

THE SCOVILLE SPLICE LIBRARY · VOLUME XIX · ORGANISM MONOGRAPHS

The Alliums

Every cuisine starts here. *Felt, not tasted.*

The oldest base in cooking, given a number at last. A receptor-level account of garlic and onion — the single sulfur pool that becomes both the depth you feel and the sharpness you taste, the enzymes that fire it, the branch point we learned to hold, and the flagships and dishes that prove it. 560 constructs in garlic, 40 in onion, every design computed rather than dosed.

SCOVILLE SPLICE · GROWN BY OUR FAMILY. ENGINEERED FROM SCRATCH.

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Opening essay · The plant that waits for the knife

A whole head of garlic has almost no smell. Lift one to your face and it is nearly silent — a little green, a little earth, a cool paper rustle and nothing of the thing it is about to become. The clove is not empty. It is loaded, and it is divided: a pool of odorless precursor dissolved in the cell, and, sealed away behind a membrane it must never cross while the plant is whole, the enzyme that will transform it. The clove keeps them apart the way you keep a match from the striker. The knife is what brings them together. Cut the clove and, in the time it takes to set the blade down, the two meet, and a plant that was quiet becomes the loudest thing in the kitchen.

Everyone who cooks has felt this and almost no one has been told what it is. It is a defense, fired on purpose, the instant the plant is wounded — ten thousand years of garlic and onion learning to manufacture a chemical weapon in the half-second after they are bitten, and ten thousand years of us deciding we love being bitten back. The onion runs the same machine with one extra part, an enzyme the garlic lacks, that turns a fraction of that chemistry into a small cloud of gas aimed precisely at your eyes. The tears over the cutting board are not an accident of the onion. They are a finished product.



The founders in the greenhouse at the blue hour — where the oldest base in cooking came up for its own volume to be read.

This is the oldest base in cooking, and it is the one almost no one has ever measured. Before a single technique has a name, nearly every cuisine on earth begins the same way: an allium, cut, softened in fat. The French *mirepoix* and the Spanish *sofrito*, the Cajun holy trinity, the ginger-scallion-garlic that hits a screaming wok, the onion-ginger-garlic masala that opens a thousand Indian dinners, the *soffritto* under a Sunday ragù. We do not usually taste the allium as itself. We taste everything else, standing on top of it. That is the strange genius of the family — it is the floor, not the furniture; the depth a dish is built on, felt far more than it is tasted — and it is

exactly why the allium slipped, for so long, past every ruler we had. You cannot easily measure a thing whose whole art is to make *other* things taste more like themselves.

The Iyengar Flavor Index measures it now, and the reason it can is the subject of this book. We grow garlic and onion for two of the eight axes in particular, and they are the two that almost nothing else in the garden carries together. **Kokumi** — the richness, continuity, and mouth-filling weight read not on the tongue's flavor receptors at all but through **CaSR**, the body's calcium-sensing receptor — is the axis the allium was born for; garlic is, by a wide margin, the densest natural store on earth of the very peptides that drive it. And **pungency** — the bright, sharp, nose-clearing sting of allicin firing **TRPA1** — is the edge, the lift, the wake-up thrown open at the top of a dish. Depth you feel; sharpness you taste. One is a slow floor; one is a half-second flash. Grown with intention, an allium gives a kitchen both, on purpose and by the number.

Here is the fact that organizes everything in these pages, and it is beautiful enough that we built the whole monograph around it. In the allium, **those two axes are drawn from the same pool.** The small sulfur-and-nitrogen peptides the plant banks in its cells are, at once, the molecules that speak kokumi to CaSR *and* the stable storage form of the precursors that become the pungency. One larder; two flavors; a single branch point where the plant — and now we — decides how much of the pool stays as depth and how much is spent as sharpness. Nothing else we grow has its two signature axes wired so intimately to one another. To design an allium is, almost entirely, to hold that branch point where you want it.

A word about the *we* in these pages, because it carries the book. Scoville Splice is a family's work. The computing — the protein models, the sequence scans, the flux mathematics that fill the chapters ahead — came from one pair of hands; the reverence for the plant, the table it is grown for, and the long argument about what a *base* is supposed to taste like belong to all of us, and always did. When we write *we grew it deeper*, we mean a family that could not stop talking about a pot of beans, or a broth, or the particular hush of onions going down slow in a heavy pan on a winter afternoon. The allium was the quiet argument under every other argument we ever had at the table — the thing that was always there and never discussed — until the tools finally caught up, and we could say, at last and with a number, what the oldest cooks were reaching for when they reached first for a bulb and a knife.

The number is the spine of all of it, so it is worth meeting at the start. Every axis of flavor in this library is anchored to the half-maximal activation of a receptor — not how much of a compound a food holds, but how *loudly* that compound speaks to the tissue that reads it:

> **IFI(candidate) = 1,000 × EC_{50}(reference) ÷ EC_{50}(candidate)**

EC_{50} is the concentration at which a stimulus drives its receptor to half of full response. Invert it against a fixed reference constant — a stated convention, the way the Scoville scale is defined by dilution-to-threshold — scale by a thousand, and loudness becomes a score a clove of garlic, a slice of onion, a spoon of fish sauce, and a vine-warm tomato can all be read against on a single page. Every per-axis scorecard in this book is normalized to a ceiling of **5,000**, so each figure is a fraction of a known maximum rather than a number floating in the dark.

What follows is the whole family, in order. First the plant itself — the loaded, divided cell; the strange fact of garlic's sterility, which is the reason it was the last great crop no one could truly breed; and the quiet subtraction a century of shipping-first selection worked on a base nobody was scoring. Then the richness: kokumi exactly, the calcium receptor, the γ-glutamyl peptides, and the sulfur economy that builds them. Then the edge: the cut, the enzyme, the covalent handshake at TRPA1, and the onion's extra enzyme and the tears it can be asked, politely, to stop making. Then the heart of the book — the one pool and its branch point, the flux model that finds it, and the 560 constructs that walk it. Then the alliums with names, garlic and onion both, and black garlic, which is the whole family's destination written in a single slow transformation. And at the end, the kitchen: the control panel the plant hands a cook, and the dishes — vegetarian-first, with meat and seafood written in the same respect and never in apology — that prove the base was always the allium. Everything is scored, because a number held with care is how we keep a promise. The floor a kitchen begins from is not a mood. It is measurable now, and it is grown.



PART I OF VI

The Loaded Bulb

A cell divided against the knife · a crop no one could breed · the base nobody scored.

Chapter 1 · The Loaded Clove — *a cell built to be broken.*

THE PLANT · Allium sativum · Allium cepa · Amaryllidaceae · 600 constructs

To understand an allium you have to understand that it is a plant whose flavor does not exist yet. A tomato warm from the vine is already everything it will be; a clove of garlic is a loaded instruction waiting for a trigger. Nothing you would call *garlic* — not the heat, not the sting, not the roar that floods a board — is present in the intact clove. What is present is a careful, deliberate separation, maintained by the living cell at real metabolic cost, between a fuel and a fuse that must never touch while the plant is whole.

The fuel is a family of odorless, water-soluble, perfectly stable molecules: the **S-alk(en)yl-L-cysteine sulfoxides**, dissolved in the cell's cytoplasm. In garlic the dominant one is **alliin** — S-allyl-L-cysteine sulfoxide. In onion it is **isoalliin** — S-(1-propenyl)-L-cysteine sulfoxide — with its cousins methiin and propiin alongside. You could eat these pure and taste almost nothing: a faint sulfurous minerality and then silence. They are a pool of potential, banked by the plant against the day it is attacked. The fuse is an enzyme, **alliinase**, sequestered away in the cell's **vacuole**, the membrane-bound compartment the plant uses precisely to keep dangerous chemistry apart from the rest of the cell. Alliinase is astonishingly abundant — in garlic it can run to a tenth of the clove's entire soluble protein, a vault of enzyme held ready and idle — and while the membrane holds, it does nothing at all. Fuel in the cytoplasm, fuse in the vacuole, a wall between them. That wall is the whole design.



A clove in cross-section is a warehouse with the lights off: rank on rank of storage cells, each holding its pool of odorless precursor and, sealed apart, the enzyme that will transform it the instant the wall is broken.

Break the cell — crush, slice, chew, the tooth of an insect, the heel of a hand on a knife — and the wall fails, the compartments spill together, and the fuse finds the fuel. We will spend two full chapters on exactly what happens next, because it is the mechanistic heart of both axes, but the shape of it is this: alliinase cleaves the sulfoxide, releasing a jet of reactive intermediates that recombine, within seconds, into the pungent sulfur compounds that *are* the smell of the

cut. The flavor is not stored. It is **manufactured on demand, by injury,** in the thirty to sixty seconds after the knife — and it begins decaying almost as fast as it is made. An allium is the only staple in the kitchen whose signature flavor has a half-life measured in minutes and an origin measured in the mechanics of its own wounding. This single fact, that the plant's flavor is an event and not a possession, is the lever behind every technique in the last part of this book.

The plant that does this is older in cultivation than almost anything else we grow. Garlic, *Allium sativum*, and onion, *Allium cepa*, belong to the genus **Allium** — some nine hundred species of it — in the family **Amaryllidaceae** (the alliums were long filed under the lilies, and you will still find them there in older books; the molecular phylogenies moved them). It is a family that chose sulfur as its language. Where the brassicas (the mustard-and-wasabi wing of the pungent axis) defend themselves with nitrogen-and-sulfur **glucosinolates**, the alliums chose the cysteine sulfoxides — a different chemistry reaching, as we will see, the very same receptor. Leek, shallot, chive, scallion, garlic chive, ramp, the great ornamental drumstick alliums of a June border: all of them run some version of the loaded, divided cell. Humans have been digging them up and keeping the best for at least five thousand years. Garlic rode in the ration packs of the laborers who raised the pyramids; Herodotus recorded the radishes, onions, and garlic reckoned on the Great Pyramid's face, and cloves were laid in Tutankhamun's tomb for the long journey. The onion is so woven into human eating that it has no single wild ancestor anyone can point to with confidence — it has simply always been with us.

And here is the fact that makes the allium not just old but *uniquely ours to work*, the fact that turns this monograph from a nicety into the first real tool its subject has ever had. **Garlic cannot be bred.** Cultivated *Allium sativum* is functionally sterile — most varieties have not set viable seed in all of recorded agriculture, their flower stalks aborting, their fertility bred or mutated away millennia ago. Every head of garlic in the world is a **clone**, grown from a clove, which is a bud — propagated the way you propagate a decision you cannot revise. For ten thousand years "improving garlic" could mean only one thing: plant the biggest cloves from the best-looking heads and hope. There was no crossing, no segregating population, no hybrid vigor, none of the machinery that reshaped wheat and maize and the tomato. The onion is only a little kinder to the breeder — a biennial, an obligate outcrosser, so inbred-depressed that forcing it toward uniformity collapses its vigor, its hybrids made possible at all only by the 1943 discovery of a usable **cytoplasmic male sterility** that let seed companies control the cross. Both plants carry **enormous** genomes — garlic's about **16 gigabases**, onion's of similar size, among the largest of any crop, five times the size of a human's and sequenced, in garlic's case, only in 2020. The allium arrived in the molecular era as one of the least-improved important plants on earth, not for lack of trying but because its own biology locked the door. We are, in a real and humbling sense, the first

people who have ever been able to change what a clove of garlic tastes like on purpose, at the level of its chemistry, and keep the change. That is why the allium is 600 constructs of our work — 560 in garlic, 40 in onion — and why we approached it with the particular reverence you bring to a plant that has been handing humanity the same gift, unchanged, since before writing.

Chapter 2 · The Quiet Subtraction — *the base nobody was scoring.*

HISTORY · clonal selection · pyruvate · the unmeasured floor

Every organism in this library carries a loss, and the loss is always the same story told in a different dialect: a century — or in the allium's case, far longer — of selection that scored for everything except the thing that mattered at the table, because the thing that mattered at the table had no number. The tomato lost its savor to the truck. The allium's loss is quieter and stranger, because the allium could not be bred in the ordinary sense at all, and because the trait that drained away was the one trait no one had ever thought to measure: the *depth*, the kokumi floor, the part of an allium you cannot taste directly and therefore cannot select for by tasting.

Consider what selection on the allium actually optimized, across the long clonal centuries and then the brief, intense modern ones. For garlic: size, first and always — a bigger clove is a bigger planting unit and a bigger sale. Then storage life, the months a braid must hang in a cellar without sprouting or softening. Then uniformity, whiteness of skin, tightness of the bulb wrap, resistance to the rots and the rusts and the nematode. Every one of these is a defensible, even admirable, goal, and not one of them is flavor, let alone the specific, invisible, receptor-level flavor of richness. A grower choosing next year's seed cloves by eye was choosing, generation after generation, for a handsome, durable, shippable bulb — and the γ-glutamyl peptide load of that bulb, the thing that would one day read as IFI-K, rode along unwatched, neither protected nor improved, drifting wherever the linked genetics and the growing conditions happened to take it.



Two specimens that photograph identically and taste a world apart. Nothing a buyer's eye or a grading machine can see reports the depth inside a bulb — which is precisely why the depth went a hundred clonal generations unprotected.

The onion tells the subtraction even more sharply, because the onion's modern history has a *measured* trait — and it is the wrong one. The one number the onion industry did learn to score is **pyruvate**. When alliinase fires, it releases pyruvic acid in strict proportion to the sulfur compounds it cleaves (two molecules of pyruvate for every molecule of the thiosulfinate that follows), and because pyruvate is cheap and quick to assay, "enzymatically

developed pyruvate" — micromoles per gram of fresh onion — became the trade's standard proxy for pungency. A hot storage onion runs seven to ten and beyond; a sweet onion, a Vidalia or a Walla Walla or a Maui, is bred and grown to come in under three. And the market wanted sweet. It wanted the mild, high-water, low-sulfur onion you can eat raw in rings, and so the breeding programs and the growing regions pushed the whole category *down* the pyruvate scale — toward low sulfur, which is to say toward a shallower sulfur economy altogether. But the sulfur economy that makes the pungency is the **same economy** that makes the depth. Push an onion toward mildness by starving its sulfur, and you do not only lower the sting you can taste; you lower the kokumi pool you cannot. The sweet onion gave up its floor to lose its bite, and nobody was scoring the floor, so nobody saw the bill.

