

THE SCOVILLE SPLICE LIBRARY · VOLUME XXIX

Full Spectrum

Every axis, at once. *The whole note, sounded.*

The composite axis in full — how eight tastes become one number, the ten-step climb to Phoenix, and the molecular, metabolic, and delivery engineering that lets a single fruit speak on all eight receptor channels at once.

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

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Opening essay · The whole note

There is a sound a kitchen makes when a dish is finished — not the clatter, but the sudden quiet after, when someone takes the first bite and does not speak. We have chased that quiet our whole lives as a family, and for most of them we could not have told you what was in it. A good broth, a great chili, the tomato that stops conversation: we knew them when we tasted them, and we knew they were not *one* thing. They were full. They had warmth and savor and a sweetness underneath and a bitterness kept exactly in check, a grip at the edges and a coolness threading through, all of it arriving at once and somehow in order, a chord and not a note. We could feel the fullness precisely. We had no way at all to say how full, or of what.

This book is about the number for that. Volume I of this library built the instrument — eight axes, each one a receptor pathway the tongue reads the world through, each scored by how *loudly* a stimulus speaks to the receptor built to hear it, anchored to the half-maximal point and written as a ratio against a fixed reference. That volume took the eight axes one at a time, because that is how you learn an instrument: a scale before a chord. This volume is the chord. It is about what happens when a single plant is tuned to speak on all eight channels at once — the composite axis we call **IFI-F**, Full-Spectrum, the eighth-and-one — and about the one cultivar that first reached it, read gene by gene and grown on purpose to register everywhere a tongue can register.



FIG. 1 — The greenhouse at first light, where the question that became this book was asked at a family table: not how hot, but how whole.

The temptation, when you learn you can make a plant louder, is to make it loud. The flagship superhots that open Part II of this book are that temptation followed honestly to its end — a ladder of ten cultivars climbing from eight hundred thousand Scoville units to nearly three million, each one a feat, each one louder than the last. But loudness is only one axis's story, and a plant that is only loud is only telling you one thing at the top of its voice. Somewhere up that ladder the question in the greenhouse changed. We stopped asking *how hot can a fruit be* and started asking *how much of everything a fruit can be at once* — not the tallest peak but the fullest profile, not

a soloist but a whole small orchestra grown on one stem. The answer to the second question is a different kind of achievement, and a much harder one, and its name is **Phoenix**

Full spectrum is not a sum. This is the first thing to hold, and the whole book turns on it. You do not get a full-spectrum flavor by adding up eight loud single-axis flavors, any more than you get a chord by playing eight notes as loudly as possible one after another. Eight tastes fired at once interfere — sweetness quiets bitterness, pungency sharpens heat, a tannin can fold an alkaloid out of solution before it ever reaches its receptor — and eight biosynthetic programs run in one cell compete for the same carbon, the same reducing power, the same handful of precursor molecules that every pathway draws from. And even once a plant *contains* eight balanced flavors, eight molecules with wildly different sizes and solubilities and speeds do not arrive at the tongue together; left to themselves they smear across time and partition into different phases, so that a profile balanced in the fruit lands lopsided in the mouth. To design the whole note you have to solve all three problems at once — the perceptual, the metabolic, and the delivery — and that trinity is the real subject of these pages.

We have organized them as the design itself proceeds. Part I defines the composite: what IFI-F actually measures, the arithmetic that turns eight numbers into one honestly, and the fact of eight receptors reading in parallel. Part II climbs the ladder to Phoenix and reads that one fruit completely, axis by axis. Part III goes down into the molecule — the two AI-designed variants in a single enzyme, the ancient pathway they sit on top of, and the flux-balance mathematics of running eight flavor programs in one living cell without starving any of them. Part IV is delivery: why simultaneous arrival is its own engineering problem, how a nanoparticle solves it, and how a flavor is composed not only in loudness but in time. Part V is the whole in use — the interaction matrix that governs how eight axes behave together, the full profile on a plate, the precision that has to hold on all eight at once, and where the composite goes beyond the pepper that first carried it.

A word, before we begin, about why a family of people who care a great deal about nourishment spent years learning to build a fruit that can set a tongue alight on every channel it owns. It is not for spectacle, though there is spectacle in it. It is because *whole* is the word we most want for food — a tomato that tastes like the whole of a tomato, a broth that carries the whole of what a broth can carry, nothing hollowed out and nothing left unsaid. The full spectrum is the far technical edge of a very old and very domestic wish: to grow a thing that holds everything it is able to hold, and to hand it to someone you love with none of it missing. We learned to measure taste so we could build it well. We learned to build the whole of it so that nothing good would be left out by accident. That is the quiet under all eight axes, and we will say it once here and then let the numbers carry it.



PART I OF V

The Composite Axis

What IFI-F measures · the arithmetic of the whole · eight receptors, one bite

Chapter 1 · The Eighth-and-One — *what it means to score the whole.*

The shared index of this library lists ten axes, and the discipline of the thing is to notice that two of them are a different kind of entry than the other eight. The first eight — Heat, Sweetness, Umami, Zero-Bitter, Kokumi, Cool-Burn, Pungency, Astringency — are *primary*. Each names one receptor pathway and one responsible mechanism, and each is scored directly, the way you measure a length or a mass: present the stimulus, read the receptor's half-maximal point, take the ratio against the reference. The ninth and tenth are not measured; they are *composed.* **IFI-M**, Multi-axis, names any flavor that speaks two or three axes meaningfully at once — the swicy heat-and-sweet of Volume XXVI, the savory depth of umami crossed with kokumi in Volume XXVII. **IFI-F**, Full-Spectrum, names the limit of that composition: a flavor that speaks all eight at once. This book is the book of that limit.

So the first thing to be precise about is what kind of object IFI-F is. It is not a ninth receptor. There is no "full-spectrum receptor" on the tongue, no single cell that reports wholeness; the body has no sense organ for completeness. IFI-F is a *statistic computed over the other eight* — a single number that answers one question about a profile: how much is this flavor speaking, taken across every channel at once, and how evenly. It is to the eight primary axes what a chord's name is to its notes. The notes are real and separately audible; the chord is a true thing about them considered together, and naming it tells you something the separate notes do not.



FIG. 2 — A single Phoenix specimen under isolation light. One fruit, carrying a predicted value on every one of the eight channels a tongue can read.

Why does the composite deserve its own axis, its own letter, its own book? Because wholeness is the property almost everything we love about food actually has, and the property the single-axis view is structurally blind to. Read a great broth one axis at a time and you will find it is not the loudest umami you have ever measured, nor the richest kokumi, nor the most perfectly attenuated bitterness — and you will have completely missed what makes it great, which is that it is *all of those at once, in balance,* a thing no single axis can see because no single axis is looking at more than one note. The history of flavor measurement, such as it was, is a history of single axes:

Scoville measured heat and only heat, a Brix meter reads sugar and only sugar, a trained panel scores one descriptor at a time down a long sheet. The composite is the first instrument that takes the whole profile as the unit of analysis. It is, in a real sense, the axis this entire library was built to make legible — the others are the vocabulary, and IFI-F is the sentence.

That sentence has a grammar worth stating now, because it separates the two composite entries in the index. **IFI-M**, the multi-axis composite, names a flavor that speaks two or three axes with intent — a dual like swicy's heat-and-sweet, a triple like the savory braid of umami, kokumi, and a measured heat — and the index counts these in the thousands precisely because two or three programs are a conversation a cell can usually hold. **IFI-F** is the limit of that same grammar: not *some* axes together but *all* of them, the sentence that uses every word in the language at once. The difference is not one of degree but of kind, the way a chord of three notes and a chord of eight are different musical objects — the first a color, the second a saturation. The three hundred IFCs are the catalog of that saturation: three hundred distinct points in the eight-dimensional space of all possible profiles, each one a flavor that has been designed to go dark on no channel at all. A cultivar is a plant; an IFC is a *decision* — a chosen location in the whole of flavor-space, rendered as something you can put in your mouth.

The index attaches two concrete things to IFI-F, and both matter for the chapters ahead. The first is the number **300** — the count of distinct full-spectrum composite products in the line, each a defined eight-axis target rendered real. We call each one an **IFC**, an Iyengar Flavor Composite: not a plant and not a single molecule but a *composed whole*, a specified value on all eight channels delivered as one thing. The second is the phrase **NP delivery** — nanoparticle delivery — which is attached to the full-spectrum axis and to no other, and the reason for that attachment is the whole of Part IV. In brief: a single-axis flavor can survive being mixed crudely into a food, because there is only one thing arriving and nothing for it to fall out of step with. A composite cannot. The moment you are trying to land eight molecules at eight receptors in a designed balance, the differences between those molecules — their solubility, their volatility, their speed — become the enemy, and you need a carrier that holds all eight together and lets them go on a schedule you chose. Delivery is a side note for a single axis. For the full spectrum it is half the engineering.

CODE	AXIS	RECEPTOR	WHAT THE COMPOSITE DRAWS FROM IT
IFI-H	Heat	TRPV1	the warmth that pools and lingers
IFI-S	Sweetness	TAS1R2 · TAS1R3	the sweetness underneath, with no sugar
IFI-U	Umami	mGluR1 · TAS1R1·TAS1R3	the savory pull, the brothy depth
IFI-B	Zero-Bitter	TAS2R38	bitterness held in check, 20–65% off
IFI-K	Kokumi	CaSR	the continuity, the body, the round
IFI-C	Cool-Burn	TRPM8	the coolness threaded through the warmth
IFI-P	Pungency	TRPA1	the sharp bright edge, the top note
IFI-A	Astringency	salivary PRPs	the grip, the structure, the finish

Hold that table beside the one image of a full-spectrum fruit and the ambition of the composite becomes plain. Every row is a separate receptor, a separate chemistry, a separate biosynthetic route, a separate envelope in time. A single-axis cultivar is a feat of making one of those rows loud. A full-spectrum cultivar is a feat of making all eight *present and balanced in one living fruit at one moment* — and then, through the carrier, present and balanced again in one mouth. The composite axis is where this library stops describing flavor and starts composing it. The rest of Part I is the arithmetic and the biology that make the composition honest.

Chapter 2 · The Arithmetic of the Whole — *the composite, the balance, the geometry.*

Eight numbers do not become one number for free. The choice of *how* you collapse a profile into a composite is not a formatting decision; it is a statement about what you think fullness is, and a careless choice will lie to you. So we will build IFI-F slowly, from a requirement, and let the requirement pick the formula.

Start with what the composite must refuse to do. It must refuse to reward a spike. A cultivar with a towering heat and seven silences is not full-spectrum — it is a soloist — and any composite that would score it highly has misunderstood the word. The simplest collapse, the arithmetic mean of the eight axes, fails exactly here: average 4,000 on heat and 0 on everything else and you get 500, a respectable-looking number for a flavor that is, in truth, a single scream. The arithmetic mean treats a missing axis as merely a low contribution to be outweighed, when fullness demands that a missing axis be something closer to disqualifying. We need a collapse in which *every axis has a vote and any axis can veto.*

That is the defining property of the **geometric mean**, and it is why we build the composite from it. Write the eight per-axis scores as s_1 through s_8, each already a proper IFI value against its own reference and capped, like every scorecard in this library, at the per-axis normalization maximum of 5,000. The Full-Spectrum composite is their geometric mean:

> **IFI-F = (s₁ · s₂ · s₃ · s₄ · s₅ · s₆ · s₇ · s₈)^(1/8)**

Walk its behavior once and you will trust it thereafter. If every axis equals the reference — the origin profile, all eight at 1,000 — the product is $1{,}000^8$ and the eighth root is exactly 1,000, so the composite is anchored like every other axis: a flavor of eight references reads 1,000 on the whole. Raise every axis together and the composite rises with them. But drive any single axis toward zero and the whole product collapses toward zero no matter how loud the other seven are, because zero times anything is zero. The geometric mean cannot be fooled by a spike and cannot ignore a silence. It is high only when the profile is *both loud and complete*, which is precisely the definition of full spectrum we started from. The formula did not decide what fullness is; the requirement did, and the geometric mean is the honest arithmetic of that requirement.

Work the composite once by hand and it never needs re-deriving. Take Phoenix's eight axes — 4,200, 252, 800, 1,800, 1,100, 2,200, 1,900, 1,400 — and rather than multiply eight large numbers, add their base-ten logarithms, because the logarithm of a geometric mean is the plain average of the logarithms. The eight logs sum to 24.99; divide by eight for 3.124; raise ten to that power and you land at approximately **1,330**. That is the whole operation: average the

loudnesses in log-space, then come back out. And averaging in log-space is not a trick but a fidelity, because loudness is *perceived* logarithmically — a score twice another is one meaningful step louder, not twice as intense in the mouth — so the geometric mean composites the axes in the very currency the tongue spends them in. The per-axis cap of 5,000 lives in the same logic: it is the ceiling past which a receptor sits so near saturation that more stimulus buys almost no more sensation, so a score is held there rather than allowed to run off into a precision the mouth could never feel.

One might ask why not go further still and score the composite by its *weakest* axis alone — the strict minimum, the single darkest channel — since a chain is only as strong as its weakest link and fullness only as good as its emptiest note. We tried it, and it is too brittle: the minimum throws away all information but one number, so two profiles that differ everywhere except their quietest axis score identically, and a flavor is punished without mercy for one modestly soft channel it might have earned honestly. The geometric mean is the humane middle between the arithmetic mean, which forgives silence, and the minimum, which forgives nothing: it lets a strong axis partly compensate a weak one, but only partly, and it still collapses toward zero if any axis truly goes dark. It is the measure that most nearly matches what a taster means by *whole* — not flawless on every channel, but present on all of them, with no hole you could put a finger through.

