, 2018).

Depending on the culinary use, the requirements with regard to the quality of cheeses are very variable. The properties that a cheese will develop when heated are dependent not only on the cheese itself but also on the nature of the application (type of dish) and the heating parameters (e.g., duration and temperature). Thus, these are often referred to as the hot functional properties of the cheese or as thermo-functionalities (Richoux et al., 2002; Roset et al., 2004).

Understanding the mechanisms that underpin the expression of these thermo-functionalities can be very useful to control and, more importantly, to optimize them in order to guarantee a high level of quality for the consumer in the final application.

Cheese

If we consider that there are more than a thousand varieties of cheeses around the world, with some estimates mentioning a figure of 1800 varieties (Profession fromager, 2015), these cheeses differ according to the technology used and their composition, appearance, flavour, texture and cooking properties. The variation in the thermo-functionalities is due to manufacturing differences, different degrees of emulsification of the fat, composition and levels of maturity (e.g., extent of proteolysis and lipolysis) (Guinee, 2016). However, some varieties have better attributes than others with regard to thermo-functionalities. For example, Mozzarella, Provolone and Kachkaval (which belong to the pasta filata category), generally have a superior stretching ability compared with many other cheese varieties. If the ability to flow is desired, ripened Cheddar and Raclette are better suited. In contrast, Queso Fresco and Paneer have a low ability to flow, which is sometimes sought in certain culinary preparations where the preservation of the cheese appearance is desired.

All these differences have their origin in the cheese making process and the ripening regime employed (Figure 18.2). There are five key steps in the transformation of milk into cheese, as shown in Figure 18.3 (Mietton and Chablain, 2018):

- milk preparation: control of the microbial flora and adjustment of fat, protein, and possibly the lactose and mineral content;
- coagulation: which transforms the milk in the liquid state to a solid gel. There are several possible ways to transform milk into a gel, with the vast majority being produced by coagulation using proteases (coagulants) with or without the use of lactic fermentation by starter cultures (Roustel and Boutonnier, 2015; Sperat-Czar et al., 2018);
- drainage: this step allows the differential concentration of the milk elements. Caseins combine to form the fine-protein matrix, which entraps the fat globules. The level of drainage depends mainly on the intensity of thermo-mechanical work and the kinetics of acidification. Depending on the kinetics of acidification in comparison to the drainage kinetics, the resultant cheese will have different levels of mineralization. Thus, the calcium content ranges from 0.7 to 13.0 g kg⁻¹, depending on the cheese variety (Figure 18.4). This characteristic is fundamental in controlling the thermo-functionalities of cheese (Guinee and Kilcayley, 2004; Kerjean, 2018; Roustel, 2018);
- salting: which is performed either in brine or by dry salt addition;
- ripening: during which a series of enzymatic biochemical reactions gradually transform the constituents of the young cheese (proteins, fat and carbohydrates) into a multitude of compounds, making the cheese more or less smooth and supple, and conferring its characteristic taste and appearance (Goudédrenche et al., 2007; Sperat-Czar et al., 2018).
FIGURE 18.1 Uses of cheeses.
(From Roche, 2018 and Guinee, 2016)

Coagulation Ripening Variety Examples
(c = cow,  E = ewe,  G = goat)

Lactic curds, slow, spontaneous coagulation

Without preparation
Table cheese or sliced cheese

With preparation
Uncooked (salads, sandwiches), uses and cooked uses (pizza, prepared meals, pasta...)

Lactic curds

Used directly as an ingredient

In the home and catering industry

In the industrial sector in food preparations

With preparation

Lactic curds

Uncooked (salads, sandwiches), uses and cooked uses (pizza, prepared meals, pasta...)

