Acids in Foods and Perception of Sourness

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Introduction
Sourness is mainly caused by the detection of protons. This perception may act as a warning signalling the presence of a high concentration of acid dangerous for the body, of unripe fruits, or of spoiled foods contaminated by microorganisms. At low concentrations, acidic stimuli evoke a sour taste, while at high concentrations, the trigeminal lingual system is activated, leading to a sensation of irritation. A low level of sour taste is attractive to humans and animals in some foods such as citruses, while it is aversive when present at a high level.

Numerous organic and mineral acids are responsible for sourness. Citric acid, malic acid, and tartaric acid are generally found in vegetal products (e.g., fruits and vegetables), while lactic acid is found in animal products (e.g., dairy products and meat). Compounds other than organic and mineral acids can also be responsible for a sour note; amino acids with a lateral acid function, such as L-glutamic and L-aspartic acids, have an acid taste, while their sodium salts are responsible for umami taste (Kato et al., 1989). Peptides with a sour taste generally contain acidic amino acids such as aspartic and glutamic acid. A dipeptide with a sour taste contains at least one acidic amino acid linked to another acidic, neutral, or aromatic amino acid (Kirimura et al., 1969).

In this chapter, I will give a non-exhaustive overview of the main characteristics of sour compounds from a physico-chemical and sensory point of view.

Influence of Food Matrix Composition on Sourness
The release of acids in the mouth during eating and the perception of sourness may be influenced by the food matrix composition and structure. For example, fat, acid, and salt were found to influence the temporal perception of firmness, saltiness, and sourness of cheese analogues (Stampanoni and Noble, 1991). Increasing salt and acid contents were both found to increase the perception of firmness, and a higher fat content resulted in softer but sourer cheese analogues. Whatever the fat level, analogue cheeses with high acid and high salt levels had higher sourness intensity and the longest sourness perception. The time to reach maximum saltiness and sourness intensity was shortest for low-salt and low-acid analogue cheeses.

The kinetic release of non-volatile compounds (leucine, phenylalanine, glutamic acid, citric acid, lactic acid, propanoic acid, sodium, potassium, calcium, magnesium, chloride, and phosphates) during the eating of a model cheese and the relationships to some oral (salivary and masticatory) parameters have also been studied (Pionnier et al., 2004a). The maximum concentration in saliva varied significantly according to the compound. However, there was no significant effect of the compound on the time to reach maximum concentration. A long time to reach maximum concentration and total quantity of released compounds could be related to high chewing time and low saliva flow rates, low chewing rates, low masticatory performances, and low swallowing rates. The time to reach the maximal intensity of the sour attribute was positively related to the time to reach the maximal concentration of citric acid and to oral parameters (Pionnier et al., 2004b).

Significant differences among several Camembert cheeses concerning bitterness and saltiness were reported, but no difference was observed for sourness (Engel et al., 2001a). During ripening, a decrease of the perceived sour note was observed in all portions of the cheese (rind, under-rind, and centre). The sour note in food products may be partially due to $\text{H}_3\text{O}^+$ concentration, which progressively varies with the consumption of lactic acid by microorganisms. However, pH and sourness may not be correlated, and $\text{H}_3\text{O}^+$ concentration was not sufficient to fully explain the sour taste; other chemical species, such as sodium chloride, may act on this taste characteristic. The effect of pH and interactions between sourness and other perceptions are detailed later. The evolution of sourness in the cheese portions may be explained by the migration phenomena of taste-active compounds such as molecules that change the pH (acids, and phosphates in particular) or those that are responsible for some enhancing effect (Engel et al., 2001c).

The fatty acid residue compositions of oil species affect taste perception. For oil-in-water emulsions with basic taste substances and oil species, Koriyama et al. (2002) reported that the type of oil extended retention of perception, and did not affect sweetness or saltiness, but suppressed sourness and bitterness. The degree of sourness was dependent on oil species, in particular the fatty
acid residue composition. Thus, oils to be added to food should be carefully selected by the manufacturer because of their effects on taste perception as well as on texture and aroma (retronasal odour).

An effect of viscosity on perceived intensity of sour taste was also reported (Sediva et al., 2004). The sourness intensity decreases with increasing solution viscosity. However, the differences depend on the concentration of thickener agents and the acid used.

