Food Flavour Perception and the Measurement of Tastes and Smells

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Chapter

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Abstract

Flavour perception of food is discussed in this chapter in two main stages of the sensory evaluation process: how flavour evokes our senses and how we measure flavour perception. Flavour stimuli are inherently complex due to the mixed nature of flavour compounds in food. Both the food matrix and individual human factors further modulate this perception. Factors influencing the identification and intensity of flavour stimuli in water- and alcohol-based food matrices are explained, linking subjective and objective sensory assessments with the instrumental measurements. Sensations are understood as raw data transmitted from our sensory receptors to the brain for processing. Flavour perception represents processed data, shaped by integration with memory and emotions related to the flavour and the food medium. When sensations are evoked by flavour stimuli, they are translated and formed in the mind through these cognitive processes. This chapter focuses on measuring flavour primarily through the senses of taste and smell. Traditional instrumental techniques such as HPLC and GC, as well as emerging machine-learning technologies like electronic nose (E-nose) and electronic tongue (E-tongue), which aim to mimic human flavour evaluation, are also presented and discussed.

Keywords: flavour in food, perceived flavour, odourants, tastants, GC-O, E-nose, E-tongue, flavour measurements, sensations, perception

1. Introduction

This book chapter brings together insights into flavour measurement drawn from our experiences as a sensory scientist and flavour chemists, gained through work with both international and local food industries.

The content will firstly establish a scope for how flavour stimuli are sensed and perceived in human subjects. We then present an alternative measurement scale as compared to the mainstream scaling method, including discussions on the practicality and complexity of measuring human perception. We also discuss the validity of responses from an implicit subjective measurement derived from emerging neuroscience approaches.

Then traditional and recent instrumental measurement tools, such as GC, HPLC, GC-MS, GC-O, the Electronic Nose as well as Electronic Tongue are presented, highlighting under what conditions these tools are optimal and how they are best used in order to validate sensory responses. The second focus of this chapter will also be on flavour perception and the flavour molecules responsible for key flavour notes in food ingredients.

2. Sensory science and human perception of flavour

Flavour is commonly explained as an integral sum of how aroma and taste are combined and perceived. We usually find the flavour term used interchangeably with taste in everyday conversations. People are not usually able to separate taste from aroma. If you would like to experiment how to do so, there is a simple and rather fun technique to distinguish the two senses, where the receptors of both senses can be temporally separated using a nose clipping trick whilst chewing strongly aromatic but bland-tasting food - all-flavour jellybeans are a good choice for demonstrating the differences of how these two senses are sensed, detected and perceived [1]. This, however, is not the way most of us taste our food (and not to be used with children or health-risk subjects!).

The field of sensory science has evolved considerably in understanding how we perceive and respond to these complex flavour experiences. When we conduct sensory evaluations, the fundamental distinction between objective and subjective measurements remains crucial for achieving reliable and meaningful results.

2.1 Understanding objective and subjective measurements

When we treat human subjects as consumers in sensory testing, we are not using them as precise measurement tools. Instead, we expect and welcome a wide range of responses; some people might love a product, whilst others hate it, even if they come from similar backgrounds. This variation in acceptance and pleasantness scores is not just normal, it is valuable for understanding consumer food choice.

However, when our goal shifts to measuring how intense a particular flavour characteristic actually is, not whether people like it, but how strong it truly is, we need consistency. This is where objective measurement comes into play. Quantitative Descriptive Analysis (QDA) using trained sensory panels is considered one [2–4]. These trained panellists can reliably assess intensity levels across different sensory attributes, supporting tasks in quality assurance, process optimisation, product reformulation, product benchmarking and product positioning. This is an ability that has proven invaluable in food business.

Recent developments have introduced what we call Rapid Sensory Descriptive Analysis methods. These use skilled panellists, experienced tasters or even naïve consumers to evaluate flavour profiles of the product range [5, 6]. It is particularly exciting how technology is now enhancing these evaluations, with new methods that mimic our human senses of smell, taste and vision to improve quality, consistency and safety assessments [7]. It's like having electronic assistants that can 'taste' alongside our human experts.