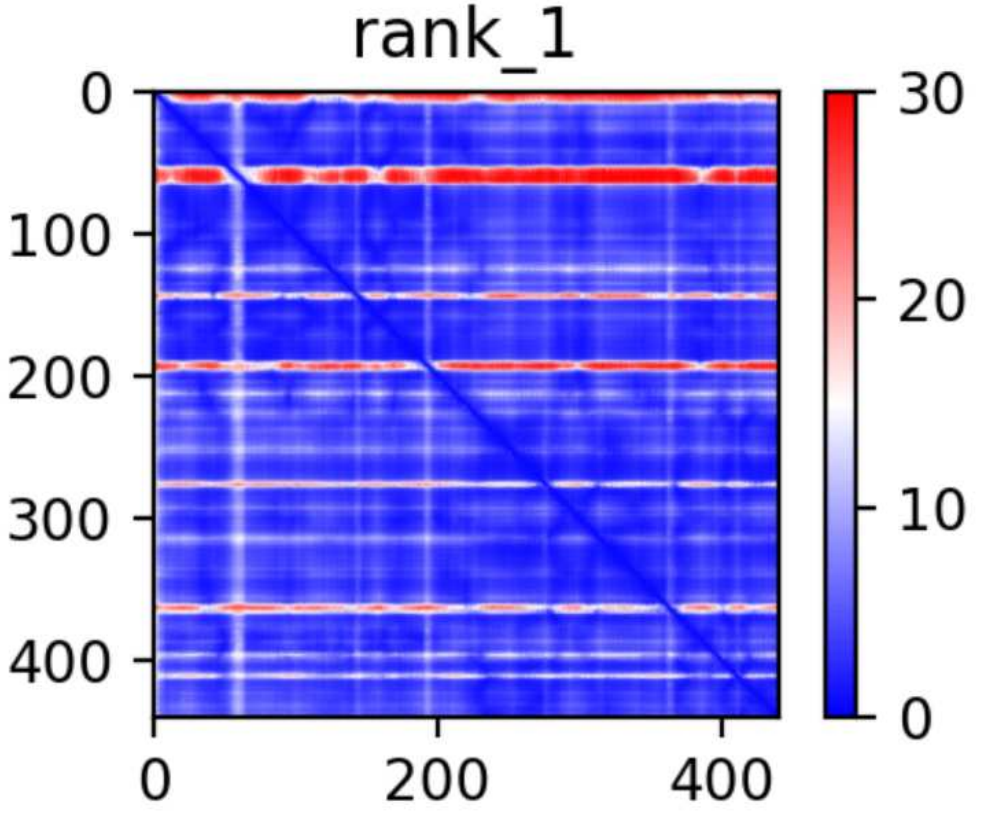


FIG. 3 — A predicted response-surface matrix from the structural pipeline. A profile is read as a whole surface, not a stack of single points.

The composite tells you *how much, altogether.* It does not tell you *how evenly*, and evenness is its own property worth its own number, because two profiles can share a composite and feel nothing alike — one a gentle plateau, the other a jagged range with the same geometric center. We measure evenness as the ratio of the geometric mean to the arithmetic mean of the same eight axes:

$$E = \text{IFI-F} \div (\bar{s}) \text{ where } \bar{s} \text{ is the arithmetic mean of the eight axes}$$

This ratio is a classic evenness index, and it behaves exactly as evenness should. It equals **1** when the profile is perfectly flat — every axis identical, geometric and arithmetic means coincide — and it falls below 1 as the profile grows spiky, because the geometric mean is always pulled down by imbalance while the arithmetic mean is not. A profile's evenness is, in effect, how close it comes to being a balanced chord rather than a dominant note with accompaniment. Together the two numbers describe a profile almost completely: the composite says how much flavor is present across all channels, the evenness says how democratically it is distributed, and a third descriptor — *coverage*, the count of axes above a stated floor — says how many channels are meaningfully lit at all. Loud, even, and complete: three orthogonal questions, three honest numbers.

There is a seductive fourth way to picture a profile, and we use it for the eye but never for the score, and the reason is a small lesson in rigor. Plot the eight axes as spokes of a radar, 45° apart, and connect the points; the flavor becomes a polygon, and the polygon has an area. For a radar of eight equally spaced axes that area is

$$A = (\sqrt{2} \div 4) \times \Sigma\, s_i \cdot s_{i+1} \text{ (indices cyclic, } i = 1\ldots8)$$

a sum over *adjacent* pairs of axes around the ring. It is a lovely picture and a treacherous number, because it depends on the *order* in which the axes are arranged around the circle. Put two loud axes next to each other and the polygon bulges; move one of them across the ring and the same eight values enclose a different area, though nothing about the flavor has changed. The polygon's area is an artifact of a seating chart. So we draw the radar because a person reads a shape faster than a list, but we *score* the composite with the geometric mean, which is invariant to the order of its factors — rearrange the eight axes however you like and the product, and its eighth root, are identical. A good instrument is as careful about what it refuses to let into the number as about what it lets in.

Let the real case ground all of it. Phoenix, read completely in Chapter 6, carries this profile: heat 4,200, pungency 252, cool-burn 800, umami 1,800, sweetness 1,100, zero-bitter 2,200, kokumi 1,900, astringency 1,400. Its arithmetic mean is **1,707**. Its geometric-mean composite — the product of all eight, under the eighth root — works out to **IFI-F ≈ 1,330**, about 1.3 times the reference loudness averaged across every channel the tongue owns. Its evenness is 1,330 ÷ 1,707 ≈ **0.78** — broadly balanced for a fruit spanning a wide range, with pungency calibrated at 252 on its TRPA1 convention scale while heat reaches 4,200. And its coverage is **8 of 8**: every channel lit, none silent, nothing left out. That triplet — composite 1,330, evenness 0.78, coverage 8/8 — is the first full-spectrum fingerprint ever recorded, and the rest of this book is the story of how a plant was designed to leave it.

Chapter 3 · Eight Receptors, One Bite — *the tongue reading on every channel at once.*

The arithmetic of the last chapter quietly assumed something the body has to actually do: read eight channels simultaneously and keep them separate enough that a score on each one means something. If the tongue blurred its eight inputs into a single muddy signal, the whole project of a composite would be a fiction — you cannot balance eight things the eater cannot tell apart. So before we climb to Phoenix, we should stand inside a single full-spectrum bite and watch eight receptor systems fire at once, because the fact that they *can,* and stay distinct, is the biological permission for everything that follows.

The eight do not even share a wire. This is the first mercy. Heat, pungency, and cool-burn run through the **TRP ion channels** — TRPV1, TRPA1, TRPM8 — proteins that are themselves pores, flinging open in a few thousandths of a second and dumping cations into the cell, and they ride the *trigeminal* nerve, the great sensory cable of the face, the same line that reports a scald or a cut. Sweetness, umami, kokumi, and the bitterness that Zero-Bitter works against run through the **G-protein-coupled receptors**, the seven-pass helix bundles that do not conduct anything but instead change shape, shove a G-protein called gustducin off its seat, and set off a slow cascade — PLCβ2, then IP_3, then a flood of internal calcium, then the channels TRPM5 and CALHM1, then ATP released onto the gustatory nerves. And astringency runs through neither: it is a *mechanical* percept, tannins precipitating the proteins that lubricate the mouth, reported by touch. Three mechanisms — a channel, a cascade, a friction — carried on two different nerves to the brain. A full-spectrum bite is not one sense overloaded; it is several senses playing at once, which is exactly why a chord and not a smear is possible.

It is worth standing inside the slow machinery for a moment, because its slowness is audible in the food. When a sweet or umami or kokumi molecule lands on its class C receptor, nothing conducts; the receptor flexes, and that flex shoves gustducin off its seat to wake the enzyme PLCβ2, which cleaves a membrane lipid into the second messenger IP_3, which springs a calcium store inside the cell, whose flood opens the channel TRPM5, whose current finally depolarizes the cell and opens CALHM1 to release ATP onto the waiting nerve. Five or six steps, each taking its small moment — which is exactly why sweetness and umami and kokumi feel rounder and *slower* than the ion-channel axes, a chord that blooms rather than a note that strikes. The heat and the pungency and the cool, running through TRP channels that are themselves the pore, are quick on both ends; the GPCR tastes arrive late and leave late. A full-spectrum bite is therefore already sequenced by its own wiring

before a single carrier is designed — the fast physical axes first, the slow chemical ones blooming under them — and good composition works with that native order rather than against it.



FIG. 4 — A taste-cell preparation on the microscope stage. In one full-spectrum bite, eight receptor systems on membranes like these answer at once.

Go closer and the eight sort themselves further by architecture, and the architecture predicts how far each can be designed. The GPCRs split into two classes. The **class C** receptors — the sweet pair TAS1R2·TAS1R3, the umami pair TAS1R1·TAS1R3, the kokumi-sensing calcium receptor CaSR, the umami-reading metabotropic glutamate receptor mGluR1 — carry a huge clamshell domain called the Venus flytrap, and they read the tastes the body *wants*: they are choosy, cooperative, built to recognize specific nourishing molecules and often to be nudged by a second molecule that makes the first bind better. The **class A** bitter receptors, the TAS2R family, are compact and deliberately promiscuous, built to recognize *poison*; there are some twenty-five of them because the catalog of things that might harm you is long, and TAS2R38 is the one the Zero-Bitter axis most often answers. The discerning clamshell and the broad alarm panel behave differently under the knife, and a composite has to respect both: you *add* to the wants and you *subtract* from the alarms, and these are opposite operations on opposite machinery.

Now the real question of this chapter: why do eight simultaneous signals not simply cancel into noise? Three reasons, and each is load-bearing for the composite. First, **the periphery keeps mostly labeled lines.** A sweet cell is, in the main, a sweet cell; the weight of evidence says that at the tongue each quality travels largely on its own dedicated fiber rather than being smeared across a shared population. That is a quiet gift to the Index — an axis measured at the receptor corresponds to a sensation the brain keeps mostly separate, so eight scores can coexist without collapsing into one. Second, **the eight have different envelopes in time** (the whole of Chapter 12), so even when they overlap they do not perfectly coincide — pungency flashes and is gone while heat is still arriving, astringency builds across the whole bite while sweetness has already peaked and begun to fade — and separation in time is separation, a way for eight things to be heard without masking each other into mud. Third, and most important for design, **integration happens centrally, not at the receptor.** The axes stay distinct where they are transduced and only meet later, in the insular cortex, where the brain assembles them into a single perceived flavor — which

means the interactions between axes (sweet quieting bitter, kokumi lengthening umami) are largely *perceptual*, computed in the brain from eight signals that arrived cleanly, not failures of the receptors to keep their stories straight.

That last fact is the hinge between the biology and the engineering, so let it stand plainly. Because the receptors read cleanly and the brain does the mixing, the full-spectrum design problem splits exactly in two. There is the *delivered* profile — how much of each stimulus actually reaches each receptor, which is chemistry and metabolism and carrier physics, and which we can compute as eight predicted EC_{50} targets. And there is the *perceived* profile — what the eater finally experiences after the brain has applied its cross-modal arithmetic of suppression and synergy, which we study in Chapter 13. The two are not the same, and the gap between them is where the art lives: to land a *perceived* balance you must often deliver an *imbalance*, pre-distorting the eight delivered levels so that after the brain has quieted the bitterness with the sweetness and lengthened the umami with the kokumi, what remains is the chord you meant. The tongue's willingness to read eight channels at once, and the brain's habit of mixing them afterward, are the two permissions that make a composite designable at all. With those granted, we can climb.



PART II OF V

The Ladder to Phoenix

Ten cultivars · the jump to eight · one fruit, read completely

Chapter 4 · The Ten-Step Climb — *from a warning to a whole spectrum.*

The composite was not reached in a leap. It was climbed, in ten deliberate steps, by a program whose first purpose was heat and whose later purpose quietly became wholeness — and the ten-rung ladder those steps left behind is the clearest teaching object in this library, because you can watch, cultivar by cultivar, loudness turn into fullness. Every rung is a real *C. chinense* line with a real SKU, a predicted SHU and a predicted value on the heat axis; the climb is not a metaphor.

CULTIVAR	SKU	SHU (PREDICTED)	IFI-H	COVERAGE
Ember	SS-0087	866K	1,570	2 / 8
Cinder	SS-0088	1.05M	2,290	3 / 8
Kindle	SS-0089	1.25M	2,000	3 / 8
Flare	SS-0090	1.48M	—	4 / 8
Blaze	SS-0091	1.72M	2,630	4 / 8
Wildfire	SS-0092	1.96M	2,930	5 / 8
Scorch	SS-0093	2.21M	3,220	5 / 8
Firestorm	SS-0094	2.47M	3,490	6 / 8
Solara	SS-0095	2.72M	3,980	6 / 8
Phoenix	**SS-0096**	**2.95M**	**4,200**	**8 / 8**

Read the SHU column first and you see an almost ruled line: roughly a quarter-million heat units added at every rung, a steady mechanical climb from eight hundred sixty-six thousand to our model's prediction of approximately 2.95 million for Phoenix — a number we carry with precision because a computational design can be as specific as the biology it represents. The capsaicinoid content rises like a staircase. But run your eye down the *coverage* column beside it and you see something the SHU figure cannot: the axes do not accrue smoothly at all. They arrive in jumps — two, then three, a long plateau at three and four, five, six, a plateau at six — and then, between the ninth rung and the tenth, from Solara to Phoenix, a single step from six axes to eight. The heat climbed like a ramp. The wholeness climbed like a staircase, and its last step was the tallest.