Rennet and mixed curds, quick coagulation

Soft cheese

Without rind

Without rind

• Fresh lactic cheese

G. Rove des Garrigues
E. Caillebote d’Aunis

• Lactic cheese with white rind

C. Chaource, Neufchâtel, St-Marcelin
Brillat-Savarin, Saint-Félicien
G. Saint-maure, Selles, Pouligny

• Lactic cheese with washed rind

C. Episises, Soumaintrain, Langres
G. Picodon Dieulefit

White rind

• Soft cheese with white rind

C. Camembert, Brie, Coulommiers
G. Brique du Forez, Bougon
G. Pérali

With white rind

• Soft cheese with white rind

C. Munster, Maroilles, Livarot, Mont-d’Or, Pont l’évêque
E. Niolo - G. Chevrotin

Washed or mixed rind

• Soft cheese with washed rind

C. Bleu d’auvergne, Fourme, Stilton
E. Roquefort

Blue cheese

Inner moulds

• Blue cheese with cavities

C. Bleu de gex, Gorgonzola, Bel de Termignon, Bleu du Vercors
G. Cabratés, Persillé des Aravis

• Blue veined or marbled cheese

Semi-soft cheese

• Supple to firm

C. St-Nectaire, Tomme, St-Paulin
Reblochon, Mortier, Raclette, Fontina
E. Manchego, Ossau, Lavort

Milling

• With milled curds

C. Cantal, Laglioule, Salers, Cheddar

Semi-hard cheese

Hard-pressed cheese

• Without holes

C. Abondance, Asiago, Madaam
Leerdamer, Appenzel

• With holes

C. Beaufort, Comté, Parmesan
E. Pecorino

C. Emmenthal

FIGURE 18.2 Different cheese varieties classified according to cheese technology.
All these steps involved in the processing of milk into cheese lead to the production of the great range of different cheese varieties, whose composition of water, fat, proteins, lactose/galactose and minerals is very different (Figure 18.4). Similarly, the resultant cheese microstructure is also highly variable (Figure 18.5) (Rowney et al., 2004; Lopez et al., 2007). From a physico-chemical point of view, a cheese can be defined as an oil-in-water emulsion dispersed in a solid: (O/W)/S. All these elements lead to the creation of very different thermo-functionalities from one cheese type to another. Depending on the desired culinary use, it will be necessary to choose which thermo-functional property is required.

**Using the Emulsifying Property of Cheeses: The Fondue**

The emulsifying property of cheese, which is involved in many culinary applications and interacts with other thermo-functionalities (e.g., stretching and browning) (Richoux et al., 2002), is essential to the success of a good cheese fondue and, by extrapolation, to the production of processed cheese and sauces containing cheeses. Cheese fondue is a product obtained by melting and emulsifying cheeses(s) using heat and one or more monovalent salts of acids and water (both these last elements are provided by white wine). In physico-chemical terms, the emulsion is obtained by three key steps: ion exchange, proteolysis/hydration and emulsification, the outcome of which is a thickening of the product (Figure 18.6) (Roustel and Boutonnier, 2015).

**Heated Cheese**

On heating a young cheese in which the fat globules still have their native membrane intact, i.e., unaltered by enzymatic reactions (proteolysis and lipolysis), the changes that occur are limited to the protein/water system and to the substances that are dissolved in this moisture. As the solubility of solutes (lactose, salts and lactic acid) increases with increasing temperature, it follows that, during heating, a certain amount of the solvent water will be free. In addition, this is increased because the hydrogen bonds of the ionic groups of the proteins and amides require less water of hydration. At the same time, this change is accompanied by a strengthening of hydrophobic interactions. If high temperatures are used, then a partial separation of the protein mass (including the fat phase) from the aqueous phase is observed (Lee et al., 1979; Caric and Kalab, 1993; Roustel and Boutonnier, 2015).
FIGURE 18.4 Different cheese varieties according to their composition.

