The Art & Science of Foodpairing

Peter Coucquyt
Bernard Lahousse
Johan Langenbick

10,000 flavour matches that will transform the way you eat

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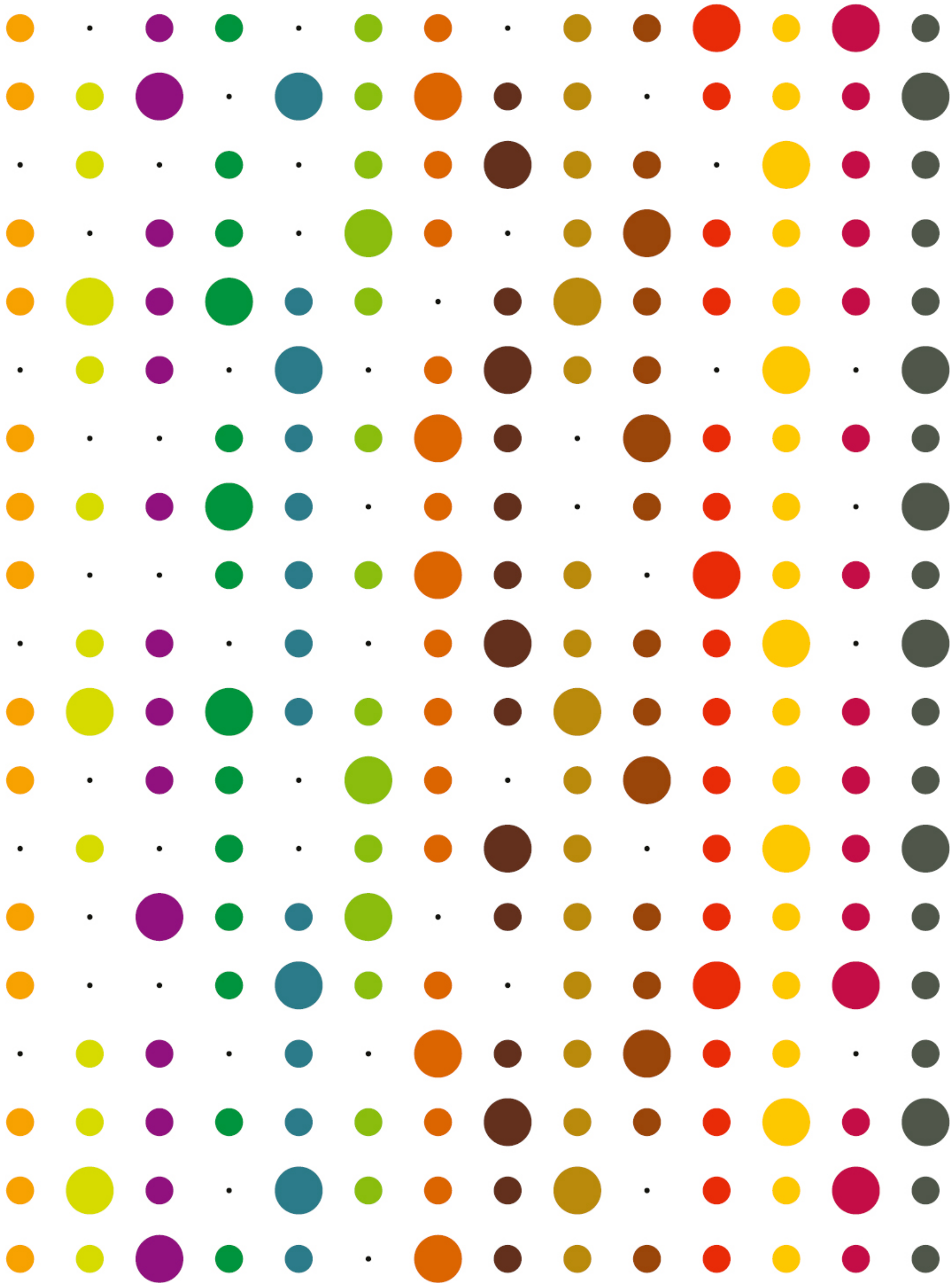


Introduction

Some ingredient pairings may appear peculiar at first, but only because we lack prior references. Consider Oaxcan *mole negro* , an intensely flavourful sauce served with chicken, in which chocolate is a key ingredient. In Japan, China and Korea, red adzuki beans are mashed to a paste, sweetened and turned into various sweet confections and desserts, while Italians drizzle balsamic vinegar over their gelato.

It just goes to show that there is no right or wrong way to pair ingredients. Whether we are comfortable winging it in the kitchen or prefer to stick to recipes, most of the ingredient pairings we encounter are intuitive. That's not a bad thing, but intuitive pairings are generally limited to familiar combinations, based either on our personal preferences or on classic pairings with some cultural basis. This is why many of us grow bored of our own cooking. But once you look beyond the confines of your own kitchen, you will find an infinite number of potential pairings just waiting to be explored.

Since launching in 2007, Foodpairing has partnered with noted chefs, bartenders and brands from around the globe on some of the most exciting projects ever tasted. In this book, we will guide you through the history and science of Foodpairing and explain why unusual pairings like kiwi and oyster actually work. We will explore the world of aromas and discuss their significance in the role of recipe creation, and how scents are detected and perceived as flavours by our brains. You will learn to use recipe-building tools and gain insights that only the world's top chefs have had access to until now. This book is designed to inspire food and drink pairings that will surprise, delight and impress.

The Story of Foodpairing

Bernard Lahousse

Why do some ingredients pair especially well together, while others do not? This is a question that has undoubtedly kept many of us in the food industry up at night.

It was my keen interest in food science and gastronomy that led me to bioengineering. In 2005 I began asking around to see if any chefs in Belgium were interested in partnering with a food scientist to expand their culinary practices. My first collaborators were Michelin-starred chefs Sang-Hoon Degeimbre of L'Air du Temps in Liernu and Kobe Desramaults of In de Wulf in Dranouter. We met regularly to brainstorm and discuss potential menu items they had in the works. It was during one of our sessions that Sang-Hoon asked, 'Bernard, why is it that when I smell kiwis, I also smell the sea? Is that possible?'

Fortunately, a fellow bioengineer by the name of Jeroen Lammertyn had access to gas chromatography-mass spectrometry (GC–MS) equipment. Together we ran an aroma analysis and found that in addition to fruity esters, kiwis also contain concentrations of green, grassy and fatty-scented aldehydes that have a marine-like scent similar to that of oysters and other types of shellfish. The aromatic link between these two seemingly unrelated ingredients formed the basis of our very first foodpairing and so the *kiwître* was born. Degeimbre's singular creation has since become a signature dish on the menu at L'Air du Temps.

As I delved deeper into the science of foodpairings, I wondered if anyone else had puzzled over my hypothesis that complementary ingredients share key aromas. I discovered that François Benzi, a food chemist at the Swiss fragrance and flavour company Firmenich, had made a similar discovery in 1992. I contacted him and we met several times in Geneva to discuss the notion that ingredients that pair well contain the same aroma molecules.

The kiwître

The story of Foodpairing starts with a dish created by chef Sang-Hoon Degeimbre: a raw oyster served over diced kiwi, with croutons and a lime-infused coconut cream. Kiwi and oysters share a marine-like aroma note.

Ingredients that share key aromas taste good together

François Benzi and Heston Blumenthal share a discovery

Food chemist François Benzi was attending a symposium in Erice, Italy in 1992 when he recognized the intoxicating scent of jasmine during a stroll through the grounds of the conference centre. Pausing to consider the blossom's unique aromatic signature, he recalled that in addition to the obvious floral notes, jasmine contains the molecule indole, which is also present in liver. This led Benzi to wonder if jasmine and liver would taste good together. He conducted a tasting at the symposium and found the pairing to be a success.

Several years later, British chef Heston Blumenthal of The Fat Duck in Bray was experimenting with salty, savoury ingredients like cured duck, dried ham and anchovies as a way to enhance the flavour of chocolate. After numerous attempts, he happened upon the 'weird but wonderful' combination of caviar and white chocolate: 'Caviar transformed the flavour far more spectacularly than I could have imagined, making it richly smooth, briny and buttery. Caviar and white chocolate, it appeared, were made for each other.'

To understand why the unusual pairing worked, Blumenthal contacted François Benzi for a scientific explanation. Benzi performed an analysis in his lab to compare the aroma profiles of the two ingredients. The results? Chocolate and caviar share some aroma molecules. Thus, they concluded that ingredients that share aromas pair well together. Emboldened by their findings, Blumenthal continued to experiment with other seemingly unconventional matches.

As word spread within the chef community about the *kiwître* and my collaboration with Degeimbre, others sought out my advice, including chef Ferran Adrià of El Bulli in Spain and Sergio Herman of the then three-Michelin-starred Oud Sluis in the Netherlands. It was 2007, at the height of the molecular gastronomy craze when many chefs were eager to test their creations against the theory of foodpairing to determine whether their own intuitively paired ingredients shared any aromatic components.

That same year, Sang-Hoon and I were invited to present our findings on the science of foodpairing at the celebrity-chef-studded Lo Mejor de la Gastronomia event in San Sebastián, Spain. Using the research on kiwi and oyster pairings that I had conducted for Sang-Hoon's *kiwître* , I enlisted the design skills of my colleague Lieven Decouvreur to visualize the ingredients' aromatic connections for the Foodpairing website. The event generated considerable interest in our theory, resulting in over 100,000 hits to the website during its first month of operation. One thing led to another, and several months later I returned to Spain to participate in a roundtable discussion organized by the Alícia Foundation with chefs Ferran Adrià, Heston Blumenthal, Joan Roca of El Celler de Can Roca and food writer Harold McGee.

Despite the attention the theory of Foodpairing had garnered throughout the global gastronomic scene, I was struck by the lack of representation of Belgium's own vibrant food scene at the culinary conferences I attended. So together with several colleagues and local chefs, I organized The Flemish Primitives, a major culinary event held in Bruges in 2009, to honour François Benzi and Heston Blumenthal for their early work in the field. Each of the participating chefs was asked to come up with a unique dish made using ingredients that shared aromatic links. Noted Belgian chefs Peter Goossens, Gert De Mangeleer and Filip Claeys, along with chefs from around the world including Heston himself, Albert Adrià and Ben Roche, partnered with Belgian universities and food companies that assisted them in implementing the foodpairing concept in their own creative processes.

More requests to collaborate followed on from The Flemish Primitives event, which had attracted more than a thousand visitors from over thirty countries. Chefs, bartenders and even food companies were eager to work on projects, so I approached Johan Langenbick, a former colleague, and chef Peter Coucquyt of the famed Kasteel Withof in Brasschaat, Belgium. Together we launched Foodpairing as a company in 2009.

The success of the first Flemish Primitives event gave rise to other such events, which were headlined by a host of luminaries from the international culinary scene, including Magnus Nilsson, Michel Bras, the Roca brothers and René Redzepi, who had his first taste of Amazonian leaf-cutting saúva ants at one of our events, thanks to Brazilian chef Alex Atala.

Since then, the global Foodpairing community has expanded to more than 200,000 members in over 140 countries. To date, we have analysed over three thousand different ingredients and amassed the largest flavour database in the world. Our ingredient-sourcing expeditions have taken us to the high altitudes of Colombia to learn about coffee varietals, diving off the coast of Spain for seaweed, and deep into the Brazilian and Peruvian Amazonian rainforest in search of exotic ingredients like saúva ants and tucupi sauce, a condiment made from cassava root. A quick online search of our Foodpairing database reveals aromatic matches for bycatch seafood, huacatay (Peruvian black mint), gochujang (fermented Korean spice paste), urfa biber (dried chilli pepper from Turkey), calamansi (citrus fruit found in the Philippines) and lots of chocolate and beer – we are Belgian, after all.

By cataloguing the individual aroma profiles for every single one of these ingredients, we are able to determine which items share aroma compounds. As we will discuss later, the aroma profiles of ingredients are quite complex, often consisting of a whole range of different odour molecules. Therefore, being able to identify the aromatic connections between ingredients is an effective way for chefs and bartenders to refine their pairings.

Eventually we arrived at the theory that synergistic pairings share certain key aromatic links that result from the complex interactions that occur between aroma molecules in ingredients.

Heston Blumenthal

The Fat Duck, Bray

'Foodpairing (or flavour pairing, as I usually call it) is now such a familiar part of the culinary landscape you might think it has always been there. In fact, though, it didn't exist at all until the 1990s, when I started exploring whether there might be some underlying reason why certain food combinations worked so well together. At this stage, no other chefs were looking into this, nor was there any obvious route to follow – I was guided by my instincts and my curiosity, piecing things together as best I could.

One key step came from talking to friends of mine [in the scientific community]. I noticed that, if I asked them about particular combinations of ingredients, they often consulted a database called Volatile Compounds in Food (VCF) to see if they had compounds in common.

I began to get very excited about this. Although such technology was used not by chefs but by food companies and chemical manufacturers, I reckoned it would work in the kitchen just as well as the lab. I could use it to find all sorts of wonderful and unexpected flavour pairings, in part because I had already been working with another authoritative source of reference: Steffen Arctander's book *Perfume and Flavor Materials of Natural Origin* . By cross-referencing one against the other, I reasoned I could take an ingredient such as [a] cherry, check its constituent compounds and then find other ingredients that shared those compounds and might thus complement it.

And so flavour pairing was born, as much out of my naivety as my curiosity and enthusiasm. For I soon came to realize that the molecular profile of even a single ingredient is so complex that, even if it shares plenty of compounds with another ingredient, it's far from guaranteed that they will work together. Foodpairing, therefore, is a wonderful tool for creativity, but only when used in concert with a chef's intuition, imagination and – above all – emotion. It's a great starting point but you still need to explore, try things out and, of course, taste constantly.'

Heston Blumenthal’s innovative techniques and unexpected flavour combinations have won him three Michelin stars and a global reputation as a creative culinary thinker.

Foodpairing: A way out of the Omnivore's Dilemma

Many times a day, we make the decision to eat or drink something. We rarely give these choices much thought, often making them almost automatically, but that does not mean they are easy choices. Humans are omnivores, meaning that in principle we can eat any kind of plant or animal. We thrive all over the planet because we can find food almost anywhere.