2.2 How we measure what people think and feel

For subjective measurements, we primarily rely on what people tell us through self-reported scales. Sensory scientists use all four types of measurement scales, but

the most popular is probably the 9-point hedonic scale. You have likely encountered this yourself. The scale runs from "dislike extremely" to "like extremely" with "neither like nor dislike" in the middle. It is simple and works well across different populations, including children as young as 9–11 years old [8].

One challenge we face is translation. The scale was developed and validated in English, so the descriptors do not always carry the exact same meaning in other languages [9]. It is a bit like trying to explain the difference between "nice" and "lovely" to someone learning English - the nuances matter. In practice, most sensory scientists treat the data as interval data and use parametric statistics, even though the scale categories are not truly equal intervals and lack a proper zero point. In some occasions, the data need to be standardised before analysis further [10–13].

The Magnitude Estimation Scale (MES) offers a different approach than the popular 9-point hedonic scale. Instead of fixed categories, we ask participants to rate intensity "in proportion" to a reference sample. Think of it like asking someone to rate how bright a light is compared to a standard bulb - if the standard is 100, how bright is this one? This generates what we call ratio data and provides much more detailed sensory information compared to fixed scales [3, 10, 12, 13]. MES works particularly well for quantifying taste intensities like sweetness and complements our instrumental measurements from techniques like Gas Chromatography (GC).

Spectrum Analysis, which combines MES with standard references, has assisted panel training and improved result consistency in limited training duration [3, 4, 12, 14]. The downside of using MES? All that numerical calculation and comparison can be mentally exhausting for the trained panellists, let alone ordinary consumers. Not everyone enjoys calculation especially whilst tasting food.

Apart from the measurement scale, we know that stimuli from food can change whilst in mouth during the eating process. This includes how trigeminal stimuli, such as the burn from chilli or the cooling sensation from mint, can modulate both flavour and mouthfeel perception [15, 16]. Eating experience is not a quick and still picture, it is a whole story.

2.3 The discovered world of unconscious responses

Beyond traditional self-reported scales, neuroscience is revolutionising how we understand flavour responses. Is it true that up to 95% of our purchasing decisions are made subconsciously [17]? We think we are being rational consumers, but our brains may have often already decided before we consciously realise it.

This has led to tools like the Implicit Association Test (IAT), which reveals how we unconsciously link flavours to emotions and positive or negative attributes [18, 19]. It is rather like word association, but for tastes and feelings. The challenge is that it is quite time-consuming as a test would require 5–12 minutes of rapid-fire responses to bypass conscious thinking of the participants. It also requires large sample sizes (hundreds of participants) for reliable results.

What is exciting is how artificial intelligence and neuroscientific methods are being integrated with traditional human sensory panels. This could well define the next generation of sensory science research [7, 19, 20]. We are essentially teaching computers to understand human taste and aroma perceptions whilst simultaneously learning more about how our own brains process flavour information.

There are still questions about test-retest reliability and how contextual factors influence results [19–21]. Cultural background plays a major role in these associations, too, raising questions about whether results reflect individual psychology or

broader cultural influences on flavour preferences and perceptions. A flavour that evokes comfort in one culture might trigger entirely different associations in another, take, for example, the case of fermented tofu or durian flavour.

2.4 How we learn to like (or dislike) flavours

Flavour learning is powerful. It is essentially about linking the taste and aroma of food with what happens afterwards. Eat something that makes you feel satisfied and energised, and you will likely crave it again. Experience nausea after eating something, and you'll probably develop an aversion that can last for years [1, 22].

The amygdala in our brain is the key player, connecting sensory experiences to emotional and behavioural outcomes. Flavour learning requires less mental effort and fewer experiences compared to other types of learning. Flavour perception is dynamic. It is constantly being updated by our experiences, with strong emotional tags (positive or negative) guiding future food choices. This explains why certain foods can instantly trigger feelings of comfort or disgust based on past experiences [23], even when the current sensory input is perfectly neutral. The nostalgic smell of your grandmother's cooking can instantly transport you back to childhood, or how a particular food might make you queasy because you once had food poisoning after eating it.

