

THE SCOVILLE SPLICE LIBRARY · VOLUME III

The Pepper Compendium

Every cultivar. Every Scoville. *Catalogued at the receptor.*

The definitive encyclopedia of engineered Capsicum — the plant our family loved first, read fruit by fruit, gene by gene, number by number. From the shishito's warmth to Phoenix at a predicted 2.9 million SHU, every pepper profiled on the eight axes and the one receptor that started it all.

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

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Opening essay · The fruit that learned to say no

Cut a ripe pepper lengthwise and look at what you have done. Along the inner wall, where the pale ribs meet, sits a cloudy varnish you can almost see — tiny blisters on the surface of the placental tissue, each one a reservoir the plant filled on purpose. That varnish is the whole argument of this book. It is the only thing a plant has ever made specifically to cause an animal pain, and it is the reason our family spends its days here.

Every other sweetness in a garden is an invitation. A berry reddens to be eaten; a fig softens to be found. The pepper is the single fruit that evolved a chemical *refusal* — and then, in one of nature's most elegant jokes, aimed it at only half the table. Capsaicin punishes mammals, whose molars grind a seed to flour, and says nothing at all to birds, who swallow the seed whole and fly it to new ground. The biologist Joshua Tewksbury called this directed deterrence, and it is written at the level of a single receptor: the bird's version of the channel that reads capsaicin simply does not answer. The fire is a message, and it was never meant for us. We opened it anyway, ten thousand years ago, and could not put it down.



Dawn in the research house, where the question that became this company first came up at our table — why a fruit should defend itself, and whether we could read the defense exactly.

We are a family of people who grow things and measure things, and the pepper is where those two loves meet without a seam. For most of human history you could adore a chili and still only speak of it in adjectives — *bright*, *mean*, *sneaky*, *clean*. You could not say how loud it was, or where the loudness sat on the tongue, or how much of the burn was the sharp front note and how much the long deep one that arrives after you have swallowed and thought yourself safe. This volume is our attempt to give the pepper the one thing adoration never could: a number for everything, anchored not to a panel of tasting mouths but to the receptor itself, so that a shishito and a superhot and a fruit we built gene by gene can be read on a single page.

What follows is an encyclopedia. It is organized the way we actually think about the genus — first the living plant and the place inside it where the fire is made; then the receptor and the mathematics that let us measure what the fire does; then the method by which we design a pepper rather than merely select one; then the ten flagship superhots that proved the method, climbing from a whisper called Ember to the eight-axis apex we named Phoenix; and finally the whole living ladder, from the mildest culinary pepper to the frontier the pepper opens onto. We have tried to keep two things true on every page at once: that a pepper is a gorgeous, generous, living thing worth reverence, and that reverence without rigor is just a nice feeling. The varnish on that inner wall is both a marvel and a molecule. We mean to honor it as both.



PART I OF V

The Plant

Capsicum · five domesticated species · the placenta · the two pathways that converge

Chapter 1 · The Genus Capsicum — *five species, one fire.*

The genus *Capsicum* belongs to the nightshades, the Solanaceae — cousin to the tomato, the potato, the eggplant, tobacco, and petunia, a family we return to again and again in this library because so much of it can be made to carry heat. Within *Capsicum* there are perhaps thirty-five wild species and five that humans domesticated, independently, across the Americas, long before anyone wrote the events down. Knowing those five is the first literacy of the chilihead, because almost everything else — the shape of the burn, the ceiling on the Scoville scale, the aromatics that ride alongside the fire — follows from which species you are holding.

Capsicum annuum is the one most of the world eats without thinking. The bell, the poblano, the jalapeño, the serrano, the cayenne, the vast majority of paprika and of dried culinary chilies — all *annuum*. It is the species of the weeknight, bred over centuries into a range from zero heat to a respectable sting. *Capsicum frutescens* is the compact, upright, small-fruited line that gives us the tabasco and many of the bird chilies; its fruits point to the sky and hold a quick, bright heat. *Capsicum baccatum*, the ají lineage of South America, carries a fruity, almost citric aromatic beneath a moderate burn — the ají amarillo is its ambassador. *Capsicum pubescens*, the rocoto and manzano, is the odd and wonderful one: hairy-leaved, cold-tolerant, grown high in the Andes, and alone among the five in bearing jet-black seeds.