The omnivore in us is always on the lookout for potentially dangerous substances: something that tastes bitter might be toxic, foods that are very sour or spicy can cause us pain, the smell of spoiled foods tells us not to touch them. There is safety in familiarity, in only eating things we have obviously survived eating before. But when it comes to choosing food, safety is not our only motivation.

A characteristic we share with many other animals is our desire to avoid boredom and seek variety. This is good too, because a monotonous diet could lead to us missing out on key nutrients. Our drive for change means that once we get used to something, we are motivated to go in search of new experiences. We want new foods, with new flavours that will keep us stimulated. But these foods also pose a risk, because we don't know if they are safe to eat. These two opposing forces – eating only familiar food and staying safe versus experiencing exciting new flavours at the risk of getting sick – constitute what is known as the Omnivore's Dilemma. [1]

How do we know if a new food will taste as good as a familiar one?

Today, we rarely encounter genuinely dangerous food. Thanks to generations of food scientists and nutritionists, we can buy a food product almost anywhere in the world and eat it without suffering any harmful consequences. In the affluent Western world, healthy, non-allergic consumers are able to choose from a virtually limitless variety of food and drink items. This poses a new problem: what to eat?

We live in a time of food choice overload. It is disappointing when the food you have chosen or made does not deliver the much hoped for exciting new flavour experience. If you run a restaurant or food company, it is a challenge to keep developing new recipes and products, because it is difficult to predict which flavours will satisfy existing customers and attract new ones. The theory of Foodpairing aims to do exactly this. Knowing which aroma and taste components make up the flavours of food and drink products makes it possible to predict which new combinations will be a good match.

Key Aromas

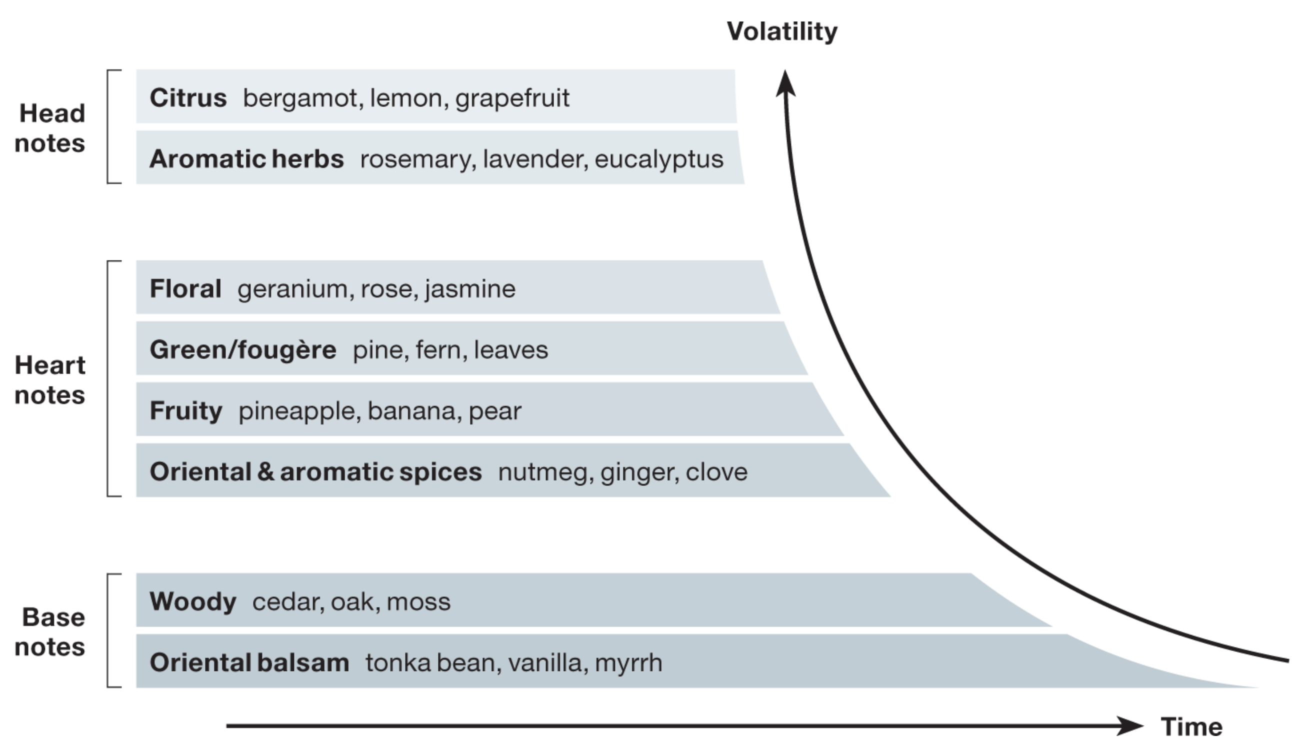
Ingredients pair well when they share key aromas at the right concentration. This theory forms the basis of our work at Foodpairing, and of this book. But what are key aromas? How do we know which volatile organic compounds are in a food product? And how do we know which ones are important, or what the right concentration is? These are just some of the questions we will address in the following pages.

Volatile organic compounds

Think of an iconic fragrance like Chanel No. 5. You might recognize this scent at first whiff, but a trained nose can parse out top notes that include bergamot, lemon, neroli and ylang-ylang, middle or heart notes of jasmine, rose, iris and lily of the valley, and base notes of vetiver, sandalwood, vanilla, amber and patchouli. Each essential oil adds to the unique complexity of the perfume's aroma profile, which is made up of different groupings of volatile organic compounds (VOCs). These are organic chemicals that vaporize easily from either solid or liquid state to gas at room temperature. You can find VOCs everywhere, including in the foods we eat. The tendency of molecules to vaporize is what we refer to as volatility.

A fine fragrance is experienced in three stages of volatility. The top or head note contains the most volatile compounds and usually only lasts between 5 and 30 minutes. The longer-lasting middle or heart notes tend to surface about 30 mintues after a good spritz. Due to their heavier molecular weights, the base notes only start to appear about 1 hour after application because they take longer to evaporate. Conversely, the lighter molecular weight of a top note makes it more volatile. That is why the most obvious aroma molecules tend to be lightweight, making them more immediately perceptible to us.

Over 10,000 different VOCs have been identified in the foods we eat. In order for us to detect these aroma compounds, they must be volatile enough to pass through the air so that they reach the olfactory receptors in our noses either orthonasally (when we sniff something) or retronasally (when we eat or drink something, see also Retronasal detection and The olfactory bulb and odour receptors).



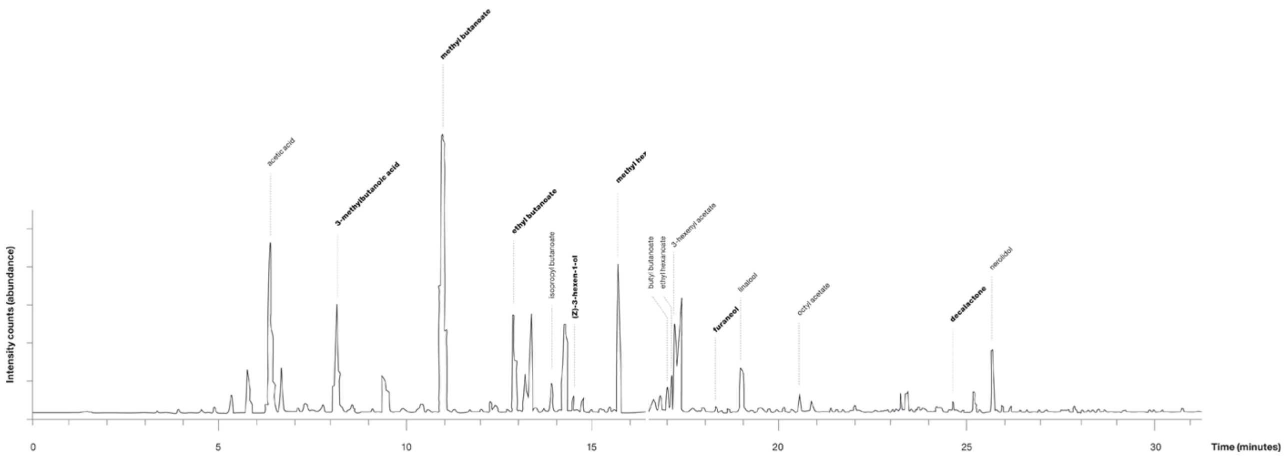
The stages of volatility in perfume

Fine fragrances are designed to be experienced in three stages, with aroma molecules vaporizing into the air at different times. The head notes provide a first impression – typically fresher scents such as bergamot, anise or lavender, they usually only last between 5 and 30 minutes. The more prominent heart notes, such as rose, pine or black pepper, add character. They appear once the top notes have begun to dissipate and can last for up to 3 hours. The deep, complex base notes, such as vanilla or cedarwood, only appear after an hour but they can linger for days.

We can separate, identify and quantify the number of different VOCs present in any ingredient or product with the aid of a gas chromatograph (GC) coupled with a mass spectrometer (MS), or GC–MS.

A dissolved sample of the ingredient is fed into the gas chromatograph, which vaporizes and separates the individual substances as they pass from the coiled column into the mass spectrometer. Depending upon their molecular weights, the compounds travel at varying speeds through the spectrometer's detector, which then records the retention time for each compound as a series of peaks on a graph (see The aroma profile of a strawberry). We refer to the time it takes for the various substances to travel through the detector as retention time. The position of each peak on the graph below represents the different retention times for each compound; the surface area under each peak represents the quantity of the molecule present in the analysed ingredient, so its concentration to be calculated.

Aroma compounds in foods are especially difficult to detect because they tend to have relatively low molecular weights (in some cases no more than 10–15mg per kg). However, GC–MS can quickly and accurately detect even trace amounts of substances, making it an especially effective method for analysing the volatile compounds in food.



The aroma profile of a strawberry

Not every peak in the gas chromatogram of a strawberry shown here necessarily contributes to the flavour of the fruit, as only a handful of the molecules can be perceived by humans. At least five groups of aroma molecules contribute to the fruity fragrance of a strawberry: coconut-scented lactones; fruity esters; aldehydes, which have a greenish scent; caramellic furanones; and cheesy acids. The aroma molecules in bold here are some the key odorants of strawberry.

The day New York City smelled like maple syrup

One day in October 2005, the sweet scent of maple syrup wafted through Manhattan, Queens and New Jersey. It took city officials a few years to track down the source of the mysterious smell: a flavours and fragrances company with a facility in North Bergen, New Jersey, where a few litres of the aroma compound sotolon had spilled into the Hudson River. At low concentrations, sotolon has a caramellic scent reminiscent of maple syrup or burnt sugar; in high concentrations, it smells like fenugreek, a spice commonly used in Indian curries.

When dissolved in water, sotolon has an extremely low odour recognition threshold (0.6 parts per billion), which explains why residents on both sides of the Hudson were complaining about a strange sweet smell. After analysing air samples and directional wind readings, the New York City Department of Environmental Protection finally solved the 'Great Maple Syrup Mystery' in 2009.

What is a key odorant?

Every aroma molecule has a unique odour detection threshold – the lowest concentration at which a volatile compound can be detected by humans. In terms of the different concentrations at which aroma molecules can be detected, there is a considerable degree of variability. For a substance such as geosmin, all it takes is a few milligrams per 1,000 tonnes, which is less than one drop in an Olympic-sized swimming pool, for us to be able to detect its distinctive earthy scent.

When it comes down to it, only a portion of volatile compounds are really responsible for the aroma profile of a particular ingredient. These key odorants will be present in concentrations that exceed the odour recognition threshold. Coffee, for example, contains more than a thousand different volatile compounds that can be easily detected by GC–MS equipment, but only about thirty or forty of them are responsible for the handful of roasted, nutty, caramellic and other flavours that we perceive.

Of course, we must also take into account every person's individual odour threshold. The ability to perceive a specific aroma molecule can differ from one person to the next by a factor of ten, ranging from hypersensitivity to complete anosmia – that is, the inability to smell a particular scent.

Aroma is synthetic

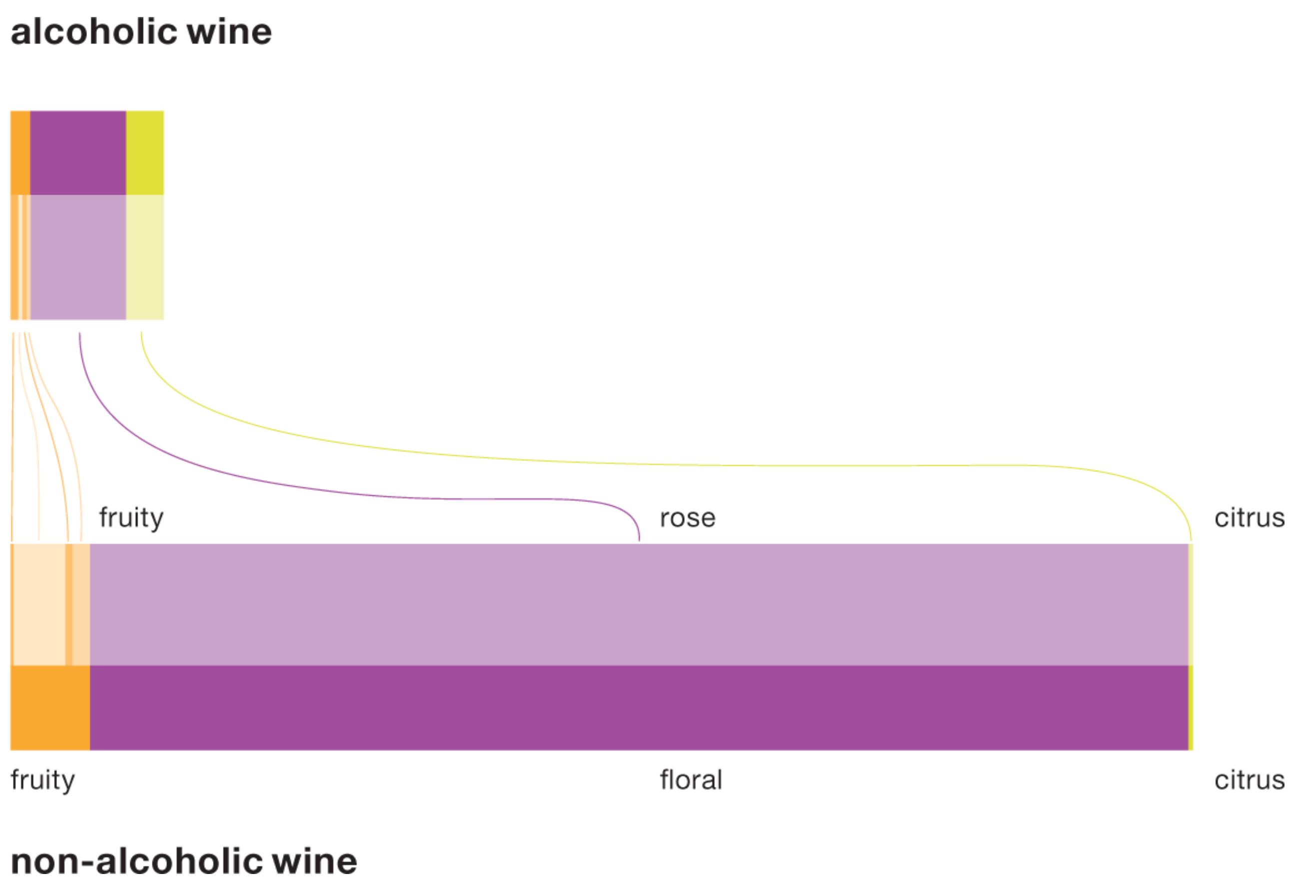
When you analyse a strawberry, none of the aroma molecules has a strawberry smell. Instead, 'strawberry' is a combination of fruity esters, coconut-like lactones and caramel, green and cheesy notes. If there is no such thing as a strawberry aroma molecule, how is it possible for us to be able to detect a strawberry aroma?