Recent research has provided insights into how various strategies and mechanisms can enhance food flavour perception, highlighting the complex interplay between our sensory systems and cognitive processing [24].

2.5 The biology behind what we taste and smell: Our complex taste system

Our taste system handles the five basic tastes: sweet, salty, sour, bitter, and umami (savoury, meaty taste). It all begins at taste receptors on taste buds in our mouth. Those little bumps on your tongue are papillae which gather many of taste buds on each bump. The taste bud each contains different types of taste receptor cells, each responding to specific taste stimuli.

G-protein-coupled receptors on surface of Type II cells detect bitter, sweet, and umami flavours [25–28]. Recent comprehensive studies have noted that whilst we understand sweet, bitter, and umami receptors pretty well, sour and especially salty taste receptors still need more investigation [25, 29]. The understanding of taste-receptor-diet mechanism is particularly important in a world full of High Fat, Salt and Sugar (HFSS) products.

Sour taste cells work differently, using ion channels rather than the G-protein system. The mechanisms for detecting salt are still being figured out. It is suggested that sodium-taste cells share some features with Type II cells but lack a key component called TRMP5 [28]. This makes them a unique subset, like a family member who shares some traits but has their own distinct characteristics. Interestingly, high salt concentrations can activate bitter and sour receptors, too, triggering what we call aversion pathways [25]. This might explain why extremely salty food does not just taste salty.

Recent neuroscience research has revealed detailed protein structures of taste receptors, like TAS2R14, which help us perceive bitter tastes [30]. Understanding these molecular details opens doors to possibilities for healthier food interventions, such as reformulating high-fat, salt and sugar foods without sacrificing taste appeal.

3. Our smell system: The dominant player of flavour

Smell is arguably the most crucial component of flavour perception, though most people do not realise just how dominant it is. Our brains can recognise hundreds of thousands of different odours simultaneously. It is an impressive capability that no other analytical instruments can beat.

Olfactory receptors, like many taste receptors, are G-protein-coupled receptors located on sensory neurons in the olfactory epithelium at the back of our nasal cavity. This location is crucial because it provides the shortest route to responsive brain functions, enabling those rapid reactions to odour stimuli that can trigger immediate memories or emotional responses [28].

Recent studies confirm what sensory scientists have long suspected: taste and smell are strongly linked. Olfactory receptors enhance flavour perception by sending signals to the brain, creating those rich, nuanced experiences we associate with different foods through what we call multisensory integration.

The integration of traditional sensory methods with advanced neuroscientific techniques and artificial intelligence represents where our field is heading. These developments promise to enhance our understanding of human flavour perception whilst maintaining what has always been central: the importance of actual human sensory evaluation. Sensory flavour perception is not only applied in food, personal care and pharmaceutical products but also applied in all other stuff we see, touch, smell, taste, hear and feel.

We will be exploring olfactory pathways further when we discuss instrumental procedures that mimic human perception – GC-O and electronic noses that attempt to replicate what we do naturally at the end of this chapter. The next section will examine how flavour stimuli behave in different food systems, including water-based and alcohol-based environments, using a case study of exotic syrup, building upon our understanding of these human sensory perception mechanisms.

4. Food ingredients: Flavour molecules and materials

Think of flavour molecules as the messengers between your food and your brain. In this section, we are going to explore how these tiny chemical messengers, tastants and odorants, behave in different conditions, particularly in water and alcohol-based solutions. We will use palm sugar as our example to demonstrate this complex journey from food stimuli to flavour perception, showing you exactly how what we measure in the lab connects to what you actually taste and smell.

4.1 Flavour compounds in water-based solutions

Flavour compounds in water solutions are typically both volatile organic compounds (VOCs) and non-volatile taste compounds Those VOCs are restless molecules and are always ready to jump ship and float up to your nose. On the other hand, the non-volatile taste compounds prefer to stay dissolved, once interacting with our taste receptors, contributing to sweetness, bitterness, sourness, saltiness and umami.