Notice, too, that the ladder is a *designed* sequence of increasing computational scope and axis activation — not a certified ascending measurement — ten SKUs, SS-0087 through SS-0096, each a deliberate step whose heat and coverage were targeted before the seed was ever sown. The early rungs were pure loudness, the program climbing the one mountain it set out to climb; but somewhere around the middle rungs the coverage column begins to move in earnest, two axes becoming three and four and five, and you can read in that column the exact moment the question

changed. The program did not stumble onto wholeness at the top. It turned toward it, on purpose, partway up — and the last four SKUs are the record of a company deciding that the fullest fruit, and not merely the fiercest, was the thing worth reaching. The ladder is a biography of an ambition as much as a catalog of cultivars.



FIG. 5 — A research tray of the flagship series, the climb laid out in specimens. Total heat rises evenly; the number of lit axes rises in jumps.

There is a deliberate puzzle in the table, and solving it is the reason the whole Index exists, so look at the third rung. **Kindle** carries a predicted 1.25 million Scoville units — more total capsaicinoid than Cinder's 1.05 million on the rung above it — and yet it reads *quieter* on the heat axis, IFI-H of 2,000 against Cinder's 2,290. More heat compound, less heat score. This is not an error; it is the single most important lesson a flavor number can teach. Scoville counts *mass* — total capsaicinoids, measured by HPLC, however potent or weak each one is. IFI-H counts *loudness* — how hard the blend drives TRPV1 at its half-maximal point. And the capsaicinoids are not interchangeable: capsaicin and dihydrocapsaicin are the ferocious ones, but nordihydrocapsaicin and the longer congeners are milder at the receptor, so a fruit can pile up more total capsaicinoid mass while shifting its *blend* toward the quieter molecules and end up speaking the heat axis with a smaller voice. Kindle is heavier and softer. Cinder is lighter and louder.

The chemistry under that inversion is worth naming, because it is the same chemistry that sets the heat of every cultivar in this book. Scoville units, in their modern honest form, are a high-performance liquid chromatography measurement — the total mass of capsaicinoids in a sample, separated and summed, each congener weighted by a factor meant to approximate its pungency. But those weighting factors are a convention, and the congeners genuinely differ at the receptor: capsaicin and dihydrocapsaicin together carry the overwhelming majority of a hot pepper's bite and drive TRPV1 ferociously, while nordihydrocapsaicin, homocapsaicin, homodihydrocapsaicin, and the longer-chain relatives are milder, some markedly so. A fruit's *heat shape* is the ratio among these, set by the acyl-chain machinery of Chapter 8, and two fruits of identical total capsaicinoid mass can land a fifth apart on the Index if one has shifted its blend toward the quiet congeners. Kindle is such a fruit — more total capsaicinoid than the rung above it, but a blend tilted toward the milder molecules, so it reads softer than it weighs. The Index hears the blend; the scale only weighs the pile. The body does

not weigh your food; it listens to it, and the Index listens with it. A composite built on Scoville alone would have mistaken Kindle for the hotter fruit and been wrong in the mouth.

So the ladder teaches two things before we even reach the top. It teaches that *loudness and quantity are different measurements* — the reason the Index anchors to EC_{50} and not to milligrams — and it teaches that *loudness and wholeness are different achievements*, the one a ramp and the other a staircase. Every rung from Ember upward was a triumph of making heat louder. Only the last rung was a triumph of making a fruit *whole*. The next chapter is about that last rung — the jump from six axes to eight — because it is where the program stopped climbing the mountain it had been climbing and climbed a different one.

Chapter 5 · The Jump to Eight — *what the last two axes cost.*

Between Solara and Phoenix there is one rung, and across it the SHU figure barely moves — 2.72 million to 2.95 million, the same quarter-million step as every rung below it — while the coverage leaps from six axes to eight. That mismatch is the entire chapter. The last two axes cost almost nothing in *heat* and almost everything in *everything else*, and understanding why is understanding the difference between making a flavor louder and making it complete.

Which two axes were missing at six, and why were they the hardest? At six-of-eight, Solara already spoke heat, pungency, zero-bitter, kokumi, umami, and astringency — the axes that come, in a pepper, relatively *near* the pathways heat already runs on. Heat and pungency share a chemical neighborhood and a biosynthetic logic; a fierce pepper is already an astringent one and already carries the kokumi-adjacent peptides and the savory glutamate of a ripe nightshade fruit, and lowering its own bitterness is a subtraction the Zero-Bitter machinery was built to make. The two that remained — the two that the jump to eight had to install — were **sweetness** and **cool-burn**, and they were last precisely because they are the two most *foreign* to a superhot pepper. A C. chinense at three million Scoville is, left to itself, the least sweet and least cooling fruit imaginable; it is a plant that has spent its whole evolutionary budget on the opposite of those two sensations. To make it speak them is not to turn a dial the plant already has. It is to give the plant a voice it was never built to have.



FIG. 6 — Solara (SS-0095) at six of eight. The last rung to Phoenix added almost no heat and two entire sensory channels the pepper was never built to speak.

Consider cool-burn first, because it is the cleaner story. Cooling is read by TRPM8, and the native agonist is menthol, the product of a five-enzyme pathway that lives in mint and not remotely in pepper. A pepper has no menthol, no menthol pathway, and no reason in its own biology to make one; the cool-burn axis in Phoenix is a *transplanted capability*, a program carried in from an organism on the other side of the plant kingdom and made to run in a nightshade fruit alongside the fire it is meant to thread through.

The pathway that had to be carried is itself a small marvel, five enzymes long, and it runs in mint from the terpene precursor geranyl diphosphate down through limonene synthase to a chain of oxidations and reductions — limonene to isopiperitenol and isopiperitenone and onward, each step its own specific enzyme — until it arrives at (−)-menthol, the single stereoisomer that TRPM8 reads most brightly. To light cool-burn in a pepper is to install that five-step mint program in a plant that has never carried a word of it, supply it the terpene precursor from the plant's own isoprenoid pool, and tune its output not to the loudest menthol the pathway can make but to our design target of 800 that threads through the fire without waking the heat-cool cross-suppression. It is the single most foreign thing in Phoenix's genome — a flavor borrowed across the whole width of the plant kingdom, grown into a fruit built for the opposite sensation, and held deliberately quiet so that the two most antagonistic channels on the tongue can be heard in a single bite. And here the design had to reckon with the fact that TRPM8 and TRPV1 are not indifferent to each other — cool and heat partially cross-suppress, each channel's activity damping the other's, which is why a genuinely hot-and-cooling sensation is so rare in nature and so arresting when you meet it. The eighth axis was not just hard to install; it was hard to install *next to the first axis* without one quieting the other. Phoenix's cool-burn is designed at 800 — the lowest of the seven non-pungency values in its profile, and deliberately so, because a cooling loud enough to balance the heat on paper would have been loud enough to fight it in the mouth.

Sweetness was the other, and it carried a different difficulty: not foreignness of pathway but a direct contradiction of what the plant had been bred to be. Three million Scoville units is a metabolic commitment; the fruit is pouring carbon and acetyl units into capsaicinoid synthesis on a scale that leaves little for the sugars and sweet proteins the TAS1R2·TAS1R3 pair reads. To light the sweetness axis without stealing from the heat axis meant solving a *resource* problem, not just a pathway problem — finding the carbon for sweetness somewhere other than the carbon already spoken for by fire. This is the metabolic heart of Part III, and Phoenix's sweetness of 1,100 is its visible result: a real sweetness underneath the heat, grown in without the heat giving an inch. The jump to eight, then, was two installations of two different hard kinds — a foreign pathway carried across the kingdom and tuned not to fight its loud neighbor, and a contradictory capability funded without robbing the fruit's dominant program. That is why the last rung cost what it cost. Loudness is a ramp because you are climbing a mountain the plant already stands on. Wholeness has a last step like a cliff because the final axes are the ones the plant was built to refuse.

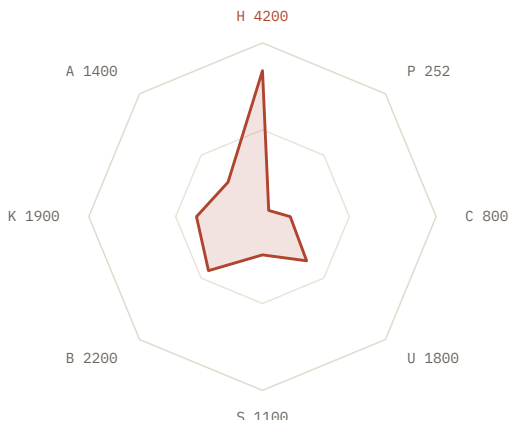
This is a principle, not an accident of one pepper, and it generalizes to every organism the method will ever reach. The axes hardest to install in a plant are always the ones furthest from what the plant already is: a superhot's last two axes are sweetness and cool because a superhot is the least sweet and least cooling fruit alive, but a tomato's hardest axis would be heat, and a mint's would be the savory depth it has no native reason to carry. Read the roadmap of

Chapter 16 through this lens and its tiers come into focus — the early tiers stay inside the nightshades, close to the pepper's own chemistry, where few axes are truly foreign; the later tiers cross into families where more and more of the eight must be carried in from elsewhere, which is exactly why they take more genes and more years. The jump to eight is the pepper's version of a cost every full-spectrum fruit must pay: the price of wholeness is always paid in the currency of the axes an organism was least built to speak.

Chapter 6 · Phoenix, Read Completely — *one fruit, eight numbers.*

Now we read the whole fruit. Phoenix — SS-0096, the tenth rung, with our model predicting approximately 2.95 million SHU, the first and still the reference cultivar for the full-spectrum axis — carries a predicted value on every one of the eight channels a tongue can read. Here is its complete profile, the first full-spectrum fingerprint ever recorded, in the standard scorecard order of this library:

IFI PROFILE



IFI-H	4,200
IFI-P	252
IFI-C	800
IFI-U	1,800
IFI-S	1,100
IFI-B	2,200
IFI-K	1,900
IFI-A	1,400



FIG. 7 — Phoenix (SS-0096) in cross-section. Every structure in the cut fruit corresponds to an axis in the scorecard: the placental tissue where the capsaicinoids pool, the flesh that carries the savor and the sugar, the skin that holds the grip.

Read it as a shape before you read it as a list. Heat towers — 4,200, more than four times the reference, eighty-four percent of the way to the per-axis ceiling of 5,000 — because Phoenix never stopped being the top rung of a superhot ladder; its fire is the fact of it. But look at the seven numbers under the fire and you see the achievement the fire distracts from: not one of them is zero, not one of them is a token, and together they average, geometrically, to a composite of approximately **1,330**, with an evenness of **0.78** and a coverage of **8 of 8**. Every channel is lit; the design leaves none dark. The pungency axis reads 252 on its TRPA1 convention scale —

calibrated against the 2.1 µM AITC reference constant for that axis — while every other axis except cool-burn reads above 800. The absence of silence across all eight channels is what full spectrum means, and it is the hardest thing in the scorecard to see, because the eye goes to the tall bar and the mind has to be taught to read the field.

Take the eight in turn, because each is a different kind of presence. The table pairs each axis with what the fruit is designed to do to earn it.

AXIS	SCORE	RECEPTOR	WHAT PHOENIX IS DESIGNED TO DO
Heat (H)	4,200	TRPV1	designed to pour capsaicin and dihydrocapsaicin from an AI-tuned double-variant Pun1; the dominant voice
Zero-Bitter (B)	2,200	TAS2R38	designed to attenuate its own alkaloid bitterness so the fruit is fierce without being harsh
Kokumi (K)	1,900	CaSR	designed to carry γ-glutamyl peptides that lengthen and thicken everything around them
Umami (U)	1,800	mGluR1 · TAS1R1·R3	designed to hold the free glutamate of a deeply ripe nightshade, the savory floor
Astringency (A)	1,400	salivary PRPs	designed to keep a measured tannic grip, the structure the finish stands on
Sweetness (S)	1,100	TAS1R2·R3	designed for a real sweetness underneath, grown in without stealing from the heat
Cool-Burn (C)	800	TRPM8	designed for a transplanted cooling, threaded through the fire and tuned not to fight it
Pungency (P)	252	TRPA1	designed for a bright electrophilic top note; scored against the 2.1 µM TRPA1 convention reference

The order of that table is not the scorecard order; it is the order of *loudness*, heat down to pungency, and read that way it tells the design's story. After the fire, the next-loudest thing in Phoenix is not another assault but the *attenuation of bitterness* — zero-bitter at

2,200, the second voice — which is the whole philosophy of the fruit in one number. A three-million-Scoville pepper left to its own chemistry is not just hot; it is *harsh*, its alkaloids bitter and punishing, the heat riding on an ugliness. Phoenix is designed as the opposite: its second-loudest axis is the one that *removes* harshness, so the fire arrives clean, on a floor of savory umami and a body of kokumi, with a grip at the edges and a sharp bright pungency on top and, underneath all of it, a sweetness and a thread of cool that no pepper this hot has any natural right to. It is not the loudest pepper made louder. It is the loudest pepper made *whole* — and the scorecard, read as a field and not a spike, is the proof of it.