Psychophysical studies have convincingly demonstrated that the perception of mixtures of odorants is not just a simple sum of the descriptors of the individual aroma components. If a mixture contains more than four components, the odorants lose their individuality and produce a new odour percept that conveys a unique odour quality not elicited by the single components. This phenomenon, known as synthetic processing, was confirmed by neurophysiological experiments that demonstrated that selected cortical neurons respond to binary odorant mixtures, but not to their individual components. This implies that the aroma descriptors of the individual odorants alone are insufficient to identify and predict the aroma descriptors of the complete food. At Foodpairing, we use machine learning algorithms to translate the machine output into how a human being will perceive an aroma.

Changing the matrix

Just because an aroma molecule is defined as a key aroma does not mean it always stays that way. Factors such as the matrix (water, air, alcohol or fat), temperature and potential synergies between aroma molecules can also affect the headspace (for example, the passion fruit smell of beer is the result of different molecules interacting).

Every aroma molecule behaves differently in solvents, depending on its physical properties. Hydrophobic aroma molecules are water-averse – they dissolve more easily in fat. When surrounded by water molecules, they tend to exit into the headspace, where they are easier for us to detect with our sense of smell. Conversely, hydrophilic aroma molecules have an affinity for water molecules and prefer to remain in liquids. Alcohol (ethanol) has partially hydrophobic properties, which explains why the hydrophobic aroma molecules found in wines or spirits remain there, despite the presence of alcohol. The proportion of liquids – water versus alcohol – determines which aromas are easier to detect.



The impact of alcohol on flavour

An aromatic comparison of Gewürztraminer wine with and without alcohol demonstrates the marked differences in flavour between the two: wine tastes less fruity than non-alcoholic grape juice.

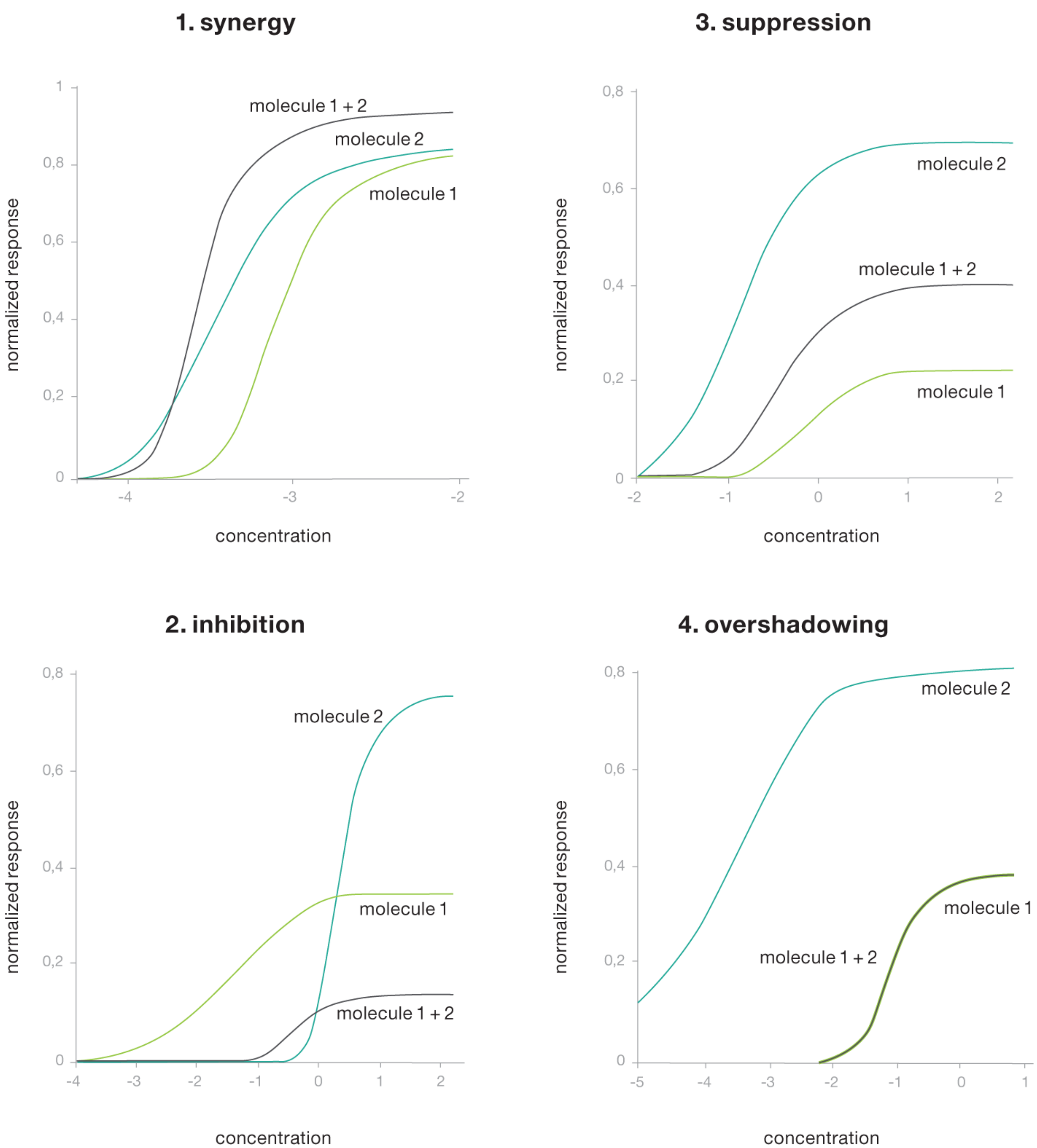
The more alcohol there is in a drink, the more hydrophilic aroma molecules will escape into the headspace. The higher the proportion of water, the more hydrophobic aromas will move from the liquid into the headspace. For example, adding water to whisky opens up different and subtle new flavours.

Adding other aromas

Just because an aroma molecule is below the odour threshold does not mean it cannot be perceived. Aromas that have a similar structure or perception to other aromas can create synergy or additivity (see graph 1). For example, ethyl octanoate and ethyl decanoate have a similar chemical structure, and the mixture of these two aroma molecules has a lower odour threshold than each individual aroma.

The combined impact of similar odorants can also produce a new scent that smells even more intense than the sum of its individual volatile components. Blue cheese owes its intense, distinctive odour to a combination of the buttery aroma molecules of 2,3-butanedione and the cheesy, buttery notes of 3-methylbutanoic acid. The interaction between aromas is not always that logical – fatty aldehydes are added to Chanel No. 5 to increase its floral notes, for example. It is also concentration dependent: at low concentrations, whisky lactone increases the perception of isoamyl acetate but suppresses it at higher concentrations.

Interactions between aroma molecules



Compounds present in concentrations too low for us to smell them on their own can be perceived if they are combined into mixtures that exceed our odour recognition threshold. More often than not, the scent we associate with an ingredient or product is the result of many different odorants interacting.

1. Synergy or addivitity describes the combined impact of similar odorants in a mixture to produce a new scent that smells even more intense than the sum of the individual volatile components.

2. Inhibitory responses triggered by the complex interactions between aroma molecules cause our olfactory receptor neurons to perceive the scents of individual components rather than their blended mixtures. For example, the fruity ester ethyl 3-methylbutanoate inhibits the bell pepper aroma of 2-isobutyl 3-methoxypyrazine.

3. Suppression is when the mixture is less intense than the aroma molecule with the highest intensity in the blend, but the mixture registers as still more intense than the other molecule(s) in the blend.

4. Overshadowing or hypoadditivity happens when the intensity of a mixture is the same as that of one of its aroma molecules, but the blend is still overshadowed by one of the components in the mix.

Olfaction versus Gustation

It is a common misconception that flavours are perceived in the mouth, when our perception of flavour really has more to do with the aromatic components in an ingredient that are volatile enough for the scent receptors in our upper nose to register. The olfactory system is responsible for detecting those airborne aroma molecules, while the taste receptors in the mouth are capable of registering only the five basic taste molecules – sweet, salty, sour, bitter and umami – when they are solved in fluids. Recent studies have shown that up to 90 per cent of our overall flavour experience has to do with olfaction.

Eating or drinking involves a complex, multisensory orchestration of olfaction, gustation and our trigeminal senses, coupled with sight and sound, of course.

Aroma perception

The human nose contains about four hundred scent receptors that are thought to be capable of detecting upwards of one trillion different odours. This number speaks to our olfactory system's ability to process an incredibly diverse range of complex and nuanced scents, especially when contrasted with our taste receptors. Studies from the 1920s indicated that humans could smell some 10,000 different odours, but a recent experiment conducted by neurobiologist Leslie B Vosshall of the Rockefeller University in New York City has determined that humans can detect many more. [2]

Vosshall's lab created three separate mixtures from a set of 128 individual odour molecules; the vials contained combinations of 10, 20 or 30 components. Each subject was given three different vials of scent mixtures – one unique and two that were identical – and asked to identify the odd one out. On average, the subjects were able to sniff out the differences if the odour mixtures varied by more than half. Vosshall's lab extrapolated from their findings that humans should be able to distinguish an average of 1 trillion smells. While the 10,000 odours was clearly an underestimate, one trillion may be something of an exaggeration – the number of odours humans can detect probably lies somewhere in between.

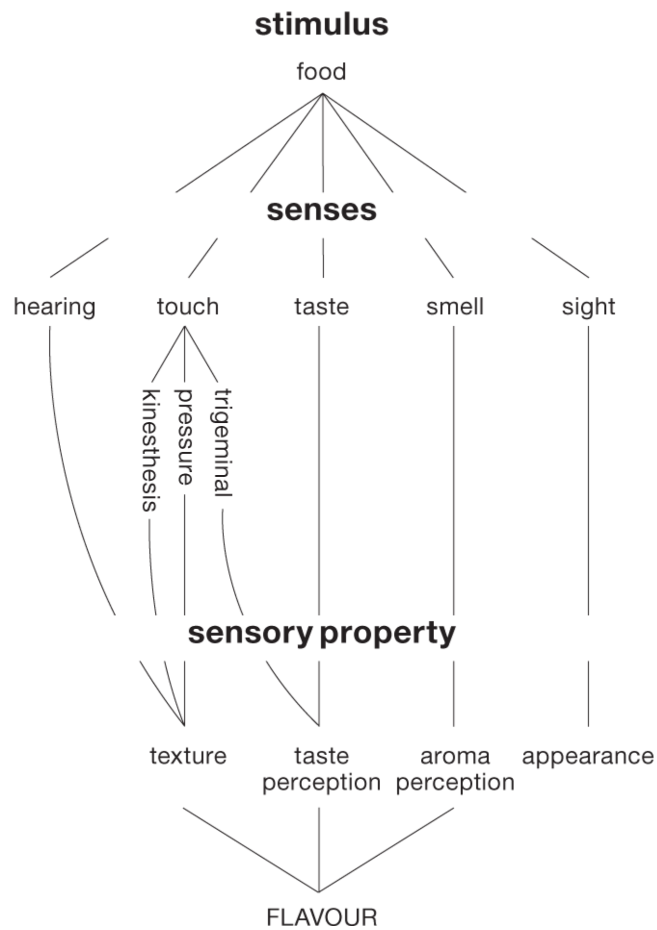
How we taste a glass of wine

Imagine tasting a fine wine for the first time. As you tilt the wineglass towards you in order to take a deep inhale, the wine's most volatile notes rise towards the rim of the glass and evaporate into the headspace. A surge of aroma molecules travels up through your nostrils towards the olfactory epithelium located along the roof of the nasal passage, where hair-like cilia extend through a layer of mucous membrane, trapping the odour molecules, which dissolve and bind with specialized neurons called olfactory receptor cells.

These receptors transmit the signals along the sensory cells up to the olfactory bulb, which is located directly beneath the frontal lobe of the brain. From there the signals continue on to the sensory neurons in the piriform cortex, where the odour molecules interact to varying degrees with different receptors, causing them to register unique patterns of activity for every single odour molecule. The overall flavour of the wine begins to take shape like a pointillist painting as the receptor cells relay the aroma information to different areas in the brain like the amygdala and the thalamus. This is orthonasal detection, our primary means of processing scents.

Notice the top notes that rise towards the rim of the glass smell different than the heavier notes that linger closer to the surface of the wine. Aerating the wine by swirling the glass opens up its fragrance, freeing some of the base volatiles that would otherwise remain trapped beneath the liquid surface. Luckily, the human brain is equipped with 40 million olfactory receptor neurons to process these different odours. New odours we encounter imprint their signature patterns in our memory so that we recognize them the next time we smell them.