The VOCs are like those friends who cannot sit still at a party. These small molecules evaporate easily, especially when things heat up or when the liquid becomes less viscous. The VOCs can evaporate and contribute to what we perceive as aroma

or off-flavours. Esters, for instance, are responsible for those lovely fruity notes, like ethyl butanoate giving you that unmistakable pineapple aroma. Ketones, on the other hand, bring us those rich, buttery, creamy notes. It is diacetyl creating that lovely buttery smell. Meanwhile, the non-volatile compounds are the steady, reliable types. They dissolve in water and interact with taste receptors, contributing to sweetness, bitterness, sourness, saltiness and umami [26, 31].

Sweet tastants come in three main varieties: natural sugars (glucose, fructose and sucrose - the classics), sugar alcohols (like sorbitol and xylitol that often pop up in sugar-free products) and artificial sweeteners (aspartame and saccharin, among others).

Bitter tastants are dominated by alkaloids - think caffeine giving you that morning wake-up call, quinine in your tonic water and theobromine in chocolate. You'll also find bitter peptides and phenolic compounds hiding in plants and beverages like tea and coffee.

Umami tastants - that savoury, meaty taste that makes everything more satisfying - come mainly from amino acids like glutamic acid and aspartic acid, plus nucleotides such as inosine monophosphate (IMP) and guanosine monophosphate (GMP).

Sour tastants are typically organic acids such as citric acid in your lemon, lactic acid in fermented foods, malic acid in apples and acetic acid in vinegar.

Salt tastants include not just regular table salt but also flavour enhancers like monosodium glutamate (MSG).

Understanding these molecular personalities helps us choose the right tools to measure them. For water-based food systems, High-Performance Liquid Chromatography (HPLC) is usually our go-to method because these tastants can be extracted using aqueous solutions. Several factors can significantly affect how these compounds behave. Temperature is crucial because warmer liquids are like more energetic dance floors, encouraging compounds to move around and release faster. Solubility matters too as less soluble compounds tend to migrate to the surface where they can escape more easily. Agitation (stirring or swirling) increases the surface area and gives compounds more opportunities to break free. Finally, the food matrix itself can either suppress or enhance flavour release. Fats and lipids, for example, can hold onto volatile compounds like a blanket, delaying their release [31, 32].

4.2 Flavour compounds in alcohol-based solutions

Now, let us step into the more complex world of alcoholic solutions such as beer, wine and spirits. Ethanol brings unique chemical properties that completely change how flavour compounds behave, and the results can be absolutely fascinating. Alcohol does not just dissolve water-soluble compounds like water does, but it also embraces a wide range of fat-soluble flavour compounds. This means flavour compounds in alcohol-based systems are often perceived as more intense and complex [31–34]. This is why flavour manufacturers often use ethanol-water mixtures in their formulations. The ethanol increases the solubility of non-polar (fat-soluble) compounds, creating those complex, layered aromas that make your favourite beverages so intriguing. Ethanol also lowers surface tension, which means volatile compounds can vaporise more easily and reach your nose or instrumental detectors more readily. This enhances retronasal aroma perception, the wonderful burst of flavour you get when you swallow [33]. At higher concentrations, ethanol can suppress taste sensitivity, particularly sweetness. It also interacts with proteins and tannins, altering mouthfeel and astringency. This explains why beers and wines deliver such diverse sensory

profiles, including those unique mouthfeel sensations that contribute to the overall flavour experience.

This is a particularly interesting bit, for polyphenolic compounds like tannins (those responsible for that puckering sensation you get from strong tea or red wine) normally bind with proteins in your saliva, creating precipitation and that dry, astringent mouthfeel. But ethanol disrupts this binding by changing how both tannins and proteins behave. As a result, alcoholic beverages often feel less astringent, especially at higher alcohol levels. The astringent sensation becomes smoother, more rounded rather than sharp [32, 34].