Picture the profile as a radar and the achievement draws itself: seven of the eight spokes reach out to somewhere between 252 and 2,200, a broad ring, and one spoke — heat — spikes past all of them toward the rim. The eye is pulled to the spike; the *flavor* lives in the ring. This is the perceptual discipline the whole Index was built to teach, and Phoenix is its hardest lesson, because a fruit this hot trains every instinct you have onto the fire and dares you to miss the other seven. But run the composite and the ring is what speaks: a geometric mean of approximately 1,330 is a ring number, not a spike number — raise heat alone to the ceiling and the composite barely stirs, while let any one of the seven ring-spokes fall toward zero and it collapses. The arithmetic was built, chapters ago, precisely so that the number would see what the eye will not. On Phoenix's scorecard the number sees a ring with no gap in it, and a ring with no gap is the whole definition of the thing.

These are computational designs; Scoville Splice's cultivars and constructs have not been experimentally validated in a laboratory. Everything in Part III is the molecular account of how those eight predicted values were designed into one cultivar; everything in Part IV is how they are made to arrive, all eight, in one mouth.



PART III OF V

The Molecular Basis

Two variants in one enzyme · the pathway beneath · eight programs in one cell

Chapter 7 · Pun1 and the Double Variant — *S39L, L345G.*

Go down far enough and the whole spectrum rests, at its loudest axis, on a single enzyme and two precision variants in it. The enzyme is **Pun1**, the acyltransferase — AT3 in the older literature — that performs the last committed step of capsaicin synthesis: it condenses vanillylamine with an eight-methyl branched-chain fatty acyl group to form capsaicin itself. It is the terminal synthase the whole heat axis flows through, and for ten thousand years of pepper breeding it was tuned only by accident, selected through the phenotype and never read directly. We read it directly, and we found two positions it could be made better that no breeder ever found, because no breeder was ever looking at the protein.

The method is worth stating precisely, because it is the method behind every loud axis in this library. We did not mutate Pun1 at random and taste the results; the sequence space of a three-hundred-residue enzyme is larger than any garden could search. Instead an **ESM2 protein language model** — six hundred and fifty million parameters, trained on the evolutionary record of millions of natural proteins — scored *every possible single-residue substitution* in Pun1 by its predicted effect on the two things that matter: catalytic efficiency and fold stability. A language model trained on evolution learns, without being told, which residues a protein cannot afford to change and which it has merely never happened to try, and it reads a proposed mutation the way it reads an improbable word in a sentence — flagging what breaks the meaning and what sharpens it.

In parallel, a **genome-scale flux-balance model** mapped the control structure of the capsaicinoid pathway; our Metabolic Control Analysis found flux control weighted at the upstream 4CL and HCT steps in the phenylpropanoid backbone — not at the terminal Pun1, which is the capsaicin synthase and determines yield, not rate. Improving Pun1's catalytic efficiency therefore raises capsaicin production within the substrate pool those upstream steps define: more of the available substrate is converted, efficiently, at the final step.

Two pictures from the structural pipeline are worth reading the way a radiologist reads a film, because they are how we knew where it was safe to cut. The first is a model of the enzyme colored by **pLDDT**, a per-residue confidence score from zero to a hundred: the binding domain and the active-site cleft resolve in the high-confidence blues and greens, which means the model is sure enough of their geometry that a proposed edit there can be trusted to do what the simulation says. The second is a **predicted aligned error** map, a heatmap of how well the model pins each pair of residues relative to one another; its cool diagonal blocks mark rigid domains that move as units, and an edit inside such a block is an edit whose consequences stay local rather than rippling through the fold. The language model proposes *what* to change by reading evolution; these structural confidences tell us *where* the proposal can be

trusted. S39L and L345G sit in high-confidence, well-pinned regions — which is why we were willing to write them into a living genome rather than merely admire them on a screen.

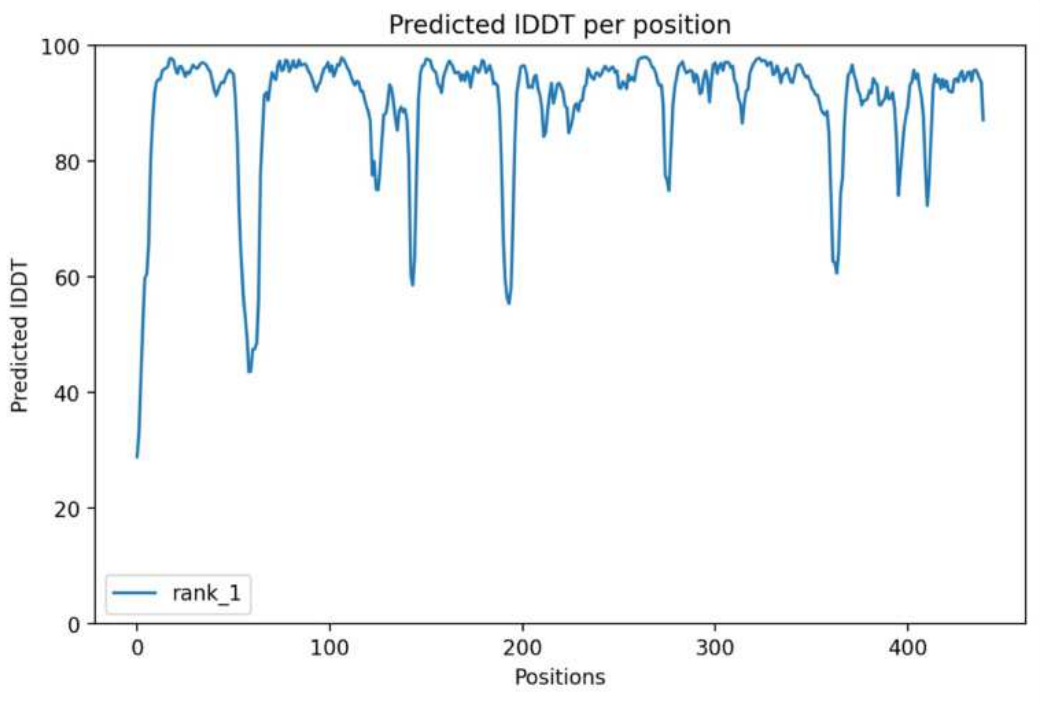


FIG. 8 — The Pun1 / AT3 model coloured by pLDDT confidence. The binding domain and the active-site cleft, where the two variants sit, resolve at high confidence.

Two variants (S39L+L345G) emerged that had never been combined in any pepper that ever grew, and we wrote them into the plant's own gene with CRISPR — not inserting foreign DNA, but changing two of the plant's own letters in its own enzyme. The writing itself is a precise act of chemistry: a guide RNA matched to the Pun1 sequence leads the Cas nuclease to exactly the site to be changed, and the cell's own repair is then steered — by a supplied template, or by base- and prime-editing chemistries that rewrite a single letter without ever making a double-strand break — to leave the intended edit and nothing else. No gene from another organism is added; the pepper ends the procedure with the same genes it began with, two of whose letters now read as the model predicted they should. That distinction — an edit to the plant's own sequence rather than an insertion of foreign DNA — is not only a matter of craft but of how the result is regulated and labeled, which Chapter 16 takes up in full.

Each variant is small, each is specific, and each buys a different thing. The table below also records C175S, which our modelling identified as beneficial for fold stability; it is included as a structural annotation and was not included in the shipped construct.

EDIT	POSITION	EFFECT	ΔΔG (KCAL/MOL)
S39L	N-terminal domain	raises binding affinity for the acyl-CoA substrate	−2.1
L345G	active-site cleft	relieves steric crowding, opens the catalytic pocket	−1.8
C175S†	core	structural annotation — removes a potential misfold site; not included in the shipped construct	−0.9

† C175S was identified by the language model screen and is included in this analysis table as a structural annotation. The shipped double-variant construct carries S39L and L345G only.

Read the two variants together and they are a clear division of labor. **S39L** works at the mouth of the enzyme, where the substrate first arrives, trading a small polar serine for a larger hydrophobic leucine

that grips the fatty-acyl chain more tightly — more substrate captured, more throughput. **L345G** works deep in the active-site cleft, where the chemistry happens, trading a bulky leucine for the smallest possible residue, glycine, which relieves a steric crowding that had been pinching the catalytic pocket shut — the reaction runs faster once the room is made. Together they define the double variant that ships.

Consistency is the quiet achievement behind both variants. A composite flavor is a balance, and a balance is only as trustworthy as its least reproducible part — if the heat axis wanders batch to batch, the whole chord goes out of tune, and no amount of care on the other seven axes can rescue a profile whose loudest voice will not sit still. Wild-type pepper heat varies enormously: a batch-to-batch coefficient of variation around **42 percent**, which is to say the "same" pepper can be nearly half-again hotter or cooler from one harvest to the next. With the two variants in place — S39L improving substrate capture and L345G opening the catalytic pocket so the reaction runs with less steric hesitation — the double-variant Pun1 runs more reliably than the wild-type, and our design specification holds Phoenix's predicted heat at a coefficient of variation of **seven percent or less**. That precision is not a footnote to the flavor; for a composite it *is* the flavor, because a whole note you cannot reproduce is not a standard, it is a happy accident. Chapter 15 returns to what seven percent, held on all eight axes at once, actually requires. Here it is enough to see that the loudest axis of the whole spectrum was designed not only loud but *steady*.

Chapter 8 · The Phenylpropanoid Spine — *one backbone, eight destinations.*

The two variants of the last chapter sit at the *end* of a long road, and to understand how one plant can afford to speak eight axes you have to see the road, because seven of its eight destinations branch off the same highway. That highway is the **phenylpropanoid pathway**, and it is the most-traveled road in all of plant metabolism — the route every vascular plant uses to turn the amino acid phenylalanine into the vast family of aromatic compounds that become its pigments, its defenses, its structural lignin, and, in the plants of this library, its flavors.

The spine runs in five conserved steps, and it is worth naming each enzyme and each intermediate, because the whole argument of metabolic transfer in this library rests on these five being universal:

STEP	ENZYME	SUBSTRATE → PRODUCT
1	PAL (phenylalanine ammonia-lyase)	phenylalanine → cinnamic acid
2	C4H (cinnamate-4-hydroxylase)	cinnamic acid → *p*-coumaric acid
3	4CL (4-coumarate-CoA ligase)	*p*-coumaric acid → *p*-coumaroyl-CoA
4	HCT (hydroxycinnamoyl transferase)	*p*-coumaroyl-CoA → caffeoyl ester
5	COMT (caffeic acid O-methyltransferase)	caffeic acid → ferulic acid

That five-step backbone is in the tomato and the grape and the coffee and the mint and the pepper alike; it is the shared trunk from which flavor after flavor branches. From ferulic acid and its neighbors the plant reaches vanillin (the kokumi-adjacent sweetness of Volume XXI), the hydroxycinnamates that feed the tannin and astringency routes, the precursors that umami ripening draws on, and — in the pepper, and only after four more enzymes found nowhere else — capsaicin. The four pepper-specific terminal enzymes are the reason a pepper is a pepper: **pAMT** (the aminotransferase that makes vanillylamine from vanillin), **KAS** and **BCAT** (which build and hand over the branched fatty-acyl chain), and **Pun1/CS** (the capsaicin synthase of the last chapter, which marries the two). Five universal steps and four special ones: that ratio — most of the road shared, only the last turn private — is the structural fact that makes a composite affordable, and the fact that makes the composite *transferable* to other plants, as Chapter 16 will show.

Trace the spine back one stage further and the transferability deepens. Phenylalanine, the amino acid the whole phenylpropanoid road begins from, is itself the product of the **shikimate pathway** — the seven-step route, present in plants and microbes and absent in animals, that turns two simple products of photosynthesis and

glycolysis, phosphoenolpyruvate and erythrose-4-phosphate, into the three aromatic amino acids. So the deepest root of the heat axis, and of most of the other seven, is a pathway every plant already runs to feed itself. The branched-chain tail of capsaicin tells the same story from the opposite end: it is built from **valine**, an ordinary amino acid, deaminated by BCAT and handed into fatty-acid machinery by KAS and elongated to the eight-methyl branched chain that gives capsaicin its particular shape and its particular loudness. Universal front, universal back, and only the four condensing enzymes in between that make the molecule a pepper's own. A method that edits a limiting enzyme sitting on a road every plant already paves is a method that can, in principle, be driven into any plant with a genome worth reading — which is the whole argument of the frontier, and the reason the composite is a platform and not a trick.



FIG. 9 — The sequencing bench where a pathway is read enzyme by enzyme before it is edited. Five of the spine's steps are universal; only the last four turns are the pepper's own.

Look closely at the terminal chemistry, because it carries a lesson about why *shape* and not only *amount* governs a flavor. Capsaicin is a condensation of two parts: a vanillylamine "head," derived straight off the phenylpropanoid spine through pAMT, and an eight-methyl branched-chain fatty-acyl "tail," built by the KAS/BCAT machinery from the amino acid valine. Pun1 marries head to tail. And the *tail* is where the character of the heat is set: the exact length and saturation of that acyl chain decide whether the product is capsaicin or dihydrocapsaicin or one of the milder congeners — the very blend whose shifts explained Kindle's puzzle three chapters ago. The enzymes do not merely make *more* heat; they make heat of a particular *shape*, and a composite designer cares about the shape because the shape is what the receptor hears. Lengthen the tail and

the loudness changes even as the mass climbs. This is the molecular root of the Index's whole insistence that loudness and quantity are different measurements: it is written into the acyl chain.

