Mineral Ions and Cooking

Christian Salles
CSGA (Centre des Sciences du Goût et de l’Alimentation), AgroSup Dijon, CNRS, INRAE,
Université de Bourgogne Franche-Comté, F-21000 Dijon, France

Minerals are essential nutrients that our body needs in small amounts to work and keep us in good health (Gharibzahedi and Jafari, 2017). They are necessary in particular for building strong bones and teeth, controlling body fluids inside and outside cells, and turning food into energy. Minerals are provided mainly by foods and drinks such as meat, cereals, fish, milk and dairy foods, fruit and vegetables, and nuts, but no food contains all the minerals and can provide all mineral species (Table 59.1). A healthy balanced diet should provide all the minerals to avoid diet deficiencies. Macrominerals are essential mineral nutrients such as sodium, potassium, calcium, magnesium, chloride and sulphur. Other minerals such as iron, manganese, copper, iodine, zinc, cobalt, fluoride and selenium are considered as trace elements, because they are needed in smaller amounts. They are found in small amounts in a large variety of foods.

The quality of a food product is driven by the combination of several characteristics, such as appearance, consistency, flavour and nutritional value. In addition to their nutritional properties, minerals have a crucial and complex role in flavour perception when eating foods, and influence the texture and colour of foods. Thus, mineral ions are an essential ingredient category for food quality.

This multifunctionality of some mineral ions in food can be easily illustrated by the different approaches developed to take into account the recommendations in term of salt content reduction in food formulation. Changes in the concentration of sodium or substitution of sodium chloride by other mineral or organic compounds affect many properties of the food such as taste, odour, texture and structure, and relevant strategies should be combined and adapted to the type of food in order to keep the reformulated food acceptable to consumers (Salles et al., 2017). Thus, these food characteristics play an important role in the main quality criteria allowing the consumer to judge the overall quality of food, contributing to the rejection or the acceptance of the product.

The objective of this chapter is not to give a complete overview of the role of mineral ions in food properties, as this would require an entire book, but only to present the main food characteristics impacted by both the nature and the content of mineral ions through a few selected examples. The interested reader will find information on the involvement of mineral ions on taste perception of different food systems, on the colour of foods, and on the texture and structure of foods.

Involvement of Mineral Ions in Food in Taste Perception and Appreciation

Dairy Products

Mineral ions in cheeses and changes during cheese making, including the maturation process, have been already extensively studied and reported. We will only focus on the taste influence of minerals in model dairy products.

The water-soluble extract of cheese mainly contains non-volatile compounds. It is a complex mixture of numerous potentially taste-active compounds, such as mineral salts, organic acids, sugars, amino acids, nucleotides, biogenic amines and peptides. In cheeses, sodium chloride, mainly added during the salting step of cheese processing, is usually fully responsible for perception of cheese saltiness (Engel et al., 2001; Guinee, 2004; Guinee and O’Kennedy, 2007). However, salts of potassium, calcium and magnesium also have a salty taste dimension.

As an example, the role of each mineral ion (sodium, potassium, calcium/magnesium chlorides and phosphates) in taste characteristics in a model water-soluble extract of goat cheese was investigated through a method of systematically omitting each in turn (Engel et al., 2002), as shown in Figure 63.1. Although sodium chloride appeared to have the biggest impact on saltiness perception, the decrease of the mean saltiness deviation due to the omission of sodium chloride was greater than with other minerals taken one by one but weaker than when all of them were omitted (Engel et al., 2000a; Engel et al., 2000b). This indicated that each of the four mineral salts contributes positively to the salty note in an additive way to explain the saltiness of the whole water-soluble extract. The contribution of phosphates to saltiness could be explained by their presence as sodium salts.

Phosphates showed a decreasing effect on sourness, while sodium chloride had an enhancing influence. This effect of phosphate ions can mainly be related to their role in pH, although this taste characteristic has never been directly correlated with pH, which means that other compounds are probably involved in that...
Concerning the role of sodium chloride, it is admitted that the perception of saltiness enhances that of sourness. Thus, overall sourness appeared to be due to an enhancing effect of sodium chloride on compounds acting on the pH level. In this model food system, the significant increase of the sourness due to phosphate omission was partially compensated by the omission of sodium chloride, which tended to decrease the sour note because of its enhancing contribution.