4.3 Impacts of heat process on flavour molecules

Heat can create magnificent new flavours, but it can also destroy delicate ones if you are not careful. We all know that hot foods tend to taste more aromatic and intense, partly because heat enhances retronasal stimulation and creates that lovely warming sensation in your mouth through thermal tactile effects [19, 27, 35]. But heat does much more than just warm things up. It fundamentally changes food matrices, altering texture, viscosity and emulsion structures, which directly affects how flavours are delivered and how long they persist in your mouth. Heat also generates new flavour compounds through several key reactions:

Maillard reactions are perhaps the most famous actions. These occur when amino acids meet reducing sugars under heat, forming melanoidins and complex volatiles that give us those roasted, nutty, meaty and caramel flavour notes that make bread crust so irresistible.

Caramelisation happens when sugars break down under heat, creating both sweet and bitter compounds that produce those characteristic sweet, burnt, toffee and bitter notes we associate with caramel.

Lipid oxidation occurs when unsaturated fats get oxidised to aldehydes or ketones, which can produce rancid, grassy, fatty and green flavour notes. They are not always desirable, but sometimes part of the intended flavour profile.

Thermal degradation of vitamins and pigments can break down natural flavour compounds, sometimes generating off-flavours or creating dull, cooked tastes.

The relationship between temperature and aroma intensity is quite straightforward. Higher temperatures generally mean stronger perceived aromas because heat promotes the evaporation of volatile compounds. Heat also reduces the solubility of some compounds in food matrices, making them more available for detection by your sensory receptors. It disrupts non-covalent interactions (like protein-flavour or starch-flavour complexes), freeing up flavour molecules that were previously bound up. However, there's a flip side because heat can also destroy or drive off sensitive aroma compounds, particularly those delicate floral and fruity esters that give foods their subtle, refined notes [31, 32].

4.4 Case study of palm syrup: A flavour transformation journey

Let us bring all these concepts together with an example that perfectly demonstrates how food matrices and processing conditions affect flavour development. Palm syrup, made from the sap of the Palmyra palm (*Borassus flabellifer*), offers a case study in flavour transformation. The journey (**Figure 1**) begins with fresh palm sap, a relatively simple starting material that undergoes complex changes through heat processing. First, the sap is heated to create pasteurised palm sap. It

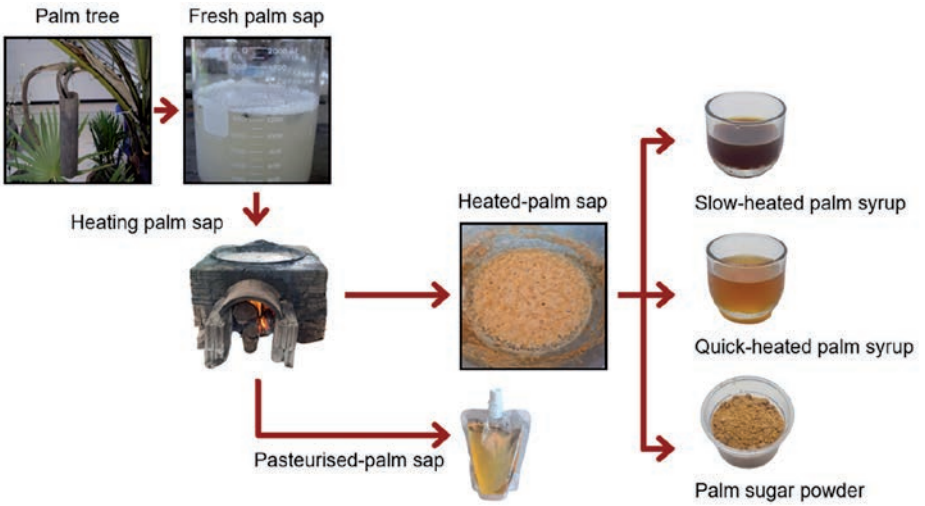

Figure 1.
Palm sap production and its products.

is at this point that the fresh, delicate flavours are lost and cooked flavours begin to form. The syrup then undergoes heat evaporation for several hours, concentrating the sugars whilst developing complex flavours and aromas through heat-driven reactions. This is where things get really interesting from a flavour science perspective. Those browning reactions such as Maillard and caramelisation reactions occur at boiling temperatures, fundamentally changing both the colour and flavour of the raw material. The result is a unique combination of sweetness and complex flavour notes.