Retronasal detection is our secondary means of processing scents, which explains why expert tasters also employ various oral agitation techniques when assessing wines. The act of swallowing or chewing pushes air up through the nasopharyngeal passage, carrying with it the aroma molecules from food or drink. Slurping air as you sip wine forces it towards the back of your throat, where the aroma molecules may come into contact with the olfactory epithelium. From there the various signals are once again transmitted to the brain via the olfactory tract. You might even detect notes in the wine that you had not noticed before. The sour or bitter aftertaste that lingers after you have swallowed is an indication of the wine's tannins.



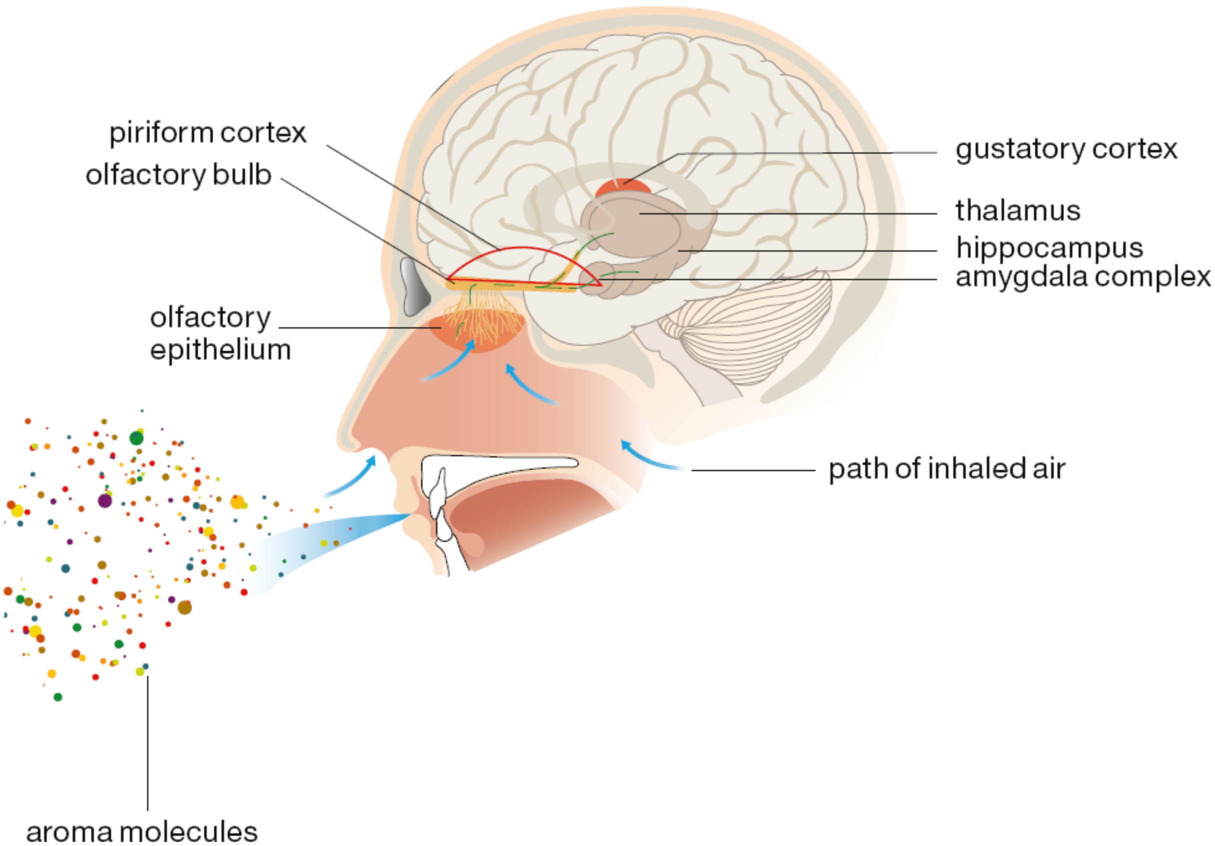
The sensory properties of food

Aroma and taste perception are two of the four main sensory properties that determine our selection, acceptance and consumption of food, along with appearance and texture.

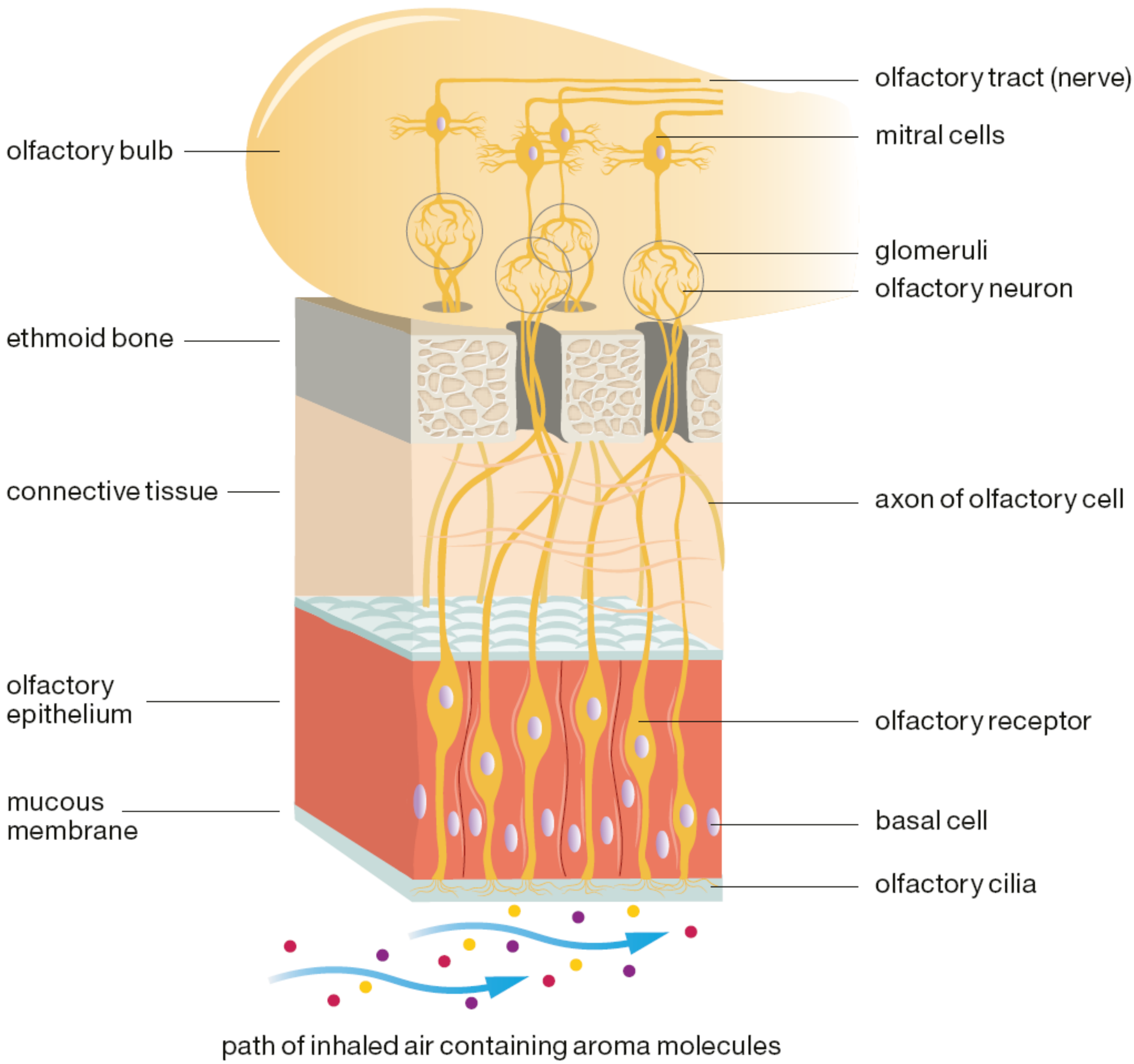
An exercise in experiencing flavour

Pour yourself a glass of orange juice, pinch your nose and take a sip. Can you describe what you have just tasted? Probably a bit of sweet and sour but not much else. Now take another sip, this time without pinching your nose. You should taste the same tanginess, but this time with an added burst of citrusy orange flavour – or rather, fragrance. This is what we mean by the full flavour experience. See what happens when you try this tasting exercise with coffee: instead of complex flavours, you will taste little more than its bitterness.

Retronasal detection



The olfactory bulb and odour receptors



Processing scents

In retronasal detection, the vacuum created through swallowing causes odour molecules to travel through the throat and nose to the olfactory bulb. You can intensify your experience of flavour and aromas by taking a deep inhale through your mouth right before or after you swallow – for example, slurping during a wine tasting.

Taste perception starts in the mouth

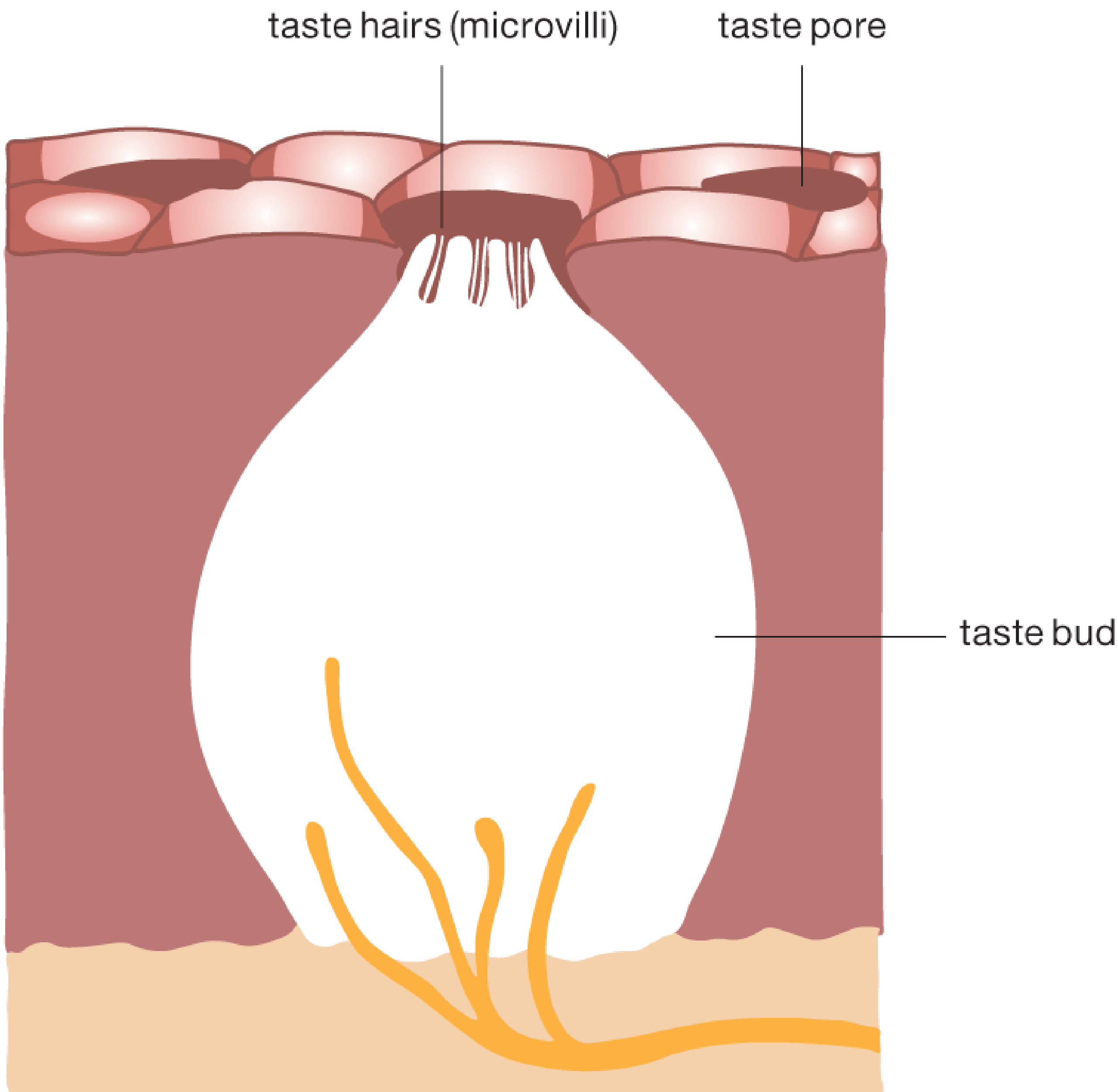
Contrary to what many of us were taught at school, there are no specific areas on the tongue that are solely responsible for distinguishing between sweet, sour, salty, bitter and umami tastes. Every part of the tongue can discern all five tastes, though certain areas may have more taste buds than others. The misperception that we taste sweet things only with the tip of the tongue and bitter foods towards the back probably arose from the tendency of bitter tastes to linger in the mouth.

Between 5,000 and 10,000 taste buds are embedded within small protuberances on the tongue called papillae, as well as towards the back of the mouth and along the palate. When we eat or drink, chemicals known as tastants (for example sugar, salt and acid) stimulate the 50–100 specialized receptors within each taste bud, sending signals from the nerve fibre endings to the cranial nerves and on to the taste regions of the brainstem. From there, the impulses are transmitted from the thalamus to a specific area of the cerebral cortex that alerts us to that particular taste.