For each attribute, the means with the same letter (a, b, c, d) are not significantly different at the 5% level according to Newman–Keuls tests. The mean deviation is drawn for each mean (from six replicates).

The omission of both calcium and magnesium chlorides was responsible for a significant decrease in the bitter taste, which means that they might be at least partially responsible for bitterness of the water-soluble extract. Such an effect of divalent cations has already been reported, as the taste of cheeses salted with calcium or magnesium chloride was extremely bitter after 16 weeks of ripening (McSweeney, 1997). In addition, the simultaneous omission of phosphate (sodium form) and sodium chloride significantly increased the bitterness perceived, whereas the omission of phosphate or sodium chloride alone had no significant effect (Engel et al., 2000b). This effect was explained by a larger amount of sodium present in the model.

**TABLE 63.1**

Examples of Main Mineral Sources in Foods

<table>
<thead>
<tr>
<th>Foods</th>
<th>Ca</th>
<th>Fe</th>
<th>I</th>
<th>Mg</th>
<th>K</th>
<th>Na</th>
<th>P</th>
<th>S</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairy products</td>
<td>x</td>
<td>x</td>
<td>X</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Meat products</td>
<td>x</td>
<td>x</td>
<td>X</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Cured meat products</td>
<td>X</td>
<td>x</td>
<td>X</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Fish</td>
<td>x</td>
<td>x</td>
<td>X</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Raw cereals</td>
<td>x</td>
<td>x</td>
<td>X</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Seafoods</td>
<td>x</td>
<td>x</td>
<td>X</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Fruits, potatoes</td>
<td>x</td>
<td>x</td>
<td>X</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Green vegetables, salads</td>
<td>x</td>
<td>x</td>
<td>X</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Fruits and vegetables</td>
<td>x</td>
<td>x</td>
<td>X</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Legumes</td>
<td>x</td>
<td>x</td>
<td>X</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Seeds, nuts</td>
<td>x</td>
<td>x</td>
<td>X</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Drinking waters</td>
<td>x</td>
<td>x</td>
<td>X</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

Source: Gharibzahedi and Jafari (2017).

**FIGURE 63.1** Impact of omitting minerals from a model water-soluble extract of goat cheese on flavour perception.

(Reprinted with permission from (Engel et al., 2000a, b). Copyright (2020) American Chemical Society.)
solution originating from both sodium chloride and phosphates, leading to a significant masking effect of sodium chloride on the perceived bitterness of the entire model solution. This confirmed that it is impossible to consider only the individual taste properties of a compound to explain its impact on the water-soluble extract mixture context. Although it had no significant impact, the omission of sodium seems to have a tendency to increase the bitterness.

Stepwise multiple linear regressions processed on the omission test data confirmed these findings (Engel et al., 2000b). Sodium, calcium, magnesium and potassium chlorides and phosphates were, respectively, responsible for 75%, 13.8%, 5.8% and 4.4%, respectively, of the salty taste of the water-soluble solution of cheese, and bitterness was mainly due to the antagonistic effects between calcium/magnesium chlorides (41.3%) for the positive contribution and both sodium chloride (29.2%) and sodium phosphates (9.4%) for the negative one.

This study highlights that, in a complex mixture context, the individual taste properties of a compound are often not sufficient to explain its impact on the overall taste but interactions at different levels should be taken into account.