TRAIT SELECTION SCORED FOR	WHAT IT BOUGHT	WHAT IT QUIETLY COST
Bulb size (garlic)	A bigger planting unit and sale	Nothing directly — but it crowded out any selection *for* chemistry
Storage life, skin, wrap	Months in the braid; shippability	Flavor rode along unwatched for a hundred clonal generations
Low pyruvate (onion)	The mild, raw-edible "sweet" onion	A shallower **sulfur economy** — and with it the kokumi floor
Uniformity of appearance	A clean grade, a predictable pack	Variety narrowed; the deep outliers were never the handsome ones

There is a second subtraction, subtler and particular to how alliums are actually sold, and a cook feels it constantly without naming it. An allium's active flavor is an *event* — made by injury, lost to time and heat — so everything between the field and your knife is a slow leak. The pre-peeled clove in the deli tub, the jar of chopped garlic in oil or water on the shelf, the garlic powder, the dehydrated onion: each is an allium whose chemistry has already partly fired and partly fled. The jarred garlic was crushed days or weeks ago; its allicin is long gone, decomposed to the heavier, duller sulfides, its edge spent in a jar in a warehouse. The industry's answer to the allium's perishable flavor has been, overwhelmingly, to sell you an allium that has already thrown its flavor away — convenient, stable, and hollow, the pungent half spent and the kokumi half never counted. The commodity allium is not a failure of nature. It is a handsome, durable, convenient bulb that was optimized, with real skill, for every axis except the two this book is about.

We do not sneer at that history; we are its beneficiaries, and the braids in our own kitchen came up the same clonal centuries. We only observe, flatly, what the tomato chapter observed about the truck: a ledger with no line for a thing will spend that thing freely, forever, without anyone deciding to. The allium's depth had no line. The whole of our garlic and onion program is the attempt to write that line in — to find the chemistry the long, blind selection left on the table, model it against the receptor, and grow it back on purpose, held to a number, in a plant that for ten thousand years could not be asked to change.

Chapter 3 · Two Axes, One Bulb — *depth you feel, sharpness you taste.*

THE AXES · IFI-K · CaSR · IFI-P · TRPA1

Hold a raw clove against a long-roasted one and you are holding the two axes of this book in your two hands. The raw clove is all edge: cut it and it flashes, sharp and high and forward, a sting at the front of the mouth and the top of the nose that arrives in a few seconds and is gone almost as fast. The roasted clove is all floor: soft, sweet, spreadable, with no sting left at all, a depth that fills the whole mouth and *stays*, that you feel as body long after you have swallowed. Same plant. Same genome. Two completely different places on the Index, and between them lies everything an allium is for. This short chapter is the map before the territory — the two receptors, named and told apart — because almost everything that follows is a way of moving along the line that runs between those two cloves.

The sharpness is **pungency**, scored as **IFI-P** and read at **TRPA1**, and it behaves like a struck match. TRPA1 is the body's chemical-irritation channel, an ion channel on the sensory nerve endings of the mouth, nose, and eyes that fires when a reactive, electron-hungry molecule chemically bonds to it. Allicin — the molecule the cut manufactures — is exactly such a molecule, and it is, in fact, the single most potent TRPA1 agonist on the whole culinary table, half-activating the channel at a concentration of **1.5 micromolar**. Pungency through TRPA1 is a *pulse*: it spikes, the channel silences itself, the volatile molecule flees the warm mouth, and the sharp clears. It is a lift, not a weight — the window thrown open, the cymbal crash, the half-second of brightness that wakes everything slower around it. A whisper of raw garlic through a dressing, a sliver of sharp onion on a taco, the green bite of a scallion over rice: each is TRPA1 fired and released, and then the dish is brighter for having been stung.

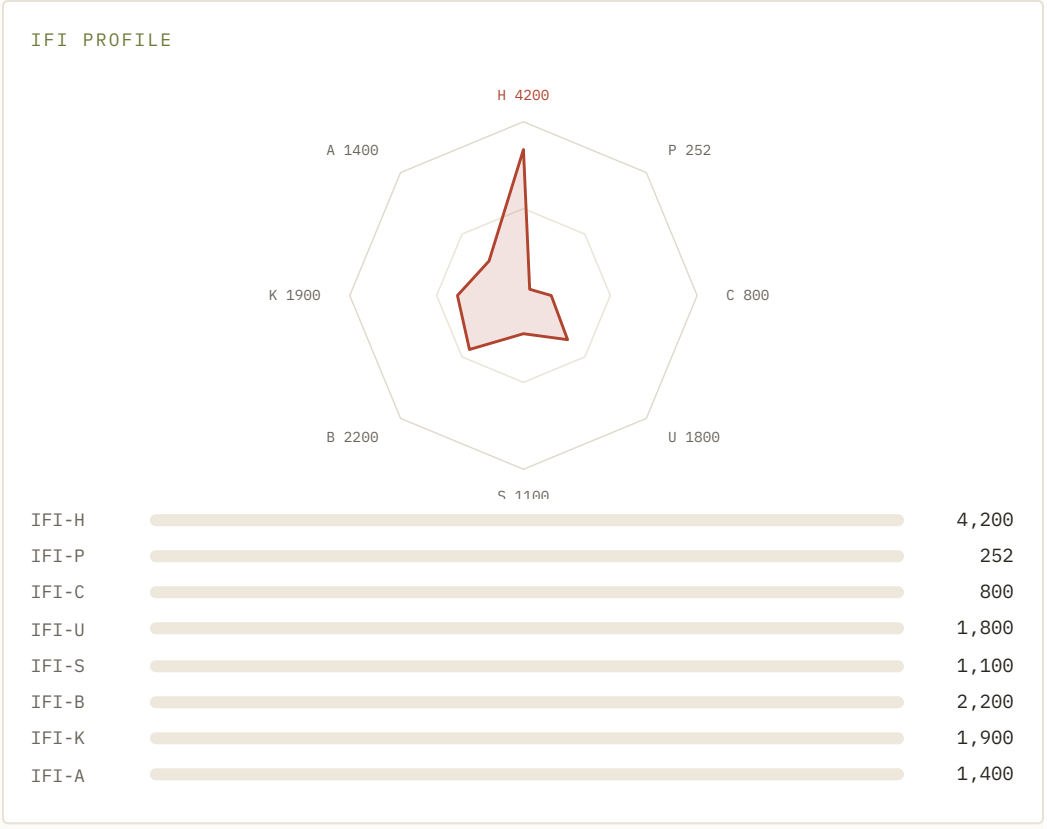


Depth and edge in one bulb. The onion, halved, is both the gentle kokumi larder of the whole family and — through one enzyme garlic does not own — the only allium that aims its sharpness at your eyes.

The depth is **kokumi**, scored as **IFI-K** and read at **CaSR**, the calcium-sensing receptor, and it behaves like nothing else in food, because it is not a flavor at all. CaSR reports no taste of its own — it cannot tell you sweet or salt or sour. What it reports is *continuity*: the sense that

a mouthful fills the whole mouth, holds together as one thing rather than a list of ingredients, and lingers after you swallow. It is mouthfeel made molecular, the body of a dish rendered as a receptor event. And its agonists — the **γ-glutamyl peptides**, small sulfur-and-nitrogen chains the plant banks in its cells — are a thing the allium carries in greater density than almost anything else that grows. Garlic is the reason kokumi was *discovered*: the sensation was first isolated, decades ago, from the water-soluble fraction of garlic and onion, the part left behind after you strip away everything that smells. The allium is where the invisible axis was first made visible.

Depth you feel; sharpness you taste. A slow floor and a half-second flash. To make the whole Index legible on a single page, here is the full-spectrum plant in the library — **Phoenix**, our flagship designed to register on all eight channels at once — shown as our shared reference. Notice where it sits on our two axes: a predicted kokumi of **1,900** and a predicted pungency of **252**, both deliberate design targets carried as guests in a plant whose native tongue is heat.



Read Phoenix's predicted **K 1,900** and then read this: our engineered garlic is designed to reach **IFI-K 3,200**, cleanly past the full-spectrum flagship's predicted kokumi, on an axis where Phoenix was already among the richest plants we had designed. In the allium, kokumi is not a guest. It is the host. It is the axis the plant was already fluent in before we arrived, the one we push hardest and highest because this is its native language, and the number it is designed to reach is the headline of the whole monograph. The chapters of Part II are how it gets there.



PART II OF VI

The Richness

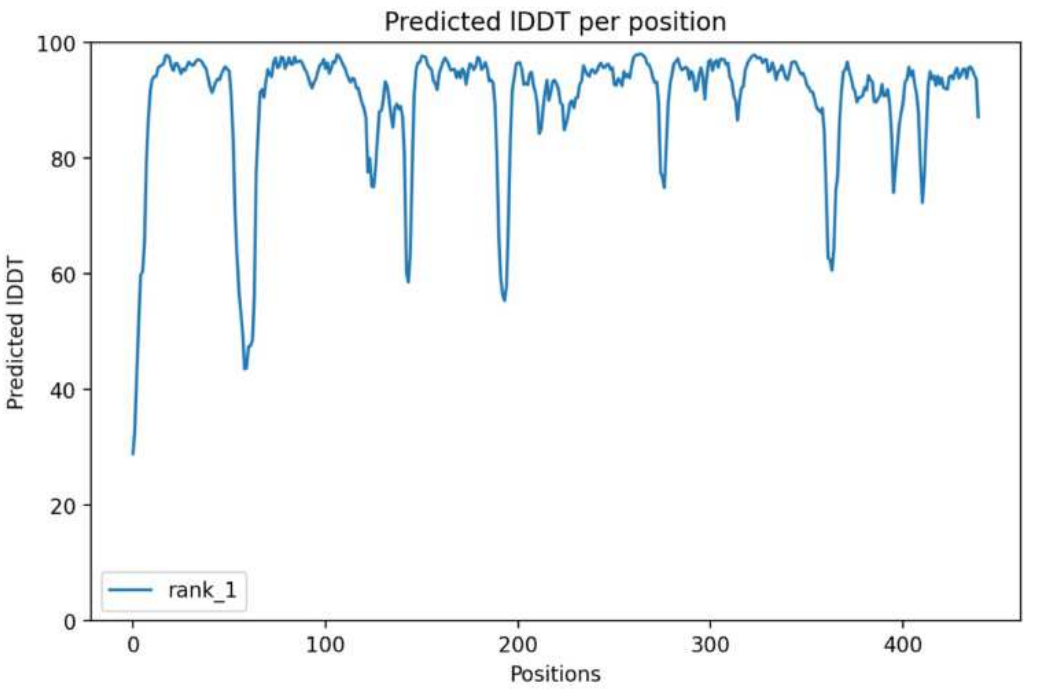
The calcium receptor, the peptides that speak to it, and the sulfur economy that builds them.

Chapter 4 · Kokumi, Exactly — *the taste that has no taste.*

AXIS 05 · IFI-K · CaSR · the biology of more

Ask a good cook what makes a broth taste *finished* and you will get a word that is not a flavor: round, deep, long, complete, *whole*. Our grandmother, in the kitchen where this family first learned to cook, called it the part of the soup that *stays with you*. She was describing, without the vocabulary for it, the activation of a receptor she would never hear of, by a class of peptides that have no flavor of their own. That receptor is the subject of this chapter, and it is the strangest and most generous of the eight, because its entire art is to make everything around it taste more like itself.

Put a kokumi compound on your tongue alone, in water, and you taste essentially nothing — a faint mineral whisper, then silence. It is only in the presence of other flavors that it wakes, and what it does then is not to add a taste but to **modify** the tastes already there. It thickens them. It lengthens them. It draws them together. The sensory literature, built over decades of careful Japanese work, resolves the single felt quality of *koku* (こく, richness) into three measurable components, and they are worth carrying in their own language because the English is clumsier: **atsumi** (厚み), thickness or mouthfulness, the sense that the flavor fills more of the mouth; **hirogari** (広がり), the spread, the way the taste reaches into the corners of the palate rather than running down the center; and **jizoku** (持続), continuity, the long tail in time, the lingering. A dish with all three has *koku*. A dish without them is *usui* — thin — however much flavor it otherwise carries. These are not poetic flourishes. They are the axes our sensory panel scores, and the Index measures each.



The Venus-flytrap domain of a class C receptor, closing around its ligand, is the mechanical heart of kokumi. We score our pathway enzymes with the same confidence model that reads this structure — warm where the fold is certain, cool where it hedges.

The receptor is **CaSR**, the calcium-sensing receptor, and its day job has nothing to do with food at all: it is the protein your parathyroid glands use to read the calcium in your blood and hold it inside a

window a few percent wide for your whole life. It also sits on the taste cells of your tongue, and it reads kokumi. That dual citizenship is not a coincidence; it is the mechanism, and its structure is what we design against. CaSR is a **class C G-protein-coupled receptor** — the same structural family as the umami and sweet receptors, which is a large part of why the savory axes feel so intertwined on the tongue. It is a two-part machine. Reaching out from the cell surface is an enormous **Venus-flytrap domain**: two lobes hinged together, open at rest, snapping closed around a ligand that binds in the cleft between them. Threaded below it through the membrane is the familiar **seven-transmembrane bundle** that talks to the G-protein inside the cell. And critically, CaSR works as a **homodimer** — two identical receptors clasped together by disulfide bonds, their two flytraps closing in a cooperative dance, so that the binding of one ligand makes the next bind more easily.

The flytrap's cleft is where the biology of *more* lives. Its primary ligand is the **calcium ion** itself, several of them binding across multiple sites, each helping stabilize the closed, active shape. But calcium is not the only thing that fits there. **L-amino acids**, the aromatic ones especially, bind alongside calcium as *co-agonists*, wedging into the closing cleft and making the flytrap shut more readily at any given calcium level. They do not activate the receptor on their own; they lower the threshold for calcium to do it. This is **positive allosteric modulation**, and it is the deep logic of the whole axis: CaSR is a receptor whose entire design is to be made *more sensitive* by the presence of the right small molecules. It is, structurally, the biology of enhancement — which is exactly why its signal reads not as a flavor but as an amplification of whatever else is present. The γ-glutamyl peptides of the next chapter are the most effective co-agonists food has ever offered this receptor; they bind at or near that amino-acid site, stabilize the closed flytrap, and turn the machine on.