Here is a perfect example of how processing conditions affect the final product: quick-heated palm syrup tends to display a lighter, yellowish colour with less flavour development, whilst slow-heated syrup develops a dark reddish-brown colour with intense, complex flavours. The high temperatures also accelerate sucrose inversion, where sucrose breaks down into glucose and fructose, fundamentally changing the sugar composition. These individual sugars can be detected and quantified using HPLC as tastants, whilst the volatile flavour compounds formed during heating can be analysed using Gas Chromatography (GC) [32].

The volatile flavour compounds in heated palm sugar syrup are formed mainly through Maillard and caramelisation reactions, which include furans, pyrazines, ketones, acids, aldehydes and phenols. The non-volatile compounds include various sugars (glucose, sucrose, fructose, and maltose), organic acids (acetic, formic, lactic, citric and malic acids), phenolic compounds (gallic, caffeic, ferulic and coumaric acids) and various Maillard reaction products.

This palm syrup example clearly illustrates the complexity of flavour stimuli in food matrices and demonstrates how environmental factors, in this case, temperature and processing time, have affected the concentration and types of flavour compounds present, ultimately influencing flavour perception. It also shows us why choosing appropriate instrumental methods for analysis is so crucial. We need techniques that can capture both the volatile and non-volatile compounds that contribute to the complete flavour profile.

5. Detection and measurement of flavour compounds

Now we understand how flavour molecules behave in different environments. To bridge the gap between what happens in your mouth and what happens in the laboratory, we are essentially trying to build instruments that can "taste" and "smell" the way you do.

The challenge is complex: how to create such instruments that can replicate the incredible sensitivity and sophistication of human sensory perception? As discussed earlier, our sensing organs, especially for 'smell', can detect compounds at unimaginably low concentrations and recognise hundreds of thousands of different odours [36].

5.1 Flavour sensing and human receptors

As mentioned earlier, flavour perception integrates three types of sensations: taste from your gustatory system, aroma from your olfactory system and those tactile sensations from your somatosensory system (e.g. hot, burn) sensations [37].

When you bite into a piece of hard candy: as you chew and it dissolves, the food structure breaks down and releases chemical molecules from the food matrix. The tastants, those water-soluble, small molecules, get dissolved in your saliva and make their way to your taste buds. When they find the right receptor proteins on taste receptor cells, they bind like a key fitting into a lock. The better the fit and the more molecules that bind, the stronger the signal sent to your brain via the chorda tympani, glossopharyngeal and vagus nerves.

Looking at instrumental analysis, to mimic this process, we need to replicate not just the chemical environment, but also the physical conditions. This means proper homogenisation and extraction in aqueous solvents, sometimes even using enzymes similar to those in saliva to mimic the mastication process [38]. Then we can use techniques like HPLC for highly specific detection of individual tastants, or electronic tongues that create patterns from arrays of chemical sensors. It is rather like having multiple taste buds working simultaneously.

The aroma side of things is equally fascinating but more complex. Those volatile aroma molecules, small, somewhat hydrophobic compounds, easily escape from the aqueous environment in your mouth into the air. When you breathe out after swallowing, these molecules travel through your oral cavity to your olfactory epithelium via what scientists call the retronasal route. It's different from the orthonasal route when you simply sniff something directly [39].

To replicate this in the laboratory, we homogenise samples in solutions that mimic saliva conditions, by matching the pH and sometimes adding saliva enzymes. We then use headspace techniques that allow only the volatile molecules to be introduced into our analytical instruments, particularly Gas Chromatography (GC). Dynamic headspace techniques are even better at mimicking real breathing because they use clean inert gases like nitrogen to carry the molecules, just as your breath carries aroma molecules to your nose.