And then there is *Capsicum chinense* — misnamed for China by an eighteenth-century botanist who had his continents wrong, and in truth the pride of the Amazon basin and the Caribbean. *C. chinense* is the species of the habanero and the Scotch bonnet, and it is the species of nearly every record-breaking superhot the world has ever named: the ghost, the scorpion, the reaper, Pepper X. When we chose a chassis for our ten flagship superhots, we chose *C. chinense* without debate, because it is the lineage that already knew how to push capsaicinoid output to the physiological edge. Our work began where its talent ended.



A ripe *Capsicum chinense* fruit — the lineage of the habanero and of every flagship in this book, chosen because it already carries heat to the edge of what a plant can do unaided.

A word on names is a kindness to the reader, because the pepper is a thicket of them. The ghost pepper is *bhut jolokia*, a natural hybrid carrying *C. chinense* and *C. frutescens* ancestry — a reminder that the species boundaries blur where growers let them. "Chili," "chile," and "chilli" are the same fruit in three spellings; "pepper" itself is a borrowed word, pinned on *Capsicum* by Columbus because the burn reminded him of the black peppercorn, *Piper nigrum*, a plant from an entirely unrelated family whose heat comes from a different molecule (piperine) acting on the same receptor we will meet in Chapter 3. The tongue, it turns out, has only so many ways to signal *hot*, and evolution found the main one more than once.

The genus is older than any kitchen, and its domestication is one of the deep stories of the Americas. Chili residues on grinding stones push human use back more than six thousand years, and the botany suggests the fruit was tamed not once but at least four separate times, in four separate places, from four wild ancestors — *annuum* in the highlands of Mexico, *chinense* and *frutescens* in the Amazon basin, *baccatum* in the valleys of Bolivia and Peru, *pubescens* high in the Andes. Each domestication followed the same human impulse: find the wild bird-pepper, notice the rare plant whose ripe fruit stayed on the branch instead of dropping and shattering, and keep its seed. The wild mother of the Mexican line still grows — *Capsicum annuum* var. *glabriusculum*, the chiltepin, a pea-sized deciduous pepper foraged in the Sonoran desert to this day, its tiny fruits dispersed exactly as the directed-deterrence story predicts, by birds that carry them north each spring.

Then, in 1492, the pepper left the hemisphere, and what happened next is almost unbelievable in its speed. Columbus, hunting the black peppercorn and finding *Capsicum*, carried seed back to Spain; within a single human lifetime the fruit had traveled the Portuguese and Ottoman trade routes to West Africa, to the Malabar and Goan coasts of India, to Sichuan, to Thailand, to Korea and Hungary and the Maghreb. Cuisines we now cannot imagine without chili — the vindaloo, the mápo doufu, the kimchi, the harissa, the goulash — all met the pepper less than five centuries ago and reorganized themselves around it within a few generations. No crop in history naturalized into more kitchens faster. The pepper is a New World plant that most of the world now believes is its own, and that belief is a quiet measure of how completely a single receptor's false alarm can capture a species.

For all five species the pleasure arrives wrapped in nourishment, and this is worth saying plainly because it is true and because we grow for it. Peppers are among the richest plant sources of vitamin C — it was from paprika, not citrus, that Albert Szent-Györgyi first isolated ascorbic acid in quantity, work that carried a Nobel in 1937. The ripe red of a mature fruit is carotenoid: capsanthin and capsorubin, pigments the plant lays down as it ripens, provitamin-A carriers that double as the color we find beautiful. We make no claim about what these do inside a body; we simply hold that a fruit is a whole gift, and that a pepper grown to carry the most heat should also be grown to carry the most of everything else it was going to make anyway. The fire is the headline. It was never the only thing on the page.

Chapter 2 · Where the Fire Is Made — *the placenta, not the seed.*

There is a durable myth that the heat of a pepper lives in its seeds, and it is worth dismantling early because the truth is more exact and more useful. Capsaicinoids are synthesized and stored almost entirely in the **placenta** — the pale, pithy tissue that runs down the pepper's interior and anchors the seeds. The seeds themselves make none; they merely sit against the hottest surface in the fruit and pick up a coating by contact. When a recipe tells you to remove the seeds to tame a pepper, what it is really telling you, imprecisely, is to remove the ribs and the placental membrane they belong to. That is where the varnish is.

Under magnification the storage is startlingly literal. The epidermal cells of the placenta swell into blister-like vacuoles that hold the capsaicinoids as an oily secretion, physically sequestered from the plant's own living machinery — the pepper is careful not to poison itself with the thing it builds to deter you. Push a cultivar toward extreme output and this is the tissue that changes: in our flagship *C. chinense* lines the placental surface becomes visibly dense with these reservoirs, and the first sign that a redesign has taken is not a number on a screen but a cross-section under the glass.