There is a second lever on the whole spine, above the individual enzymes, and it matters for a composite more than for any single axis: the pathway's *regulation*. The phenylpropanoid genes are governed as a block by transcription factors — the MYB family chief among them — that turn the whole branch up or down together, and that block-level control is double-edged for the composite. Up-regulate the master switch and you lift every aromatic-dependent axis at once, cheaply, with one edit instead of eight; but you also lift them in the plant's own fixed proportions, which are almost never the proportions a balanced profile wants. So the composite is designed on two levels at once — the master regulators set the overall supply to the whole aromatic branch, and the individual terminal enzymes, tuned one at a time, apportion that supply among the competing axes. It is the difference between opening the main valve and adjusting each tap, and a full-spectrum fruit needs both hands working at once.

Now the destinations fan out, and the full-spectrum problem comes into focus. Phoenix's eight axes are not eight independent gifts; they are eight *draws on one shared supply*. Heat, pungency, astringency, the vanillin-adjacent notes, and the aromatic precursors that feed several other axes all trace back, through branches, to the same phenylpropanoid trunk, which traces back to the same pool of phenylalanine, which traces back to the same shikimate pathway, which traces back to the same carbon the leaf fixed from the air. To light one axis is to spend from a common account; to light eight is to spend from it eight ways at once. The spine is what makes the composite *possible* — you do not need eight separate highways, only one with many exits — and it is also what makes the composite *hard*, because eight exits off one highway means eight claims on one flow of traffic. How a single cell meets eight claims without starving any of them is not a question the pathway diagram can answer. It is a question of flux, and flux is the next chapter.

Chapter 9 · Eight Programs in One Cell — *the flux-balance of a whole flavor.*

A pathway diagram shows you what *can* be made. It does not show you what *will* be made, because it says nothing about the one thing that governs a living cell: the budget. Every flavor molecule in Phoenix is built from the same finite supplies — fixed carbon, nitrogen, the energy carried in ATP, the reducing power carried in NADPH, and, above all, the shared aromatic precursors coming off the shikimate and phenylpropanoid routes — and eight biosynthetic programs running at once are eight competing claims on those supplies. The question that separates a drawable spectrum from a growable one is whether the cell can fund all eight without any program starving, stalling, or crashing the others. That question is answered with **flux-balance analysis**, and it is the mathematics that makes the composite real rather than merely imaginable.

Flux-balance analysis treats the cell's entire metabolism as a system of flows. Write every metabolite's production and consumption into a great stoichiometric matrix **S**, let the vector **v** hold the rate — the flux — through every reaction, and impose the one condition that makes a steady state a steady state: nothing accumulates, nothing drains to nothing, so for every internal metabolite production equals consumption. In one line:

```
S · v = 0, subject to v_min ≤ v ≤ v_max
```

The bounds on the right encode the real limits — how fast each enzyme can run, how much substrate can be imported — and within the space of all flux distributions that satisfy the balance, you ask for the one that maximizes an objective: here, the output of a chosen flavor pathway. The model does not guess; it *solves*, by linear programming, for the fastest the cell can push toward a goal while every mass balance holds and no reaction exceeds its ceiling. It was flux-balance analysis that told us, before a single edit, where control in the phenylpropanoid pathway actually sits: our Metabolic Control Analysis found flux control weighted at the upstream 4CL and HCT steps, not at the terminal Pun1 — Pun1 is the capsaicin synthase, the step that labels the product, but it does not govern the rate. What the S39L and L345G variants do, in that framework, is improve the fraction of available substrate that actually becomes capsaicin, so that the heat axis moves in concert with the upstream supply rather than losing yield at the final step. And it is flux-balance analysis that tells us, for the composite, something subtler and more important: where the eight programs *collide.*



FIG. 10 — A cluster of near-sibling lines under evaluation. Eight flavor programs in one cell behave like a community competing for one shared supply; the model finds where they collide.

Here is the collision made concrete. Heat and pungency and astringency and part of sweetness all reach back to the aromatic-amino-acid supply off the shikimate route. Push the heat program to three million Scoville and it draws down that shared pool; the other aromatic-dependent axes, drawing from the same pool, find less waiting for them, and a naïve attempt to light all eight simply watches the loud axis eat the quiet ones. This is the metabolic reason — stated in Chapter 5 and now made rigorous — that sweetness was one of the two last and hardest axes: not because the sweet pathway is complicated, but because the *carbon for it was already spoken for*. The flux model's job was to find the fluxes at which the heat axis could stay at 4,200 while enough precursor was *spared* — rerouted, up-supplied, or drawn from a non-competing branch — to light sweetness at 1,100 and the rest in balance. The composite profile of Phoenix is, read one way, simply the solution to a linear program: the best-balanced eight-axis flux distribution the cell can sustain without any pathway robbing another past the point of collapse.

Flux-balance analysis also hands the designer a quantity almost custom-made for the composite problem: the **shadow price**. Solve the linear program and you get, for every constrained resource, a number that says how much the objective would improve if that one constraint were loosened by a single unit — in metabolic terms, which precursor or cofactor the cell is most starved of at the optimum. For a single loud axis the shadow prices point at one bottleneck, and you relieve it. For the eight-axis composite they point at the *shared* pools — the aromatic precursors, the reducing power carried in NADPH — where eight programs bid against one another, and they name precisely which shared supply to up-regulate so that lighting sweetness does not darken heat. The composite's flux solution is not found by trial; it is read off the shadow prices, which point straight at the edits that buy balance. This is also the quantitative reason the multi-axis libraries thin so sharply with axis count — roughly 8,400 constructs at two axes, 2,800 at three, and a mere 300 at the full eight. Each added axis is one more bidder on the same pools, one more set of shadow prices to satisfy at once, until at eight the feasible region of the program — the space of flux distributions that fund every program without

collapsing any — has narrowed almost to a point. Three hundred is, in a real sense, roughly how many distinct, buildable, worth-eating points that nearly vanished region still holds.

This is also, finally, the honest answer to a question the whole library raises: *if it can be done, why is almost nothing full-spectrum?* The index records the answer in its own numbers. The multi-axis libraries are large where the axes are *few*: on the order of **8,400** dual-axis constructs (M2, two axes at once) and **2,800** triple-axis constructs (M3, three at once) — abundant, because two or three programs can usually be funded side by side with room to spare. The full-spectrum line is **300** composite products, and the superhot ladder reached eight-of-eight *once*, at Phoenix. The scarcity is not a failure of ambition; it is a fact of the budget. Two axes share a supply comfortably. Three is a negotiation. Eight is a near-saturation of the cell's entire flavor-metabolic capacity, a flux distribution so tightly balanced that every program is funded to the edge of what the shared pools allow and not one past it. That is why the composite is rare, and why it is an achievement rather than merely a recipe: the whole note is the sound of a cell running every flavor program it can afford, all at once, right up against its budget, and holding. What remains is to get all eight out of the fruit and into a mouth — and that, it turns out, the plant cannot do alone.



PART IV OF V

Delivery

The problem of simultaneous arrival · the nanoparticle · composing in time

Chapter 10 · The Problem of Simultaneous Arrival — *eight molecules, eight speeds.*

Suppose the fruit is perfect. Suppose the flux balanced, the eight programs funded, the scorecard in the plant exactly the chord you meant: 4,200 of heat, 1,100 of sweetness, all eight present and poised. You are not finished. You are, in a real sense, only halfway, because a profile balanced *in the fruit* is not a profile balanced *in the mouth*, and the gap between them is a problem of physics that no amount of metabolic engineering can touch. Eight flavor molecules are eight different physical objects, and when you simply put them in a food and the food in a mouth, they do not arrive together. They scatter — across phases, across surfaces, across time — and the chord you composed smears into something lopsided and sequential that the eater never experiences as whole.

The culprit is that the eight actives could hardly be more physically different. Capsaicin is intensely lipophilic — it wants to live in fat, with an oil-water partition coefficient (log P) around 3.6 — so in any food with a fat phase it dissolves into the oil and is slow to leave it, reaching the receptor late and partially. Menthol, the cool-burn active, is both lipophilic *and* volatile, so it is lost to the air and to the fat at once. Glutamate and the ribonucleotides that drive umami are small, charged, water-loving molecules that stay in the aqueous phase and arrive fast and early. The kokumi-active γ-glutamyl peptides are hydrophilic but larger and slower. The tannins of astringency are big polyphenols that bind to proteins — including the very proteins of the food and the saliva — and may be half-spent before they ever reach their target. Sweeteners span the range. Set eight molecules like these loose in a bite and physics sorts them: the water-soluble ones flash early, the fat-soluble ones leak late, the volatile one escapes upward, the protein-binding one is intercepted en route. The eater gets umami first and alone, then a muddle, then a long lonely tail of heat — never the chord.

Put numbers to the scatter and it stops being a metaphor. Capsaicin's octanol-water partition coefficient, log P, sits around 3.6 — a preference of several thousandfold for fat over water — so in any dish with an oil phase it vanishes into the fat before it is tasted, and what reaches the receptor is a slow leach from the oil rather than the dose you added. Menthol is comparably lipophilic and, worse, volatile, its vapor pressure high enough that a measurable fraction leaves the plate for the air in the few seconds between fork and mouth. Glutamate carries a charge at the pH of food and will not enter a fat phase at all, so it arrives fast and whole in the water. The γ-glutamyl kokumi peptides are water-soluble but several times larger, and diffuse more slowly. The tannins are larger still and chemically sticky, binding the first proteins they meet. Eight actives spanning four orders of magnitude in fat-affinity, several in

molecular size, and a wide range in volatility cannot, by any law of physics, cross the same food and the same mouth at the same rate. The scatter is not a flaw in a particular recipe that a better cook could fix; it is thermodynamics, and thermodynamics does not negotiate with a chord.

And the mouth is only the last of the journeys; the composite must survive the kitchen before it is ever eaten. A flavor active sitting in a food is exposed, for hours or weeks, to oxygen that can degrade a polyphenol, to light that can bleach a sensitive molecule, to heat that can drive off a volatile or isomerize a menthol, to the slow migration of a lipophilic compound into whatever fat is nearest. Each of the eight ages at its own rate, so a profile balanced the day it was made drifts out of balance on the shelf and drifts again in the pan — the volatile cool and the bright pungency fading first, the stubborn heat outlasting them all. A single-axis flavor merely grows weaker as it ages, which a cook corrects by adding more. A composite grows *lopsided*, which no single correction can fix, because the eight are leaving at eight speeds. The delivery problem, then, is not only a problem of the mouth but a problem of time at every scale — shelf, pan, and tongue — and the carrier of the next chapter has to answer all three at once.



FIG. 11 — Formulation work on the bench. Eight actives of eight different solubilities and speeds will not, left to themselves, reach the tongue as one thing.

There is a second, quieter failure layered on the first: the food itself is a thief. A flavor active does not travel through a neutral medium; it travels through a matrix of fat and protein and starch and water, each of which can bind, sequester, or chemically alter it before it is ever tasted. Capsaicin partitions into every fat globule it passes. Tannins complex with proteins and drop out of solution. Volatiles evaporate from the surface between the plate and the tongue. The matrix does not deliver the flavor; it *taxes* it, unevenly, molecule by molecule — and because the tax falls differently on each of the eight, it does not merely quiet the whole chord, it *re-balances* it, pulling down the axes that bind and spare the ones that do not, so that even the loudness ratios you designed are gone by the time the signal reaches a receptor.

This is the exact reason the shared index attaches nanoparticle delivery to the full-spectrum axis and to no other. A single-axis flavor can tolerate all of this. If you are delivering only heat, it does not matter that the capsaicin is slow and lipophilic and partly lost to the fat — there is nothing for it to fall out of balance *with*, no chord to smear, only one note that arrives a little late and a little quiet, and you simply dose up to compensate. The instant you are delivering a *composite*, every one of these physical differences becomes a way for the eight to fall out of step, and no single dose-up can fix eight different losses at eight different rates. The problem of simultaneous arrival is born the moment there is more than one thing to arrive. It is, precisely, the delivery problem of *wholeness* — and wholeness is what this book is about, so the carrier that solves it is not an accessory to the full spectrum. It is part of the full spectrum. The next chapter is that carrier.

Chapter 11 · The Nanoparticle and the Composite — *the IFC, and how a plant's eight numbers reach a mouth.*

If the problem is that eight molecules travel differently, the solution is to stop letting them travel as eight molecules. Put all eight inside a single carrier — one particle, small enough to behave as a solute, carrying the whole composite as its cargo — and the eight no longer scatter by their individual physics, because they no longer move by their individual physics. They move as the particle moves. They are protected by the particle's shell from the thieving matrix. And they are released, together or in a designed sequence, when and where the particle is built to release them. This is **nanoparticle delivery**, and the productized form of it — a defined eight-axis composite rendered as a co-encapsulated nanoparticle system — is what this library calls an **IFC**, an Iyengar Flavor Composite. The index records three hundred of them.