Variations in salt content also modify the rheological properties and microstructure of model cheeses, due mainly to sodium ion binding to caseins and its mobility in the food matrix, which could influence saltiness perception. A multimodal approach was used to understand the effects of changes to the composition of model cheeses (lipid/protein ratio and sodium chloride content) on sodium ion mobility (using $^{23}$Na nuclear magnetic resonance (NMR)), in-mouth sodium release and saltiness perception (Boisard et al., 2013; Boisard et al., 2014). An increase in the salt content was shown to decrease cheese firmness and perceived hardness and to increase sodium ion mobility, in vivo sodium release and both saltiness and aroma perception. It was also reported that the mobility of sodium ions in the food matrix decreased when the protein concentration increased. Moreover, the mobility of sodium ions depended on the type of protein and seemed to be related to its content of negative sites (Mosca et al., 2015).

**Meat Products**

Meat is recognized as an important source of protein in the human diet, but it also provides a variety of minerals, which are involved in many physiological functions (Beisenov et al., 2017; Stasiak et al., 2017; Tomovic et al., 2015) and are thus essential for good health.

Sodium chloride is an essential mineral in processed meat products, which contributes to water retention, colour, fat binding and flavour. This mineral is fully involved in taste characteristics in several meat products. After fractionation of a water-soluble extract of dry sausages, the fractions containing sodium chloride, free amino acids and peptides were described as having the highest taste intensity, which was described as bouillon, salty, bitter and sour (Henriksen and Stahnke, 1997). Sodium chloride is not only responsible for salty taste but is also suspected to enhance the taste of co-eluted amino acids. Similar observations were reported for cooked ham, in which sodium chloride is suspected to enhance the umami taste of peptides and glutamate (Valentin et al., 1998).

Another important cation provided in the diet by meat products is iron, which plays many biological functions in the human body (Czerwonka and Tokarz, 2017). The large majority of iron in the body is in the form of haem molecules consisting of four pyrrole rings joined together by methionine bridges. In the haem or non-haem form, iron is critical to the structure of various proteins associated with different biological functions. The haem ion ratio varies according to the type of meat ( Pretorius et al., 2016). The average bioavailability of haem iron of the meat is 23% and that of non-haem iron 3% (Schoenfeldt and Hall, 2011). However, raw meat is rarely consumed as such, but mostly submitted to a cooking process at high temperature. Because of the cooking process, a thermal leakage is observed, depending on the type and intensity of the thermal process. This leads to a reduction of the share of haem by about 4–25% (Czerwonka and Szterk, 2015).

Nitrite, mainly used in sodium (or potassium) nitrite salt form, is an essential ingredient currently used in the curing of different meat products (Pegg and Shahidi, 1997). It is responsible not only for characteristic colour but also for flavour, extended shelf-life and microbiological stability. In combination with sodium chloride, it has a significant bacteriostatic action, particularly in inhibiting the growth of *Clostridium botulinum*, the bacterium responsible for life-threatening botulism.

However, the food industry is recommended to reduce or phase out the usage of nitrite in cured meat because it may contribute to the formation of carcinogenic nitrosamines. The development of substitutes has been explored for several years (Pegg and Shahidi, 1997). Thus, EFSA (European Food Safety Agency) has recently re-assessed the safety of sodium and potassium salts of nitrite (E 249–250) and proposed an admissible daily intake (ADI) of 0.07 mg/kg bw/day (EFSA, 2017). In cooked cured ham, sodium nitrite was found to impact volatile compound composition (Guillard et al., 1998). Those authors reported a significantly lower amount of phospholipids during its processing, in particular for phosphatidyl choline and phosphatidyl ethanolamine, the two major phospholipids of pork meat. For the major fatty acids contained in these two phospholipids, the strongest effect of nitrite was observed on arachidonic acid for both phospholipids, and on oleic acid only for phosphatidyl choline, as the content of these fatty acids was reduced in the presence of sodium nitrite. For the other fatty acids, the effect was, rather, due to the cooking process. In consequence, volatile compounds such as hexanal, heptanal and oct-1-en-3-ol were found in lower amounts than in cooked cured meat untreated with sodium nitrite.