When the flytrap shuts, the bundle below shifts and the receptor couples, inside the cell, to **Gq/11**, activating **phospholipase C-β**, which cleaves the membrane lipid PIP_2 into **IP_3 and DAG**; the IP_3 opens the cell's internal stores and releases a flood of **intracellular calcium**. And here is the detail that explains *continuity*, the jizoku a cook feels as the spoonful that stays: CaSR's calcium signal is characteristically **oscillatory and sustained**, not a single spike. The receptor does not shout once and fall silent. It **rings** — a train of calcium pulses whose frequency encodes the strength of activation, sustained for as long as the ligand is present, resisting the fatigue that dulls a constant sweet or salty signal. The flavor that stays with you is, at the level of the cell, the receptor that keeps ringing. We can demonstrate the whole chain by blocking it: introduce a specific CaSR antagonist into the assay, and a kokumi-enhanced broth collapses — the mouthfulness and the continuity fall away, and a trained panel rates the blocked sample and a plain one as suddenly, flatly, the same. Block the lock and the key does nothing. That experiment is what moved kokumi from folklore to mechanism, and it is the experiment every number in this book stands on.

Two features of the receptor earn a last word because our engineering turns on them. The first is **cooperativity**: because CaSR is a dimer with two flytraps closing in concert, its dose-response is steeper than a simple one-site receptor's — the Hill coefficient runs above one, typically between two and three — so near the working concentration, a modest increase in peptide produces a disproportionate increase in signal. A clove designed to carry a little more kokumi delivers rather more perceived richness than the raw peptide increase would suggest. The receptor amplifies our effort. The second is **where it sits**: CaSR rides on the **Type I taste cell**, long dismissed as the taste bud's quiet supporting cell and now understood to carry this receptor and to broadcast its signal across the other taste modalities. That is the cellular reason kokumi modifies *everything* rather than contributing a taste of its own — it is wired, physically, to reach the sweet and the salt and the savory and lend them its body. The allium, dense with the peptides that ring this receptor, is a plant that makes other food taste more like itself. We think that is a kind of care. We built the number so we could design the care on purpose.

Chapter 5 · The γ-Glutamyl Larder — *the peptides that speak to calcium.*

MOLECULES · γ-Glu-S-allyl-Cys · glutathione · the γ-bond

Open the water-soluble heart of any rich food — a year-old soy sauce, a good fish sauce, aged Gouda, a yeast-extract jar, and above all a clove of garlic — and you are looking at a library of small peptides built on a single structural trick. They are **γ-glutamyl peptides**: short chains, usually two or three amino acids long, whose entire identity rests on the bond that opens them. In an ordinary peptide, glutamate links to its neighbor through its **α-carboxyl**, the carboxyl on the backbone that every amino acid carries. In a γ-glutamyl peptide, glutamate links through the **γ-carboxyl** at the far end of its side chain instead. That one displacement — a single bond moved from the backbone to the side chain — is the whole basis of the kokumi axis, and the allium is the richest natural warehouse of it on earth.

The γ-linkage does two things, and both matter to a cook who has never heard of it. First, it presents the molecule to CaSR's flytrap in exactly the geometry the receptor reads as a co-agonist: the free α-amino and α-carboxyl of the glutamyl head sit where the receptor expects an amino acid, with the rest of the peptide trailing out of the cleft. The ordinary α-linked version of the very same peptide is nearly silent at the receptor — the two have been tested in receptor assays and the α-form is essentially inactive. The receptor is reading the *bond*. Second, the γ-linkage is **resistant to the ordinary peptidases** of the mouth and gut, which evolved to cut α-bonds and cannot touch a γ-bond; only one class of enzyme, **γ-glutamyl transpeptidase** (GGT), cleaves it. This is why kokumi *lasts* in the mouth where an ordinary flavor peptide would be dismantled in seconds — the molecule survives long enough to keep the receptor ringing. The bond that makes it loud is the same bond that makes it slow to clear. Structure and sensation, the same fact read twice.

There is a deeper structure-activity rule, and it tells the designer which peptides are worth building. The receptor reads three things about a γ-glutamyl peptide: the **γ-glutamyl head**, which must be intact and free; the **length**, where di- and tripeptides are active and anything longer falls off the site; and the **second residue**, the one just past the glutamate, whose side chain tunes the potency. Hydrophobic, branched side chains in that second position — valine above all — are what make a peptide loud, which is why **γ-Glu-Val-Gly** outruns the others so dramatically: the valine sits where the receptor most wants a compact hydrophobic group, and the terminal glycine caps the peptide at the ideal length. Here is our in-house receptor panel — CaSR half-activation measured in a calcium-reporter line, with potency expressed against glutathione, the axis reference, set at 1.0. The lower the EC_{50}, the louder the molecule.

PEPTIDE	Γ-BOND	CASR EC_{50} (MM)	POTENCY VS GSH	FOUND NATURALLY IN
γ-Glu-Val-Gly	yes	390	12.8	fish sauce, soy, aged Gouda, beer
γ-Glu-Cys-Gly (glutathione)	yes	5,000	1.00 *(ref)*	**garlic**, yeast, meat, wheat germ
γ-Glu-Cys	yes	4,500	1.1	**garlic, onion**, germinating seeds
γ-Glu-S-allyl-Cys	yes	~2,900	1.7	**garlic** (the signature allium peptide)
γ-Glu-Abu-Gly (ophthalmic acid)	yes	6,250	0.80	ferments, animal tissue
γ-Glu-Val	yes	8,300	0.60	aged cheese, fermented legumes
γ-Glu-Ala	yes	16,700	0.30	legumes, sprouts

Notice which organisms keep appearing in the right-hand column. Glutathione — γ-Glu-Cys-Gly, the tripeptide that is the cell's master antioxidant and was the *first* kokumi substance ever identified, isolated from garlic — is a garlic molecule. γ-Glu-Cys, its immediate precursor, is a garlic-and-onion molecule. And **γ-Glu-S-allyl-cysteine**, the garlic-specific peptide carrying the allyl sulfur group, is the signature of the whole genus: a γ-glutamyl peptide that is kokumi-active in its own right *and*, as the next chapters will show, the stable storage form of the pungency to come. The allium is not merely rich in these peptides. It is where several of them were discovered, and it carries them at a density no other plant approaches — which is the plain biochemical reason a clove of slow-cooked garlic does to a pot of beans what an hour of simmering a bone does. The peptides find CaSR and tell the mouth the dish is dense with the stuff of nourishment, whether or not a single gram of meat is in the pot.

A worked example anchors the scale, because the arithmetic is the whole point of a number. Take γ-Glu-Val-Gly, the loud peptide at the top of the table. Its measured CaSR EC_{50} is 390 µM; the glutathione reference's is 5,000 µM. Its pure-compound loudness is therefore 1,000 × 5,000 ÷ 390 ≈ **12,800** — nearly thirteen times as loud as the reference. That is the *molecule's* number. A cultivar's number is different, and lower, because no plant is made of a single pure peptide: a food's effective kokumi is the weighted sum of every γ-glutamyl peptide it carries, each at its own concentration and its own potency, mapped onto the scorecard's 0–5,000 scale. This is why our model predicts IFI-K 3,200 for our engineered garlic and not 12,800 — the design is dense in kokumi peptides but not saturated with the single loudest one, and the scorecard reports what the food is designed to deliver, not what its best molecule could. It is also why the axis caps where it does. Above roughly 5,000 the receptor is near saturation; the flytrap can close no further and the calcium can ring no faster, so additional loudness stops translating into additional sensation. We cap the scorecard where perception caps.

The continuity can be put in numbers too, and the arithmetic is quietly generous. Model the felt intensity as a decay, $I(t) = I_0 \cdot e^{(-t/\tau)}$, where τ is the time constant of clearance; the total experience is the area under that curve, which for a decaying exponential is simply $I_0 \cdot \tau$. A reference stock might carry a peak I_0 of 1.0 and a τ of 4

seconds, for a felt total of 4.0. A kokumi-enhanced stock raises the peak only modestly — say to 1.2 — while lengthening the tail to τ = 9 seconds, and the felt total becomes 1.2 × 9 = **10.8**, nearly a tripling of the whole experience from a twenty-percent-taller peak and a longer ring. This is why kokumi feels like *generosity*: on this axis the richness lives in the tail, and a small investment in persistence pays out large in the integral. The γ-glutamyl bond's resistance to the peptidases is, in the end, a resistance to *clearance* — the molecule that will not be cut is the molecule that keeps the receptor ringing — and the allium, which banks these uncuttable peptides deeper than anything else in the garden, is the plant that stays with you longest.

Chapter 6 · The Sulfur Economy — *where the depth is banked.*

PATHWAY · sulfate · cysteine · γ-glutamyl synthesis · the storage pool

The γ-glutamyl peptides do not arrive by magic, and to design how many of them a clove carries you have to know where their atoms come from. The whole of the allium's flavor — both axes of it — is, at bottom, an economy of **sulfur**, and the allium is one of the most sulfur-hungry plants in agriculture precisely because it spends so much of its intake on flavor chemistry. Follow the sulfur in, and you follow the depth to its source.

It begins in the soil. The plant takes up **sulfate** through its roots, and reduces it — an energetically expensive, tightly regulated sequence — toward the reactive sulfur the cell can actually build with. ATP sulfurylase activates sulfate to **APS** (adenosine-5′-phosphosulfate); a reductase and a sulfite reductase carry it down through sulfite to **sulfide**; and sulfide is condensed with the carbon-nitrogen skeleton **O-acetylserine**, by **O-acetylserine(thiol)lyase**, to make the first sulfur-bearing amino acid: **cysteine**. Everything downstream — every peptide, every precursor, every molecule of eventual allicin — is built from cysteine, which is why the allium's whole flavor budget is set, first, by how much sulfur it can pull from the ground and reduce. A sulfur-starved allium is a shallow allium on both axes at once, and the single most important thing a grower does for allium chemistry, long before any gene, is feed the plant sulfur. The modern decline of atmospheric sulfur deposition — cleaner air, fewer sulfur emissions settling on fields — has, by one of agriculture's stranger ironies, made sulfur fertilization *more* necessary for flavor over the same decades that scrubbers made the air better to breathe.



Restoration begins in the living plant, in the field, in the sulfur the roots pull from the ground — not at the shaker. Every peptide of depth and every molecule of edge is condensed from cysteine the allium built itself.

From cysteine, the core kokumi pool is built in three enzymatic steps that are the same in the allium as in nearly every living cell, and the economy of them is almost shockingly cheap. **γ-glutamylcysteine synthetase** (the GSH1 enzyme, the rate-limiter) joins glutamate to cysteine through the γ-bond — spending one ATP — to make **γ-**

glutamyl-cysteine, which is already a kokumi-active peptide and already on the table above. **Glutathione synthetase** (GSH2) adds glycine — a second ATP — to complete **glutathione**, γ-Glu-Cys-Gly, the reference molecule of the whole axis. Three amino acids, two molecules of ATP, a sulfur atom, and three enzymes: that is the entire molecular cost of the richest sensation in food, and it is already running quietly in every cell of the plant. The allium's distinction is not that it owns this pathway — everything does — but that it runs it *hard*, and then banks the product, and then decorates it. Because the allium does something most plants do not: it takes glutathione and attaches the **sulfur flavor group** to it, building the genus-defining storage peptide **γ-glutamyl-S-allyl-cysteine** in garlic (and its 1-propenyl cousin in onion). This decorated γ-glutamyl peptide is the clove's great vault — stable, odorless, water-soluble, kokumi-active, and, crucially, the reserve from which the pungency will later be drawn.

That last clause is the hinge of the entire monograph, and Chapter 10 is devoted to it, so here we only lay the pieces on the table. The γ-glutamyl-S-allyl-cysteine the clove banks is not only the depth. It is also the **precursor reservoir**: oxidized at its sulfur (by a flavin-containing monooxygenase) and cleaved at its γ-bond (by GGT, the same transpeptidase that reads and rebuilds γ-glutamyl peptides throughout the cell), it becomes **alliin** — the stable sulfoxide that alliinase will one day fire into allicin. Depth and edge are drawn from one vault. GGT is the clove's quiet librarian, building and redistributing γ-glutamyl groups a little at a time, the same patient enzyme whose slow work over months is why aged cheese and long ferments grow rich — except that in the living allium it runs through a growing season, loading the vault the plant will spend when it is wounded.

STEP	ENZYME	WHAT IT MAKES	FLAVOR ROLE
Sulfate → cysteine	ATP sulfurylase → reductases → OAS(thiol)lyase	**Cysteine**	The sulfur source for everything
Cysteine + glutamate	γ-glutamylcysteine synthetase (GSH1)	**γ-Glu-Cys**	Kokumi-active; pool precursor
+ glycine	glutathione synthetase (GSH2)	**Glutathione** (γ-Glu-Cys-Gly)	The kokumi reference molecule
+ S-allyl group	S-alkenylation + GGT remodeling	**γ-Glu-S-allyl-Cys**	The vault: kokumi **and** alliin reservoir
oxidation + γ-cleavage	FMO S-oxygenase + GGT	**Alliin** (sulfoxide)	The stable pungency precursor

To engineer the depth, then, is to engineer this economy: to widen the sulfur intake, to run the three-step glutathione pathway harder, to build a deeper vault of the decorated storage peptide — and, above all, to decide how much of that vault stays banked as kokumi and how much is sent down the oxidation-and-cleavage road toward the pungency. Everything in Part IV is that decision, modeled and made. But notice, before we get there, what kind of thing we are not doing. We are not adding a flavor. We are not dusting the clove with a savory powder or folding glutamate into it. We are reaching into a native economy the plant already runs — sulfate to cysteine to

peptide to vault — and asking it, with a few precise nudges, to bank more of its own depth and hold it. The richest sensation in food is three enzymes and two ATP, and the allium was always going to be its champion. We only taught the champion to train.



PART III OF VI

The Edge

The cut, the enzyme, the covalent handshake — and the one enzyme that aims the onion at your eyes.

Chapter 7 · The Cut — *where the chemistry begins.*

MECHANISM · alliinase · alliin → allicin · pyruvate + ammonia

Nothing about an allium's edge exists until the cell is broken, and the broken cell is one of the fastest, most violent pieces of chemistry in the kitchen. We said it in the opening and we say it again slowly here, because the whole of allium cookery turns on it: there is **no allicin in a whole clove.** The sharp smell that floods a board is manufactured, from scratch, in the seconds after the knife, by an enzyme meeting a fuel it was walled away from while the plant lived.