Mechanisms Leading to Sour Perception

The Acid Receptor

The molecular mechanisms of detection of sourness are not well known yet. A wide range of cell types, receptors, and even receptor-independent mechanisms have been proposed to mediate acid detection in the tongue. It has been proposed that sour taste is mediated by a unique cell type, independent of all other taste qualities (Huang et al., 2006). In the tongue, polycystic kidney disease 2-like 1 (PKD2L1) ion channel, coexpressed with PKD1L3, has been demonstrated to be necessary for the detection of sour compounds. Therefore, sour, salty, sweet, bitter, and umami tastes are each mediated by a unique cell type, independent of all other taste qualities. Salty and sour tastes directly activate ion channels while bitter, sweet, and umami tastes are elicited by G-protein-coupled receptors (Briand and Salles, 2016). Recently, it has been shown that the Otop gene family encodes a family of ion channels that are unrelated structurally to previously identified ion channels and are highly selective for protons (Tu et al., 2018).

Particular proteins were reported to be able to convert sourness to sweetness. Miraculin, a tetramer and dimer of a 25 kDa protein, was found to transform a sour taste into a sweet taste (Kurihara and Beidler, 1968). Both the tetramer and the dimer have taste-modifying properties. Miraculin has been estimated to be as much as 400,000 times sweeter than sucrose on a molar basis. The mechanisms involved in the sweetness of miraculin are unique; at neutral pH, miraculin interacts with the sweet taste receptor T1R2/T1R3, but it does not activate the receptor and partially suppresses the response to other sweeteners. At acidic pH, miraculin changes its conformation and activates the sweet taste receptor (Briand and Salles, 2016). Another protein named neoculin (previously named curculin) elicits a sweet taste and also exhibits sweet taste-modifying properties able to convert sourness to sweetness. In addition, it is noteworthy that peptides generated from pork loin during cooking were capable of strongly suppressing sourness (Okumura et al., 2004). The proposed mechanism of sourness suppression by the peptide was an inhibition of the binding of sour taste substances at the proton-sensitive ion channel level.

The Role of Saliva in Sourness Perception

Sourness is related to the proton concentration and thus pH, as sourness intensity decreases with increasing pH. However, pH does not fully explain the intensity of acid solutions. It has been shown that sourness perception is fully dependent on titratable acidity: Norris et al. (1984) showed that binary acid mixtures of equal pH and titratable acid differed significantly in sourness intensity and in saliva-inducing capacity. They observed significant differences in both maximum intensity of perceived sourness and parotid flow as a function of the specific anionic composition (i.e., citric, tartaric, or fumaric) of the samples, since they had equal potential (titratable) hydrogens and equal free hydrogens (pH). For example, in tartaric–fumaric acid mixtures varying in pH (3.0–3.75) at a constant titratable acidity and varying in titratable acidity at a constant pH, sourness intensity and salivary flow rate increased with acidity and decreased with pH. A large contrast between subjects with high and low salivary flow rate and perceived intensity of sourness was also reported (Norris et al., 1984). In response to variation in pH and total acid, the high-flow subjects demonstrated marked alteration in flow but little change in sourness perception, while low-flow subjects responded at a lower absolute level of acids but showed marked changes in sourness and little change in salivary flow rate.

Another study reported that changes in solution pH were related to individual salivary flow rates. Greater increases in expectorated solution pH were observed for individuals with higher flow rates (Christensen et al., 1987). Moreover, on measuring threshold and suprathreshold responses to different volumes of acids, those authors demonstrated that individuals with high salivary flow rates were less sensitive to the taste of acids and that large volumes of acid were more easily perceived. It was suggested that dilution by saliva with different pH is not the correct mechanism and also that adaptation of taste receptors to differing concentrations of free hydrogen ions was unlikely, because the sour threshold results were opposite to those predicted by an adaptation model. This was interpreted as greater flow rate adding a greater quantity of saliva to taste solutions and consequently adding a greater total amount of salivary buffers as bicarbonate concentration increased (Christensen et al., 1987).

Comparing low-flow judges and high-flow judges, it was found that salivary flow rate did not affect temporal responses for sourness, sweetness, or fruity flavour (Bonnans and Noble, 1995). Large differences in sweetness and small, insignificant differences in sourness were produced at a constant acid concentration by increasing sweetener levels. However, salivary flow rate was significantly correlated only with sourness ratings. Changes in perceived sourness intensity influenced salivary flow independently of acid concentration, suggesting that salivary response is not only due to stimuli concentration and may be mediated by the cognitively processed taste response (Bonnans and Noble, 1995).