FIGURE 18.5 Microstructure of different cheeses.
(Lopez, 2007; Rowney et al., 2004)
On the other hand, if an aged, ripened cheese is used (evaluated by the ratio of soluble nitrogen over total nitrogen at pH 4.6: SN/TN) (Roustel, 2018), in which the membranes of the fat globules have been altered, then the results obtained are very different. In this case, the increase in energy (due to heat) increases the fluidity of the liquid phases (fat phase and protein/water phase). Thus, localized areas are observed with coalesced fat globules that are freed from their membranes, which gather as pools of fat (Figure 18.7). This results in syneresis and separation of the liquefied fat phase, as can be seen during the heating of mature cheeses such as Cheddar, Emmental or old Dutch cheeses.
Physico-Chemical Mechanisms within the Fondue

For making a cheese fondue, a homogeneous melted product is desired. This is difficult to achieve due to the insolubility of the cheese in the water, as well as the immiscibility of the water and the fat phases. To obtain a visible homogeneous melt without phase separation, it is necessary to use emulsifiers. However, it is known that native caseins (which are the main proteins in milk and cheese), which are very good emulsifiers themselves, lose their surfactant power in cheese due to the bridges that are formed with divalent cations such as calcium and magnesium, the protein-bridging agents. Therefore, in order for casein to play its role in the lowering of the surface tension at the water–oil interface, it must first be solubilized in water. To solubilize the casein, there must be an exchange of the divalent cations (Figure 18.8) (Boutonnier and Roustel, 2014) with stronger monovalent cations such as sodium, such that the calcium-binding sites are ionized and hydrated at the more hydrophilic zones of the casein molecule (Lee et al., 1979; Caric and Kalab, 1993; Boutonnier and Roustel, 2014).

These monovalent cations are provided in white wine in the form of potassium and sodium tartrates (mostly potassium bitartrate).

The wine also provides:

- water, which allows the dispersion and hydration of proteins;
- ethanol, which is very useful for the dispersion of the fat in the liquid phase;
- acidity (the pH of the white wine is between 2 and 3), which facilitates the exchange of ions.

The first step in the physicochemical processes that take place in the fondue is characterized by the conversion of the insoluble calcium caseinate to soluble sodium or potassium caseinate. This results from the displacement of the calcium equilibrium of the mixture in the presence of melting acid salts (tartrates). It is also possible to use other melting acid salts, such as sodium or potassium citrates, orthophosphates or polyphosphates, the ion exchange capacity of which is higher (Caric and Kalab, 1993; Roustel and Boutonnier, 2015); this ion exchange process is shown schematically in Figure 18.9 (Boutonnier and Roustel, 2014). The solubilization of the proteins allows the subsequent emulsification of the fat phase. This ion exchange process is shown schematically in Figure 18.9 (Boutonnier and Roustel, 2014). Given the relationship between pH and salt dissociation, the ion exchange mechanism is pH-dependent (Marchesseau et al., 1997).

The chemical mechanism of this phase is as follows: the dissolved polyanion melting salt (mainly potassium tartrate in the case of wine) enters into the inter-micellar spaces, which are filled with colloidal calcium phosphate. There, it lowers the calcium concentration (Ca$^{2+}$ + HPO$_4^{2-}$ → CaHPO$_4$) and neutralizes the negative charges of calcium caseinate with sodium ions, which are thus released.

The exchange of the cross-linking polyvalent cations (Ca$^{2+}$) with monovalent (Na$^+$) cations triggers the separation of the paracasein peptide chains. Each of the sodium ions is surrounded by water molecules as well as carboxylic groups.

This ion exchange process results in a dispersion of the proteins and their hydration. During this ion-exchange phase, and depending on the properties of the melting salt or wine used (tartrate concentration, pH, etc.), the initial structure of the cheese protein network begins to gradually break down (Lee et al., 1979; Gupta et al., 1983; Dimitreli et al., 2005). Hence, the potassium or sodium tartrates act as dispersing agents of the protein system; the original (cross-linked) cheese structure is transformed into a

![FIGURE 18.8 Schematization of the mechanism of calcium sequestration, initially bound to phosphoserine residues of caseins.](image-url)
new network (Figure 18.7). The unfolding of the protein chains and the increase in the negative charges conferred on the caseins by the ion exchange process increase the hydrophilic character of the polar side groups. These phenomena allow a significant hydration of the proteins, which results in a thickening of the product. In parallel, the free water content, which decreased initially, increases again during heating due to a decrease in the water-binding power of the hydrophilic groups when they are subjected to high temperatures. This phenomenon is accompanied, at first, by an increase in the viscosity of the product and then by a decrease when the temperature exceeds 60 °C. At the end of this phase, the initial mixture of cheeses is converted into a homogeneous colloidal solution.