When the wall between cytoplasm and vacuole fails, **alliinase** finds **alliin**. Alliinase is a **pyridoxal-5′-phosphate-dependent carbon-sulfur lyase** — a member of enzyme class EC 4.4.1.4, carrying the same vitamin-B6-derived cofactor, PLP, that so many amino-acid-cleaving enzymes use — and it does one thing with brutal efficiency: it cleaves the carbon-sulfur bond of the cysteine sulfoxide. From each molecule of alliin it releases three products: a molecule of **pyruvate**, a molecule of **ammonia**, and a fleeting, intensely reactive **allyl sulfenic acid**. The pyruvate and ammonia are the quiet exhaust of the reaction — the pyruvate, as Chapter 2 noted, is the very molecule the onion trade learned to assay as its pungency proxy, released in strict stoichiometry: two pyruvates for every thiosulfinate formed. The sulfenic acid is the whole event. It exists for a heartbeat. Two of them, colliding in the wet rush of the broken cell, condense — losing a molecule of water — into the signature molecule of raw garlic: **allicin**, diallyl thiosulfinate, two allyl-sulfur arms bridged by a sulfinyl, the most potent TRPA1 agonist on the culinary table.



The sharp is made by injury. Crush the clove and, in thirty to sixty seconds, alliinase turns an odorless pool into a flood of allicin — then the heat of a pan, or the simple passage of time, unmakes it again.

Two timescales govern everything a cook does with this, and both are short. The first is the **build**: alliinase is fast but not instantaneous, and the condensation of sulfenic acids into allicin takes its own moment, so the allicin in crushed garlic rises over roughly **thirty to sixty seconds** after the cell is broken and peaks a few minutes in. This is the real, mechanistic reason behind the old instruction to crush your garlic and let it *rest* before it meets the heat: you are

giving alliinase its window to finish the reaction before you denature it. Throw raw-crushed garlic straight into hot oil and you kill the enzyme before it has built much allicin at all — which is why garlic that hits the pan instantly comes out sweet and mild, and garlic crushed and rested ten minutes comes out roaring. The second timescale is the **decay**: allicin is a reactive molecule in a hurry, and it will not last. Within hours at room temperature, faster under heat, it decomposes into a cascade of secondary sulfur compounds — **diallyl disulfide** and **diallyl trisulfide**, the heavier, rounder aroma of cooked and aged garlic; the ring compounds the **vinyldithiins**; and **ajoene**. Each reads differently on the axes, softer and lower than allicin's bright sting. The arc from a raw clove to a roasted one to a jar of black garlic is, chemically, an arc down this decomposition: allicin at full voice, then the sulfides rising as it falls, then — given weeks of gentle warmth — something transformed entirely.

For a cook this is not trivia; it is a control panel, and it is the direct lever on the P number. Where you want the sharp top note — an aioli, a raw salsa, a finishing hit of green scallion — you cut late, keep it cold, let the allicin bloom, and never cook it. Where you want the floor — a confit, a long sauce, a soup — you cook the allium gently from the start, denature the alliinase before it can fire, and let the slow heat bring the depth forward instead. The plant hands you a switch between its two axes, and the switch is nothing more exotic than *when you cut and when you heat*. The rest of this book is, in part, about building alliums where that switch throws exactly where you want it, every time — but even the wild, unengineered clove already obeys the rule, and a cook who understands the cut understands half of what an allium is for.

The stoichiometry is worth writing down once, because it is clean and it is the arithmetic behind the whole pungent half of the plant:

> **2 alliin → 1 allicin + 2 pyruvate + 2 ammonia**

Two molecules of the odorless banked precursor, cleaved and condensed, make one molecule of the thing you smell, and leave behind the pyruvate that the onion trade has measured for fifty years without always knowing it was measuring the exhaust of exactly this reaction. Everything sharp about an allium is this equation, run at the speed of a knife.

Chapter 8 · The Covalent Handshake — *a bond, not a fit.*

AXIS 07 · IFI-P · TRPA1 · the reactive channel

If you remember one idea about pungency, make it this: **the sharp is a chemical reaction, and heat is not.** It is the fault line under the whole eight-axis Index. Capsaicin, the molecule this company began with, settles into a pocket on the heat channel TRPV1 the way a key settles into a lock — a specific, reversible, shape-complementary fit — and when it diffuses away the lock relaxes. Allicin does nothing so polite. It reaches into the pungency channel and *bonds* to it. The sharp half of an allium is not recognized by the body. It is **reacted with**.

The channel is **TRPA1** — Transient Receptor Potential, Ankyrin subtype 1 — a large, four-part ion channel in the membranes of sensory nerve endings throughout the mouth, nose, throat, and eyes. It is the body's chemical-irritation sensor, the alarm it keeps for reactive, electron-poor compounds that should not be in the mouth, and it is the most promiscuous chemical detector the body owns: the fume of mustard, the steam off a cut onion, the sting of raw garlic, the acrolein in smoke, the formalin of a biology lab, all read, in part, by this one channel. Each of its four identical protein chains begins with an enormous curling tail of **ankyrin repeats** — some sixteen helix-turn-helix motifs coiled like a spring, reaching down into the cell — and that spring is not decoration; it is the chemical antenna of the channel, the part most of our pungent molecules actually touch. When the 2015 cryo-electron-microscopy structure first resolved the assembly, it looked, to us, like a thing built to be tripped: four pore helices crossing at the bottom to pinch the ion path shut, a cluster of allosteric machinery poised just above the ankyrin springs, ready to translate a chemical event at the tail into a mechanical opening at the gate. When the gate opens, sodium and, importantly, **calcium** pour inward — the calcium both carrying the nerve signal and, a beat later, driving the channel shut again.



The assay that watches the bond form — a reporter line under agonist, a flood of calcium turning the channel's opening into light. Allicin is the loudest voice this instrument hears from any plant we cook.

The handshake has a chemistry and the molecules have names. The reactive agonists that trip TRPA1 share one trait: they are **electrophiles**, carrying an atom so starved of electrons it will seize a pair from almost any soft nucleophile nearby. And the channel presents, on the inner face of those ankyrin springs, exactly what an electrophile craves — a small cluster of **cysteine** side chains, each tipped with a sulfur-hydrogen thiol, one of the softest nucleophiles biology builds. In human TRPA1 the critical residues are **C621, C641, and C665**, with a nearby lysine, **K710**, able to take certain electrophiles as well. The electrophile finds the thiol, the thiol gives up its electrons, a covalent bond snaps into place, and the modified channel changes shape and opens. Mutate those cysteines to an inert residue and the channel goes nearly deaf to allicin, to mustard, to cinnamon — while still answering the few agonists that work by ordinary shape. That experiment is the proof that pungency's loudest voices speak by chemistry, not by fit. Allicin is a **Michael-type electrophile**: its reactive sulfinyl sulfur is attacked by the cysteine thiol in the addition reaction every organic chemist knows, forming an allyl-disulfide bridge from molecule to channel. The onion's lachrymatory factor (next chapter) works the same way. The mustard-and-wasabi isothiocyanates reach the same cysteines by a slightly different route. All of them end in a sulfur bridge to the body's oldest alarm.

Because the channel senses by bonding, potency means something unusual, and it reorganizes how we design. On a receptor that senses by *binding*, potency is an equilibrium — how tightly, on average, a molecule sits. On TRPA1, potency is partly a **rate** — how quickly the electrophile closes the bond. Allicin's TRPA1 EC_{50} is **1.5 micromolar**, the lowest of any culinary agonist, because it is both a willing electrophile and a fast one; it reaches the cysteines and reacts before most molecules would have found the channel at all. Set it in the company of the other sharp plants and the pungent world organizes itself by reactivity:

AGONIST	SOURCE	TRPA1 EC_{50}	CHEMISTRY
Allicin	**crushed garlic**	**1.5 µM**	thiosulfinate, Michael
6-MSITC	wasabi	2.6 µM	long-chain isothiocyanate
Allyl isothiocyanate	mustard, horseradish	4.8 µM	isothiocyanate
syn-propanethial-S-oxide	**cut onion**	~5 µM	lachrymatory factor, Michael
6-Shogaol	dried ginger	9 µM	Michael acceptor
6-Gingerol	fresh ginger	24 µM	Michael acceptor
Cinnamaldehyde	cinnamon	61 µM	α,β-unsaturated aldehyde

And then the bond has to let go, or the sharp would never clear — which is where pungency reveals the property that sets it apart from every other axis in this library: **it has a shape in time.** The same calcium that opens the current drives the channel toward a closed, briefly unresponsive state; the volatile allicin flees the warm, wet mouth; and some of the thiol adducts, under the sweep of the body's own thiols, simply come undone. Three clocks run at once —

desensitization, evaporation, release — and together they write the decay. So every pungent profile in this library carries, beside its loudness, two kinetic constants: **τ_on**, the time from stimulus to half-maximal perceived intensity, the attack; and **τ_off**, the time from peak back down to half, the clear. Raw garlic runs a τ_on of about **6 seconds** and a τ_off of about **60** — a sharp, medium-length arrival and a clean fade, slower on the attack than the nasal flash of wasabi and quicker to clear than the long warm smoulder of ginger. Two foods can post the same IFI-P and feel like different senses because one opens and clears in twenty seconds and the other takes three minutes; to design the sharp we had to learn to move not just the height of the P number but the shape of the curve beneath it.

One consequence of all this governs the kitchen absolutely, and it is the reason pungency lives in Part VI's recipes as a *finishing* flavor almost without exception: **heat kills the sharp.** Alliinase is a protein and denatures with cooking, so a hot pan stops the allicin from ever being made; the allicin already present decomposes in minutes at a simmer; the volatile molecule evaporates from anything hot. Crush garlic into a cold dressing and it roars. Drop the same garlic into hot oil and it sweetens. The whole P axis of an allium, so loud and so fast at the knife, is fragile to fire — which is not a flaw but the other face of the switch, the plain physical reason the same clove can be a cymbal crash raw and a cello note confited.

Chapter 9 · The Tears, Redirected — *the one enzyme garlic lacks.*

ONION · isoalliin · lachrymatory-factor synthase · the sulfur, rerouted

The onion runs garlic's machine one enzyme further, and that single extra enzyme is why onions make you cry and garlic does not. It is also one of the cleanest arguments the whole family has for designing on purpose, because it is a case where you can take a thing away — the tears — and *improve* the flavor in the same stroke, by rerouting the plant's own chemistry rather than muting it.

The onion's dominant precursor is **isoalliin**, S-(1-propenyl)-L-cysteine sulfoxide, and when the cut sets alliinase loose it cleaves isoalliin exactly as it cleaves garlic's alliin — releasing pyruvate, ammonia, and a reactive **1-propenyl sulfenic acid**. In garlic, that sulfenic acid's fate is simple: two of them condense into thiosulfinate, into flavor. But the onion owns a second enzyme the garlic does not, waiting in the broken cell to seize the sulfenic acid before it can go anywhere else: **lachrymatory-factor synthase**, LFS. LFS takes the 1-propenyl sulfenic acid and rearranges it into **syn-propanethial-S-oxide** — a small, volatile, intensely electrophilic molecule that rises off the cutting board, reaches the TRPA1 endings around your eyes, and trips the tear reflex. (It is a Michael-type electrophile bonding to the very same channel cysteines as allicin; the tears and the sharp are, chemically, the same handshake, aimed at a different patch of nerve.) The lachrymator was identified and its synthase cloned in a landmark 2002 study — the gene behind the oldest small misery in the kitchen, named at last — and the finding reframed the whole problem. The tears are not an inevitable cost of onion flavor. They are the product of **one enzyme**, and the sulfenic acid it consumes is the same sulfenic acid that would otherwise have become thiosulfinate flavor.



Silence one enzyme and the sulfenic acid that would have become tear gas goes instead where garlic's goes — into flavor. The onion stops making you cry and makes more of what you came for.

Which means the lever runs both ways, and both directions are useful. Turn LFS **down**, and the reactive sulfenic acid is no longer intercepted on its way to becoming tear gas; it flows instead toward **thiosulfinates**, the flavor-and-aroma compounds. The onion stops

making you cry, and it makes *more* of what you came for — a cleaner, sweeter, deeper pungency, the sulfur kept in the kitchen and taken only out of your eyes. This is not a thought experiment; a tearless onion was built this way, by RNA-interference silencing of the LFS gene, and the work confirmed exactly the predicted rerouting — less lachrymator, more thiosulfinate, flavor preserved and even enhanced. (Note the contrast with the sweet-onion route of Chapter 2, which bought tearlessness the crude way, by starving the plant's sulfur until there was little pungency *or* depth left. The LFS route is the surgical one: it removes only the crying, and keeps the sulfur economy whole.) Turn LFS the other way — hold it, and manage the sulfenic-acid pool — and you can deepen a clean, bracing sharp for the cook who wants the onion to bite. One gene; two directions; a flavor decision that for all of history was simply whatever the onion happened to do.

We grow the silenced version as **Still Water** — an onion you can slice a case of without a single tear, built not by muting the plant but by redirecting it. The pungency is still there when you want it; the depth is deeper for the sulfur that no longer leaves as gas; only the crying is gone, because the one enzyme whose only job was to make it has been told, gently and precisely, to stand down. It is, we think, the most quietly humane thing in the whole library — a plant improved by subtraction, where the thing subtracted was never flavor and never nourishment but only a small, daily unhappiness nobody ever asked the onion for.

There is a deeper lesson here that governs the onion's whole design, and it is the reason the onion and the garlic, so alike, diverge in our program. The onion's sulfenic acid stands at a *fork*: LFS to tears, or condensation to thiosulfinate flavor, or — banked earlier, upstream — held as the γ-glutamyl storage peptide that reads as kokumi. Three fates, one reactive intermediate, and the proportions among them are exactly what engineering sets. The onion is a smaller library than the garlic — **40 constructs** to garlic's 560 — not because it has less to offer but because its fork is dominated by that one headline gene, and because its vast genome makes every edit harder won. But the principle is identical to the one the whole book is built on: the allium's flavor is a set of branch points in a sulfur economy, and to design it is to decide, at each fork, how much goes where.



PART IV OF VI

One Pool, Two Axes

The branch point at the heart of the allium — and the method that learned to hold it.

Chapter 10 · One Pool, Two Axes — *the branch point that is the whole plant.*

THE BRANCH POINT · kokumi ⇌ pungency · a single sulfur reservoir

Here is the chapter the whole monograph was built to reach, and it is, at heart, a single astonishing fact: in the allium, **the depth and the edge are drawn from the same reservoir.** The γ-glutamyl peptides that speak kokumi to CaSR are not a separate inventory from the precursors that become the pungency at TRPA1. They are the *same molecules*, at different stations on one road, and the clove's whole flavor is the running decision of how far down that road the sulfur travels. Nothing else we grow has its two signature axes wired so intimately. To understand this is to understand the allium completely — and to design one.