Saliva has been suggested to act as a buffering system affecting the way we perceive the sourness of acids. Moreover, Bonnans and Noble (1995) observed that the maximum intensity of sourness and salivary flow rate decreased as the level of sweeteners was raised at constant acid concentration. This suggested that salivary flow rate is mediated by cognitively processed taste response and not only the concentration of stimuli. Salivary flow rate was found to increase when the pH of different beverages decreased (Guinard et al., 1998).
The chemical properties of the sour molecules, such as pKa, number of carboxyl groups, hydrophobicity, and salivary flow rate, influence sour temporal perception. High-flow subjects and low-flow subjects were submitted to a continuous stimulus delivery flow rate of acid solutions, and the time–intensity perception and the pH on the tongue surface were continuously measured (Lugaz et al., 2005). The results showed that the saliva of high-flow subjects decreased the acidity of the acid solution more efficiently than the saliva of low-flow subjects. However, high-flow subjects exhibited higher perceived intensity for acid solutions than low-flow subjects. The saliva of high-flow subjects can modify the pH of an acid solution more efficiently than the saliva of low-flow subjects, thanks either to a dilution effect or to a difference in buffering capacity of saliva between high-flow subjects and low-flow subjects. Moreover, by comparing the effect of different weak acids, the authors reported that titratable acidity rather than pH has to be considered to explain sour perception. They reported also that the difference in sensitivity between high-flow subjects and low-flow subjects might be due to a higher permeability of epithelial tissue to hydrophobic molecules (Lugaz et al., 2005). Acid stimuli also influence the composition of saliva. Annexin A1 and calgranulin A, anti-inflammatory compounds involved in inflammation, were overrepresented after umami, bitter, and sour stimulations (Neyraud et al., 2006).

Interactions of Sourness Perception with Other Perceptions

In mixtures, the various tastes are known to interact through binary taste–taste interactions (Breslin, 1996; Keast and Breslin, 2002; Figure 1.1). The physiological mechanisms involved in these interactions, while not well understood yet, occur at the taste receptor cell level. However, the integration of taste signal at the central level cannot be excluded. Concerning sourness, it was reported that sour and salty mixtures symmetrically affect the intensity of each other, with enhancement at low concentrations and suppression or no effect at high concentrations. At low concentration, sourness had variable effects on sweetness, while at higher concentrations of mixed of sour and sweet compounds, sweetness and sourness were mutually suppressed. Mixtures of sour and bitter compounds enhanced each other at low concentration; at moderate intensity, bitterness was suppressed and sourness enhanced, while at high concentration, sourness was suppressed, and the effect on bitterness was variable (Keast and Breslin, 2002).

These taste–taste interactions are functional in complex media such as real foods. For example, in goat cheeses, sourness is mainly due to a synergistic effect involving sodium chloride, phosphates, and lactic acid (Engel et al., 2000). Omission tests using model goat cheese extracts showed that the sourness of lactic acid was enhanced by sodium chloride but lowered by the presence of phosphates. The enhancement of sourness due to lactic acid by sodium chloride was also reported in Camembert cheese (Engel et al., 2001b). In tomato juices, the omission of all the sugars led to an almost total disappearance of sweetness and a significant increase in sourness and saltiness, which had been partly masked by the sugars (Salles et al., 2003). Thus, sourness is mainly due to citric and malic acids but modulated by sugars. Such interactions between sourness and sweetness perceptions were also reported in champagne (Martin, 2002).

Interaction between sourness and saltiness was also reported in rice vinegar. Both detection and recognition sourness thresholds were decreased when vinegar ingredients (salt) were added, inducing sourness (Hatae et al., 2009). These authors studied the interaction of saltiness and sourness at the threshold level. They measured the detection and recognition thresholds for salt solution to which vinegar of subthreshold concentration was added, and for vinegar solutions to which salt of subthreshold concentration was added. When vinegar at a half concentration of the detection threshold of each panellist was added to the salt solution, both the detection and the recognition threshold of salt were reduced significantly. This phenomenon was more pronounced with rice black vinegar than with rice vinegar. In contrast, when
NaCl solution was added to vinegar at half of the concentration level of the detection threshold for each panellist, no intensifying or weakening effect on the detection and recognition threshold was observed. Thus, this saltiness–sourness interaction was found to be asymmetrical, as no effect of sourness was observed on saltiness with the same model. Moreover, this result shows the potential of vinegar to partially substitute salt to give a satisfactory salty taste in dishes.

Aroma was found to interact with sourness perception through crossmodal perceptive interactions. It has been shown that no physicochemical mechanism was involved in the odour–taste interactions (Pfeiffer et al., 2006). For example, the sourness of a citric acid solution can be lowered by caramel aroma (Stevenson et al., 1999), while an increase of the fruitiness of a water solution flavoured with orange was observed when sourness and sweetness were perceived (Bonnans and Noble, 1993). The influence of the concentration of sucrose and citric acid on the flavour of drinks and sherbets containing orange and lemon aromas was studied (Stampanoni, 1993); there was a positive effect of citric acid and sucrose on all the rated descriptors, fruitiness, freshness, juiciness, and global impact, but not on peely note. In the case of orange sherbets, sourness was correlated with freshness and peeliness, while in the case of lemon sherbets, sourness was correlated with freshness and juiciness. Citric acid and sucrose were able to contribute to retronasal aroma intensity of a citral solution for some panellists (Kuo et al., 1993). Lemon and strawberry odour were found to enhance the sourness of citric acid (Frank, 2003).