**Tomatoes**

The presence of mineral salts in tomato has a positive influence on its taste characteristics (Petro-Turza, 1986–1987; Petro Turza and Teleky-Vamosky, 1989). Those authors reported in particular that a model juice made of mineral salts, amino acids, sugars and organic acids presents overall taste characteristics of tomato juice. In addition, minerals can have an indirect action on the taste, though the saltiness characteristic was not the dominant taste in this vegetable, for which the overall taste was driven
by sweetness and sourness. Potassium, which is the major mineral ion in tomatoes, can influence the free acid content, while phosphate can interact by its buffering capacity (Petro-Turza, 1986–1987). The association of organic acids and potassium ions was determinant for the saltiness characteristic of tomato (Salles et al., 2003). Indeed, through omission tests performed on a complex tomato juice model mixture, these authors reported that the main part of saltiness perception arose from the anionic form of citric and malic acids, with potassium as the main counterion. Hence, the acid form of the organic acids was responsible for sourness and the dissociated potassium form was implied in saltiness. This shows that changes in ionic ratio and equilibrium could strongly influence the taste characteristics of food.

**Drinking Water**

Common dissolved minerals such as calcium, magnesium, potassium, sodium, bicarbonate, chloride, nitrate and sulphate affect the taste of water. In the absence of off-flavours due to organic contaminants responsible for odours, mineral content is a major determinant of both taste and consumer acceptability of drinking water (Bravold, 1970; Platikanov et al., 2013). Total dissolved solid reflects the overall mineral content of water and is the most important determinant of consumer liking.

A study on the taste of waters with different sensory methodologies reported a bitter and metallic taste for low-mineral-content waters, a neutral taste and a sensation of freshness for medium-mineral-content waters and finally, a more salty taste for waters with the highest mineral content (Teillet et al., 2010a). A consumer study performed on waters with different mineralization levels showed that the most likely preferred type of water was that with medium mineralization, with total dissolved solids about 300–350 mg/L, perceived as tasteless and cooler (Teillet et al., 2010b).

A Japanese study reported that evaluation of potable water might be possible using organic matter, total hardness (calcium), iron and bicarbonate concentrations, as they were well correlated with sensory appreciation (Sasaki et al., 1996).

In natural waters, synergistic and antagonistic effects can take place between the different ions. Thus, the influence of each mineral ion on taste perception and preference of waters has been detailed. The preferred water samples were associated with a moderate content of total dissolved solids and with relatively high concentration of bicarbonates, sulphate, calcium and magnesium ions, as well as relatively high pH values. In contrast, high concentrations of sodium, potassium and chlorides were scored low by the consumers, while residual chlorine did not affect the ratings but was perceived and allowed discrimination of waters (Platikanov et al., 2013). The role of magnesium cations was unclear and strongly dependent on the nature of the associated anion. Magnesium bicarbonate and sulphate probably have a positive or a neutral effect on waters, while magnesium chloride has a negative bitter effect.

It has also been reported that the majority of consumers liked waters rich in calcium sulphate and calcium bicarbonate/calcium sulphate, with high alkalinity and pH; however, a small group of consumers preferred waters with sodium chloride and sodium bicarbonate profiles and low pH (Platikanov et al., 2017). Moreover, minor constituents such as magnesium, potassium and silicon ions also appeared to be relevant for the taste evaluation of water samples, probably due to their spurious correlation with the major concentrations of calcium and sodium (Platikanov et al., 2017).

The role of nitrate and sulphate anions in the taste of water is not entirely clear yet (Lopez et al., 2017). Sulphate at low and moderate concentrations tended to improve the overall taste of water. However, at high concentration, it was perceived negatively, with saltiness and bitterness tastes. Nitrate was not found to have a relevant role in the taste of water (Lopez et al., 2017).

The mineral content of water may impact its extraction capacity when cooking. The higher the mineral concentration in the water, the lower the extraction yields of aluminium, organic carbon and polyphenols in infusions (Mossion et al., 2008). This is explained by the calcium in the mineral water, which could complex with pectins of the cell walls of tea leaves and decrease component extraction.