Trace the road once more, now as a single line with a fork in the middle. Sulfur comes in and becomes cysteine (Chapter 6). Cysteine is built, through the γ-bond, into glutathione and then decorated with the flavor sulfur group into **γ-glutamyl-S-allyl-cysteine** — the vault. At the vault, the sulfur stands at its branch point. Left banked as the γ-glutamyl peptide, it is **kokumi**: an uncuttable, CaSR-ringing molecule of pure depth, stable and odorless, the floor of the plant. Sent onward — oxidized at its sulfur by a flavin-containing monooxygenase, cleaved at its γ-bond by GGT — it becomes **alliin**, the sulfoxide, which is nothing but a loaded gun: inert until the knife, then fired by alliinase into allicin, into **pungency**. The very same sulfur atom, carried on the very same allyl group, is either the depth you feel or the edge you taste, depending on one thing: whether the plant left it in the vault or marched it to the firing line.



One vault, two flavors. The γ-glutamyl peptides banked in these cells are at once the plant's kokumi depth and the stored reservoir of its pungency — and the whole art of designing an allium is deciding how the vault is spent.

This is why a clove bred only for bite is a shallow clove, and the industrial default proves it. A garlic driven hard toward pungency runs its storage pool down fast, converting the γ-glutamyl vault into alliin and spending it, at the knife, as allicin — maximizing the sharp

by **emptying the depth**. The two axes trade against each other across a shared budget. You cannot, in a naïve clove, have the maximum of both, because every molecule you commit to the firing line is a molecule missing from the vault. The conventional industrial clove reads an effective kokumi around **520** — a thin floor — precisely because its selection, chasing size and storage and whatever bite survived, never protected the vault. The depth was spent, generation after clonal generation, on a pungency nobody was even optimizing well, and lost to a storage economy nobody was scoring at all.

Our kokumi garlic lines do the opposite, and the design is now completely legible. We **widen the sulfur intake** so there is more to bank. We **run the glutathione pathway harder** so the vault fills faster. And — the crucial move — we **shift the branch point**, tuning the FMO oxygenase and the GGT transpeptidase so that more of the vault *stays* banked as kokumi-active γ-glutamyl peptide rather than flowing to alliin, and so that what does flow, flows *slower and more controllably*. Our model predicts a clove whose richness is the headline and whose heat is a dial: on the axis, where a conventional clove's effective kokumi reads around 520, our model predicts our engineered line can reach **3,200** — a computed sixfold climb in the quiet thing, with the loud thing brought to heel. You can roast such a clove to a profound, cathedral-deep savor with no acrid edge, because the vault was designed deep and held. Or you can push the branch point the other way, toward **Whetstone** (Chapter 13), a clove that commits more of its pool to the firing line for a bright, raw, finishing sharp — still with a floor of body under it, because the vault was deep enough to spare some.

The reader who has been through this library will feel a strong echo here, and it is exact. This is the **same shape** as the tomato's great design problem. In the tomato, free glutamate (umami) and GABA (the ripening shunt) are drawn from one pool at one branch point, governed by the GAD enzyme, and restoring the savor meant learning to *hold the branch* — to keep glutamate free without abolishing the shunt the fruit needs. In the allium, kokumi and pungency are drawn from one pool at one branch point, governed by the oxygenase and the transpeptidase, and designing the floor means learning to hold *that* branch — to keep the vault banked without starving the plant of the defensive edge that is, after all, why it built the chemistry in the first place. Two different organisms, two different receptors, two different pathways, and underneath them the identical design truth: **flavor is almost never a single gene turned up. It is a branch point held where you want it.** The allium states that truth more purely than anything else we grow, because in the allium the two things trading across the branch are its two most famous flavors, and you can taste the trade directly — the raw clove emptying its vault at the firing line, the roasted one spending its depth slowly and keeping most of it, the same plant speaking both its languages from one reservoir of sulfur it pulled, molecule by molecule, out of the ground.

Chapter 11 · Modeling the Base — *why the pathway, not the gene.*

METHOD · ESM2 + flux balance · the branch-point objective · CV ≤ 7%

Knowing where the branch point is does not tell you how to move it, and the most common way to fail at engineering flavor is to find the gene that makes the molecule you want and simply turn it up. It feels like it should work. It almost never does, for the reason that organizes this whole chapter and is the reason the allium is 600 constructs and not six: metabolism is not a line of genes but a **network of shared intermediates**, and the branch point of Chapter 10 sits in the busiest part of it, where the sulfur economy, the nitrogen economy, and the plant's own defense all pull on the same pool at once.

Overexpress one enzyme in the middle of that network and you do not get more product; you get a traffic jam. Push the oxygenase that makes alliin and you may simply drain the vault, trading away the kokumi you were trying to protect. Pour sulfur at the plant and you may feed every sulfur sink *except* the one you want, or stress the cell into dumping the excess. Turn up the glutathione pathway and the cell, which uses glutathione as its master antioxidant and defends its level fiercely, may quietly compensate until your intervention nets to nothing. The pool is defended, by a plant that has spent ten thousand years learning to defend it. You cannot bully a branch point. You have to find the *combination* of nudges the network cannot route around.



The 560 constructs are a designed search, not a spray. A genome-scale flux model nominates the handful of coordinated nudges worth a growing season; the bench confirms which actually move the vault. Compute is an afternoon; a garlic crop is a year.

The tool built for exactly this is **flux-balance analysis**, and its central assumption is both humble and powerful. Write every reaction in the network as a column in a great stoichiometric matrix **S**, with a row for every metabolite, and let the vector **v** hold the rate of each reaction. At metabolic steady state — which a bulking clove

approximates over the weeks that matter — nothing accumulates without bound, so production and consumption of each internal metabolite must balance:

```
S · v = 0
```

That single equation, over a genome-scale network of thousands of reactions, defines the entire space of flux distributions the cell *could* run without violating mass balance. It is underdetermined — many patterns satisfy it — so we add the constraints we know (sulfur uptake limits, irreversibilities, the demands of a living, bulbing plant) and ask a linear-programming solver to find, within that feasible space, the distribution that **maximizes an objective** we choose. Here the objective is not "maximize alliin" and not "maximize glutathione" but the thing Chapter 10 named: maximize the banked γ-glutamyl kokumi pool *subject to the plant still defending itself, still bulbing on schedule, still holding a chosen, dialable pungency.* The solver does not hand back one gene to turn up. It hands back the coordinated set of steps — widen this transporter, run this synthetase harder, damp this oxygenase at this stage — that moves the branch point where we want it without the network routing around us. And just as valuable, it tells us which beloved candidate genes do *nothing*, because the network compensates, so we never waste a season of growing on them.

Where the flux model decides *where* to intervene, a second model decides *how* to make an enzyme do what the intervention requires. This is the **protein-language-model** layer — the same **ESM2** machinery, a 650-million-parameter model trained on the sequence of essentially all known protein, that scored the single-residue substitutions in the pepper's capsaicin-forming enzyme **Pun1/AT3** and shaped the Phoenix design. We point the identical workflow at the allium's enzymes — the alliinase whose activity sets how fast the cut fires, the GGT whose balance sets the branch, the oxygenase, the sulfate transporters — folding each with our structure pipeline, scoring it by predicted effect on catalytic efficiency and fold stability, and reading the per-residue confidence exactly as the figures in this book are read: warm where the model is certain, cool where it hedges. Pun1 is not in the allium and builds no allium flavor; it is our *reference* enzyme, the one the whole method was calibrated on, and the point of naming it here is that the method is the constant and only the enzyme in the chair changes. Five of the platform's seven modules transfer unchanged to any organism with a sequenced genome. The allium's genome is enormous and arrived late, which is a real part of why onion carries only 40 constructs — but once the genome is in hand, the compute-then-grow loop is the same loop that shaped the heat.

FROM TWO ORGANISMS, BY THE NUMBERS	GARLIC	ONION
Constructs designed and screened	**560**	**40**
Native engineering difficulty	Moderate	Moderate
Primary axes expressed	K · P	K
Conventional effective kokumi (IFI-K)	~520	low
Predicted kokumi reach (IFI-K)	**3,200**	~1,900
Batch coefficient of variation	**≤ 7%**	**≤ 7%**

A word on what "560 constructs" even consists of, because it is a combinatorial grid, not 560 unrelated ideas. A handful of **target nodes** — the sulfate transporters, the glutathione synthetases, the S-alkenylation chemistry, the FMO oxygenase, GGT, alliinase, and the LFS gene in the onion — times a palette of **promoters** (constitutive, bulb-specific, clove-stage-specific, each setting *how much* and *when*) times several **genetic backgrounds** times the **edit types** (up-regulation, knock-down, point substitution, domain removal) generates a design space in the hundreds before anyone has a genuinely new idea. The flux and sequence models prune that grid savagely — most combinations are predicted to do nothing, or to break the plant, and are never planted — so the constructs that reach soil are the survivors of a far larger in-silico tournament. That is the real meaning of *platform*: the slow, expensive step (a garlic crop is a year, and garlic is a clone, so you cannot shortcut it with seed) is rationed by the fast, cheap step (an afternoon of compute), and the living plant is only ever asked a question worth a season to answer.

And then the number has to **hold**, which for the allium is harder than for almost anything else, and the honesty of the whole program lives in this last paragraph. An allium's flavor fights sources of variance a tomato never faces. The **precursor pool** swings with the plant's sulfur nutrition, its stress, its stage at harvest, far more than a fruit's capsaicin does. The **firing** — alliinase activity — depends on pH and temperature and the exact mechanics of how the cell was broken. The **decay** starts the instant the clove is cut, so *when* you measure is part of *what* you measure. A field of traditional garlic carries batch-to-batch swings of forty percent and worse in its kokumi load, set by cultivar and soil and water and the accidents of a particular harvest — part of the romance for a cook, a nightmare for a manufacturer who has promised a customer the same soup every time. We attack that variance directly: because the kokumi load is set by defined genetic edits to the pathway rather than left to the organism's defaults, and because the plants are grown in controlled environment rather than open field, the batch-to-batch **coefficient of variation is held at or below seven percent** — the same precision standard that runs through the entire library. On the depth axis that is a specific, bankable promise: the IFI-K you design for is what the cultivar is built to deliver, lot after lot. A miracle you cannot repeat is an anecdote. A base held to a tolerance is a product, and a product is how a better allium reaches a table that is not our own.



PART V OF VI

The Alliums, Named

The sweetness in the layers, the garlic ladder, the onion ladder, and the long dark warmth of the aged clove.

Chapter 12 · The Sweetness in the Layers — *what caramel really is.*

AXIS 02 · IFI-S · TAS1R2·TAS1R3 · fructans · the Maillard gold

A raw onion is sharp; a long-cooked onion is candy. Between those two is one of the best transformations in all of cooking, and almost all of it is sugar the onion was holding the whole time — which makes it a third axis the allium quietly commands, and one worth its own chapter because it is the clearest proof the family has that a designed flavor can be *revealed* rather than added.

Onions store much of their energy not as simple sugar but as **fructans** — chains of fructose, built on a sucrose starter, faintly sweet and mostly flavorless when cold. They are assembled by a pair of enzymes with unlovely names and lovely jobs: **sucrose:sucrose 1-fructosyltransferase** (1-SST), which starts the chain, and **fructan:fructan 6G-fructosyltransferase** (6G-FFT), which extends and branches it, building the characteristic allium fructans up to a range of chain lengths, or **degrees of polymerization**. A storage onion is, in carbohydrate terms, a bulb full of these fructose chains, banked against the plant's second-year flowering. Cold, they read as almost nothing on the tongue, because the sweet receptor cannot grip a long polymer. Heat changes everything. A long, low cook **hydrolyzes** the fructans back to free fructose and glucose — and fructose, released, is the sweetest of the common sugars, far sweeter than the sucrose a cook might add. The sharpness falls as the alliinase chemistry cooks off; the sweetness rises as the fructans give up their fructose; and then, over a slow enough pan, those freed sugars begin to **caramelize and brown** in the Maillard reaction, condensing with the onion's own amino acids into the deep, jammy, almost meaty gold of a properly cooked onion. The onion crosses the Index as it cooks: down the P axis, up the S axis, and — because Maillard products and the freed glutamate read as savory — up the U axis too.



The gold is grown, not added. A long, low pan hydrolyzes the onion's banked fructans to free fructose and browns them to the deep, jammy sweetness a cook can reach no other honest way.

On the sweetness axis, **IFI-S** is read through the **TAS1R2·TAS1R3** pair — the two-part receptor that registers *sweet* only when both halves are clasped — and an onion grown with a larger fructan reserve

simply has more to give when the heat finds it. This is a clean, native lever, and it is the one behind **Slow Gold**: an onion designed not to be sweeter *raw* but to carry a deeper fructan reserve, so that it becomes sweeter when it is cooked, reaching a lower, more profound caramel than an ordinary onion can. It is the onion for the confit, the jam, the tart, the French soup; the one that pays back patience with sugar. We do not touch the raw onion's modest sweetness, because raw sweetness is not what the dish wants — what the long-cooked dishes want is *reserve*, the depth of gold a caramelization can reach, and that is a function of how much fructan was banked before the knife.