Your olfactory system is remarkable, it can differentiate more than 400,000 different odours due to the wide variety of odorant binding sites on receptor proteins, coded by more than 350 genes [37]. This is why creating instruments with comparable sensitivity and range requires such sophisticated detector arrays and advanced signal processing.

5.2 Detection of odorants and tastants: The instrument

5.2.1 Gas chromatography: The aroma detection

Since aroma molecules must be volatile to reach your olfactory receptors, it makes perfect sense that Gas Chromatography became our go-to technique for aroma analysis. Think of GC as a molecular sorting system with three main components: an injection port that converts liquid samples to vapour, a separating column that acts like a molecular obstacle course and a detection system that identifies what comes out the other end [40].

The real art lies in sample preparation and Static headspace techniques have been popularly applied and proven to be fundamentally essential. The techniques simply let volatile molecules accumulate above a food sample in a closed container, and they are then amenable to separation and subsequent detection. However, they do not really match real-life consumption conditions. It is more like leaving food sitting in a sealed jar then sniffed, rather than actually eating it.

More sophisticated approaches use tools like Solid-Phase Microextraction (SPME) and Stir Bar Sorptive Extraction (SBSE), which concentrate volatile compounds on specially coated surfaces before releasing them into the GC. These can enhance detection of the GC system [38, 41]. Dynamic headspace techniques are even better at mimicking actual eating because they continuously purge the sample with inert gas and trap the volatile compounds, much like the continuous process of breathing and tasting [39, 41, 42].

The crucial point is when odour-active compounds exist at extremely low concentrations in food (parts per billion to parts per trillion). Your nose can detect some compounds at these trace levels, so our instruments need to be substantially sensitive [31].

5.2.2 Odour activity values: The impact calculator

Not all volatile compounds are created equal when it comes to aroma impact. This is where the Odour Activity Values (OAV) concept comes in to bridge instrumental analysis with human perception. You calculate OAV by dividing the measured concentration of a compound in your food sample by its odour detection threshold in humans [43]. If the OAV is greater than one, that compound is classified as 'odour active', meaning it actually contributes to what you smell and taste.

It could be said to be a relevance filter for your analytical results. You might detect hundreds of volatile compounds, but only those with significant OAVs are likely to influence the actual eating experience.

5.2.3 Gas chromatography-Olfactometry: The human-instrument partnership

This is where things get really interesting. GC-Olfactometry (GC-O) creates a unique partnership between human perception and instrumental analysis. As volatile molecules exit the GC column, the flow splits - some goes to the instrumental detector, whilst the rest goes to a 'sniff port' where trained panellists literally smell what's coming out [44].

These human "detectors" record three key parameters: when they smell something (retention time), what it smells like (odour attributes) and how strong it is (intensity). The result is an "aromagram" that reveals not just what volatile compounds are present, but which ones actually contribute to the aroma profile you perceive.

This technique illustrates need of human and instrumental analysis - machines can detect, identify and quantify, but humans provide the crucial link to actual sensory experience.

5.2.4 High-performance liquid chromatography: The taste analyser

For non-volatile tastants, those compounds responsible for sweet, salty, sour, bitter and umami sensations, HPLC is our primary tool. Unlike GC, which works with vapourised samples, HPLC separates compounds in liquid phase, making it perfect for those water-soluble tastants that dissolve in your saliva [32].

The beauty of HPLC lies in its versatility. Different column types can separate different classes of compounds, whilst various detectors (UV/Vis, fluorescence, mass spectrometry) can identify and quantify them with high accuracy. The key to success is matching your analytical conditions to your food matrix and target compounds.

5.3 E-tongue and E-nose: The digital sensory panel

5.3.1 Electronic tongues: Arrays of artificial taste buds

Electronic tongues represent a fascinating approach to taste analysis, instead of trying to identify individual tastants like HPLC does, they use arrays of low-selectivity chemical sensors that respond to multiple compounds simultaneously [45]. It provides a collection of artificial taste-buds with different but overlapping sensitivities.