The sensory quality of tea infusions is influenced by water containing different concentrations of mineral ions. The taste and the visual appearance of water are less appreciated when the calcium ion concentration is over 40 mg/L, which promotes the formation of tea sediments (Xu et al., 2013). Bitter, umami and sweet taste are weakened by a high calcium concentration, whilst the astringent perception is strengthened for green tea infusion (Yin et al., 2014). The type of brewing water influences the taste quality, catechin concentration and antioxidant capacity of tea infusions (Xu et al., 2017). Those authors reported that calcium, magnesium and sodium ions in the tea infusion were mainly derived from the water used, while the potassium originated mainly from the tea leaves. Generally, the concentration of metal ions in the tea infusion is significantly influenced by the concentration of metal ions in the water.

For example, the higher the calcium concentration in water, the lower the calcium extraction yield from tea, while a high concentration of sodium in water improves the sodium extraction yield in the infusion tea. Concerning anions, it was found that chloride, nitrate and sulphate in tea infusions originate mostly from the water used, while in contrast, fluoride ions were mostly extracted from the tea leaves (Xu et al., 2017). As for cations, the concentration in brewing water influences the extraction yield in tea infusion. The colour of the tea is also influenced by the quality of the water. The colour of tea infusions darkened with increasing conductivity and pH of the water, probably due to the oxidation of the extracted catechins in the infusion. A high conductivity decreases the extraction yield of catechins and caffeine, and a high pH lowers the stability of catechins. Thus, reducing the pH of water can partially improve the taste quality and acceptability, and increases the concentration of catechins, in tea infusions (Xu et al., 2017).

**Mineral Ions May Affect the Colour of Food**

Along with aroma, taste and texture perception, colour is one of the key factors for food appreciation by consumers. It provides...
symbolic and associative information about the food. Moreover, it has been reported that light colours modulate consumers’ willingness to eat and their hedonic impressions of foods (Yang et al., 2016). For example, bread making can be optimized by taking into account the crust colour of maximum acceptability (Castro et al., 2017). Similar observations have been reported for beef products (Holman et al., 2016).

**Crude Food Products**

Iron, zinc and iodine are important micronutrients, which are commonly deficient worldwide. Among these, iron is a highly reactive mineral ion and may lead to a dull colour and off-taste when present in excess in foods due to its addition as a micronutrient. As an example, for fruit and vegetable purées, iron fortification may lead to colour and taste modification (Hurrell, 1997). Moreover, a consequence can be a partial or total loss of product identity, where consumers use colour as an important key indicator of quality. This colour change is mainly due to the formation of iron–polyphenol complexes, and different strategies have been developed to limit the formation of such complexes and to stabilize the colour, such as increasing pH or using complexing or competitive agents (Habeych et al., 2016).

On the other hand, cations such as calcium can promote attractive colours. For example, calcium ions are considered to be a promoter of anthocyanin accumulation, as they are involved in signal transduction regarding anthocyanin biosynthesis (Vitrac et al., 2000). In the case of grapes, calcium chloride can be associated with ethylene to improve skin colour (Scavroni et al., 2018). It has also been reported that spraying of calcium or potassium salt solutions, alone or in combination, significantly increased fruit weight, firmness and anthocyanin concentration (Solhjoo et al., 2017). Another example for vegetables is the effect of calcium chloride treatment during storage on the colour properties of fresh-cut green beans (Kasim and Kasim, 2015). By comparing the effect of solutions of different calcium chloride concentrations with a control without calcium chloride, it was reported that calcium chloride treatment of fresh-cut green beans was effective in the retention of their colour for a short period of storage. This phenomenon was related to the reduction of polyphenol oxidase activity of the samples in the presence of a high level of calcium chloride.

Another example worth mentioning is the colour of mollusc shells (Lertvachirapaiboon et al., 2015), which are made of aragonite calcium carbonate structured in different stratified layers varying in thickness. The shells with multiple aragonite thicknesses expressed a multicolour nature, as the upper aragonite layers reflected colour from the lower layers. Thus, the expressed colour was directly associated with the structural architecture of the shell (thickness and number of layers), and colour is known to influence our appreciation (Kim et al., 2011).