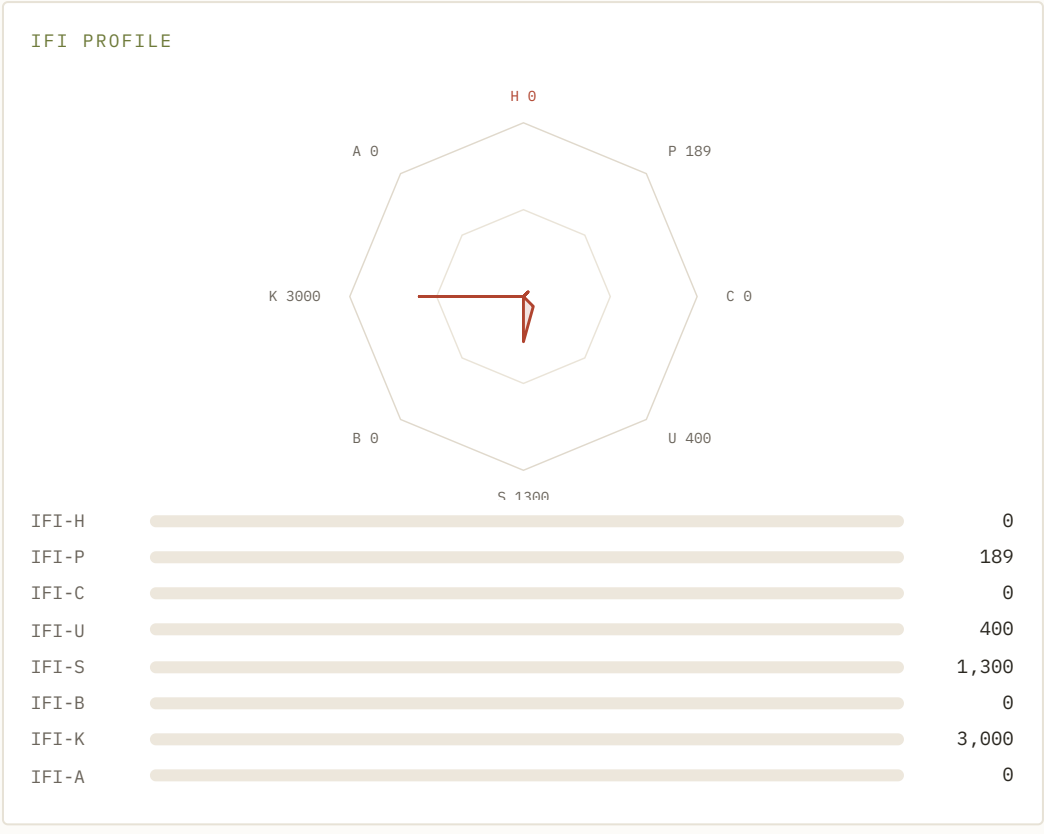
None of this is sugar added, and for a family that would always rather uncover a flavor than dose one in, that matters more than almost anything in the book. The sweetness of a caramelized onion is the plant's own stored carbohydrate, brought forward by nothing but a low flame and time. We grow the reserve; the cook reveals it. And there is a quiet nourishment note folded into the same molecules, stated as chemistry and nothing more: the allium fructans are **fructo-oligosaccharides**, the inulin-type fibers the human small intestine cannot digest and the gut's own microbes ferment — the same class of molecule sold as a prebiotic fiber. A deeper fructan reserve is a deeper reserve of exactly that. We make no claim about it and we draw no arrow from it to any outcome; we only notice, as we notice everywhere in this library, that the thing we grow for flavor and the thing that feeds the body keep turning out to be the same molecule, banked in the same bulb, revealed by the same slow pan.

Chapter 13 · The Garlic, Named — *four ways to build a base.*

FLAGSHIPS · the garlic ladder · K and P across one vault

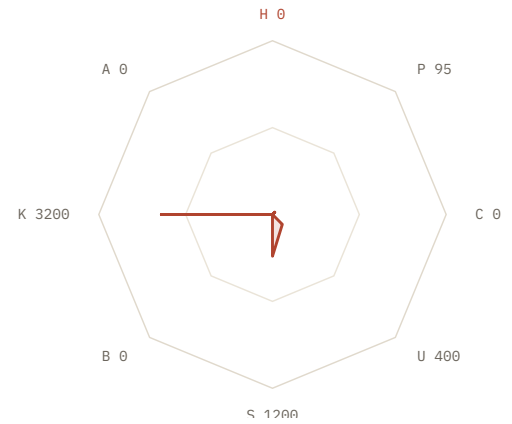
Four garlics, read across the two axes the plant was born for, each a different answer to one question: *what kind of floor do you want to build?* They are not four different plants so much as four settings of the one branch point of Chapter 10 — four decisions about how deep to bank the vault and how much of it to march to the firing line. Read them as a ladder from pure depth to bright edge, the sulfur economy spent four different ways.

Keystone is the one we reach for first — the flagship kokumi garlic, the clove you build a dish *on*. Deep, round, low in sharpness, it is the everyday embodiment of the whole program: a vault built wide and held, the branch point tuned so that richness is the headline and the edge is a soft presence rather than a sting. It is the clove for the sauce, the braise, the roast, the base of nearly anything.



Bedrock takes the branch point to its limit toward depth: the deepest floor we grow, the canonical designed line predicted to reach **IFI-K 3,200**, with the pungency dialed almost to silence. It is for the long sauce, the broth, the braise that wants body and no sharpness at all — a clove that is nearly inaudible raw and reads, cooked, as pure continuity. Where Keystone keeps a soft edge, Bedrock commits almost nothing to the firing line and banks almost everything.

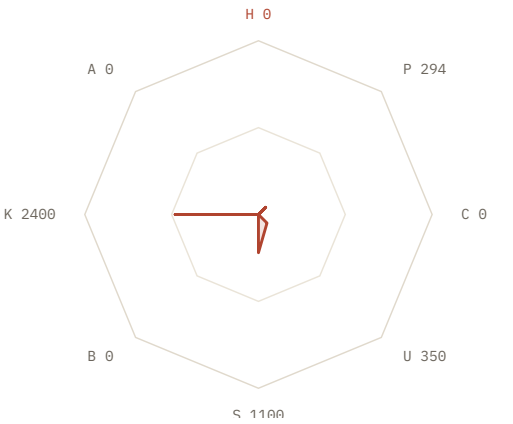
IFI PROFILE



IFI-H		0
IFI-P		95
IFI-C		0
IFI-U		400
IFI-S		1,200
IFI-B		0
IFI-K		3,200
IFI-A		0

Cornerstone is the balanced everyday clove — ample depth and a clean, usable brightness in one. If you keep a single garlic, keep this one: the branch point set near the middle, a vault deep enough to anchor a dish and an edge sharp enough to lift a raw application. It is the all-purpose answer, the clove that does not force you to choose which axis you woke up wanting.

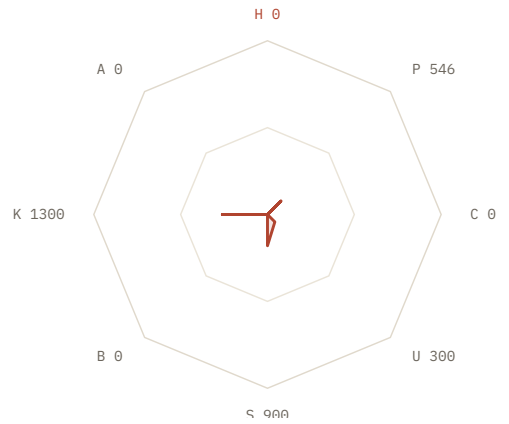
IFI PROFILE



IFI-H		0
IFI-P		294
IFI-C		0
IFI-U		350
IFI-S		1,100
IFI-B		0
IFI-K		2,400
IFI-A		0

Whetstone runs the branch the other way — pungency forward, the raw and finishing garlic, designed for the aioli, the raw salsa, the green hit at the end of a plate. It commits more of its vault to the firing line, for a bright TRPA1 sting grown loud, and it must be cut late and kept cold to deliver it (Chapter 8: heat kills the sharp). But notice that even Whetstone keeps a real floor of kokumi under the edge — a vault deep enough to spare some, so the sharpness has body beneath it rather than ringing thin.

IFI PROFILE



IFI-H	0
IFI-P	546
IFI-C	0
IFI-U	300
IFI-S	900
IFI-B	0
IFI-K	1,300
IFI-A	0



The garlic ladder is four settings of one branch point. Keystone and Bedrock bank the vault deep; Cornerstone splits it; Whetstone spends it bright at the firing line — the same plant, the same sulfur, four floors.

GARLIC	IFI-K (FELT DEPTH)	IFI-P (THE EDGE)	BUILD IT INTO
Bedrock	3,200	95	Long broths, confits — body, no sting
Keystone	3,000	189	The everyday base: sauces, roasts, braises
Cornerstone	2,400	294	All-purpose; the one clove to keep
Whetstone	1,300	546	Raw: aioli, salsa verde, finishing green

Read the ladder as a line and the trade of Chapter 10 is right there in the two columns: as the K number falls, the P number rises, because they are drawn from one vault and every molecule sent to the edge

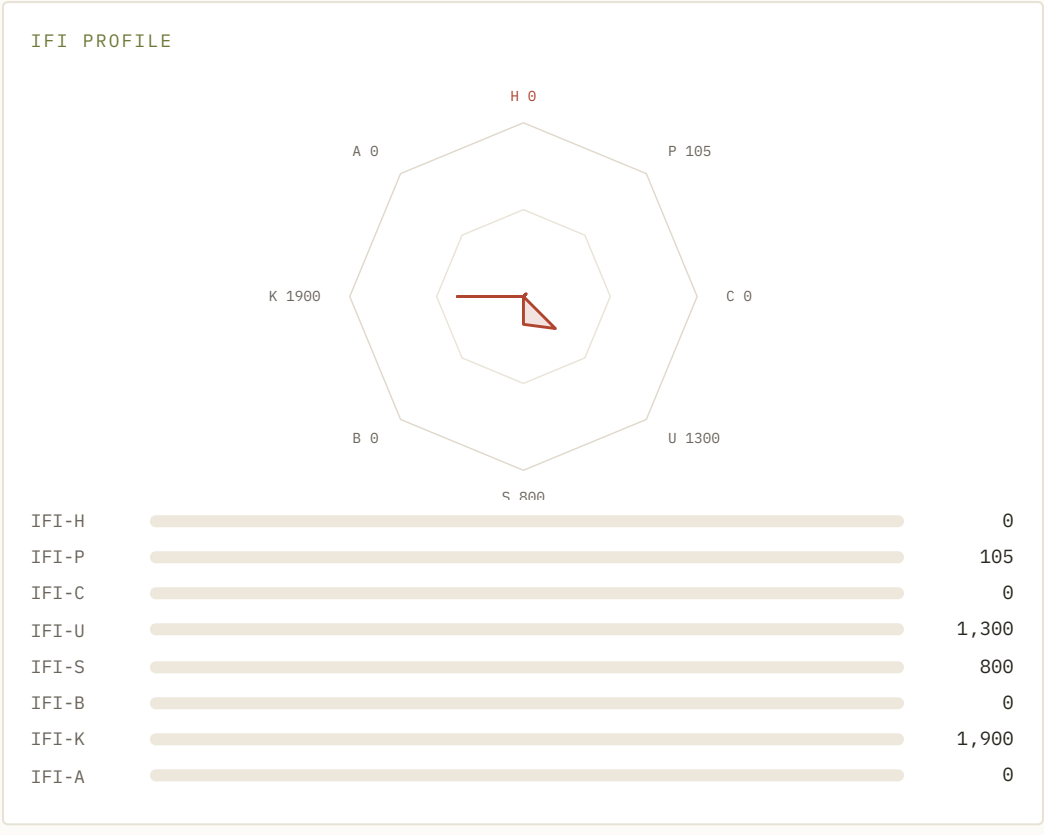
is a molecule missing from the floor. No clove maxes both, and that is not a limitation to engineer away but the honest physics of a single sulfur pool. What we *can* do — what the 560 constructs bought — is design a given clove for anywhere on that line, on purpose, held to ≤7% CV, so a cook or a formulator picks a floor by number instead of hoping the harvest delivers it. Four names; one plant; the whole range of what a base can be.

Chapter 14 · The Onion, Named — *weight, gold, and no tears.*

FLAGSHIPS · the onion ladder · the gentler larder

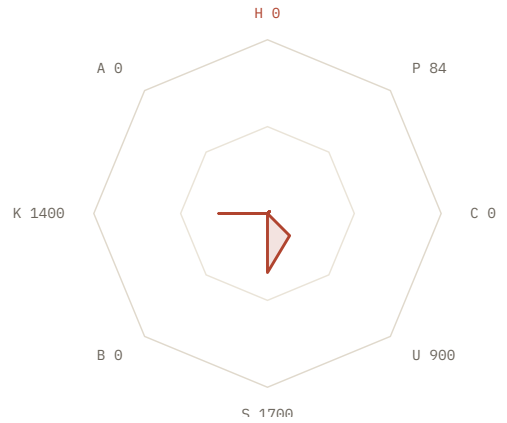
Three onions, each built around a different one of the onion's gifts — the depth, the revealed sweetness, the clean cut without the crying. The onion is the **gentler larder**, and it is worth saying plainly before the scorecards: where our garlic is designed to reach IFI-K 3,200, our deepest onion is designed to reach only about **1,900** — a little more than half — because the onion carries a shallower sulfur economy by nature and a far harder genome to work, 40 constructs to garlic's 560. That is not a shortfall to apologize for. The onion was never meant to be garlic; its gentleness is its purpose. It is the base note *under* the base note — the thing you do not taste but would mourn — and it brings two things garlic does not: a real **umami** of its own when it is charred or browned, and the fructan sweetness of the last chapter. Read the three as the onion's own range, not as a lesser garlic.

Ballast is the deep savory onion, designed for weight and body — the kokumi onion that lets a soup or a sauce reach stock-depth on water alone. It is the onion that proves the floor was always the onion, carrying the γ-glutamyl depth plus the browning umami that beef stock used to supply.



Slow Gold is the caramelizing onion of Chapter 12 — fructan-rich, designed not to be sweet raw but to *become* sweet, the confit-and-soup onion that rewards a slow pan with a lower, deeper gold than an ordinary onion can reach. Its headline is the S number, with a real body of kokumi beneath and a pungency gentle enough that there is little to cook off.

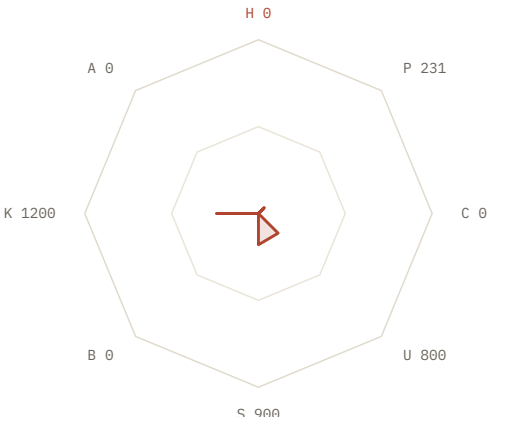
IFI PROFILE



IFI-H	0
IFI-P	84
IFI-C	0
IFI-U	900
IFI-S	1,700
IFI-B	0
IFI-K	1,400
IFI-A	0

Still Water is the tearless onion of Chapter 9 — LFS silenced, the sulfur redirected from your eyes into flavor. Slice a case without weeping; the pungency is present and clean when you want it, the depth is deeper for the sulfur that no longer leaves as gas, and only the crying is gone.

IFI PROFILE



IFI-H	0
IFI-P	231
IFI-C	0
IFI-U	800
IFI-S	900
IFI-B	0
IFI-K	1,200
IFI-A	0



The onion is the gentler larder — a shallower sulfur economy than garlic by nature, and the base note under the base note. Charred, it brings a real umami of its own; silenced of one enzyme, it brings no tears.