The International Union of Pure and Applied Chemistry defines an electronic tongue as 'an analytical instrument comprising an array of nonspecific, low-selective, chemical sensors with high stability and cross-sensitivity to different species in solution' [45]. The magic happens in the data processing, where sophisticated statistical methods like multivariate analysis and pattern recognition create unique taste profiles for different samples. Bear in mind that samples analysed by this method need to be prepared in liquid form, where tastants get dissolved and can therefore be detected.

Three main sensing techniques dominate: potentiometry (measuring electrical potential), voltammetry (measuring electron transfer during chemical reactions) and impedance spectroscopy (measuring electrical resistance changes) [46, 47]. Each has its strengths, but voltammetry is particularly popular due to its simplicity, robustness and ability to generate large amounts of data [48].

5.3.2 Electronic noses: Digital olfaction

Electronic noses work on similar principles but focus on volatile compounds. They use sensor arrays to detect and classify complex aroma profiles, creating unique 'smellprints' that can be compared against databases using machine learning algorithms [31].

The advantages are persuasive: they can process large sample volumes in automated, high-throughput environments; they are not influenced by personal preferences or physiological conditions; and they provide objective, reproducible results. However, they are better suited for screening and quality control than for the detailed aroma compound identification that GC-O provides.

5.4 Bringing it all together: The practical approach

In flavour analysis, neither sensory evaluation nor instrumental analysis alone tells the complete story; we need both, but we need to use them strategically.

The most practical approach starts with screening using whichever method is the most convenient for your situation. If dealing with numerous samples and suspect quality issues, electronic noses or tongues can rapidly flag problems. When investigating specific off-flavours, GC-mass spectrometry might be your first port of call. Then we confirm and validate our findings with the complementary approach such as GC-O.

The ultimate goal is developing robust correlations between instrumental and sensory data. When we can reliably predict sensory responses from instrumental measurements, we can substantially reduce the workload on sensory panels whilst maintaining the connection to human perception that makes flavour analysis meaningful.

This integrated approach is particularly valuable for applications like shelf-life prediction, quality control and product development, where you need both the objectivity of instrumental analysis and the relevance of human sensory experience.

The field continues to evolve rapidly, with advances in sensor technology, data processing and our understanding of human sensory perception driving new possibilities for flavour analysis. Successful flavour analysis remains about bridging the gap between chemistry and human experience. The understanding is not just what are in the food, but how they make us feel when we eat it.

6. Conclusion: The future of sensory in flavour science

The measurement of flavour perception relies on human sensation, influenced by emotional and physical conditions. Instrumental analysis detects flavour molecules objectively, but various factors must be considered for accurate, reproducible results such as sample preparation, instrument calibration, method standardisation and sensitivity maintenance.

For flavour analysis purposes including exotic food investigation, flavouring ingredient development, process improvement, quality control, off-flavour problem-solving or commercial disputes, using only human responses or instrumental analysis alone can prove inadequate. However, maintaining both analytical approaches constantly is costly and time-consuming.

The practical solution involves screening with whichever method is the most convenient, then confirming results with the complementary approach. This reduces sample numbers requiring both analyses. When inter-correlations between analyses are well-defined, running only the convenient method becomes reasonable.

Since outputs are numerical, the sensory QDA data, chemical analysis concentrations, chromatogram peak areas, GC-O dilution factors, electronic sensor signals and simple correlations can be calculated and interpreted. Multivariate statistical analysis on both datasets creates predictive models which can forecast flavour changes and estimate shelf-life without continuous sensory analyses. This instrumental approach reduces trained panellist workload and shorten development timelines.

This is a rapidly evolving field, offering increasingly sophisticated methods for understanding complex relationships between food chemistry, sensory perception and consumer behaviour. Yet at its heart, sensory science remains fundamentally about human experience and about understanding what makes food appealing, memorable and satisfying to real people in real situations.

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