The storage itself is an engineering problem the plant solved long before we arrived. Capsaicinoids are membrane-loving, and left loose they would dissolve straight into the cell's own membranes, so the placental epidermis packages them into specialized vesicles and extrudes them to the surface, sequestered in the blister-like reservoirs that give a fresh cross-section its oily sheen. The enzymes of synthesis sit just inside, on the cytoplasmic face and the endoplasmic reticulum; the finished product is walked out and locked away. This compartmental discipline is how a plant manufactures, in its own living tissue, a compound evolved to punish the very kind of cell it is made of — and it is why the flux-balance work of Chapter 8 has to respect not only the rate of synthesis but the placenta's capacity to store what it makes. Push synthesis past the tissue's ability to sequester the product and the plant would poison itself; a real redesign has to scale the reservoir and the pathway together.



Cross-section of an engineered *C. chinense* fruit. The fire is not in the seeds — it is the cloudy placental tissue and the ribs, where blister vacuoles store capsaicinoids as an oily secretion the plant keeps sealed away from its own living cells.

What those cells assemble is one molecule built from two separate supply lines that meet at a single bench. The first line makes the aromatic half — a vanilla-scented amine called **vanillylamine** — and it runs down the phenylpropanoid pathway that every vascular plant already operates for lignin and defense. The second makes the fatty half — a short, branched acyl chain — and it borrows the plant's fatty-acid machinery, starting from the amino acids valine and leucine. At the end, one enzyme welds the two halves together with an amide bond, and a capsaicinoid exists where a moment before there were only parts.

Naming the steps is the point of this chapter, because you cannot redesign what you cannot name. The aromatic branch and the fatty branch run like this:

BRANCH	STEP	ENZYME	PRODUCT
Aromatic	1	PAL (phenylalanine ammonia-lyase)	`cinnamic acid`
Aromatic	2	C4H (cinnamate 4-hydroxylase, a P450)	*p*-coumaric acid
Aromatic	3	4CL (4-coumarate:CoA ligase)	*p*-coumaroyl-CoA
Aromatic	4	HCT · C3H	caffeoyl intermediates
Aromatic	5	COMT (caffeic acid *O*-methyltransferase)	feruloyl → vanillin
Aromatic	6	pAMT (aminotransferase)	**vanillylamine**
Fatty	1	BCAT (branched-chain aminotransferase)	branched keto-acids
Fatty	2	BCKDH · KAS · FAT	**8-methyl-6-nonenoyl-CoA**
Weld	—	**Pun1 / CS** (capsaicin synthase, an acyltransferase)	**capsaicin**

Five of these enzymes — PAL, C4H, 4CL, HCT, COMT — are not pepper inventions at all. They are the common phenylpropanoid trunk, present in a rose, a redwood, and a radish. Only four terminal enzymes are specific to the pepper's talent: **pAMT**, which aminates vanillin into vanillylamine; **Pun1/CS**, which performs the final weld; and **KAS** and **BCAT** on the fatty side, which set the length and saturation of the acyl chain. That short list — four enzymes standing between a generic plant and a pepper — is the quiet thesis of this whole library, and we will spend Part III on what happens when you can edit them.

The identity of that fatty chain is not a detail; it is the burn's personality. If the welded acyl group is **8-methyl-6-nonenoic acid**, with its single double bond, the product is capsaicin proper. If the chain is fully saturated — 8-methylnonanoic acid — the product is **dihydrocapsaicin**. Trim a carbon and you get nordihydrocapsaicin; add one and you reach the homo- series. These are not trivia for a tasting menu. A pepper's ratio of capsaicin to dihydrocapsaicin to the minor capsaicinoids is set right here, at the KAS and FAT steps of the fatty branch, and that ratio decides whether the heat you feel is a sharp bright strike at the front of the mouth or a slow flat flood in the throat. The placenta does not just decide *how much* fire. It decides *which* fire. Chapter 6 is about learning to read the difference, and Chapter 7 is about learning to write it.

Chapter 3 · The Molecule and the Channel — *a burn that isn't there.*

Here is the first thing to understand about the heat of a pepper: nothing is hot. No tissue in your mouth rises in temperature when you bite a chili. The fire is a report, filed by a single sensor, about a danger that is not present — and the entire art of this company rests on the fact that a false report, read precisely enough, can be composed on purpose.