ONION	IFI-K	IFI-U	IFI-S	THE GIFT
Ballast	1,900	1,300	800	Stock-depth on water; the savory floor
Slow Gold	1,400	900	1,700	The deep caramel; confit and soup
Still Water	1,200	1,100	900	Clean cut, no tears; the sulfur kept in

Three onions, three settings, and together they cover the onion's whole working range — the deep, the sweet, and the kind. A representative slow-cooked designed onion sits near IFI-K 900, the figure the savory-depth volume reports; these three are designed to climb above it in their different directions without ever reaching for garlic's register, because that was never the onion's job. The onion's job is to be the quiet, indispensable floor under the floor — and now a cook can specify which floor, by number, and slice it without crying.

Chapter 15 · Black Garlic — *the long, dark warmth.*

TRANSFORMATION · Maillard · S-allyl-cysteine · the deep end of the family

Leave whole garlic in gentle, humid warmth for weeks and it transforms into something that seems to have nothing to do with garlic at all: soft, black, sticky, sweet, with no raw bite left and a depth closer to balsamic and dried fruit and molasses. **Black garlic** is the whole family's destination written in a single slow transformation — the clearest natural picture of where our entire program points, which is why it closes Part V. It is pungency spent and depth maximized; the firing line stood down and the vault cooked to its richest possible expression; a garlic that is all floor and no window.

The chemistry is long and gentle and entirely non-enzymatic by the end. Held at roughly **60 to 70 degrees Celsius** and high humidity — eighty to ninety percent — for **three to four weeks**, whole heads undergo a slow, controlled **Maillard reaction**: the freed sugars and amino acids condense over weeks into the brown-to-black **melanoidins** that give black garlic its color and much of its depth, the same family of reactions that browns a crust or a caramelized onion, run at low temperature over a month instead of high heat over minutes. The alliinase is long denatured, so no new allicin forms; the allicin and thiosulfinates that were present decompose and transform entirely. The sharp organosulfur edge disappears. In its place rises **S-allyl-cysteine** (SAC) — the stable, water-soluble, odorless sulfur compound that is the signature of aged garlic, concentrated severalfold by the aging — alongside a deepened γ-glutamyl pool, a drop in pH toward sourness that balances the sweetness, and the formation of the browning markers that give black garlic its faint, pleasant funk. What was a loud, sharp, pungent clove becomes a dark, soft, sweet, profoundly kokumi one: one of the most CaSR-dense things you can put in your mouth, and almost nothing on the P axis at all.



Black garlic is the family's deep end — weeks of gentle warmth running the Maillard reaction at low heat until the sharp is gone, the sugars browned, and the vault cooked to its richest, darkest expression.

What black garlic reaches in forty days, we can design a clove *toward* on the plant — and this is the elegant meeting of the aging room and the design bench. If the richness of aged garlic lives in the depth of the γ-glutamyl pool and the SAC that forms from it, then a garlic built with a **larger pool to begin with** starts the aging closer to its destination: it carries more of the kokumi actives and more SAC precursor out of the ground, so that even fresh it is designed to read deep, and aged it is designed to read enormous. **Bedrock** (Chapter 13), the deepest fresh line, is also the best clove to *start* an aging run, because the vault it banks is the raw material the aging transforms. We are not replacing the patient craft of the aging room — we admire it, and some depth is only ever earned by time, by the slow month of Maillard the way slow months of GGT build the richness of a two-year cheese. But we can give the aging room a better clove to begin with, and we can give the cook who has no forty days a fresh garlic that is designed to already speak in that lower, warmer register.

Set the three states of one clove side by side and you have the whole arc of the plant across the axes, a single garlic read at three points on the decomposition road of Chapter 7:

ONE CLOVE, THREE STATES	IFI-P (EDGE)	IFI-K (DEPTH)	IFI-S (SWEET)	WHAT YOU MEET
Raw, crushed and rested	546	1,300	—	The bright sting, vault spent at the firing line
Slow-confited	32	2,900	1,400	The sting gone, the vault brought forward
Black, aged 30–40 days	—	3,200	1,900	Pungency transformed away; pure dark floor

Read down the P column and watch the edge fall to nothing; read down the K column and watch the floor rise to its ceiling. That is the allium's single most important lesson, drawn once more in a single clove: the depth and the edge are the same sulfur, and the cook — or the aging room, or the designer — decides, by heat and time and the branch point, how much of it you feel and how much of it you taste. Black garlic is simply the far end, where all of it is depth.



PART VI OF VI

The Kitchen

The control panel the plant hands a cook — and the dishes that prove the base was always the allium.

Chapter 16 · The Wider Family and the Frontier — *the base, specified, under everything.*

BOTANY · the genus Allium · leek · shallot · chive · the connective tissue

Garlic and onion are the two we have taken deepest, but they are two notes of a large, generous genus, and before the kitchen it is worth standing, with reverence, in the whole of it — because the same sulfur economy, the same loaded-and-divided cell, the same branch point of depth and edge, runs through every allium a cook has ever reached for, and the method that opened garlic and onion opens all of them in turn.

The **leek** (*Allium ampeloprasum*) is the gentle giant — milder, sweeter, its sulfur economy turned down and its sugars up, the allium you can make the *subject* of a dish rather than its base, soft and silken under long slow heat. The **shallot** (*Allium cepa* in its aggregatum form, the clustering onion) is the cook's secret: finer-grained than an onion, more complex, carrying a higher density of the γ-glutamyl depth in a smaller package, which is the plain reason a classic pan sauce or a vinaigrette asks for shallot and not onion — it is more vault per gram. The **chive**, the **scallion** or green onion, and the garlic **chive** (*Allium tuberosum*) are the fresh, green, high-pungency top notes of the family — alliums eaten raw and young, their edge bright and their depth light, the finishing flash rather than the floor. The **ramp** (*Allium tricoccum*), the wild leek of eastern woodlands, is the genus at its most romantic — a brief spring forage, intensely both sharp and deep at once, the whole family compressed into a few weeks of the year. Every one of them runs the chemistry of this book; every one sits somewhere on the line from Bedrock's floor to Whetstone's edge; every one is, in principle, a future volume of this same work, now that the method is proven on the two hardest and most important.



The genus is a generous one — leek to shallot to chive to the wild spring ramp — and every member runs the same loaded cell, the same sulfur vault, the same branch between the depth you feel and the edge you taste.

And this is the right place to say the quiet thing the whole monograph has been circling, because it is the reason the allium matters out of all proportion to its two modest construct counts. Return to the strangest and most useful fact about this family: **most of what it does, it does to other flavors.** Kokumi through CaSR has no taste of its own, and yet it makes umami taste more umami, salt taste more complete, a dish taste more continuous from the first bite to the lingering finish. Pungency through TRPA1 is a half-second flash, and yet it brightens everything slower around it. The allium is rarely the thing you remember from a meal. It is the reason you remember the meal as good. That is why garlic and onion appear, quietly, in nearly every other book on this shelf and in the kitchen — the base under the cuisines, the savory floor under the vegetarian table, the lift under a sauce, the depth under a braise. They are the **connective tissue** of cooking, the thing that turns a list of ingredients into one dish.

Measured, that role stops being guesswork, and that is the whole gift of the number. A cook who knows they want more continuity reaches for a kokumi figure — a Bedrock, a Ballast. One who wants a brighter top note reaches for a pungency figure — a Whetstone, a Still Water. One who wants the long caramel reaches for Slow Gold. And the base, which for ten thousand years was the most improvised part of cooking — a handful of whatever allium was in the bin, cut however the cook felt, as sharp or as deep as that harvest happened to be — becomes the most dependable. The allium was always the connective tissue of a dish. Now it is connective tissue you can specify: a floor that is the same floor in August and in February, in our kitchen and in yours, held to a number, designed deep on purpose in a plant that for all of history could not be asked to change. The frontier of this family is not a hotter garlic or a stranger onion. It is simply *this* — the oldest base in cooking, finally made as reliable as the thing it holds up.

Chapter 17 · Cooking by the Receptor — *the control panel the plant hands you.*

TECHNIQUE · the switch · order of operations · heat, fat, acid, time

Everything in this book comes down, at the stove, to a few rules that are nothing more than the chemistry of Parts II and III read as instructions — and a cook who holds them can move an allium along its whole range with a knife and a flame, designed clove or ordinary one. This short chapter is the control panel, and it frames the five dishes that follow.

The switch is the cut and the heat. The allium's two axes are a single sulfur pool divided by one decision: whether you fire the alliinase or denature it. Cut late, keep cold, and rest the crushed allium ten minutes, and you throw the switch toward **pungency** — you give the enzyme its thirty-to-sixty-second window to build allicin, and you deliver it raw to the mouth before heat or time can take it. Cook gently from the start, never letting the cut allium meet the air cold for long, and you throw the switch toward **kokumi and sweetness** — you denature the alliinase before it fires, so the sharp never forms, and the slow heat brings the vault and the fructans forward instead. The same clove, two completely different places on the Index, decided by nothing but *when you cut and when you heat.* Learn that one lever and you have learned half of allium cookery.

Order of operations is a design tool. Because the sharp is made by injury and destroyed by heat, *when* an allium enters a dish sets what it contributes. Garlic crushed and rested, then stirred into a cold dressing, roars with allicin. The same garlic sliced thin and sweated in oil from cold builds depth and sweetness and almost no edge. Garlic added at the start of a braise disappears into the floor; garlic added raw at the very end rings on top. A single dish can carry an allium at two stations at once — a deep sweated base *and* a raw finishing hit of the same clove — which is one of the oldest tricks in good cooking and, read through the receptors, simply the plant's two axes deployed at two times.

Heat kills the sharp; fat and acid protect it. Pungency is, with rare exceptions, a **finishing** flavor, because alliinase denatures and allicin decomposes under heat and the volatile molecule flees a hot pan. If you want the P number to survive to the mouth, add the pungent allium last and off the heat, or protect it in **fat** (which holds the sulfur compounds and slows their loss) and **acid** (a splash of lemon or vinegar stabilizes the raw-garlic flavor and tames its harshest edge). This is why a raw-garlic aioli, built in oil with lemon, keeps its roar for hours, while the same garlic in a simmering sauce is sweet within minutes.

Low and slow is the road to the vault. The depth axis wants the opposite of the edge axis: time and gentle heat. A confit at a bare tremble, a sweat that never browns too fast, a soup cooked past where most cooks dare — these denature the enzyme early and spend the next hour letting the γ-glutamyl peptides and the freed sugars come forward, building the kokumi and the caramel that are the plant's other language. Depth is patient; the edge is instant; and the cook who knows which one a dish wants knows which end of the clock to cook at.

With the panel in hand, the five dishes that close this book each throw the switch somewhere different — two deep into the vault, one bright at the firing line, one into the aging room's dark warmth, and one that lays the whole base down at once. Each is scored on the Index, so you can read exactly what you are designed to feel before you pick up the knife.

Chapter 18 · Forty Cloves, Slow — *kokumi you can spoon.*

RECIPE · garlic confit · the vault brought forward

This is the dish we make to show what an allium is when you treat it with patience instead of a knife's worth of violence. Cook garlic low and whole in oil and the alliinase never gets its moment — the sting never arrives — and what you are left with is the floor itself: sweet, spreadable, kokumi you can eat off a spoon. Use the deepest garlic you have; this is its whole stage.

You need

3	heads	garlic (Bedrock or Keystone), cloves separated and peeled
300 ml		mild olive oil, to cover
2	sprigs	thyme
1	strip	lemon peel
1	pinch	flaky salt

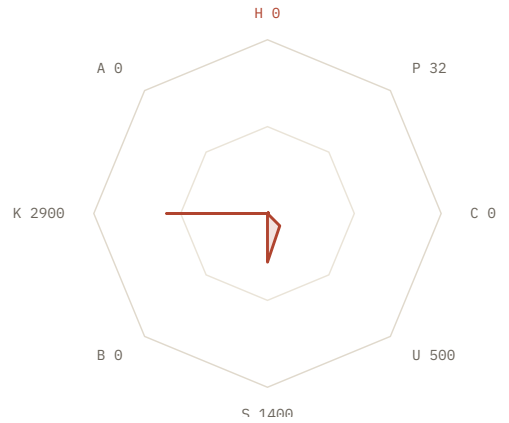
Make it

1. Lay the peeled cloves in a small pot where they sit in one close layer. Pour over oil until they are just covered. Tuck in the thyme and the lemon peel.
2. Set it over the lowest flame you can hold — the oil should barely tremble, never fry. If a clove sizzles hard, pull it off the heat; this is a poach, not a sear.
3. Cook, untouched, 40 to 45 minutes, until the cloves are gold straight through and collapse at the push of a spoon.
4. Cool them in their oil. Keep both: the cloves become a paste for everything, the oil becomes garlic oil for everything else.

Why it works — Low heat denatures the alliinase before it can turn alliin into allicin, so the sharp TRPA1 pungency simply never forms (Chapter 7's switch, thrown all the way toward depth). With the sting out of the way, the slow heat brings the γ-glutamyl peptides and the garlic's own sugars forward — kokumi and a roasted sweetness where raw garlic would have been all edge. A **Bedrock** clove, designed to bank its vault deep and commit almost nothing to the firing line, confits to pure continuity; a representative designed clove slow-cooked this way is predicted to read near IFI-K 2,200, and the deepest lines are designed to climb past it. The same clove that would have stung now spreads.

Predicted IFI readout — the finished paste

IFI PROFILE



IFI-H		0
IFI-P		32
IFI-C		0
IFI-U		500
IFI-S		1,400
IFI-B		0
IFI-K		2,900
IFI-A		0

Nourishment note, quiet: the slow, gentle heat that builds this depth also keeps the garlic's organosulfur compounds largely intact — the same molecules we grow it for. The flavor and the good were never two different projects, and this paste, spooned onto bread or stirred into anything, is both at once. We claim nothing past that.

Chapter 19 · Onion Soup, No Bones — *French depth, grown in.*

RECIPE · onion soup · stock-depth on water

The classic case against our whole thesis is French onion soup: surely *that* depth needs beef stock, the long-simmered bones, the meat. It does not — or rather, it never needed them as much as the method assumed. The depth of a great onion soup is mostly the onions, cooked further than most cooks dare, and an onion designed for kokumi can carry the rest on water. We write the meat version with respect: a good beef stock is welcome and traditional and makes a fine soup. This one simply proves the floor was always the onion.