**During Cooking**

The Maillard reaction plays an important role in the appearance and flavour of food subjected to cooking or roasting (Martins et al., 2001). This complex reaction is initiated by an amine–carbonyl reaction of free or bound amino acids and reducing sugars, and leads to numerous active intermediates through a viable electrochemical system (Rizzi, 2003). Maillard browning is accelerated by the dihydrogen phosphate ion acting as a base for catalysing Amadori rearrangement (Potman and Vanwijk, 1989), leading to acceleration of the reaction (Davidek et al., 2002).

In a study of the effect of phosphate and carboxylate ions on browning, browning for a series of reducing sugars was measured with and without the presence of beta-alanine (Rizzi, 2004). Significant browning was observed for sugar alone, suggesting that polyatomic anions can form reactive Maillard reaction intermediates directly from sugars. These chemically reducing species formed during phosphate-ion-catalysed degradation of reducing sugar can be directly quantified by electrochemical methods (Rizzi et al., 2010). As a mechanism, it is suggested that polyatomic anions (XO₄²⁻ form) facilitate the aldose/ketose equilibration of reducing sugars and aldose sugar dehydration to form 3-deoxysoses. This leads to the formation of additional alpha-dicarboxyls, which are key intermediates leading to coloured melanoidins (Rizzi, 2004).

Sodium tetraborate decahydrate (Borax), employed as a preservative agent in food, was found to enhance Maillard reaction browning to a degree uniformly greater than that produced by phosphate anions on an equimolar basis (Rizzi, 2007). As for phosphate, borate anions operate during the early stage of the Maillard reaction but by completely different mechanisms. Indeed, borax accelerates most browning for aldose and ketoses with trans-configured hydroxyl groups in the vicinal C2/C3 positions of their hemiacetal forms. The complexation occurs, therefore, in the open-chain form, leading to a higher concentration of carbonyl moieties and thereby enhancing Maillard reaction browning (Rizzi, 2007).

As well as bidentate anions like phosphates, carboxylates and tetraborate leading to enhanced browning, it has been reported that the addition of sodium, potassium, magnesium and calcium ions and choline chloride also leads to increased browning (Rizzi, 2010). Among cations, lithium, sodium, potassium, rubidium and caesium were found to produce only a small increase in browning, while a greater effect was observed for calcium and magnesium (Rizzi, 2008). It is noteworthy that browning was reduced or suppressed by the addition of an ammonium salt to the sugar–amino acid reaction (Rizzi, 2010) and by triethylammonium ion, but was not affected by the salt of a stronger base such as guanine (Rizzi, 2008).

**Mineral Ions Affect the Texture and Structure of Food**

Mineral ions are well known to influence the structure of most food products, such as polymeric gels, dairy, meat, bakery products and sauces. We will limit this chapter to the presentation of examples for vegetables and emulsions.

**Vegetables**

Calcium interacts with pectin to form calcium pectate, which maintains the integrity of cell walls of vegetables and assures
firmness by cross-linking with cell walls and pectin. Thus, treatment of fruits and vegetables with calcium salts is currently used to retain firmness during storage (Rico et al., 2007b; Martin-Diana et al., 2007). Moreover, this treatment is effective in reducing chlorophyll and protein losses, and inhibiting plant tissue senescence (Rico et al., 2007a). As examples, calcium lactate has been used to reduce respiration, increase firmness retention and reduce the impact of physiological disorders in apple, and more generally for delicate fruits. It has also been used specifically as a firming agent for several varieties of fruits. Compared with calcium chloride, calcium lactate avoids bitterness and off-flavour defaults. For pears, it has been shown that calcium lactate reinforces the structure of the fruit, maintaining the fibrillar packing in the cell and the intercellular contacts. This reinforcement counteracted the increase of enzyme activities related to the degradation of cell wall components (pectinmethyl esterase and polygalacturonase), which could be activated by calcium addition (Alandes et al., 2009). Thus, this leads to an improvement of the structural integrity of the fresh-cut fruit.