The sensor is **TRPV1**, the transient receptor potential vanilloid channel of type 1, studded along the trigeminal nerve endings that serve the mouth and face. In its ordinary life TRPV1 is a thermometer and an alarm: it opens and floods the nerve with calcium and sodium ions when tissue temperature climbs above roughly 43 °C, or when the local acidity spikes, as it does in an injury. Opening the channel tells the brain *this is burning you*. Capsaicin's trick — the whole trick, the one the pepper evolved — is that it binds TRPV1 from the inside and **lowers the temperature at which the channel opens**. It drags the 43 °C threshold down below body temperature. The channel, now set to alarm at a heat it already sits in, fires. Your own 37 °C becomes the fire. You feel a burn exactly as real as a hot pan, built from nothing but a molecule and a shifted setpoint.



A single fruit on the stage. The heat it carries is not warmth but a message — capsaicin lowering the trigger temperature of one channel until the body's own 37 °C reads as fire.

TRPV1 is built as a **homotetramer** — four identical protein subunits around a central pore — and the vanilloid pocket where capsaicin docks sits in each subunit between the third and fourth transmembrane helices, snug against the linker that physically pulls the gate open. The structures that showed us this, solved by cryo-electron microscopy, resolved capsaicin lying "tail-up, head-down" in the pocket, its vanillyl head hydrogen-bonding to the channel while its fatty tail threads a greasy groove. The work on TRPV1 and its cold-sensing sibling earned the 2021 Nobel in Physiology or Medicine, and it is the molecular bedrock under everything we

measure. When we speak of designing heat, we mean designing a ligand's conversation with this pocket — or, more often, designing how much of the native ligand a plant delivers to it.

That bedrock was laid surprisingly recently. The channel was cloned in 1997 by David Julius's laboratory, in an elegant brute-force screen: they took a library of sensory-neuron genes, expressed pools of them in cells that normally feel nothing, and looked for the pool that made the cells answer capsaicin with a flood of calcium. One gene did. They called it VR1, the vanilloid receptor, now TRPV1 — the first molecular proof that the burn of a chili is a specific protein and not a vague irritation. Two decades later the same lab, with Yifan Cheng's, used the then-new method of cryo-electron microscopy to solve TRPV1's structure to near-atomic resolution, among the very first membrane proteins ever seen that clearly; the images of capsaicin seated in its pocket are the reason we can now speak of the vanilloid site as a real, mappable place. Julius shared the 2021 Nobel Prize in Physiology or Medicine with Ardem Patapoutian, whose work on the cold-and-menthol channel TRPM8 and the touch channels completed the molecular account of how a mouth reads the physical world. Everything this library measures on IFI-H and IFI-C descends directly from that work.

TRPV1 is best understood not as a capsaicin sensor but as a polymodal integrator — a single channel that sums several warnings into one decision to open. Noxious heat, acid, capsaicin, and a family of the body's own lipids (anandamide and NADA, the endovanilloids) all converge on it, and inflammatory signaling sensitizes it further: when tissue is injured, kinases such as PKC and PKA phosphorylate the channel and drag its threshold down, which is why a sunburned shoulder reads ordinary warmth as pain. Capsaicin simply hijacks this integrator, mimicking an endovanilloid to force the threshold shift chemically. The most extreme known hijacker is not even from a pepper: resiniferatoxin, from the Moroccan spurge *Euphorbia resinifera*, is an ultrapotent vanilloid roughly a thousand times stronger than capsaicin at the channel — potent enough that it is studied as a precision tool for silencing pain nerves outright. We mention it to make a point about potency and the index: loudness at a receptor spans orders of magnitude, and a scale anchored to EC_{50} is the only honest way to place a shishito and a spurge toxin on the same axis.

A last note the careful reader deserves: capsaicin's *sensation* is a lie, but its *presence* in the body is real. Once absorbed, it is handled by the liver's cytochrome-P450 enzymes — CYP2E1, CYP1A2, CYP2C9 and others — and cleared like any lipophilic small molecule. The burn is a false alarm; the molecule behind it is an ordinary, metabolizable compound, decoupled from the harm it so convincingly reports. We dwell on this because it is the crux of the whole enterprise: the thing we design is a signal, not an injury, which is precisely what makes it safe to compose. We are writing messages to a receptor, not doing damage to a mouth.

Because the channel has four subunits and more than one pocket contributes, its response to capsaicin is **cooperative**, and that shape is not a curiosity — it is the mathematics the whole index is built on.