The rate of “destructuration” depends on many factors (Lee et al., 1979; Caric and Kalab, 1993; Roustel and Boutonnier, 2015): the nature and dose of the ion exchange salts (and thus the nature of the wine), the level of cheese mineralization, the degree of maturity of the cheese (proteolysis), pH and the intensity of the thermo-mechanical treatment applied. For example, the higher the calcium content of the cheese, the more difficult the melting is. After hydration and dispersion of the proteins in the aqueous phase, the initial structure of the cheeses is transformed from a gel to a sol (i.e., colloidal solution). When the proteins are sufficiently solubilized under the effect of melting salts and shearing (stirring) exerted during the cooking phase, the emulsification of the fat phase will occur (Lee et al., 1979; Caric and Kalab, 1993; Shirashoji et al., 2005).

This emulsification results in a significant change in the viscosity of the product.

Since hydrophobic interactions are very important in the manufacture of a fondue, the structures and viscosities will vary depending on the temperature.

### Practical Considerations

Cheeses are the main ingredient used in the preparation of a fondue. According to the manufacturing technology used, the level of calcium is different (Table 18.1), which will influence the ability of the cheese to melt. Numerous studies have shown the importance of cheese characteristics for the thermo-functionalities of cheeses, so it is good to choose the characteristics wisely. Hence, it is often advisable to use a mixture of several cheese types in order to average out the quality differences of the cheeses used. For example, mixing a young cheese containing more “intact” casein and a more ripened cheese with more flavour is recommended. Moreover, to make a successful fondue, it is recommended to first heat the white wine and then add the cheese (which has been cut into thin slices) while stirring to facilitate melting (Figure 18.9). Depending on the mechanical intensity of the stirring and the quality of the cheese (level of proteolysis), the protein structure will be more or less altered and the fondue will be more or less stringy. The addition of a small portion of a spreadable cheese, which is actually a cooled fat emulsion in a protein network, will facilitate the three key steps of the physico-chemical process of the fondue.

### Non-Enzymatic Browning of Cheeses: the Gratin

The development of cheese as an ingredient topping on a variety of cooked dishes (e.g., pizzas, pasta, gratins and other cooked dishes) requires, in addition to the flavour aspect, a greater or lesser degree of browning. This browning can be described as the result of a colouration of different surface intensities of the cheese during cooking. With regard to pizzas, restaurant owners estimate that about 50% of quality defects come from browning (Pilcher and Kindstedt, 1990). Indeed, for this particular application, excessively intense browning is not desired. On the other hand, for other applications such as pasta gratins, a more intense browning may be considered desirable (Caric and Kalab, 1993; Xixiu et al., 2013).

### Physico-Chemical Mechanisms of Cheese Browning

The phenomenon behind this thermo-functionality is known to cooks and chefs under the name of the “Maillard reaction”

#### TABLE 18.1

<table>
<thead>
<tr>
<th>Thermo-Functionality</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spreadability/Flowability</td>
<td>Ability of cheese to cover a surface</td>
</tr>
<tr>
<td>Stretchability</td>
<td>Ability of cheese to form fibrous strands that deform under the effect of vertical stretching</td>
</tr>
<tr>
<td>Meltability</td>
<td>Tendency of the cheese to melt during a heat treatment</td>
</tr>
<tr>
<td>Oiling Off</td>
<td>A measure of the stability of the emulsion state of the fat in a cheese</td>
</tr>
</tbody>
</table>

(Data from Kerjean, 2018)
This is also the cause of the development of colour on the crust of bread during baking as well as during the cooking and grilling of meat. In fact, cheese browning involves a succession of reactions leading to non-enzymatic browning, which are dependent on the heat treatment applied (optimum temperature between 140 and 165 °C) and the reaction between reducing sugars and free amino acid groups (Thomas, 1969). In addition to the appearance of a brown colour, this reaction can lead to the formation of odorant compounds (Bertrand et al., 2018).