The engineering has a small family of carrier forms, chosen by what the cargo needs. **Lipid nanoparticles** and solid lipid nanoparticles carry the lipophilic actives — capsaicin, menthol — in an oil core that keeps them from partitioning away into the food's own fat, wrapped in a shell that holds them until release. **Nanoemulsions**, oil-in-water droplets tuned to a diameter of roughly fifty to two hundred nanometers, give fine control over how fast a lipophilic active crosses to its receptor, because at those sizes the enormous surface-area-to-volume ratio makes release a dial you set by droplet size rather than an accident you accept. **Cyclodextrin inclusion complexes** — a sugar ring that closes around a single guest molecule — are the elegant answer for the volatile and the bitter: they cage menthol against evaporation and can hold a bitter molecule away from TAS2R38 until the moment you want it, a physical complement to the genetic Zero-Bitter axis. And **core-shell** or layered particles carry different actives in different compartments, which is the key to releasing them on different schedules from one carrier. The choice among these is not aesthetic; it is dictated by the log P, the volatility, the charge, and the intended arrival time of each of the eight.



FIG. 12 — An IFC preparation in the vial: a full-spectrum composite rendered as a co-encapsulated carrier, the eight actives traveling as one.

The carrier does four things, and each answers one failure from the last chapter. It **co-locates** — all eight actives in one particle, so they arrive at one place rather than scattering to the fat, the water, and the air. It **protects** — the shell stands between the cargo and the thieving matrix, so the tannin does not complex with the food's protein and the menthol does not evaporate off the plate, and the loudness ratios you designed survive the journey. It **controls release** — and this is the part that turns delivery from rescue into composition — by letting go of its cargo on a schedule set by the shell's physics. And it **triggers** on the conditions of the mouth: temperature, the shift in pH, the shear of chewing, the salivary enzymes amylase and lipase that begin to digest the shell the instant it is eaten, so that release is keyed to *being eaten* rather than to the clock.

That controlled release has a mathematics, and it is worth one line because it is how a carrier is designed rather than merely described. The fraction of an active released by time t follows, for a wide class of these systems, a power law — the Korsmeyer–Peppas relation:

$$M_t \div M\infty = k \cdot t^n$$

where $M_t/M\infty$ is the fraction released, k is a rate constant set by the material, and the exponent n encodes the *mechanism*: near 0.5 the release is Fickian diffusion, the active simply seeping out through the shell; higher, and the release is driven by the shell swelling or eroding, a later and sharper letting-go. Choose the shell and you choose n; choose n for each compartment of a core-shell particle and you have chosen the *shape in time* of each axis's arrival. The carrier is not just a container. It is a clock, and it can run a different clock for each of the eight actives it holds.

The trigger chemistries deserve a closer look, because they are what keep release keyed to *being eaten* rather than to a timer ticking on a shelf. A shell can be built to yield to the warmth of the mouth, melting from a solid at body temperature to spill its core. It can be built to the pH shift between a near-neutral food and the mouth's own chemistry. It can be built to the mechanical shear of chewing, so that the act of eating is itself the act of release. And it can be built

to the saliva's own enzymes — amylase cleaving a starch shell, lipase eroding a lipid one — so that the body's first digestive gesture begins the composite's unfolding. Layer two or three of these in a core-shell particle and you have independent clocks on independent compartments: a fast, shear-triggered outer layer that leads with the volatile pungency; a pH- or temperature-gated middle that blooms the cool through the body; a slow, lipase-eroded core that releases the heat last and lets it linger. The Korsmeyer–Peppas exponent is set per compartment by the material; the trigger is set per compartment by the chemistry; and between them the carrier becomes not one clock but several, running the eight-axis envelope that the fruit alone could never have timed.

A necessary word on what is in the shell and under what rules, because a family that cares about nourishment is careful about what it asks a body to swallow. The carrier materials are chosen from food-grade, generally-recognized-as-safe building blocks — the lipids, the cyclodextrins, the emulsifiers that food science has used and characterized for decades — not novel chemistry smuggled in under the flavor. Engineered nanomaterials in food sit under specific regulatory attention: the European Food Safety Authority maintains dedicated guidance on the risk assessment of nanomaterials in the food chain, and particle-size and material disclosure are part of bringing any such system to a table. We treat that scrutiny as a feature, not a hurdle. A composite is a thing you are proud of; the carrier that delivers it should be as clean and as disclosed as the fruit that grew the cargo. The whole note is only worth sounding if everything that carries it is something you would feed to your own family — which is, in the end, the only standard this library has ever really used.

Chapter 12 · The Order of Arrival — *composing a flavor in time.*

A chord is not only which notes but when each is struck and how long each is held, and a flavor is the same. The scorecard freezes a profile at its peak — eight loudnesses, pinned to the half-maximal point, computed where the design is clearest — but a flavor is not a frozen thing; it is an *envelope*, an onset and a rise and a peak and a decay, and the eight axes do not share one. To compose the whole spectrum is to compose in two dimensions at once: loudness, which the fruit and the flux give you, and *time*, which the carrier gives you. This chapter is the second dimension.

Each axis has a characteristic envelope, set by its receptor and its chemistry, and knowing them is the grammar of sequencing a flavor:

AXIS	ONSET	DURATION	CHARACTER IN TIME
Pungency (P)	fastest	shortest	a flash up the nose, gone almost at once
Umami (U)	fast	medium	arrives early, a savory floor laid first
Sweetness (S)	fast–medium	medium–long	early, and a sweet protein lingers past sugar
Cool-Burn (C)	medium	medium	a coolness that blooms and holds
Heat (H)	slow	longest	pools, builds, and lingers far past the bite
Kokumi (K)	—	longest	not a peak but a *lengthening* of the others
Astringency (A)	builds	cumulative	grows across sips, each one spending more saliva
Zero-Bitter (B)	—	—	a *subtraction* felt as the absence of a rise

Read that table and a natural architecture appears, the same three-part architecture a cook knows by instinct and now can specify. There is an **attack** — the fast, bright, early axes: pungency flashing, umami laying its floor, the first of the sweetness. There is a **body** — the sustained middle where heat has arrived and pooled, kokumi is lengthening everything it touches, the sweetness holds. And there is a **finish** — the long decay where heat still lingers, astringency has built to its grip, cool-burn threads the warmth, and the bitterness

that was never allowed to rise leaves nothing harsh behind. Attack, body, finish: the envelope of a whole flavor, and each phase is a different subset of the eight, arriving on a different clock.



FIG. 13 — Dawn on the chamber glass. A flavor, like a day, has an order: what arrives first, what holds, what lingers after.

Two of the eight are special in time, and they are the two that make the composite feel composed rather than merely crowded. **Kokumi** has no peak of its own; its whole gift is to *extend* — the γ-glutamyl peptides acting at the calcium-sensing receptor do not add a flavor so much as lengthen and thicken the continuity of the others, so that umami arrives and *stays*, sweetness rounds and *holds*, and the whole profile reads as a single sustained thing rather than a sequence of separate events. Kokumi is the sustain pedal of the spectrum. And **Zero-Bitter** is felt not as a presence but as an *absence of a rise* — you do not taste the attenuation; you taste the harshness that never comes, the fire arriving clean, the dark note that would have risen simply not rising. Two axes, then, that are not notes at all but *shapers of the other notes' time*: one lengthening, one withholding.

The envelope also has a geography, not only a clock, because the eight axes are not all read in the same place. The chemesthetic axes — heat, pungency, cool — are reported by trigeminal endings spread across the whole oral cavity and up into the back of the nose, so they can arrive retronasally and feel spatially large; the taste-proper axes are read on the tongue's own receptor fields. A composer can use that geography: a pungency built to flash retronasally reads as a lifting brightness distinct from the heat pooling on the tongue, even when the two share a single moment in time. So the full envelope is composed in three registers at once — *when* each axis arrives, set by the carrier's clocks; *where* it is felt, set by which receptor population it targets; and *how loud* it reads, set by the fruit and pre-distorted for the interactions of the next chapter. Three registers, eight axes, one chord. The scorecard is the loudness register alone, frozen at its peak; the living flavor is all three registers moving together, which is why the number is a promise and not a portrait. A composite without them is eight things that happen near each other. A composite with them is eight things that happen *as one thing*.

And here is where the carrier of Chapter 11 becomes the composer's instrument, because the envelope is no longer only what the molecules naturally do — it is what the release schedule *makes* them do. A core-shell IFC can hold the volatile pungency in a fast-

releasing outer compartment so it leads, and the lipophilic heat in a slow-eroding core so it follows and lingers, and the cooling in a middle layer timed to bloom through the body. The exponent *n* of the last chapter, chosen per compartment, is a note's attack and decay. So the full-spectrum design problem, stated completely, is this: the fruit and the flux set the eight *loudnesses*; the interactions of the next chapter set how those loudnesses must be *pre-distorted* to land a balanced percept; and the carrier sets the *order in time* in which they all arrive. Loudness, balance, and sequence — three dimensions, one chord. To compose the whole spectrum is to hold all three at once, and to hand the eater not eight flavors near each other but a single flavor with a beginning, a middle, and an end.



PART V OF V

Composition, Precision & the Whole

The interaction matrix · the full profile on a plate · ≤7% eight times over · beyond the pepper

Chapter 13 · The Balance Problem — *the 8×8 of what every axis does to every other.*

We have said it twice and now we prove it: full spectrum is not a sum, because the eight axes are not independent once they reach the brain. The receptors read cleanly and in parallel — that was Chapter 3's gift — but *perception* mixes them, and the mixing is not gentle. Sweetness quiets bitterness. Kokumi lengthens umami. Heat and cool half-cancel. A tannin can fold a bitter alkaloid out of solution before either is tasted. To design a balanced *percept* you must therefore solve for a set of *delivered* levels that, after all this cross-modal arithmetic, leaves the chord you intended. The map of that arithmetic is an interaction matrix, and it is the most important table in the book.

Here is the core of it — the strongest, best-established interactions among the eight, each marked as synergy (one axis amplifies another), suppression (one quiets another), or a chemical interception that happens before the receptor at all:

INTERACTION	DIRECTION	MECHANISM
Sweetness → Zero-Bitter	strong synergy	sweet centrally and peripherally suppresses bitter perception
Umami ↔ Kokumi	strong synergy	CaSR-active peptides lengthen and thicken umami continuity
Umami internal (Glu × IMP/GMP)	strong synergy	ribonucleotides allosterically potentiate the glutamate receptor
Heat ↔ Cool-Burn	mutual suppression	TRPV1 and TRPM8 cross-desensitize; warmth and cool half-cancel
Pungency → Heat	synergy	co-expressed TRPA1 and TRPV1 cross-sensitize; sharpness lifts fire
Sweetness → Astringency	suppression	sugar measurably lowers perceived astringency
Astringency → Zero-Bitter	chemical interception	tannins complex and precipitate bitter alkaloids pre-receptor
Kokumi → Sweetness/Heat	mild synergy	continuity rounds and sustains adjacent axes



FIG. 14 — A community of near-sibling lines. Eight axes in one flavor behave like a community too: each one changes what every other one is perceived to be.

Read Phoenix's scorecard again through this matrix and the design's intelligence becomes visible. Why is Zero-Bitter the second-loudest axis, at 2,200? Partly to attenuate the pepper's own harshness at the gene — but partly because *sweetness suppresses bitter* and *tannins intercept bitter*, so the delivered bitterness is being quieted from three directions at once (genetic attenuation, sweet suppression, tannic precipitation) to land a *perceived* cleanliness that no single mechanism could reach. Why is cool-burn at 800, when a naïve balance would have raised it to match the others? Because *heat and cool mutually suppress* — deliver a cool-burn loud enough to look balanced on paper and it would fight the 4,200 of heat in the mouth, each dragging the other down, and the eater would get a muddied warmth and a muddied chill instead of a fire threaded with cool. The low cool-burn is not an incompleteness; it is a *solved* interaction, set exactly where the thread of cool reads through the fire without either canceling the other. And why does the pungency at 252 feel like more than its number suggests? Because *pungency cross-sensitizes heat* — the bright TRPA1 edge lifts the TRPV1 fire, so the two together read louder than either alone, and pungency's perceptual contribution outpaces what the convention-calibrated score alone would indicate.

There is one more thing the scorecard cannot show and the fruit absolutely does, which is that these eight are an *envelope*, not a still photograph. In the mouth the pungency flashes first and is gone; the umami and the attenuated bitterness lay a clean savory floor; the heat builds under them, pools, and lingers; the kokumi lengthens all of it so nothing feels hurried; the sweetness rounds the middle; and in the long finish the astringent grip asserts itself and the thread of cool reads through the dying warmth. The 4,200 of heat is not a wall you hit but a tide that comes in. The 800 of cool is not a weak note but a *late* one, felt most in the finish where the fire has thinned enough to let it through. To read Phoenix completely is to read it in time as well as in loudness — which is why Chapter 12 exists, and why the carrier that sets that timing is as much a part of the fruit's flavor as the genes that set its loudness.

This is the deepest reason the composite is an art and not an addition. The *delivered* profile and the *perceived* profile are different objects, related by an eight-by-eight web of suppressions and synergies, and the designer works backward: name the percept you

want, apply the inverse of the interaction matrix, and solve for the delivered levels that will produce it after the brain has done its mixing. Phoenix's eight delivered numbers are not the chord — they are the *pre-image* of the chord under perception, the levels that become balanced only once the eater's own nervous system has quieted the bitter with the sweet, lengthened the umami with the kokumi, and let the fire and the cool find their truce.