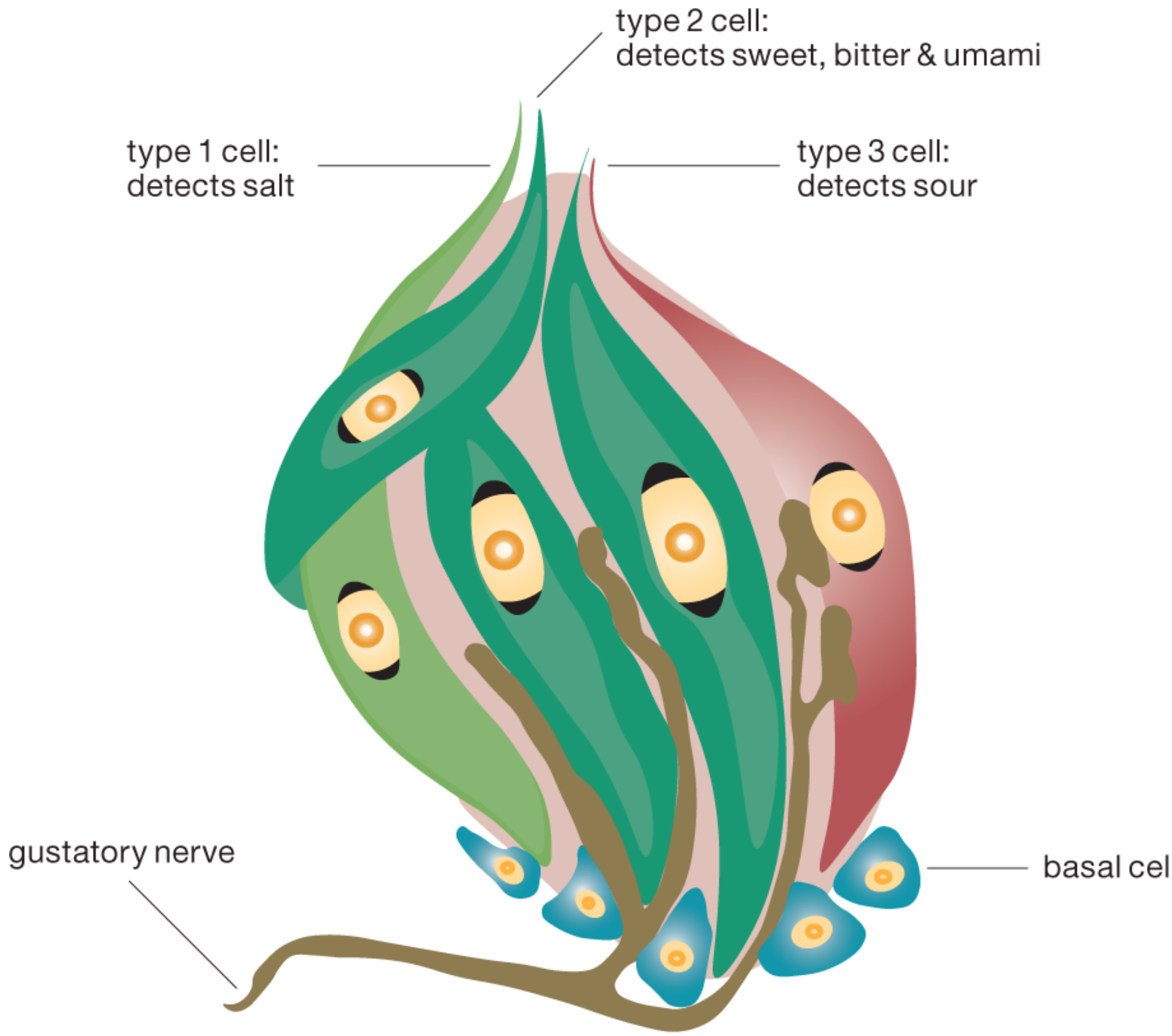
G-protein-coupled receptors are responsible for detecting sweet, bitter and umami tastants. The T1r2/T1r3 receptor complex, formed by two proteins, recognizes sweet tastants like sucrose and fructose, as well as artificial sweeteners such as stevia and saccharin. Glutamates in savoury foods like the L-glutamate amino acid most commonly associated with monosodium glutamate (MSG) bind with the receptor proteins T1r1/T1r3, which also recognizes guanosine monophosphate, a molecule responsible for the umami tastants we find in shiitake mushrooms.

Humans possess many more sensory receptors for detecting bitter substances than any of the other tastants, probably to protect us from accidentally ingesting toxic substances – there are at least one hundred known variants of the TAS2R set of taste receptors, which indicates their evolutionary importance. Salty and sour tastants enter the taste receptors directly through the transient receptor potential (TRP) channels, which are tiny pores on the surface of the cell membrane. We also have receptors that react to fatty acids, presumably because our bodies need fat to survive. Some scientists think we also have receptors for detecting a metallic taste, but this is still being investigated.

Surface of the tongue



Taste bud



Taste buds

Up to 10,000 taste buds are embedded in the surface of the human tongue, and each taste bud is formed of up to 100 taste receptor cells.

Science fact

Molecular mass (m) is the mass of a given molecule measured in atomic mass units (u) or daltons (Da). The average aroma molecule weighs less than 200 Da – it would take 221 molecules to equal a single gram.

What is that sweet scent?

At 342 daltons, sugar molecules (sucrose) are too heavy for us to register through orthonasal detection, so when we say that something smells sweet, we are actually referring to the smell-taste association of flavours like vanilla and cinnamon, familiar from desserts with a high sugar content. The term 'sweet' is also often applied to fruity scents and caramellic flavours, but these associations are subjective because they are shaped by our cultural or personal experiences. For instance, in France, where desserts are often flavoured with vanilla, incorporating the spice into a recipe may cause a dish to be perceived as sweeter than it is. In Vietnam, however, fresh lemon juice is commonly added to sweeten drinks, so consumers may form their own associations between lemons and sweetness.

Trigeminal sensations

Apart from the five basic tastes, we experience other pleasurable – and sometimes painful – sensations when we eat. Temperature, texture, pain and cooling are just some of the trigeminal sensations that enhance our olfactory and gustatory experiences. Certain chemical compounds stimulate the trigeminal nerve, which sends signals to the brain. For example, Sichuan peppercorns contain hydroxy-alpha-sanshool, which causes a tingly, numbing sensation known as paresthesia. Spilanthol is responsible for the analgesic effect of Sichuan buttons – the edible flowers of the pepper plant – and several other plant varieties. Capsaicin gives chilli peppers their fiery burn, and menthol leaves behind its minty cooling effect. The fizz in carbonated soft drinks comes from citric acid.

Texture also plays a crucial role in our enjoyment of food: you might reflexively spit out a stale potato crisp or cereal that has gone soggy. But mouthfeel conveys more than just the physical state and structure of our food; it also informs our oral somatosensory system about everything from touch and temperature to pain, pressure and more.

Specialized receptors located on the tongue and in the epithelial layer of the mouth send signals to the brain about the size, shape and texture of whatever we eat or drink. We have more sensory receptors clustered towards the front of the tongue and in the mouth than anywhere else on our bodies; these receptors alert us immediately about whether something tastes pleasant or off, evidenc of yet another evolutionary selfdefence mechanism that is critical to our survival.

Taste happens in the brain

Unlike olfaction, which is synthetic, our perception of taste is analytical, meaning that the individual tastes can be isolated in the brain. Charles S Zuker, a professor of biochemistry, molecular biophysics and neuroscience at Columbia University in New York, recently proved that taste perception occurs not on the tongue, but in the brain where the neurons responsible for different tastes are triggered. According to Dr Zuker, 'Dedicated taste receptors in the tongue detect sweet or bitter and so on, but it's the brain that affords meaning to these chemicals.'[3]

Are you a supertaster?

About 25 per cent of the population can be considered supertasters. They are hypersensitive to taste, not flavours, so to them, sweet, sour and salty foods have a heightened intensity, while some vegetables and bitter drinks like coffee and beer are positively unbearable.

Whether you qualify as a supertaster or not is determined by the number of fungiform papillae on your tongue. The average person has about 15–35 papillae in an area 6mm (¼in) in diameter, whereas supertasters may have as many as 60. Non-tasters, who make up another 25 per cent of the population, have fewer than 15 papillae within the same area.

The Importance of Aroma

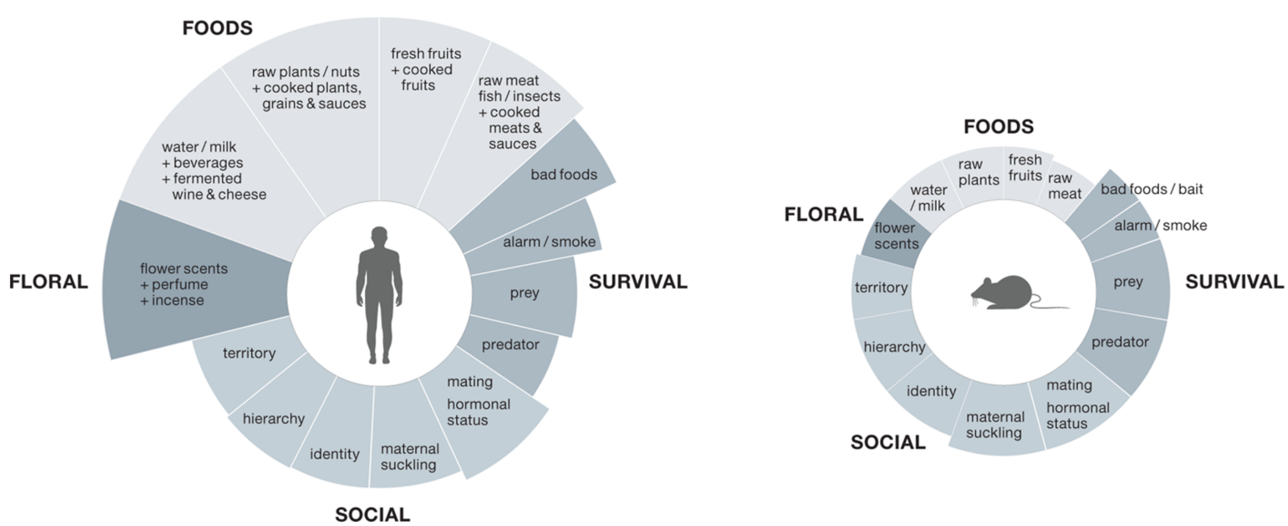
Over the course of human evolution, scents have played a crucial role in our species' survival as a key driver of the flavour experience. From a microbiological standpoint, our sense of smell protects us from accidentally consuming foods that are unfit to eat. One whiff of the off-putting ammoniac odour of rotten eggs or seafood past its prime, and you don't have to think twice about reaching for another (safer) meal option. Women possess a heightened sense of taste and smell during pregnancy, presumably to protect themselves and their unborn children from ingesting foods that could pose potential harm. Infants can also recognize their mother's scent soon after birth.

Odours are essential cues when it comes to social bonding. In a study conducted by the University of British Columbia's department of psychology, 96 female subjects were randomly assigned and asked to smell a brand-new T-shirt, or one that had been previously worn by their spouse or a complete stranger, before undergoing a stress test. The women who smelled and correctly identified their spouse's worn T-shirts had lower levels of cortisol, while the women who were assigned a stranger's T-shirt to smell showed elevated levels of cortisol. It just goes to show that humans are extremely sensitive to body odour, even if only subconsciously. [4]

The biology of smell

As we evolved to claim our place at the top of the food chain, reliance on our sense of smell diminished as we came to rely more heavily on our vision for survival. The number of functioning olfactory receptor neurons is but one measure of an organism's capacity to discern scents. Studies have shown that humans have approximately 350 functional receptor genes compared to the 1,100 receptor genes found in mice. However, the ability to distinguish between odours may have more to do with the central olfactory region in our brains, and its ability to process the input received from the nose and mouth.

Competing noses: Human versus mouse



The role of smell in survival

Recent studies suggest that evolution has played a fundamental role in shaping the abilities of different species to sniff out specific scents that are critical to their own survival. Mice are extremely adept at detecting their predators, whereas dogs are sensitive to the carbolic acids present in their natural prey. The Bactrian camel's olfactory receptors are so finely attuned to the scent of geosmin that they can detect the damp-earth smell of an oasis from a distance of 80km (50 miles). Humans outperform dogs when it comes to detecting aldehydes, which are common in fruits and flowers, while also exhibiting a keen sense for blood and urine. [5] Humans have also proven themselves to be better at odour detection than even the most sensitive gas chromatography equipment. [6]

1 in 20 human genes is an odour receptor

The human body contains a total of 20,000 genes. What is incredible is that 1 out of every 20 of these genes is actually an aroma receptor. So if you imagine for a moment that our human DNA functions like a library, that means 1 out of every 20 books holds key odour information that enables us to detect and decipher different smells.

Our biology of smell must be measured by more than just the number of functioning receptor neurons we have, because other variables also affect our ability to perceive scents. For example, the size of the nasal cavity and our larger brains afford humans greater cognitive ability when it comes to distinguishing between aromas.

Beyond just the initial processing of odours, humans employ higher cognitive thinking than other species when it comes to comparing scents and flavours against ones we have previously experienced. Coupled with our system of language, this allows us to identify and catalogue the familiar and unfamiliar scents we encounter in our everyday lives. It is believed that this power of higher association, which forms the basis for our human perception of smell, makes up for the fact that we possess fewer odour receptor neurons than other mammals. Over time, we may have evolved to become less reliant upon our sense of smell than other species, but the trained nose of a sommelier, a perfumier or any other sensory expert proves that with some practice, we are capable of smelling exceptionally well.

Another key factor that distinguishes humans from other species is that we process most of what we eat and drink prior to consumption. The elaborate methods we use to cook, ferment, season and combine ingredients have exposed us to a much broader range of retronasal aromas than other species get to experience.

No two noses smell the same

Recent studies have found that approximately 30 per cent of our olfactory receptors differ from one person to the next due to genetic variations. Our olfactory receptors work together to form a sophisticated network of about four hundred specialized sensors that are capable of detecting and analysing different aromas. For instance, when you take a whiff of cinnamon, it activates your receptors, which encode the aroma information into a patterned signal that is sent up to your brain: *citrusy lemon, spicy cinnamon, clove and camphor* . These encoded patterns are recognized by the brain, which identifies the ingredient you are smelling as cinnamon.

Approximately 140 of these 400 odour receptors vary slightly from one person to the next, causing us to perceive the scents in our environments differently. The Weizmann Institute of Science in Israel has developed an olfaction test that asks subjects to identify 34 separate odours using a set of 54 aromatic descriptors. Based on the subject's responses, a unique olfactory fingerprint can be generated for every person on the planet. [7]

Flavour associations: Learning to like

Our reasons for liking or disliking certain foods are rarely inherent – most of the time, our preferences are shaped by a series of experiences. It is less a matter of being 'born that way' than a matter of psychology.