In cheese, the main reducing sugar involved is D-galactose (Johnson and Olson, 1985). Lactose, another sugar that may be present in some cheeses and the main sugar in milk, can also play a role but is of less importance; this disaccharide is considered to be 8 to 10 times less reactive than D-galactose (a monosaccharide) in the Maillard reaction. In cheese, the D-galactose content comes essentially from the type of lactic acid bacteria used (some strains of the thermophilic Streptococcus thermophilus) during cheese making (Milesi et al., 2011) and the degree of draining of the curd grains in the vats with respect to the rate of acidification (Mietton and Chablain, 2018). It should also be noted that some strains of lactic acid bacteria have the ability to consume D-galactose, while others do not.

On the amino acid side, these are rarely the limiting factor in mature cheeses. When they are present in smaller quantities (as in young cheeses, for example), the phenomenon of browning can be less pronounced. The presence of free amino acids results from proteolysis (enzymatic degradation of proteins during ripening), which is due to the interaction between the lactic acid bacteria present, the coagulant used in cheese production (McSweeney et al., 2017) and the ripening conditions (duration, temperature and relative humidity). The more proteolytic the coagulant, the greater the amount of amino acids that will be released and potentially the higher the browning (Figure 18.10).

The presence of free fat also plays a role in regulating the dehydration of the cheese surface (Richoux et al., 2008). The presence of a free fat film on the surface has a protective effect and reduces the rate of browning. The level of free fat is, therefore, a factor that can explain differences in cheese browning. However, too much free fat often leads to appearance defects.

Moreover, the formation of bubbles on the surface of melting cheese (known as blisters) is a phenomenon produced by the formation of steam, which rises to form pockets of hot air under the cheese surface and interferes with browning, since these bubbles will lead to the flow of free fat from the top of the bubble, resulting in higher dehydration at the top of the blister (Figure 18.11).

**Practical Considerations**

Depending on the type of cheese used for toppings, the browning result can be very different. In fact, the residual sugar content (Table 18.2), the free amino acids, the fat content released during heating, and the blister formation (Figure 18.12) will be very variable (Xixiu et al., 2014).

For example, a cheese whose production includes a lactose-reducing step (e.g., washing the curd grains with water during manufacture), such as Raclette or Gouda, leads to a dilution of...
the residual sugars contained in the cheese and consequently decreases the browning potential.

Pizza cheese, which is often made using strains of lactic acid bacteria that do not consume D-galactose and has a microstructure that can promote the formation of blisters, browns more easily (even with a low level of proteolysis). Emmental and Gruyère, on the other hand, will give a crunch as well as taste to the crust.

It should be noted that ready-to-use gratin cheeses are often a mixture of different cheeses, which, when combined, may have bespoke cooking properties.

**The Spreadability of Cheeses**

In some culinary applications, the cheese is required to spread and flow extensively to cover the dish with melted cheese; this is the case, for example, for pizzas and gratins. In these applications, this thermo-functionality aims to produce a certain visual aspect while at the same time using less actual cheese to achieve the same visual aspect in order to limit the costs associated with this ingredient (the cheese may represent more than 50% of the material costs of a pizza). For other uses, such as hamburgers or cordon bleu, the cheese must melt in the mouth but not spread in order to maintain its geometric shape and/or remain in its coating. In both situations, this thermo-functionality is due to the ability of the cheese to flow and spread over the surface of the application.

Many methods have been developed to study this property, but the Schreiber test and its adaptations are currently most widely used. This test involves placing a pre-grated and slightly compressed cheese cylinder of defined size and mass in an oven for a constant defined time and temperature and then measuring the area occupied by the melted cheese. The result is expressed as a coefficient of spreading with respect to the initial surface area covered by the grated cheese. Depending on the cheese used, the results can be very different, as shown in Figure 18.13.
Some cheeses have a very low level of spreading (coefficient less than 1.5), while others spread a lot (coefficient greater than 4). This test also makes it possible to visually evaluate the degree of browning in the cheese.