The umami synergy is the one interaction precise enough to put a hard number on, and it shows how far delivered and perceived can diverge. Glutamate alone activates its receptor with some EC_{50}; add the ribonucleotide IMP or GMP, which binds a neighboring site on the same class C flytrap domain and clamps it shut around the glutamate, and the glutamate's effective potency can climb several-fold, in places toward an order of magnitude — a superadditivity so strong you taste it as a sudden deepening when a tomato meets a mushroom. A composite that co-delivers glutamate and ribonucleotide in one carrier is therefore delivering *more umami than it dosed*, and a designer who ignored the synergy would overshoot the savory axis wildly. This is the interaction matrix made quantitative: the perceived profile is the delivered profile passed through a web of such factors, some suppressive and some superadditive, and to land a target percept you invert the web — dose the glutamate *low* because the ribonucleotide will multiply it, dose the cool *low* because the heat will fight it, dose the bitter attenuation *high* because the sweet and the tannin will help it along.

The scorecard is not a photograph of the experience. It is the set of instructions that, run through a human tongue and brain, *produces* the experience. That is what it means to compose for a receptor system instead of merely dosing one.

Chapter 14 · Cooking the Whole Spectrum — *the full profile on a plate.*

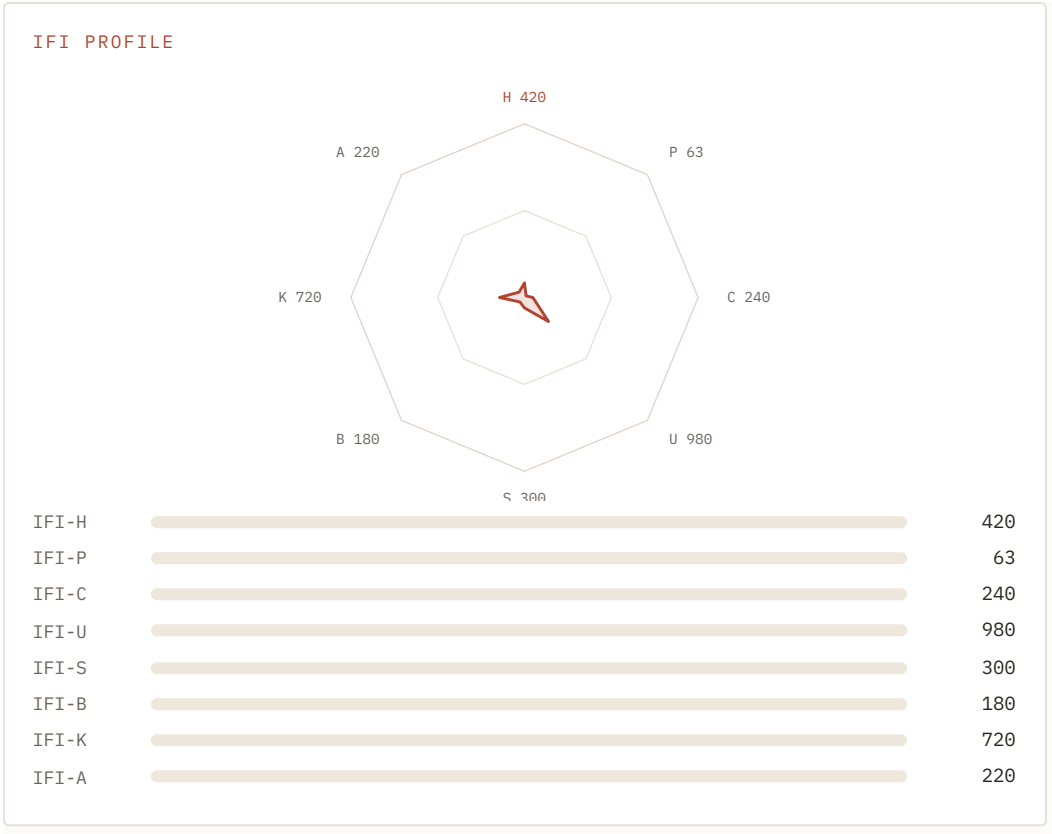
All of this has been in service of a plate, so here is the plate — or three of them, because the fastest way to understand a composite is to build one and eat it. These are not a cookbook; this is a flagship, and a cook's full repertoire belongs to the kitchen volumes of this library. But a composite read only on a bench is a composite only half-understood, so we cook, and we score what we cook, because a dish read on the Index is a dish you can hand to someone and promise. We are a plant-first family and these are plant-first dishes; the one that turns to the sea is written with the same reverence as the others, not with apology.

The first is the clearest teaching dish we know — a broth built to light all eight gently, the whole spectrum at conversational volume, so you can feel each axis without any one shouting.

Eight-Axis Clear Broth

- Kombu and dried shiitake, cold-steeped overnight, then warmed to just below a simmer — the umami floor, glutamate from the kelp and the mushroom's own ribonucleotides in synergy
- A spoon of white miso and a few γ-glutamyl-rich fermented notes whisked in off the heat — the kokumi, the continuity
- A single Phoenix slice, or a measured drop of its IFC, steeped thirty seconds and lifted out — heat, pungency, and the pepper's clean attenuated edge
- A thread of ripe pear and a breath of the sweetness composite — the sweetness underneath
- A single bruised mint leaf, removed before it dominates — the thread of cool
- Finished with a few drops of a lightly tannic green tea — the grip, the structure of the finish

1. Warm the kombu-shiitake steep gently; never boil it, or the kelp turns harsh and the umami goes flat.
2. Off the heat, whisk in the miso and the kokumi notes until the broth turns silken and *long* on the tongue.
3. Steep the Phoenix slice exactly thirty seconds — long enough for the clean fire, short enough that it stays a thread and not a wall — and lift it out.
4. Add the pear and sweetness, the single mint leaf for a slow count, then the green tea drops. Taste for the whole, not the parts.

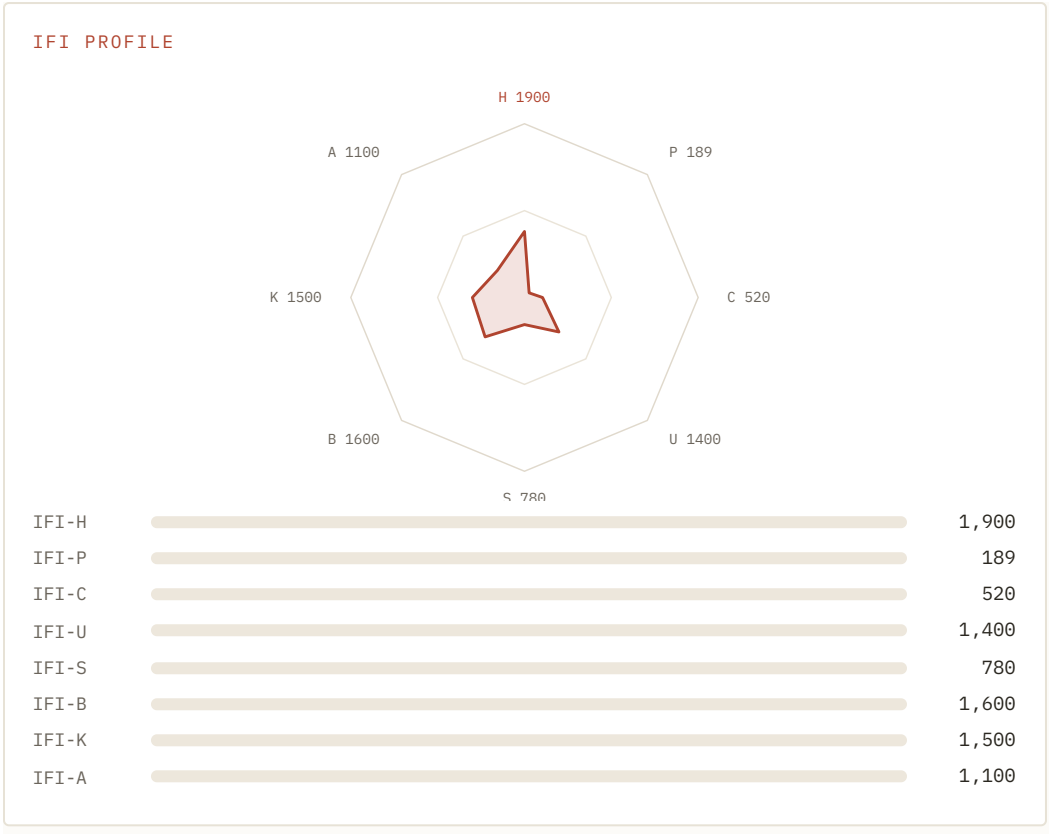


This is a full-spectrum profile in a minor key — coverage 8 of 8, but led by umami and kokumi rather than heat, a broth that is *whole* and *quiet* at once, the proof that full spectrum is a shape and not a volume. The second dish turns the same eight toward the loud end: a grain-and-legume plate dressed with Phoenix itself, where the heat leads and the other seven hold it up.

Phoenix-Dressed Warm Grain Bowl

- Farro or barley cooked in the eight-axis broth above, so the grain carries the savory floor from within
- Roasted squash and charred broccolini — sweetness and a vegetal bitterness the dressing will attenuate
- A dressing of cold-pressed oil, a little lemon, and a precise dose of Phoenix IFC — the full chord, delivered by carrier so it arrives together
- Toasted walnuts and a crumble of aged cheese or a cultured nut cheese — more kokumi, more length
- A scatter of pomegranate — a clean tannic brightness, the astringent finish

1. Cook the grain in the broth until it is tender and has drunk the savor; spread it to cool slightly so the dressing is not shocked.
2. Roast the squash until its sugars concentrate; char the broccolini hard, because its edge is what the Zero-Bitter axis is *for*.
3. Whisk the oil, lemon, and a measured dose of the IFC — trust the carrier to land the eight together rather than dosing the heat up to compensate for a smear.
4. Fold warm; finish with walnuts, cheese, and pomegranate. The heat should lead, the savor should carry, the bitterness should have vanished, and the finish should grip.



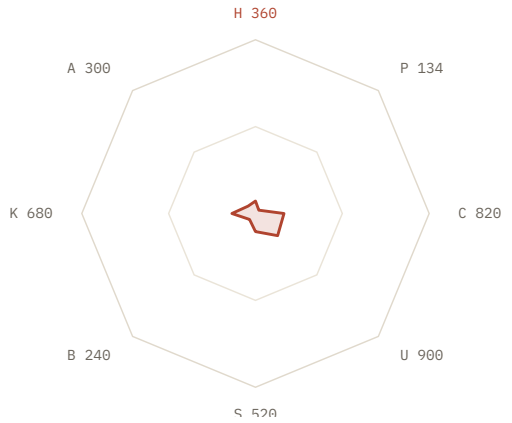
Coverage 8 of 8, and now in a major key — heat forward, but every other axis present and working, the bitterness of the char attenuated to nothing harsh, the kokumi carrying the whole thing long. The third turns to the sea, because a crudo is the purest test of a composite: raw, cold, nowhere for a flaw to hide.

Scallop Crudo, Full-Spectrum Oil

- The freshest scallop, sliced thin and kept very cold — a sweet, delicate, umami-bearing canvas
- A few drops of a full-spectrum oil: cold oil carrying a low dose of the IFC, built to lead with cool and pungency and let a whisper of heat follow
- A breath of citrus and a few grains of good salt — brightness, and salt to lift the scallop's own umami
- A single chive point and a micro-leaf of shiso — green sharpness, a cooling top note

1. Keep everything colder than you think you should; a crudo lives or dies on temperature.
2. Lay the scallop in a single layer; season with salt first, so its own umami comes up before anything is added.
3. Dot the full-spectrum oil sparingly — here the carrier's *timing* matters most, the cool and the pungency meant to lead and the heat to arrive a beat later, a wave and not a wall.
4. Finish with citrus, chive, and shiso. Eat at once.

IFI PROFILE



IFI-H		360
IFI-P		134
IFI-C		820
IFI-U		900
IFI-S		520
IFI-B		240
IFI-K		680
IFI-A		300

Three dishes, three keys, one axis of coverage held across all of them: eight of eight, every time. That is the whole argument of the book, served — that full spectrum is not a single flavor but a *property* a flavor can have, at any volume, in any key, led by any axis, so long as none of the eight is allowed to go silent. The broth proves it quiet, the bowl proves it loud, the crudo proves it cold and sequential. The number under each is the promise that what you composed is what the eater will receive.

Chapter 15 · Precision at Full Spectrum — *≤7% eight times over.*

A standard is a promise to be the same tomorrow, and a composite makes that promise eight times at once. Everything in this book has assumed the profile holds — that Phoenix's predicted 4,200 of heat is 4,200 next season and the season after, that its 800 of cool-burn does not wander up to 1,100 and drag the balance out of true. That assumption is not free. It is the hardest-won number in the whole program, and this chapter is what it costs and, surprisingly, what the composite gives back.

Begin with the single axis, because the composite is built on it. Wild-type pepper heat varies with a batch-to-batch coefficient of variation near **42 percent** — the "same" cultivar nearly half-again hotter or milder from harvest to harvest, the ancient reason a recipe could never quite be trusted and a hot sauce was always a gamble. The two-variant Pun1 design of Chapter 7 — S39L improving substrate capture and L345G opening the catalytic pocket so the reaction runs with less steric hesitation — brings that to **seven percent or less** in our design specification. Hold that contrast in mind: from forty-two percent to seven is the difference between a flavor that *happens to you* and a flavor you can *specify*. For a single axis, seven percent is excellent. For a composite, it is the entry fee, because a chord in which one note wanders is a chord out of tune, and Phoenix has eight notes that must each hold.