While studying the digestive system in dogs, Russian physiologist Ivan Pavlov (1849–1936) noticed that after a while, his dogs started salivating before even receiving any food. He discovered that any stimulus that was associated with food (in his classic experiment, it was the sound of a buzzer or a metronome) would eventually lead to a salivary response on its own. Similar learning processes also govern what humans learn to like and dislike. The principles of classical conditioning help explain how we can grow to like flavours that we may initially dislike. A positive consequence of a food ingested is the reward that is needed to establish an association. This reward can come in the form of energy (from sugars, for example) or from physiological effects, like those of alcohol or caffeine. Both these substances taste bitter, but their pleasurable consequences can overcome our inborn dislike of bitterness, even to the extent that we learn to like bitter aromas. Less harmful rewards, such as the refreshing sensation of cool water in the mouth, can also work. When such a bodily reward is coupled to a specific flavour, this flavour will over repeated exposure start to become liked.

We can also learn to like a new (neutral or even disliked) flavour through associating it with a flavour that we already like. This type of transfer of liking is known as evaluative conditioning, or flavour-flavour learning in the context of food. Repeatedly pairing a new flavour with a flavour we know and like lets us learn to like a new flavour too. Sweetness is a universally liked taste, which makes it a good candidate when it comes to learning to like flavours. Adding sugar to bitter coffee or sour plain yogurt makes them instantly more palatable. Over time we acquire a taste for the unsweetened version – the association with sweetness has done its trick.

Associating a flavour you like with a new flavour you do not like will lead to you liking the initially unliked flavour more. In the context of Foodpairing, this is a very interesting finding. If one flavour in a new combination is liked, any other flavour in that pairing will over time become liked too.

Flavour–flavour learning: Combining disliked and liked ingredients in order to learn to like disliked flavours

	Dislikes		Likes		Likes
PERSON 1	broccoli fennel black salsify	+	carrot blue cheese coconut mango beetroot	=	**blue cheese with mango and fennel salad**
PERSON 2	Brussels sprouts asparagus	+	walnut leek pomegranate tarragon endive	=	**roasted Brussels sprouts with pomegranate, walnut and roast chicken**

Aroma Molecules

Every aroma begins as a precursor in your food – a carbohydrate, an amino acid, a fatty acid or a vitamin. Some aromas are already present in raw ingredients, while others are formed by cooking or processing them.

Most of the fragrances we associate with fresh fruits develop as they ripen. Sugars may be metabolized into starches or even lipids (in the case of olives) during the fruit's growth phase. As the fruit matures, these and other precursors are converted into secondary metabolites that are responsible for most of its aroma. Of course, species, sun and soil also play a role in determining a fruit's flavour and sweetness.

Vegetables have little to no discernible odour when whole. It is only after you slice into a cucumber, for example, that unsaturated fatty acids in the now damaged cell membranes are exposed to oxygen, triggering enzymatic oxidation and producing the distinctive cucumber-scented aldehydes nonadienal and nonenal.

Heat triggers a series of non-enzymatic reactions during the cooking process to bring out new flavours. Moisture from the ingredient begins to evaporate in the form of steam, kick-starting the oxidation and caramelization processes. At 140ºC (285ºF), the Maillard reaction occurs, leading to the formation of hundreds of new aroma molecules, most notably baked, roasted or fried notes. The amino acids in an ingredient combine with its sugars, resulting in the lovely brown crust that forms over the surface of cooked food. At 160ºC (320ºF), caramelization occurs: the sugars already present in an ingredient turn golden or brown as it develops a more nutty, caramellic flavour.

Fermentation is another non-enzymatic process that occurs when yeast or bacteria cause the sugar molecules in an ingredient to split into alcohols and carbon dioxide. As the bacteria or yeasts feed on available sugars, the rate of fermentation influences the production of certain aroma compounds, as in the case of beer. Wine, fish sauce and kimchi are other examples of fermented products.

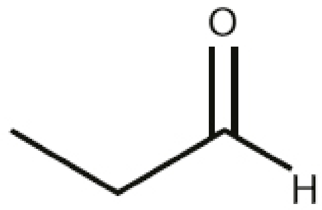
The building blocks of flavour

Aromas are volatile compounds that contain some configuration of the five basic atoms: carbon, hydrogen, oxygen, nitrogen and sulphur. Every aroma compound has a unique atomic structure that tells us about the intensity and lasting power of its scent. Many volatile structures consist of between four and sixteen carbon atoms. Aroma molecules with fewer carbon atoms tend to be more volatile; longer molecular structures have more complex, enduring fragrances. Every additional carbon atom causes a fragrance's lasting power to double. Aroma molecules with structures consisting of eight to ten carbon molecules are usually thought to have the most pleasing scents.

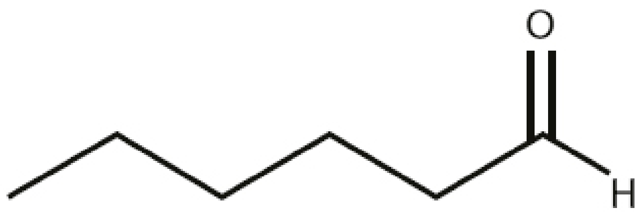
The most important aroma compounds in an ingredient are classified into groupings based on their similar atomic structures. These chemical compounds are further classified into functional groups that determine the characteristics of the aroma molecules.

The aromatic building blocks

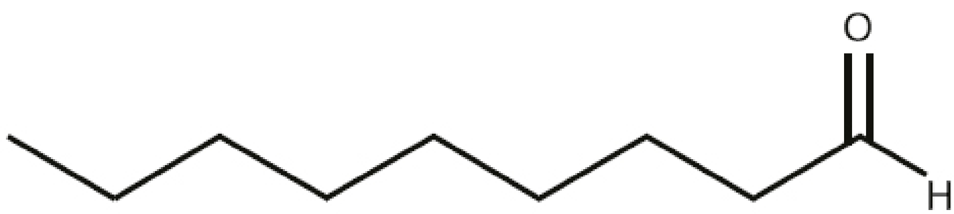
Approximately 10,000 volatile compounds have been identified so far in the foods we eat. The same chemical nomenclature is applied to describe the chemical compounds in food, perfumes and other products. Listed overleaf are the aroma molecules that are most relevant when it comes to our food and drink.



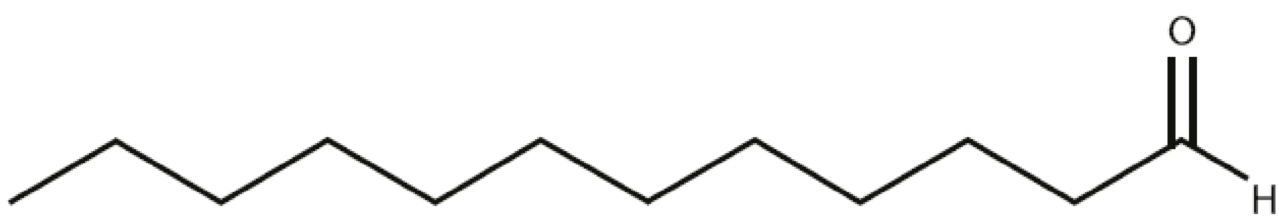
propanal: fruity smell



hexanal: grass-like smell



nonanal: citrus, orange-like smell



dodecanal: soapy smell

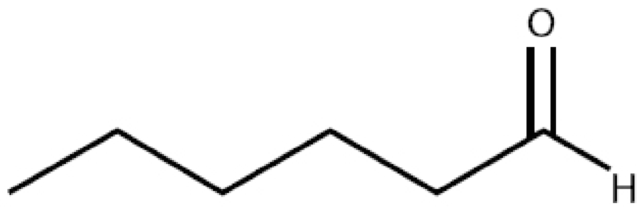
The power of carbon atoms

The more carbon atoms an aroma molecule contains, the greater its staying power – the fruity scent of propanal disappears long before the soapy smell of dodecanal.

1. Aldehydes

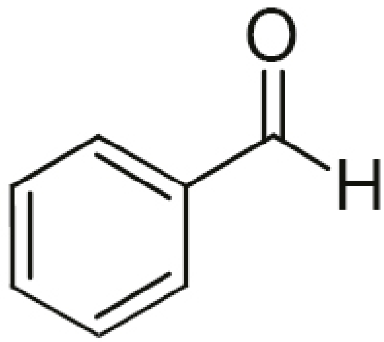
Aldehydes have a low odour detection threshold. Their easily detectable scent changes from green to citrus to fatty as the carbon chain lengthens.

- **Hexanal (C6)** is a six-carbon chain aldehyde that has a fresh, green scent and is present in ingredients like apples, tomatoes and avocados.
- **Nonanal (C9)** smells similar to orange peel.
- **Undecanal (C11)** has the fatty, waxy scent we smell in olive oil and butter.



hexanal

The formation of various **branched aldehydes** is triggered by the conversion of amino acids during cooking or fermentation, producing flavours like the malty notes in chocolate. Other commonly occurring examples of branched aldehydes include **vanillin** (vanilla), **cinnamaldehyde** (cinnamon) and **benzaldehyde** (almonds).

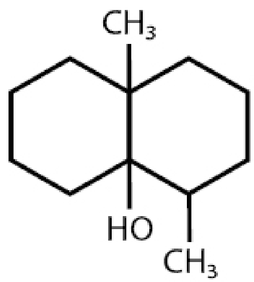


benzaldehyde

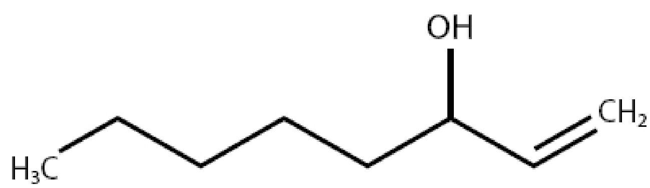
Unsaturated aldehydes give apples, strawberries and tomatoes a fresh, grassy quality. They are also largely responsible for the flavours of fresh coriander and cucumbers. French fries and fried chicken are also full of these waxy, fatty compounds; amino acids (proteins) in the French fries and chicken skin turn into unsaturated aldehydes as they cook in hot beef fat or oil.

2. Alcohols

These organic compounds can smell fruity, waxy and even soapy, depending on the concentration. The fermentation process involved in producing beer, cognac and rum tends to produce fruity notes. Citrus fruits like lemons and oranges also contain alcohol, which is responsible for their waxy fragrance. Earthy **geosmin** and the mushroomscented **1-octen-3-ol** are both naturally occurring.



geosmin

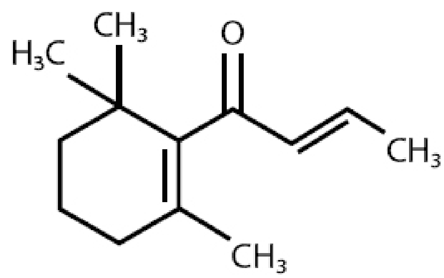


1-octen-3-ol

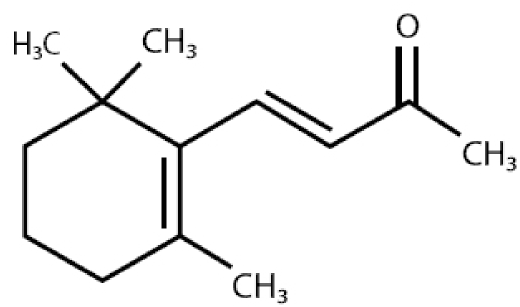
3. Ketones

In terms of fragrance, ketones vary considerably, with aroma descriptors that range from buttery to hazelnut-like (as in **filbertone,** which is typical of hazelnuts) to floral. The two most common floralscented ketones are:

- **Beta-damascenone** , which lends its floral scent to apples and berries, as well as tomatoes and whisky.
- **Beta-ionone,** which is responsible for the violet-like fragrance found in violets and raspberries.



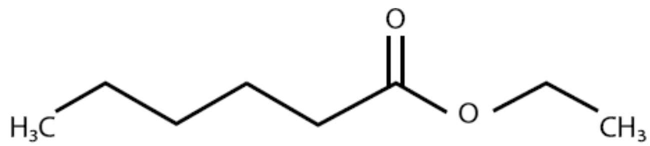
beta-damascenone



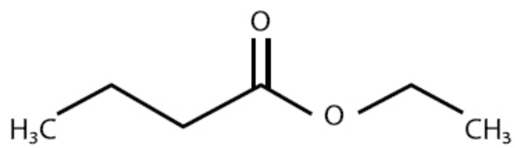
beta-ionone

4. Esters

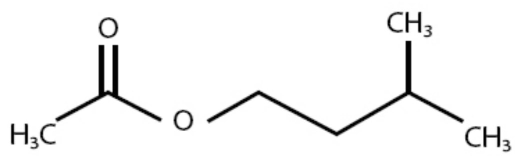
All fruits contain esters. Ethyl esters like **ethyl butanoate** are key contributors to their fruity fragrances. Additional carbons in the molecular chain of ethyl esters transform these scents from fruity or tropical to more pear-, rum-or even soaplike. Esters like ethyl butanoate have a generic fruity scent, while others are more specific, like the banana-scented **isopentyl acetate** or the pineapplescented **ethyl hexanoate** . Fermentation also produces esters like the ones we find in beer, which contains both applescented ethyl esters and acetate esters that have a banana-like quality.



ethyl hexanoate



ethyl butanoate

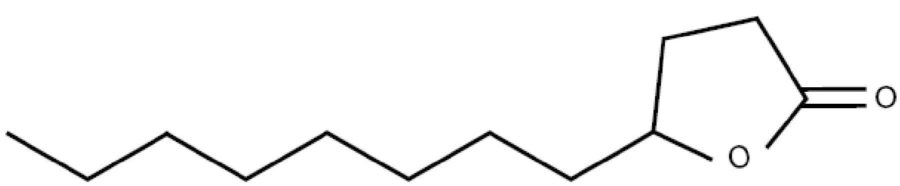


isopentyl acetate

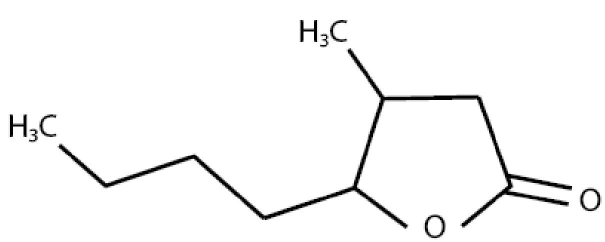
5. Lactones

Lactones are cyclic esters that are made up of a ring-like formation of different atoms. As their name suggests, lactones are common in milk products. **Gamma lactones** smell coconut-or peach-like and can be distinguished by their furan ring. **Delta lactones** have a pyran ringbased structure that gives them either a creamy or coconut-like scent.