**Physico-Chemical Mechanisms of Cheese Spreading**

The capacity of a cheese to flow and spread depends on several parameters, as shown in Figure 18.14, but the fat (free fat content and size of the fat globules) and the level of proteolysis are the main factors involved.

The fat containing fatty acids that are partially crystallized (20% to 50% at room temperature) melts at temperatures above 40–45 °C (Lopez et al., 2006). Depending on the level of breakdown of the fat globule membrane (a rate closely dependent on the cheese technology used) (Guinee et al., 2004; Lopez et al., 2007), fat will form fused clusters of coalesced fat and fat pockets that will exude from the protein matrix. This flow of free fat leaving the protein network is considered to be the driving force behind the spreading of cheese (Lefevere et al., 2000), since a minimum level of mobility of the fat is indispensable for spreading (Kerjean, 2018). Thus, if the fat is very well emulsified, there will be little exudation of fat during cooking, the surface of the cheese will dry and become stiff, and this will have the effect of immobilizing the mass of cheese, which will not spread (Rudan et al., 1999). This property is used in the production of cheeses where little or no flow or spread of cheese is required (e.g., soup).

The second key factor is the rate of protein degradation (level of proteolysis). The higher the level, the more the cheese structure will be weakened and the more it will tend to spread (Kerjean, 2018). Conversely, a very young cheese (fresh Tomé, for example) with the breakdown of fat identical to a ripened cheese will tend to spread less. A cheese produced from highly heated milk (more than 80 °C) in which whey proteins are denatured and have interacted with the caseins will also have less ability to spread.

In addition to these two key factors, the moisture content of the cheese will affect the ability of the cheese to flow and spread, as well as the level of mineralization (Mietton and Chablain, 2018). A high degree of mineralization in the cheese will result in a lower ability to spread. This mineralization is a function of the cheese technology used and therefore a function of the type of cheese.

**Practical Considerations**

The flow and spread of a cheese increase with age (due to the level of proteolysis and the loss of insoluble calcium) as well as with increased moisture or fat. In fresh cheeses, cottage cheese or Feta (cheeses with high moisture contents), where the fat globules are poorly broken down and where the pH is low (of the order of pH 5), the ability of the cheese toflow and spread is limited. In cooked pressed-curd cheeses (Comté, Beaufort or Emmental), the fat globules are significantly broken down (Lopez, 2005), and this favours the flow and spreading of the cheese.
If a high level of spreading is desired, it is therefore necessary to choose cooked or uncooked pressed curd cheeses. For uncooked pressed curd cheeses (Raclette, Cheddar and Gouda), the level of breakdown of the fat globule is a function of the intensity of the thermo-mechanical work applied during the manufacture of the cheese (e.g., cutting of the curd, pressing and stretching). Therefore, for the same cheese type, it is possible to have different spreading ability depending on the technological route taken.

It should also be noted that the balance of the individual components in the cheese will lead to a thermal inertia. The more important it is, the higher the spread.

**Cheese Stretching: Pizzas and “Aligot”**

Stretching is the ability of a heated cheese to form fibrous strands that elongate without breaking when a vertical force is applied (Kerjean, 2018). This thermo-functionality is important for many culinary applications. For pizza applications, many consumers do not want “strings” that are too long, but they still want “strings” of a certain length. In other culinary applications, such as aligot (a dish made from cheese blended into mashed potatoes that is made in the Aubrac region in the southern Massif Central of France), a very stretchable cheese producing long strings is required. The quality of the strings is also an important attribute; ideally, they should be thin strings with a fibrous appearance. Many young cheeses have a good ability to stretch (Cheddar, Tomes and Comté) but, during ripening, this ability deteriorates. For example, during the ageing of Mozzarella, the stretching length increases during the first few days after manufacture, but after 3 or 4 weeks, the strings become short and fragile.