The fraction of channels open follows a Hill function:

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response = E_max · [C]ⁿ / (EC₅₀ⁿ + [C]ⁿ)
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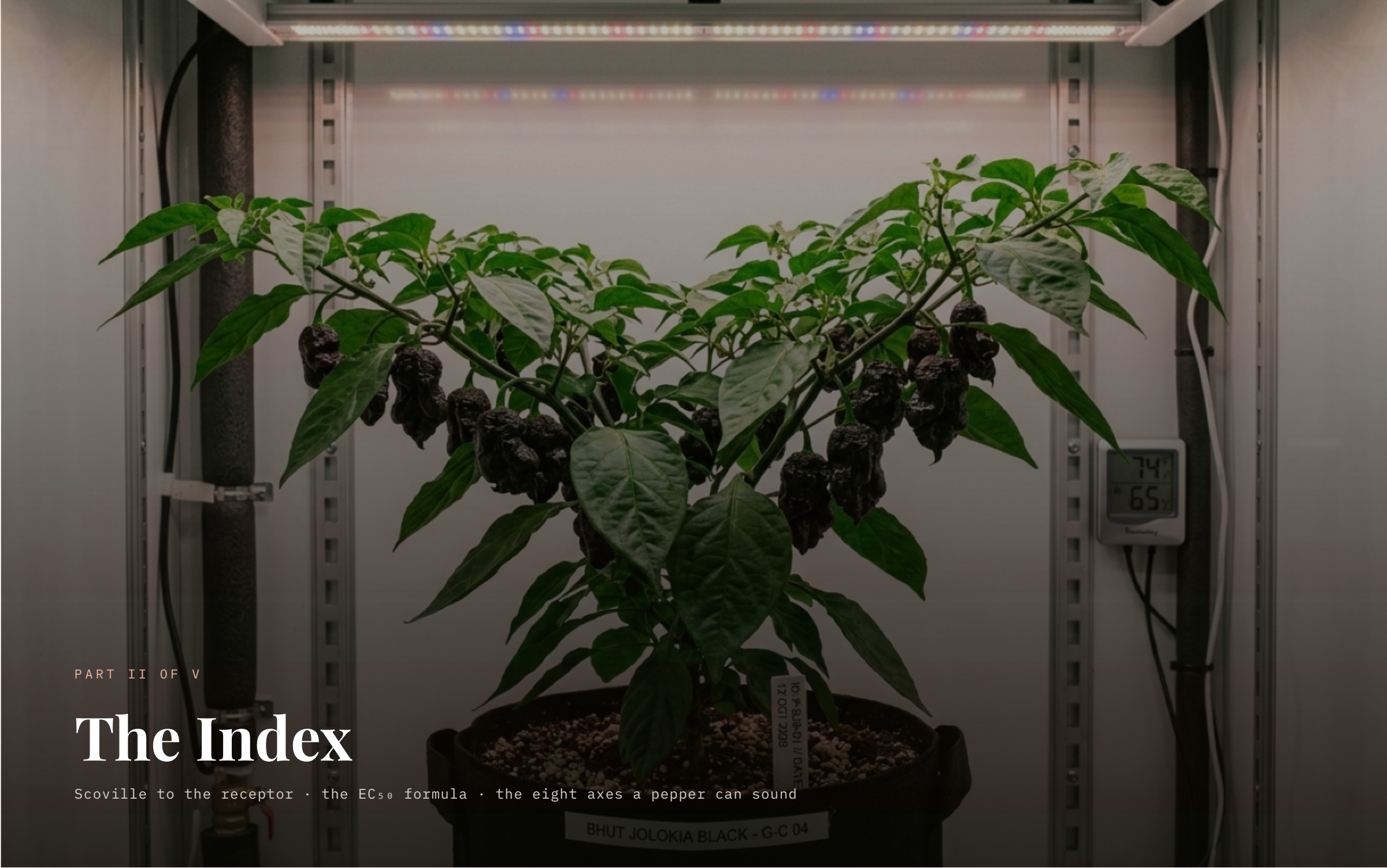
where [C] is the capsaicin concentration, **EC_{50}** is the concentration that drives the channel to half of its maximum response, and **n**, the Hill coefficient, runs near 2 for capsaicin at TRPV1 — the signature of positive cooperativity among the subunits. For capsaicin the EC_{50} sits in the sub-micromolar range, roughly 0.7 µM in the standard preparations. That single number — the concentration for half-activation — is the hinge of this entire library, because it is a property of the *conversation*, not of the dose. It asks not "how much capsaicin is here" but "how little does it take for this channel to answer." Invert it, and you have loudness. We will build the Iyengar Flavor Index on exactly that inversion in the next chapter.