- **Whisky lactones** are produced as whisky is aged in oak barrels, imparting a woody or coconut-like smell.
- **Jasmine lactones** have a fruity peach, apricot-like flavour and occur naturally in the essential oils of jasmine and other flowers, stone fruit and ginger.



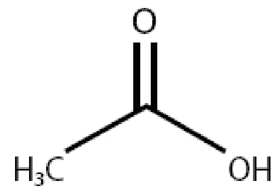
dodecalactone



whisky lactone

6. Acids

Acids are by-products created during fermentation. Shorter acids like **acetic acid** give off a pungent, perspiration-like odour; longer chains are less acrid and take on more of a creamy, cheesy smell.

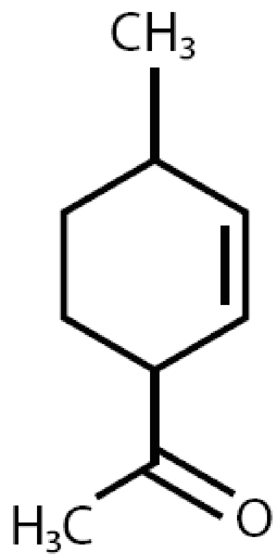


acetic acid

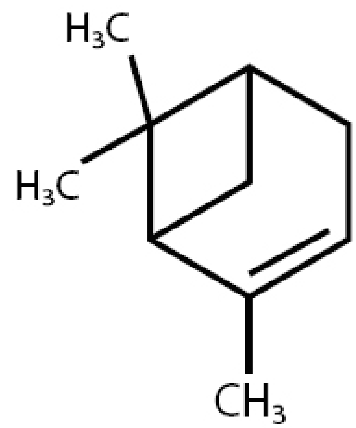
7. Terpenes

Terpenes, terpenoids and sesquiterpenes are responsible for the woody, piney notes in citrus, herbs and spices. These naturally derived compounds are the key aromatic components of essential oils.

- **Limonene** has a sweet orange fragrance
- **Pinene** has a piney fragrance that is typical of juniper berries and gin.



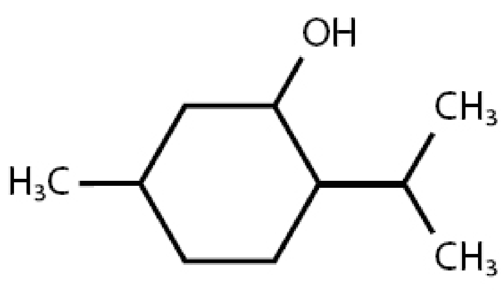
limonene



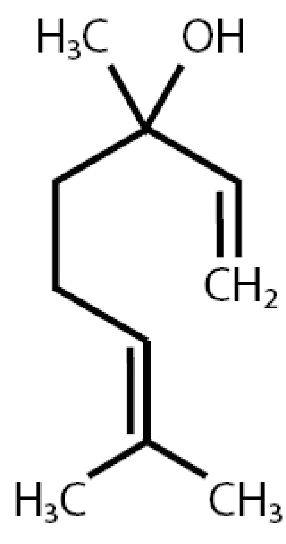
pinene

Terpenes transform into **terpenoids** through oxygenation, as oxygen molecules attach to their structure:

- **Menthol** has a cool, minty fragrance.
- **Linalool** is a major component of fresh coriander that is often described as soapy.



menthol



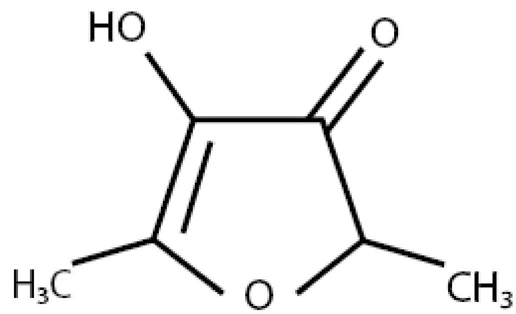
linalool

Sesquiterpenes are **terpenene aldehydes** that are commonly found in citrus fruits, herbs and spices like lemongrass, which contains **geranial** and **neral** . The same sesquiterpenes are also present in Brazilian saúva ants, which have a citrusy lemon flavour.

8. Furans and furanoids

Furans form during the Maillard reaction as an ingredient's lipids start to oxidize as a result of heat and cooking.

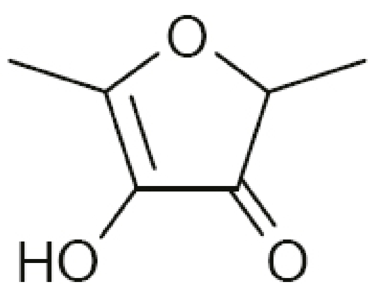
- **Sotolon** has a maple syrup or burnt-sugar scent at low concentrations, but smells like fenugreek or curry at high concentrations.



sotolon

9. Furanones

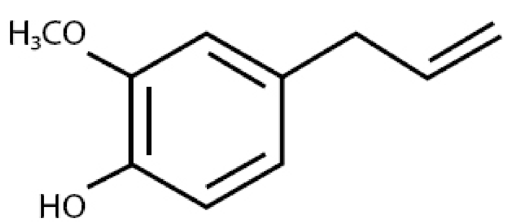
Roasting ingredients like chocolate and coffee turns their furans into **furaneol** molecules as the Maillard reaction occurs, leading to new caramellic notes. Furaneol is also naturally present in fresh ingredients like strawberries and pineapples, which are full of **strawberry furanones** and **pineapple furanones** , respectively.



furaneol

10. Phenols Methyoxyphenols have a spicy fragrance.

- **Eugenol** gives cloves their warm, spicy scent.



eugenol

Building Your Aroma Library

Unlike other forms of sensory input, such as texture or taste, our perception of smell and the way in which our brains interpret aromas is partially determined by our previous experiences. Most of us rarely – if ever – smell individual aroma molecules in isolation. In our everyday lives, we are exposed to a constant barrage of odorants with varying chemical structures and concentrations.

For reasons still not completely understood by science, humans are better at differentiating between complex mixtures of volatile compounds than at identifying individual aroma molecules. Even trained sensory experts have difficulty identifying more than four odorants in mixtures involving eight or more compounds. [8] These complex mixtures are perceived as taking on an entirely new scent and losing their individual characteristics. Push the mixture past eight compounds, and you end up with what is known as 'olfactory white'. Blends of more than 20 different odorants that are basically of equal intensity and evenly span the olfactory space tend to smell similarly generic, even if they do not share any of the same aroma compounds. [9]

To make sense of the daily onslaught of complex odour stimuli, our olfactory systems have evolved to discriminate only what is truly relevant at any given moment. Processing these odorant mixtures means our brains must be able to instantly and simultaneously recognize, code and store the olfactory information it receives into familiar spatial and temporal maps known as 'odour objects' that we can recall as needed.

Expanding your frame of reference

If you have ever read the tasting notes on a bottle of wine but not been able to detect any of the flavours mentioned, you have probably wondered how on earth experts come up with the kaleidoscope of fancy descriptors they use when talking about wines, coffees, cheeses, chocolates and other fine food products. How do they even know what they are smelling?

Sommeliers build their 'aroma libraries' by smelling and tasting wines all the time, which helps them develop plenty of reference points for the colourful range of volatile compounds they encounter. Each of us brings to the table a different frame of reference informed by a lifetime of personal and cultural experiences. The most familiar sights, smells, sounds, flavours and tastes are often the ones that make up our daily habits or dining preferences, while others may be coupled with specific memories or certain emotions that draw from our past.

It will get easier to parse out the subtle aromatic differences in ingredients as your reference collection grows. This becomes especially useful when you are trying to describe processed ingredients like chocolate, which is made up of about 1,500 different odorants, between 50 and 100 of which register above the odour recognition threshold. As there is no such thing as a single chocolate aroma molecule, being able to make out the nuances of an ingredient will help you better appreciate its complexity. The most obvious odour links may be the ones that stand out to us, but the less obvious ones could inspire intriguing new ingredient pairings you otherwise would not have thought of.

Odours account for 80 per cent of the overall flavour experience, yet most people use words like bitter, sweet, sour and salty to describe food or drinks. We notice tastants first because it takes longer for our brains to create new odour associations or retrieve them from our memory bank of existing ones. As you build your aroma library, look past the confines of your kitchen. Sommeliers describing wines in terms of their minerality will refer to freshly mowed grass or breaking waves – there is no limit to the sea of odours around us. We naturally make associations based on objects, events or concepts that are already familiar and end up using descriptors like fruity, floral, citrus, green, mossy, woody, piney, smoky, musky, earthy and so on.

Contrast these descriptors with the trigeminal sensations you experience every time you eat or drink something. Menthol in fresh mint has a slightly cooling effect, while the sanshool molecule in Sichuan peppercorns (see Trigeminal sensations) causes a tingly numbness. The bitter astringency of coffee, tea and red wine tannins can leave your mouth feeling puckered and dry.

An exercise in recognizing aromas

The key to expanding your personal aroma library is to expose yourself to as many different ingredients and products as possible. Smell everything you can as often as you can. Start with the spices in your food cupboard. Without looking, can you smell the difference between cinnamon and cloves? How about cloves and nutmeg? Oregano and marjoram? Turmeric and ground ginger?

Aroma and memory

Have you ever caught a whiff of something that triggered a distant memory you might have otherwise forgotten about? Maybe the warm, toasty scent of freshly baked cookies transported you back to your childhood, or perhaps some passing stranger's perfume or cologne reminded you of a former lover. It is no coincidence that certain smells evoke such intense emotional responses from us. As incoming scents waft up through the nose, the odour information is processed by the olfactory bulb, which has fibres that connect directly to the amygdala and the hippocampus. These two areas of the brain are responsible for emotion and memory. No other sensory stimuli – visual, auditory or tactile – pass through the amygdala and hippocampus, which explains why odours can evoke such strong responses.

Training your senses

Unless we are treating ourselves to something special, many of us take eating and drinking for granted – except for those who happen to be in the business of smelling and/or tasting things for a living. Learning to distinguish between different ingredients and products requires some conscious effort and training, but even just our regular three meals a day provide us with plenty of opportunities to improve our sense of taste and smell.

As you introduce yourself to a wide variety of new products and ingredients, make sure to identify and keep track of each one by name. Coming up with a system of reference for each item will help cement a more lasting impression in your memory.

Allow yourself short breaks in between smelling and tasting sessions to avoid fatiguing your palate and developing a temporary anosmia. You can always give your mouth a break by eating a cracker or drinking a glass of room-temperature water to neutralize the taste. If you find that everything starts to smell the same, take a good whiff of your armpit (seriously!) or the palm of your hand. The smell of our own body odour has a neutralizing effect. Soon you will start to see improvements in your ability to recognize different flavours and scents, so try as many new things as you can.

How Foodpairing Works

At Foodpairing, we have developed a system for classifying scents based on aroma types and their descriptors. With this ‘language of scent’, we can describe and create visualizations for the aroma profiles of all the ingredients and products we encounter.

Aroma molecules, descriptors and types

To visualize the aromatic links between different odorants, we created a virtual threedimensional space to model the connections between all 10,000 aroma molecules in the Foodpairing database. This dense perceptual web reveals striking similarities between certain clusters of molecules, some of which we split into separate groupings, such as green and vegetable. Altogether, we have identified 14 separate categories of aroma types that we use to describe the broad range of scents found in the aroma profiles of different ingredients. These aroma types have been further divided into subcategories of descriptors according to the base scent of each molecule (to view the entire odour network, visit odournetwork.foodpairing.com).

Every aroma molecule has its own distinct base scent. For example, pineapples contain methyl hexanoate, an odorant with a base scent that smells like the fruit. After analysing an ingredient, we look at which volatile compounds register above the odour recognition threshold and then identify the base scents of the various aroma molecules so that we can assign the individual molecules to the appropriate descriptor groups. The descriptor labels tell us about the base scent of an aroma molecule: when we use the label ‘pineapple’ as a descriptor, it means that all the molecules within that descriptor group have a distinct pineapple smell. Altogether we have identified a total of 10,000 aroma molecules that we have classified into 14 different aroma types and 70 descriptors in the Foodpairing database. This classification allows us to make a visualization of the flavour profile of an analysed ingredient, across all product groups.

The Foodpairing methodology

The premise that ingredients that share the same key defining aroma molecules taste good together is the scientific basis of our creative methodology. Any ingredients that share a subset of aroma molecules will have some overlap, and therefore combine well.

The science of Foodpairing begins with an aroma analysis of an ingredient or product. The pairing selections generated from these profiles are based on a selection of key odorants with concentrations high enough so that we can perceive them.

In this book, you will find aroma wheels and pairing grids , which serve as visual references for the key components that characterize an ingredient’s aroma profile.