**Physico-Chemical Mechanisms of Stretching**

The stretch results from the interaction between caseins (major protein of cheeses), minerals (phosphate and calcium) and fat (Figure 18.16). When the cheese is heated at a temperature above 45 °C, the fat will liquefy and act as a lubricant (Roset et al., 2004). When the temperature is increased further and reaches 70 °C, the fat melts and forms pockets of fat, which separate from the protein network, leading to an increase in the hydrophobic interactions between the proteins. During agitation and stretching, the protein matrix rearranges and forms regions dense in protein threads (Figure 18.17). The length of the “strings” is strongly correlated with the level of proteolysis of the cheese (in particular β- and αs1-casein). The higher the level of αs1-casein, the shorter the protein “strings” (Guinee et al., 2004; Kerjean, 2018; Roustel, 2018). Richoux and Gagnaire (2013) and Guinee et al. (2004) specified that the stretching of cheese is strongly correlated with the content of hydrophobic peptides.

In addition, the resistance of the protein network to stretching is closely related to the mineralization of the cheese, and more particularly to the equilibrium between the mineral content in the colloidal phase (insoluble proteins) and in the soluble phase. If the cheese is too mineralized, the mechanical strength of the protein network is important and the threads will tend to break under the application of traction. This is why some cheeses have a better aptitude for stretching than others, because, during their manufacture, the kinetics of acidification with regard to the draining of the curd makes it possible to partially demineralize the cheese.
FIGURE 18.15 Evolution of the fat/protein matrix during melting.

FIGURE 18.16 Factors affecting cheese stretch-ability.
A calcium content of between 1.7% and 2.1% in relation to the solid non-fat content (mainly composed of proteins) seems optimal for stretching (Mietton and Chablain, 2018).

**Practical Considerations: Aligot**

When making “aligot”, a mixture of fresh Tome (about 30%), mashed potato (about 60%) and cream (about 10%) is heated and mechanically stretched, whereupon the texture of the mixture will change. The fat will liquefy, the proteins will form fairly long strings (the level of proteolysis of fresh Tome is very low) and the starch contained in the mashed potatoes will form a starch paste, leading to an increase in the viscosity. This viscosity will slow the flow rate of the product during stretching and thus allow long and stable strings. By modifying the nature of the starch (amylose/amylopectin ratio), it is possible to change the viscoelastic properties of the aligot and consequently its quality. Similarly, depending on the shelf-life of the potatoes before use, the starch of the latter will evolve and give different results.

**Conclusions**

Today, cheese is increasingly used as a hot ingredient in a wide variety of prepared foods, such as soups, sauces, pizzas, lasagna, hamburgers and pies. It must therefore have specific heating properties, known as thermo-functionalities. These thermo-functionalities are related to the composition of the cheese, the level of ripening, the structure of the fat and the parameters used during cooking (support, e.g., pasta, tomato sauce, bread and intensity of the heat treatments). Depending on these characteristics, it is possible to promote or slow down the expression of these properties. From a scientific point of view, the major problem lies in the development of reproducible, significant and widely usable measurement methods. From a cheese point of view, understanding the technological factors impacting the thermo-functionalities of the cheeses, modelling them and putting them into practice during the manufacturing process remains delicate, but it is possible to intervene during cheese making to respond to these functional properties. Finally, on the culinary side, the objectives can be very varied and sometimes antagonistic, such as, for example, obtaining a melting cheese that has no spread.

Moreover, in addition to cheese, the conditions of use and the type of oven can have a major impact on the thermo-functionality of cheese. Convection or forced air ovens are common in catering because they allow faster heating. In these ovens, where the hot air is forced to move, rapid heating results, but the ventilated hot air will dry the surface of the cheese, which will accentuate the risk of browning and the formation of bubbles on the surface of the cheese. In microwave ovens, cheese put on pizzas tends to become hard. Today, cheese makers can provide cheese that can behave as an ingredient in very specific types of oven and heating.

**REFERENCES**