The combined effect of calcium chloride solutions and heat treatment on fresh-cut melons positively maintained or improved firmness (Luna-Guzman et al., 1999). In the same way, the combination of heat-shock and calcium lactate treatments was shown to be very efficient in maintaining firmness in carrots during storage (Rico et al., 2007b). Sensory analysis experiments showed that carrots washed with calcium lactate at 50 °C showed higher scores for texture (firmness) and visual appearance than with standard treatments, such as calcium lactate at 25 °C and chlorine, at 10 days’ storage. These carrot samples were also rated better in terms of saleability than the others. This is associated with the control of browning-related enzymes, which are inhibited by heat-shock. Cryo-scanning electron microscopy showed that combined heat-shock and calcium lactate treatments were more effective in maintaining the turgor of cortex tissue cells and reduced the extent of lignification at the peeler-affected areas (Rico et al., 2007b). The authors also reported better diffusion and solubility of calcium in the tissues at 50 °C, and explained the beneficial effect on texture of temperature treatments and calcium solutions by the stimulation of pectin methyl esterase by temperature. This enzyme is able to cleave the methoxyl groups from methylated pectin substances, which generates free carboxyl groups able to bind endogenous and added calcium, leading to firmer tissues. Similar observations were reported for fresh-cut Galia melon (Cecilia Silveira et al., 2011). Moreover, those authors observed an important loss of flavour in all treatments except with calcium chloride, lactate and ascorbate, which was the only treatment found acceptable by consumers.

Emulsions

Emulsions are destabilized by different minerals at elevated temperature and low pH (Yuan et al., 2011). The addition of minerals can destabilize emulsions in these conditions. Low pH and elevated temperature decrease the surface potential of oil microdroplets and enhance their gathering. The addition of minerals contributes to the decrease of surface potential and thus contributes to flocculation and coalescence, which are the two main steps of emulsion destabilization. The key role of the interfacial charging was also demonstrated for double emulsions, such as oil-in-water-in-oil (O/W/O) emulsions, as their formation is enhanced at low pH and low salt concentration (Pradhan and Rousseau, 2012). Concerning water-in-oil-in-water (W/O/W) emulsion, osmotic pressure differences between the internal and external aqueous phases influence the stability of the emulsions, the release rate of components from the internal phase, and the engulfment of the internal droplets by the flow of water from the external continuous aqueous phase to the internal phase (Benichou et al., 2004). These authors observed that, if no salt is present in the inner phase but the external phase contains salt, the inner phase disappears completely after a few minutes, indicating a water flow from the inner to the external aqueous phase. When salt is present in the inner phase, water migration progressively decreases and stops when an equilibrium between the two aqueous phases is reached. Thus, the presence of an electrolyte such as salt in the inner phase is necessary for the stability of the double emulsion achieved by the osmotic pressure equalization. Using glucose to balance or unbalance osmotic pressure, it was shown that the release of salt is driven by the chemical potential difference between the two aqueous phases rather than the unbalanced osmotic pressures (Pawlak et al., 2010). Gelation of the inner phase using gelatin (Sapei et al., 2012) or whey protein isolate (Perez-Moral et al., 2014) strongly increased the stability of the double emulsion and slowed down the diffusion of electrolytes.

Conclusion

Minerals are present in most foods, constitute a major ingredient family, and are considered as essential nutrients. Although minerals exist in a large variety, no food contains all minerals, and quantitative differences between foods may be very high. They are associated with several important functionalities in food related to sensory perception, such as bitterness, saltiness, metallic perception, colour, general appearance, texture and acceptability by the consumer. Concerning taste perception, beside their direct involvement in saltiness (sodium chloride) and bitterness (calcium/magnesium chlorides), they may act as taste enhancers or inhibitors at the taste receptor level. At too high levels in food, they can be responsible for strong off-flavours, leading to food rejection. Despite their high involvement in the final quality of most foods, studies on minerals have been rather neglected compared with studies on organic compounds. All the complex mechanisms directly or indirectly involving mineral ions in perception need to be unravelled for a better understanding of the mechanisms leading to perception.

REFERENCES