Aroma Types & Descriptors

Fruity

Esters play a key role in the aroma profiles of many fruits such as strawberries, bananas, pineapples and other tropical fruits. Depending on the concentration, lactones can have a peachy or coconut smell and are found in fruits, milk, cheeses and other dairy products.
• *apple, banana, berry, coconut, fruity, grape, peach, pineapple, tropical*

Citrus

Lemons, limes, grapefruit and gooseberries contain mostly citrusy notes, which are also present in ingredients like coriander seeds, lemongrass and lemon balm.
• *citrus, grapefruit, lemon, orange*

Floral

Beta-damascenone, beta-ionone and (Z)-1,5-octadien-3-one are responsible for the intoxicating fragrances of roses, violets and geraniums, while also lending their floral notes to ingredients like apples, pears, raspberries and sweet potatoes.
• *floral, geranium, honey, rose, violet*

Green

Green smells range from cucumber-ish to fatty (like olive oil), from freshly mowed grass to waxy (like orange peel), depending on the concentration of aldehydes. Milled grains also contain green volatile compounds that smell like oat flakes, while epoxides give seaweed a metallic note.
• *cucumber, fatty, grass, green, oat flakes, waxy*

Herbal

Menthol and thymol give fresh mint and thyme their distinct herbal notes.
• *herbal, mint, thyme*

Vegetable

Pyrazines, 1-octen-3-one and methianol are largely responsible for the vegetal odours of bell peppers, mushrooms and potatoes. Alliums and brassicas contain sulphurous volatile compounds. Cooking creates new sulphurous, potato- and mushroom-scented aroma molecules.
• *bell pepper, cabbage, celery, garlic, mushroom, onion, potato*

Caramel

Compounds like furaneol, maltol and sotolon are characterized by the sweet caramellic smell of caramelized sugar and maple syrup.
• *caramel, maple*

Roasted

The Maillard reaction causes new volatile compounds to form that smell roasted or popcorn-like. Some roasted descriptors smell malty or coffee-like, whereas pyrazines and geosmin have more of an earthy scent.
• *coffee, earthy, fried, malty, popcorn, roasted*

Nutty

Benzaldehyde is the character impact compound in almond extract, while the intoxicatingly sweet hay-like fragrance of tonka beans comes from coumarin. Ketones provide hazelnuts with their distinctive smell.
• *hazelnut, nutty, tonka*

Woody

Some ingredients contain woody-scented terpenes and pinenes (pine). Using wood to grill meat, fish or any other ingredients will impart the same woody, smoky flavours, whereas the process of cold-smoking fish or meats infuses their flesh with phenolic compounds.
• *balsamic, phenolic, pine, smoky, woody*

Spicy

Many of the warm notes in spices come from aroma molecules like cinnamaldehyde, cuminaldehyde, eugenol (cloves) and vanillin. Camphor and estragole (anise) offer more refreshing notes.
• *anise, camphor, cinnamon, clove, cumin, pungent, spicy, vanilla*

Cheesy

Cream, butter and ripe cheeses all contain cheesy notes. Vinegars and fermented dairy products like yogurt, buttermilk and sour cream contain other cheesy and acidic volatile compounds.
• *acidic, buttery, cheesy, creamy*

Animal

Strong animal-like odours are associated with meat-based stocks and ingredients like venison or fish. Liver contains the aroma molecule indole, which can smell faecal, earthy, phenolic, perfumy or even floral. Skatole has a similar animal-like odour, described as smelling faecal or like a civet.
• *animal, fishy, meaty*

Chemical

Burnt, musty, petroleum, soapy and solvent (as in paint or glue) are some of the descriptors used to describe the undesirable off-odours that develop as a result of improper storage or poor packaging.
• *burnt, dusty, petroleum, soapy, solvent*

Foodpairing's aroma types

Each of the ingredients featured in this book is classified and described according to our system of 70 aroma descriptors, which are grouped into 14 key aroma types, ranging from fruity to chemical.

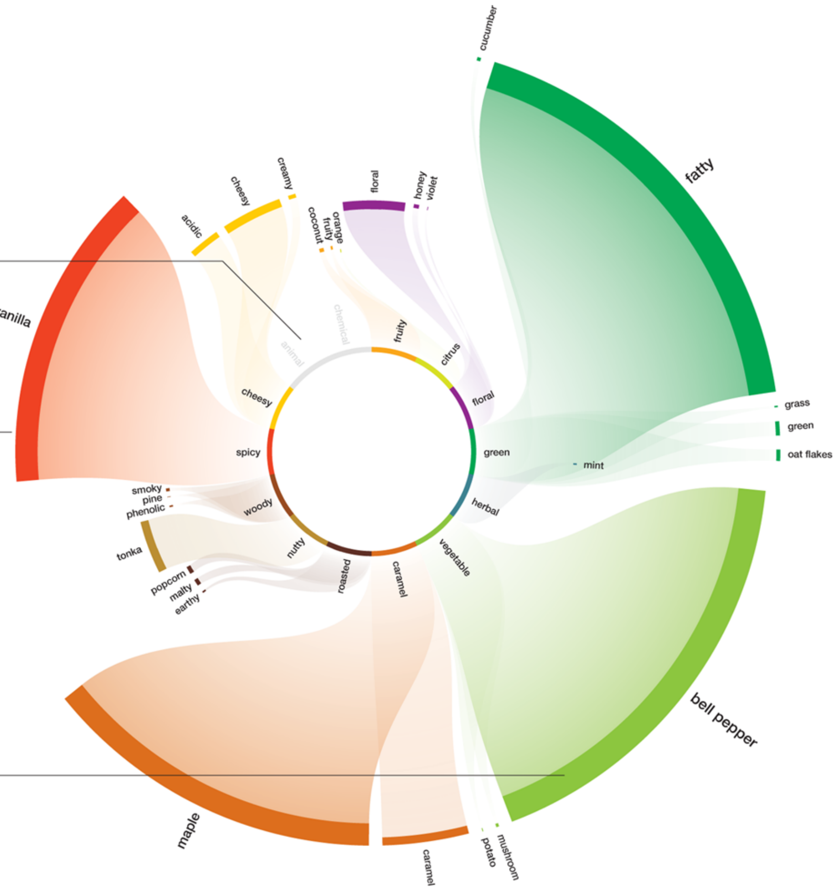
How to read an aroma wheel

An aroma wheel is a visual representation of an ingredient's unique aroma profile. The wheel consists of two separate rings: an inner ring that displays the 14 different aroma types, and a broken outer ring that indicates the concentrations of the available aroma descriptors in that ingredient.

Aroma types that are not present in the aroma profile of a given ingredient are greyed out: in this aroma wheel for quinoa, we see that this grain contains no animal or chemical aromas.

The greater the distance between the inner ring and a band of colour in the outer ring, the higher the concentration of the aroma type that band represents. In this example, the bands for the descriptors of the green aroma type – cucumber, fatty, grass, green and oat flakes – are furthest from the inner ring, followed by those of the vegetable, caramel and spicy aroma types. Mint, a descriptor for the herbal aroma type, is closest to the inner ring and present only in a low concentration.

The thickness and length of the bands in the outer ring indicate the concentration of each aroma descriptor. Within the vegetable aroma type, bell pepper is the most prominent aroma descriptor, followed by mushroom and potato.

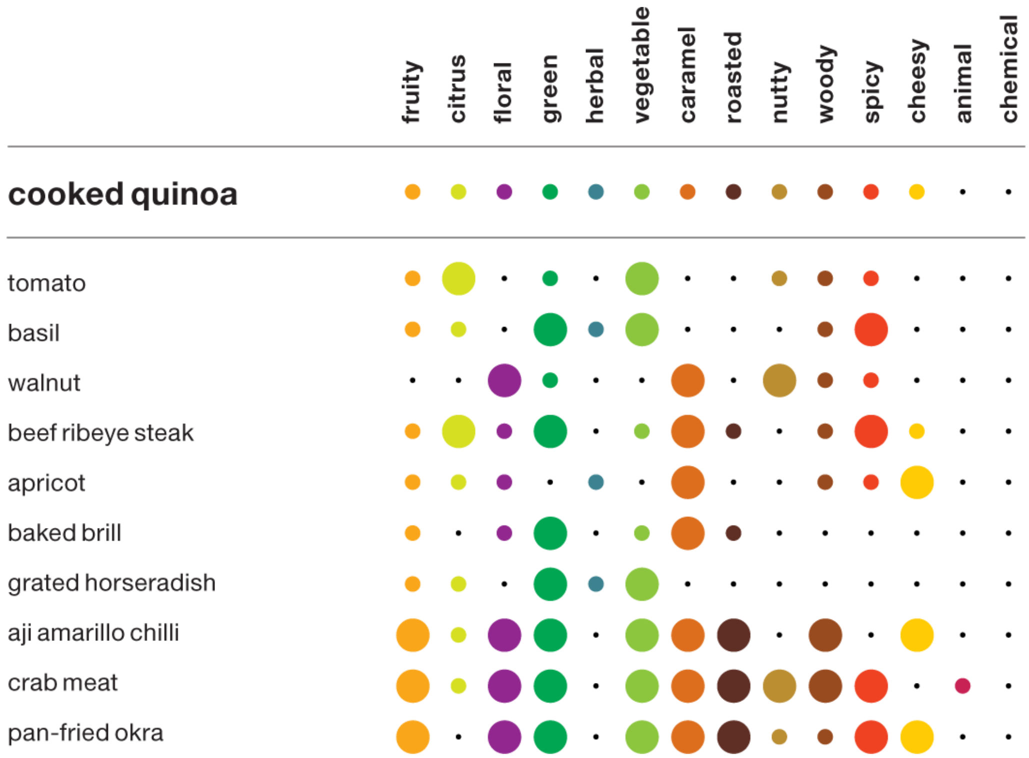


Fingerprint aroma wheels

Some ingredients are represented by small aroma wheels, which convey the key aroma information in a simplified form.

How to read a pairing grid

The main ingredient of the pairing grid, in this case cooked quinoa, is in bold, with ten potential pairing ingredients listed below. The columns of coloured dots correspond to the 14 different aroma types shown in the aroma wheel, from fruity to chemical, so the horizontal rows of dots represent a schematic version of the aroma profiles for the main ingredient and the ten suggested pairings.



A coloured dot indicates the presence of an aroma type within an ingredient, while no coloured dot means the aroma type is not present. Looking at the first row, we see that the aroma profile of quinoa does not feature animal and chemical aroma types. Looking at the first column, we see that every ingredient in this grid contains fruity aromas, except walnut.

A large dot means that the main ingredient and the suggested complementary pairing share a specific aroma molecule for that type. Looking at the second row of dots, we see that tomato shares key citrus and vegetable aroma molecules with quinoa, as well as featuring five other aroma types.

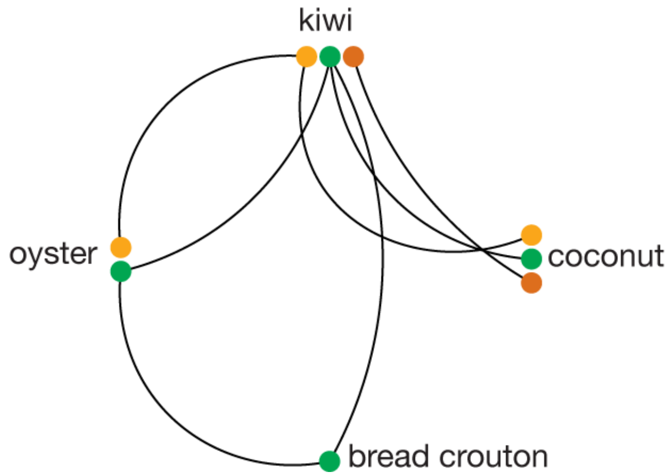
Ready, set, pair!

Each of the aroma wheels in this book is accompanied by a pairing grid, which lists ten potential pairings for the main ingredient. More than 750 further ingredients are represented in the form of a pairing grid only. You can use the pairing grids to help build aromatic bridges between ingredients as you develop new recipes.

To begin pairing, select one or more of the items you see listed beneath the main ingredient. So for quinoa, as seen in the grid above, one option would be to go down the list and combine the cooked grains with fresh tomatoes, basil, crab meat and apricots to create a refreshing summer salad. You can expand your search by looking up the pairing grid for one of the suggested pairings, using the Index of Ingredients . From the grid above, you could begin with cooked quinoa and basil, then refer to the pairing grid for basil and choose one of the ten ingredients suggested there – chorizo, for example. You could then look up the pairing grid for chorizo to make further connections.

Recipe visualizations

The Ingredients & Pairings section of this book, which starts with kiwi and ends with oyster , features a selection of recipes developed by Foodpairing and chefs from around the world – such as Sang-Hoon Degeimbre's *kiwître* , for example. Each of these recipes is accompanied by a graphic that shows a selection of its most important ingredients and visualizes the key aromatic links between them, with coloured dots indicating the different aroma types – as in the example below for the *kiwître* .


kiwi
oyster
coconut
bread crouton

Foodpairing:
The Basics in Brief

Aroma Types & Aroma Descriptors

The ingredients in this book are classified according to our system of 70 aroma descriptors, which are grouped into 14 aroma types.

Fruity	*apple, banana, berry, coconut, fruity, grape, peach, pineapple, tropical*
Citrus	*citrus, grapefruit, lemon, orange*
Floral	*floral, geranium, honey, rose, violet*
Green	*cucumber, fatty, grass, green, oat flakes, waxy*
Herbal	*herbal, mint, thyme*
Vegetable	*bell pepper, cabbage, celery, garlic, mushroom, onion, potato*
Caramel	*caramel, maple*
Roasted	*coffee, earthy, fried, malty, popcorn, roasted*
Nutty	*hazelnut, nutty, tonka*

Woody	*balsamic, phenolic, pine, smoky, woody*
Spicy	*anise, camphor, cinnamon, clove, cumin, pungent, spicy, vanilla*
Cheesy	*acidic, buttery, cheesy, creamy*
Animal	*animal, fishy, meaty*
Chemical	*burnt, dusty, petroleum, soapy, solvent*

How to read an aroma wheel

- The wheel consists of two separate rings: the inner ring displays the fourteen different aroma types, and the broken outer ring indicates the concentrations of available aroma descriptors.
- The length and/or height of each wavy band of colour indicates the concentration of an aroma type present.
- Aroma types that are not present are greyed out.
- Some ingredients are represented by small aroma wheels, which convey the key aroma descriptors in a simplified form.

How to read a pairing grid

- The primary ingredient is in bold, with ten potential pairings listed below.
- The columns of coloured dots correspond to the 14 different aroma types, so the horizontal rows of dots represent the aroma profiles for the main ingredient and the pairings.
- A coloured dot indicates the presence of an aroma type within an ingredient, while no coloured dot means the aroma type is not present.
- A large dot means that the main ingredient and the complementary pairing share a specific aroma molecule for that particular type.

How to begin pairing

- Select one or more of the items you see listed beneath the main ingredient in a pairing grid.
- Expand your search by looking up the grid for one of the suggested pairings, and start building aromatic bridges between different ingredients (see also 'Ready, set, pair!').

How the ingredients are organized in this book

- Each section begins with an aroma wheel for a key ingredient (kiwi, for example) and any related ingredients (kiwi berry, for example), followed by a selection of pairing grids. The key ingredient is usually one of the potential

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