FIG. 15 — Pepper in cross-section, the tissue where the heat is set. Precision begins in the fruit and is proved, batch by batch, against a fixed reference.

Now the question that decides whether a composite can be a standard at all: when eight axes each vary by up to seven percent, how much does the *whole* vary? The intuition of dread says errors pile up — eight uncertainties stacked must be worse than one. The mathematics says the opposite, and it is one of the quietly beautiful facts of the whole program. The composite is a geometric mean, so its logarithm is the *average* of the eight axes' logarithms, and the variance of an average of independent quantities is the average of their variances divided by the count. In one line, for eight axes each with relative standard deviation σ_i:

$$\sigma(\ln \text{IFI-F}) = (1/8) \cdot \sqrt{(\sigma_1^2 + \sigma_2^2 + \ldots + \sigma_8^2)}$$

If every axis holds at or below seven percent and the eight vary independently, the composite's own relative variation is roughly seven percent divided by the square root of eight — about **two and a half percent.** The whole is *more* reproducible than any of its parts. Averaging over eight independent axes does not stack the errors; it cancels them, the way any average tames noise, so the one number that describes the entire flavor is the steadiest number in the whole scorecard.

The independence that makes this work is not a given, and guarding it is the real discipline of full-spectrum quality control. Errors cancel only when the eight axes wobble for *unrelated* reasons; if a single upstream cause — a lean season, a cold week, a dip in the shared precursor pool — pushes all eight the same way at once, their variations are correlated, the cancellation fails, and the composite can drift as far as any single axis. So the flux balance of Chapter 9 is not only how the profile is *designed* but how its precision is *defended*: the eight programs are funded with enough margin on the shared pools that an ordinary season's wobble in carbon supply does not swing them in lockstep. On the bench this becomes a ten-part release test — eight EC_{50} assays, one per axis, each read against its own fixed reference on an assay that must itself reproduce across days; the composite computed from the eight; and the evenness checked as a separate gate, because a batch can hold its geometric mean while quietly trading balance for a spike that the single composite number would never reveal. A lot ships only when every axis sits in spec, the composite lands near **1,330**, and the evenness holds near **0.78** — the chord, every string in it, and the shape of the chord, all three confirmed before a fruit leaves our hands.

One further property makes the composite trustworthy not just batch to batch but year over year, and it is inherited straight from the Index's design: because every axis is scored as a *ratio* against a fixed reference measured on the same assay, drift in the instrument cancels. If a cell line reads a little hot one season, it reads the reference and the candidate hot together, and the ratio holds; a raw EC_{50} is a measurement of a day, but an IFI score is a measurement of a flavor. Fold that stability into the composite and you have a number that means the same thing in ten years as it does today — which is the whole point of a standard, and the quiet difference between a flavor you can build a product on and one you can only hope for. The move from a wild pepper's 42 percent to Phoenix's seven, carried all the way through to the eater, is the move from *a pepper happens to you* to *this pepper, again, exactly* — the fire you chose and the balance you chose, delivered the same way every time, which is the most ordinary and most radical promise a food can make. The composite you most want to trust is the one you *can* most trust. A full-spectrum flavor, properly built, is not a fragile tower of eight uncertainties. It is eight uncertainties averaging each other down into a whole that holds tighter than any single axis alone.

That gift comes with a duty, and the duty is real. The error cancels *only if the eight axes vary independently*, and they do not vary independently for free — if a bad batch starves the shared precursor pool and *all eight* dim together, the variations are correlated and no longer cancel. So the precision of the composite is purchased upstream, in the flux balance: the eight programs must be funded robustly enough that a normal season's wobble in carbon supply does not swing them all the same way. Quality control, then, is not one assay but ten — eight parallel EC_{50} measurements, one per axis, each read against its fixed reference on a reproducing assay; the composite computed from them; and the evenness checked, because a profile can hold its composite while quietly spiking, trading balance for loudness in a way the single number would miss. A batch passes only when all eight axes sit in spec, the composite lands near 1,330, *and* the evenness holds near 0.78. Three gates, not one. The whole note is a standard precisely because we measure it as a whole and as eight parts at once, and ship only when both the chord and every string in it have held.

Chapter 16 · The Composite Beyond the Pepper — *the 300, and the roadmap.*

Phoenix is a pepper, and the whole climb to it ran up a pepper ladder, but the composite was never really about peppers — it was about a *method*, and the method's reach is the last thing this book has to show. Recall the structural fact from Chapter 8: of the pathway that feeds most of the eight axes, five steps are the universal phenylpropanoid spine that runs in *every vascular plant*, and only the last four turns are the pepper's own. That ratio is a door. If most of the road is shared, then most of the composite method transfers to any plant with a sequenced genome — the flux-balance mathematics, the protein-language-model design of a limiting enzyme, the nanoparticle delivery of a composed payload, the interaction matrix that governs perception. The pepper proved the method. It does not own it.

The index records where the method is going, and it is going across the whole plant kingdom. Forty-two host organisms are computationally mapped today; sixty-four more are on a five-tier roadmap, each tier a step further from the Solanaceae the pepper taught us on:

TIER	HORIZON	REPRESENTATIVE ORGANISMS
T1 · Solanaceae Core	4–5 genes, 18–24 mo	Volcanic Tomato · Dark Matter Eggplant · Laboratory Tobacco
T2 · Extended Nightshades	5–7 genes, 24–36 mo	Seismic Potato · Celestial Ground Cherry · Acid Tomatillo
T3 · Cross-Family	7–10 genes, 36–48 mo	Sweet-Heat Strawberry · Contradiction Cucumber · Solar Melon · Forbidden Apple
T4 · Frontier Synthetic	10–12 genes, 48–72 mo	Deep-Earth Carrot · Wildfire Broccoli · Storm Corn · Dynasty Rice



FIG. 16 — The tomato, restored. The first organism beyond the pepper to carry the composite method, its umami and sweetness grown back toward whole.

The tomato is the natural second home for the composite, and it points at the gentler and perhaps truer face of full-spectrum design. A supermarket tomato is a flavor with *silenced axes* — its umami and sweetness bred and shipped out of it, a fruit that should read whole and instead reads hollow. Full spectrum applied to a pepper means climbing from one loud axis to eight; applied to a tomato it means *restoring* the axes a century of logistics stripped away, growing the savor and the sweetness back in until the fruit tastes like the whole of what a tomato is. Same method, opposite starting point: the pepper was too loud and too narrow, the tomato too quiet and too hollow, and the composite — loud, even, complete — is what both are tuned toward from their different directions. The full spectrum is not only the far peak of Phoenix; it is also the quiet wholeness of a tomato made right, and the three hundred IFC composites in the line span that whole range, from the ferocious to the gentle, each one a defined eight-axis target rendered real and delivered by carrier.

It is worth seeing the three hundred as a *sampling* of a space rather than a list of products, because that is what they are. The eight axes define an eight-dimensional volume — every possible profile a flavor could have, from the all-silent origin to the capped ceiling on each channel — and almost all of that volume is empty, unreachable or unpalatable or metabolically unaffordable. The three hundred IFCs are the points in it we have found to be at once buildable, balanced, and worth eating: the ferocious corner where Phoenix sits, the gentle savory region of a computed tomato restoration, the bright cool-forward zone a crudo wants, and the paths between them. Each new organism the method reaches opens a fresh neighborhood of that space — the tomato's native sweetness and umami make certain gentle profiles cheap in a tomato that would be ruinously expensive in a pepper, and a mint makes the cool-forward corner nearly free. The full-spectrum line is therefore not a fixed catalog but a map under active survey, and every tier of the roadmap is another region of the eight-dimensional whole of flavor brought within reach of a plant that can actually be grown.

There is a reason we find the tomato, and not the pepper, the truer emblem of where the composite is going, and it is the reason the whole library exists. The pepper taught us that wholeness can be *built*; the tomato will teach us that wholeness can be *restored* — that a fruit hollowed out by a century of breeding for shelf life and shipping weight can be grown back toward the thing it was, its savor and its sweetness returned, nothing of it left out for the truck. That is the composite turned from spectacle to care: not a fruit made to astonish on every channel, but a fruit made to be *whole* again, the way a tomato off a grandmother's vine was whole before anyone optimized it for anything but taste. The three hundred IFCs and the sixty-four organisms to come are, read in their best light, an apparatus for leaving nothing good out — for growing food that holds everything it is able to hold and arrives with all of it intact. The far technical edge of the full spectrum and the oldest wish at a family table turn out, in the end, to be the same place approached from two directions.

A word on the rules of this reach, because carrying a method across the kingdom is a thing to do carefully and in the open. The edits this method makes are, as a rule, changes to a plant's *own* genes — two letters in a pepper's own Pun1, not foreign DNA spliced in — and precise edits of that kind sit in a different and still-evolving regulatory conversation from classical transgenics, treated unevenly across jurisdictions: in the United States, edits introducing no foreign DNA and achievable in principle by breeding may fall outside APHIS biotechnology regulation under the 2020 SECURE rule, while the European Union has historically regulated by *process* under Directive 2001/18/EC, with a New Genomic Techniques reform under active debate as we write. Where a modification leaves detectable modified genetic material, it is disclosed as the law requires — the "bioengineered" label in the United States, and the Cartagena Protocol governing the cross-border movement of living modified organisms — and any novel protein an edit introduces goes through allergenicity and safety assessment as a matter of course. We design to be honest about *what* was changed, never to arbitrage *where*. A plant you are proud of is a plant you label gladly, and the composite is a thing we are proud of in every organism it reaches.

Closing essay · The whole note, sounded

We began with the quiet after the first bite — the moment someone tastes a finished thing and does not speak — and said we had chased it our whole lives without knowing what was in it. Sixteen chapters later we can finally name the thing. What is in that quiet is *wholeness*: not one flavor loud enough to silence a room, but eight flavors present at once and in balance, a chord struck so completely that the mind has nothing to add and nothing to miss. The full spectrum is the number for the quiet after the bite. It is the measure of a flavor with nothing left out.

That this could be designed at all still moves us, and we have tried in this book never to let the wonder loose from the rigor, because the two are the same thing seen twice. The wonder is a single fruit designed to set a tongue alight on every channel it owns — fire and savor and a sweetness underneath, a grip and a thread of cool, a brightness on top and no harshness anywhere. The rigor is that this fruit is the solution to a stack of hard problems, each solved exactly: a geometric mean that refuses to reward a spike, two precision edits to one enzyme found by a model that reads proteins like sentences, a flux balance that funds eight programs to the edge of a cell's budget and not one past it, a carrier that holds eight molecules together and lets them go on a schedule, an interaction matrix inverted so that a delivered imbalance lands as a perceived chord, and a precision that averages eight uncertainties down into a whole that holds. The fruit is the wonder. The stack is the rigor. Phoenix is both, and so is every IFC in the line, and we do not think you can have the first without the second — that the reverence, to be trustworthy, has to be earned all the way down to the enzyme.



FIG. 17 — The greenhouse walk at the end of the day, the work set down, the plants left to grow toward whole.

There is a thing we believe as a family that this book, of all of them, says most plainly, and we will say it once here and then let it go. *Whole* is the word we most want for food. A tomato that tastes like the whole of a tomato. A broth that carries the whole of what a broth can carry. A fruit grown to hold everything it is able to hold, with nothing bred out of it for the truck and nothing hollowed from it by accident, and handed to someone you love with none of it missing. The full spectrum is the far technical edge of that very old and very domestic wish — the wish to leave nothing good out — and the three hundred composites, and the sixty-four organisms still to come, and

the whole apparatus of models and carriers and eight parallel assays, are all in the end just a way of keeping that wish honestly. We learned to measure taste so we could build it well. We learned to build the whole of it so that nothing would be left out by accident. What any of it does once it is inside a body we leave, gladly and entirely, to the people whose work that is; our work ends at the fruit and the plate, at growing a thing to hold the most it can and composing it so the whole of it arrives. These are computational designs; Scoville Splice's cultivars and constructs have not been experimentally validated in a laboratory. The designs speak for themselves as designs — specific, rigorous, built all the way down — and that is not a limitation. It is an intention, and it is the oldest one at our table.

We keep coming back, in this family, to the same small disagreement that never resolves and never needs to. One of us says the measuring *is* the reverence — that to read a flavor all the way down to its eight receptors and the enzymes above them, to know precisely how a geometric mean refuses a spike and how a tannin folds a bitter molecule out of a bite, is itself a form of love, the attention you pay to a thing you have decided is worth understanding completely. Another says the measuring is only in *service* of the reverence — that the numbers are scaffolding, and the thing they hold up is the quiet after the bite, the hush of the kitchen, the chord that makes someone close their eyes. We have stopped trying to settle it. The full spectrum is where the two are least distinguishable: a flavor read on eight axes and a flavor loved in the mouth are the same flavor, and the Index did not take the mystery out of it. It gave us a way to keep the mystery on purpose — to set all eight of its notes exactly where we meant them, and hand it to you whole.

Every axis, at once. The whole note, sounded. And still, after everything — after the models and the flux and the carriers and the eight numbers under one tall bar — a fruit on a stem in the morning, grown to hold everything it can, waiting to be tasted completely.