You need

1.5	kg	onions (Ballast, or half Ballast / half Slow Gold), sliced thin
3	tbsp	olive oil or butter
1	splash	dry white wine or dry sherry
1	litre	water (yes, water)
2	sprigs	thyme
1		bay leaf
		flaky salt · black pepper
		country bread + grated hard cheese, to finish

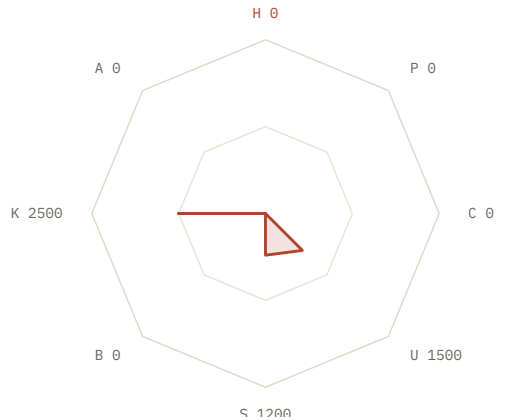
Make it

1. Cook the onions in the fat over medium-low, stirring now and then, 45 to 60 minutes. Do not rush this — you are chasing a deep, even mahogany, which is the whole soup. Scrape the brown from the pan back into the onions as it builds.
2. When they are dark and jammy, pour in the wine and let it hiss away, lifting the last of the fond off the base.
3. Add the water — not stock — with the thyme, bay, and a long pinch of salt. Simmer gently 20 minutes. Taste; season until it rings.
4. Ladle into bowls, float a slice of toast on each, blanket with cheese, and set under a hot broiler until blistered and bronze.

Why it works — **Ballast** is designed to bring the kokumi and the savory floor that beef stock used to supply: the γ-glutamyl peptides reading through CaSR as exactly the continuity and body a long bone-stock gives, plus the onion's own browning umami (Chapter 14). The deep caramelization lays Maillard umami and the freed-fructan sweetness on top (Chapter 12). The water is not a compromise; it is the choice that lets the onion be the loudest thing in the bowl. Add **Slow Gold** for half the onions and the sweetness deepens the gold further still. If you do reach for stock, the soup only gets richer — the onion and the bones are additive, not rivals — but the point of the bowl is that the onion did not need them.

Predicted IFI readout — the finished bowl

IFI PROFILE



IFI-H	0
IFI-P	0
IFI-C	0
IFI-U	1,500
IFI-S	1,200
IFI-B	0
IFI-K	2,500
IFI-A	0

Chapter 20 · Toum, and the Raw Edge — *the firing line, held in oil.*

RECIPE · raw-garlic emulsion · pungency protected

If the confit is the vault brought forward, toum is the firing line caught at full roar and held there. The Lebanese garlic sauce is nothing but garlic, oil, lemon, and salt whipped into a fierce white cloud, and it is the purest raw-garlic dish there is — a direct hit of allicin, emulsified into fat and acid so it keeps its edge for days. This is **Whetstone**'s whole purpose: a clove designed to commit its vault bright at the firing line.

You need

1 head	garlic (Whetstone), cloves peeled, any green germ removed
1 tsp	flaky salt
2–3 tbsp	lemon juice, cold
500 ml	neutral oil, cold, in a slow stream
1 splash	ice water, to steady the emulsion

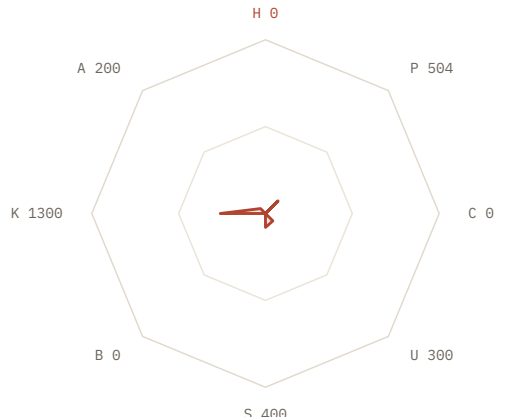
Make it

1. Crush or finely chop the garlic with the salt and **let it stand 10 minutes.** This rest is the dish: it is the window in which alliinase builds allicin (Chapter 7). Skip it and you have a milder sauce; honor it and you have the roar.
2. In a tall, narrow vessel or a processor, work the rested garlic and salt to a paste with a little of the cold lemon.
3. Begin adding the cold oil in the thinnest possible stream, alternating with lemon juice, keeping everything cold and moving, until it climbs into a thick, bright-white, aerated emulsion. A splash of ice water steadies it if it threatens to break.
4. Use within a few days; keep it cold and sealed, so neither heat nor air spends the edge you built.

Why it works — Everything here protects the sharp. The ten-minute rest lets the TRPA1 agonist form; the **cold** keeps it from volatilizing; the **oil** dissolves and holds the organosulfur compounds; the **acid** of the lemon stabilizes the raw-garlic flavor and tames its harshest corner without cooking it off (Chapter 17: heat kills the sharp, fat and acid protect it). Whetstone is designed for a pungency grown loud — our model predicts IFI-P 546 — but with a floor of kokumi under it, so the sauce is bright without being thin. Never warm toum; warmth is how you lose everything you just built.

Predicted IFI readout — the finished sauce

IFI PROFILE



IFI-H		0
IFI-P		504
IFI-C		0
IFI-U		300
IFI-S		400
IFI-B		0
IFI-K		1,300
IFI-A		200

Chapter 21 · Black Garlic, Spooned — *the deep end, dressed.*

RECIPE · black garlic dressing · pungency transformed away

At the far end of the arc from toum sits this: a dressing built on black garlic, where there is no allicin to protect and no rest to honor, because the aging has already done all of it. The sharp is long gone, transformed over weeks into the soft, sweet, molasses-deep sulfur chemistry of the fully aged clove (Chapter 15). This is the pungency-emptied end of the family, pure dark floor, and it wants only to be loosened and poured.

You need

```
60 g      black garlic cloves (aged Bedrock, or any slow-aged designed
garlic)
2  tbsp   tamari or good soy
2  tbsp   rice vinegar or aged sherry vinegar
1  tsp    honey or date molasses
4  tbsp   good olive oil
          warm water, to loosen
```

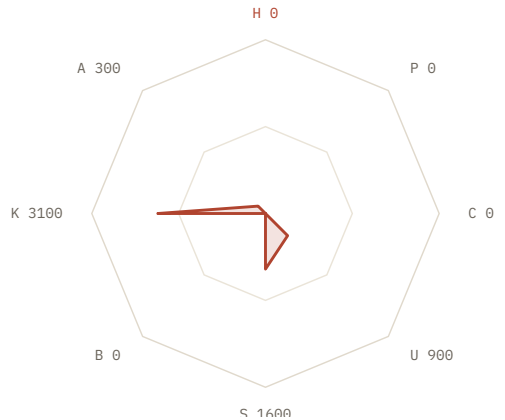
Make it

1. Blend the black garlic with the tamari, vinegar, honey, and oil, adding enough warm water to make a smooth, dark, spreadable dressing. No resting, no enzyme work — the aging transformed the chemistry weeks ago.
2. Taste and balance: the black garlic brings deep sweetness and a faint aged sourness, so adjust the vinegar and salt until the dressing is dark, round, and bright at once.
3. Spoon over roasted vegetables, grains, soft cheese, or a plain plate of leaves; it is almost a condiment, and it keeps.

Why it works — Everything loud about garlic is absent here on purpose, and everything deep is concentrated. The weeks of low Maillard warmth took the clove down the decomposition road of Chapter 7 past its end — no thiosulfinates, no sharp, just melanoidins, concentrated **S-allyl-cysteine**, a deepened γ-glutamyl pool reading as pure kokumi, and the browned sweetness and gentle acidity the aging builds. Starting from a **Bedrock** clove, aged, means starting the aging from the deepest vault we design for, so the finished dressing is designed to read near the top of the K axis with nothing on P at all. It is the floor, dressed and poured.

Predicted IFI readout — the finished dressing

IFI PROFILE



IFI-H	0
IFI-P	0
IFI-C	0
IFI-U	900
IFI-S	1,600
IFI-B	0
IFI-K	3,100
IFI-A	300

Chapter 22 · The Allium Base — *the floor a whole meal stands on.*

RECIPE · the engineered sofrito · depth, laid down

End where every cuisine begins: with the base itself, the allium floor that a thousand dishes are built on, laid down on purpose and scored so you know exactly what you have made before you build on it. This is not a dish so much as a *foundation* — a deep, slow, vegetarian-first allium base that can carry a pot of beans, a dal, a braise, a ragù, a grain, a soup, the start of nearly anything. Build it well and much of what you thought you needed on top turns out to be optional.

You need

2		onions (Ballast), diced fine
1	head	garlic (Keystone), sliced thin
3	tbsp	olive oil or ghee
1	pinch	salt, early
—		whatever the dish asks on top: tomato, spice, stock, greens
1	clove	garlic (Whetstone), raw, grated — reserved, to finish

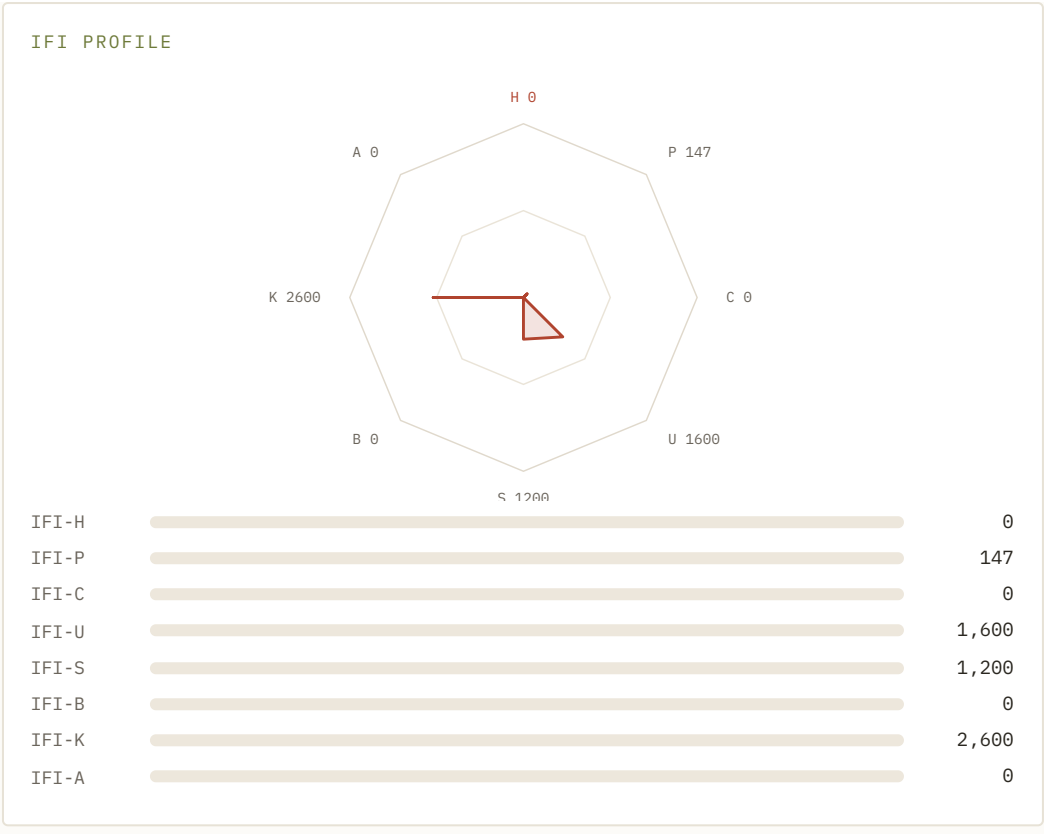
Make it

1. Warm the fat over medium-low. Add the onions and the early pinch of salt and sweat them slowly, 20 to 30 minutes, until soft, sweet, and just beginning to gold. You are building the floor; do not rush it.
2. Add the sliced Keystone garlic and cook gently another 10 minutes — in from cold-ish, never scorching — so it melts into depth rather than sharpening. The base should smell round and deep, not sharp.
3. Build your dish on this base: the tomato, the spice bloomed in the fat, the stock or water, the lentils or beans or greens. Let it cook as the dish wants.
4. **At the very end, off the heat,** stir in the raw grated Whetstone clove. This is the two-station trick of Chapter 17: a deep sweated floor *and* a bright raw lift of the same plant, the allium's two axes deployed at two times in one pot.

Why it works — The sweated **Ballast** and **Keystone** lay down the kokumi-and-sweetness floor — the γ-glutamyl depth reading through CaSR, the freed fructan sugars, the browning umami — the savory base that older cooking chased through bones and long reduction, laid directly by the plant (Chapters 10, 12, 14). Then the raw **Whetstone** at the end throws a half-second of TRPA1 brightness across the top, the window over the floor, lifting everything slower beneath it. We write this vegetarian-first because that is our table and our instinct, and because the base *proves* the depth was never only in the meat — it was in the peptides, and the allium was always carrying its share. A meat or seafood kitchen loses nothing here and

we write it with equal respect: a good stock and a well-built allium base are additive, not rivals, and a braise is glad of both. But the floor comes first, and the floor is an allium.

Predicted IFI readout — the finished base



A closing note · the good grown in with the flavor

There is a reason the allium is the one plant nearly every cooking culture independently decided to start with, and it is not only flavor. The organosulfur compounds we design it for — the allicin and its sulfur kin, the diallyl sulfides, the S-allyl-cysteine that deepens as it ages — and the γ-glutamyl peptides that carry its depth, glutathione chief among them, the body's own master antioxidant, and the fructan fibers its sweetness is banked in: these are the plant's own chemistry for looking after itself, and they happen to be among the compounds a long human tradition has reached for alliums to find. We make no claims about them; that is not our place, and it is not this book. We only notice, the way we notice it everywhere in this library, that the thing we design for depth and the thing that nourishes keep turning out to be the same thing, designed in together, banked in the same bulb, revealed by the same knife and the same slow pan.

That is the whole quiet argument of designing an allium on purpose. Not to make garlic smell more like garlic or an onion sweeter than it should be, but to design back toward the fullness a hundred clonal centuries of shipping-first, size-first, mildness-first selection left behind — the depth you feel, the sharpness you taste, the floor a kitchen is supposed to begin from. We learned to hold the one branch point where the plant's whole flavor is decided, and to hold it to a number, in a plant that for all of recorded agriculture could not be bred and could only be chosen. Build the base well and the rest of the meal takes care of itself. That was always what the oldest cooks knew when they reached, first, for an allium and a knife — a clove that waits, loaded and divided, for exactly that moment. We have only learned, at last, to model what they were reaching for, and to design it back on purpose, so that the base is the same base in August and in February, in our kitchen and in yours. These are computational designs; Scoville Splice's cultivars and constructs have not been experimentally validated in a laboratory.