Acceptability of Sourness

Sour taste is related to the presence of organic acids, but the association between nutrient content and taste varies among foods that have diverse taste profiles (Liem and Russell, 2019). Among these, nutrient-rich foods such as fruits were mostly classified as sweet/sour in different studies.

There are several biological underpinnings to the sense of taste. At birth, humans can already distinguish between sweet, sour, and bitter tastes, as shown by distinct facial expressions of newborns when exposed to tasting substances. As judged by facial expression, their sucking responses to and to some extent, intake of these tastants follow the positive (e.g., sweet taste) or negative (e.g., bitter and to some extent, sour taste) facial expressions (Steiner et al., 2001). Strong sour and bitter solutions are both disliked by newborns, but the facial response to sour solutions (e.g., lip pursing) is remarkably different from the facial response to bitter solutions (Desor et al., 1975; Steiner et al., 2001). The combination of lip pursing and sucking, seen typically in response to tasting sour substances, contributes to stimulation of salivary flow in the oral cavity. In adults, it has been suggested that the increased flow and buffering capacity of saliva neutralize sour-tasting substances, as described previously.

Infants’ ingestive responses to sour taste do not indicate a clear rejection; no difference in the infants’ ingestion has been observed in response to water and water with added citric acid (Cowart et al., 1990). Some infants and young children showing a preference for high concentrations of citric acid in a sugar solution were found to be more likely to consume fruit than others (Blossfeld et al., 2007; Liem et al., 2006; Liem and Mennella, 2003). This suggests that sour taste preferences directly influence food consumption. Thus, dietary learning and experience are important for the acceptance and intake of sour fruits (Liem and Mennella, 2002). Children fed on formula containing sour-tasting protein hydrolysates tended to have higher acceptance and intake of sour foods and higher levels of citrate in orange juice (Liem and Mennella, 2002). Similarly, children tend to have a higher preference for sourness during childhood (Liem and Mennella, 2003).

A perception study of sourness and food behavioural data for apple juice and fruit drinks with different dry matter levels showed that children on average had a higher preference for versions of beverages perceived as less sour (Kildegaard et al., 2011); however, a minor segment of children with high liking and wanting for the apple juice perceived as most sour was observed.

To date, the application of sourness intensity has been little studied as a stimulus in adults in relation to its impact on food intake or the onset of satiation. Moreover, similarly to bitterness, many sour foods tend to have low energy density and are unlikely to contribute significantly to energy intake (Forde, 2016). It has been reported that sourness of citric, malic, tartaric, and acetic acid solutions could be related to an interaction of the titratable acidity and the pH of the solution. Sourness also influenced the overall acceptability of imitation fruit beverages prepared with these acids (Coseteng et al., 1989). Pre-stirred flavoured commercial yogurts were evaluated for sweetness and sourness rather than for overall liking. The results showed that overall consumer liking was significantly correlated with sweetness intensity, sweetness–sourness ratio, and the cumulative impact of sweetness and sourness for strawberry and raspberry yogurt. Generally, it was found that the sweeter the yogurt, the higher the acceptance of these fruit-flavoured yogurts by consumers (Barnes et al., 1991).

Conclusion

The sour note found in many foods is caused by the presence of protons and by substances that lead to their production by hydrolysis. The sour compounds are, in particular, organic acids, the structure, size, polarity, or pKa of which influence the intensity of the sour note. There is a great variety of these, because they come from the major metabolic pathways; however, some of them are predominant in certain foods. Due to their physicochemical properties, they are sensitive to the buffering capacity of saliva. This acid perception is modulated by the presence of other stimuli responsible for bitterness, sweetness, and saltiness. For example, in cheeses, the perception of the acid note can be influenced by the presence of sodium chloride. The perception of particular aromas can also modulate acid perception through perceptual interactions. Overall, there is less work on sour perception than on bitter, salty, and sweet perceptions. Indeed, the masking of bitterness and the strengthening of saltiness and sweetness are of definite economic interest, either to
improve the taste quality of food, drink, or medicines, in the case of bitterness, or for public health reasons, in the case of saltiness and sweetness. However, perception of sourness is important in some cases, as it brings a certain balance with other perceptions, thus impacting appreciation by consumers. This sour perception is appreciated in certain contexts but is often rejected if it is too intense. The mechanisms at play in the perception of acid at the peripheral level are still little known; they deserve deeper study to better control this perception.

REFERENCES

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