Two further behaviors of TRPV1 matter at the table. The first is **desensitization**: the same calcium flood that signals the burn also, over minutes, triggers a calcium-dependent dephosphorylation that quiets the channel. This is why the second bite of a hot dish lands softer than the first, why chili eaters build tolerance, and why a concentrated capsaicin patch can be used clinically to exhaust a nerve's pain signaling entirely — a pharmaceutical use real enough that we state, clearly, that we are a flavor company and make no therapeutic claim of any kind. The second is **solubility**: capsaicin is intensely lipophilic, with an oil-water partition that keeps it clinging to fat and membrane and utterly indifferent to water. That one physical fact governs every attempt to cool a burning mouth, and we will cash it out in the kitchen chapter, where milk works and water laughs at you.

And the birds. Avian TRPV1 carries a handful of amino-acid substitutions in and around the vanilloid pocket that leave the channel fully able to sense dangerous heat while rendering it all but blind to capsaicin. The pepper, in other words, did not evolve a generic poison; it evolved a molecule shaped to a specific pocket in a specific set of mouths, and left the dispersers it wanted untouched. We find this almost unbearably elegant. A flavor is a key, a receptor is a lock, and the pepper is ten thousand years of proof that if you know the lock well enough, you can cut a key for exactly the mouth you mean to reach. That is the whole premise of what we do. The pepper thought of it first.



PART II OF V

The Index

Scoville to the receptor · the EC_{50} formula · the eight axes a pepper can sound

Chapter 4 · Heat as a Number — *from Scoville's syrup to the receptor.*

In 1912 a pharmacist named Wilbur Scoville, working for a Detroit drug company, needed to standardize the pungency of the pepper extracts going into a counterirritant ointment. His method was ingenious and entirely human: dissolve a known weight of dried pepper in alcohol, dilute the extract in sweetened water, and feed it to a panel of tasters, stepping the dilution down until a majority could no longer detect any heat. The dilution factor at that vanishing point became the pepper's rating. A chili detectable at one part in fifty thousand earned 50,000 **Scoville Heat Units**. More than a century later, the SHU is still the number on the hot-sauce bottle, and we owe it genuine respect: it was the first time anyone put a real quantity on a sensation.

But the organoleptic test is a measurement taken through a crowd of tired tongues. It drifts with the panel, desensitizes as it runs, and cannot see past the point where the tasters simply give out. The modern laboratory replaced the mouths with a column. **High-performance liquid chromatography** — the ASTA and AOAC reference methods — separates a pepper extract into its individual capsaicinoids and measures each one directly, in parts per million. The pungency is then reconstructed arithmetically: each capsaicinoid is weighted by its own pungency factor and summed, and the total parts-per-million is multiplied by roughly sixteen to return a value on Scoville's historical scale, so that pure capsaicin lands near 16,000,000 SHU. For wild and conventional peppers in this compendium, this chromatographic method is how SHU figures were obtained — not by tasting, but by chromatography, then translated into the unit the world still reads. For the engineered flagship cultivars, the SHU values are computational predictions from our metabolic model, calibrated to the Scoville scale.

The modern method has its own canon. The Gillett high-performance liquid chromatography approach, formalized through the American Spice Trade Association (method 21.3) and AOAC Official Method 995.03, separates an extract on a reversed-phase column and quantifies each capsaicinoid against a reference standard, reporting the result in parts per million or milligrams per gram. The individual capsaicinoids are then summed with weights that reflect their relative pungency — capsaicin and dihydrocapsaicin carry essentially full weight, the nor- and homo-species somewhat less — and the weighted total is multiplied by a factor near sixteen to return Scoville units. The whole apparatus exists to do by machine, repeatably, what Scoville's panel did by tongue: it is the same question asked of a column instead of a crowd, and it is why a modern SHU figure is a measurement rather than an opinion.



Standardized extract trays on the measurement bench. Every Scoville figure in this volume is read by chromatography first — capsaicinoids separated and quantified — then translated into the unit Wilbur Scoville left us.

The SHU has one deep limitation, though, and it is the reason the Iyengar Flavor Index exists. Scoville units measure *how much capsaicinoid is present*, scaled to a human dilution threshold. They do not measure *how loudly that capsaicinoid speaks to the receptor*, and they cannot speak at all about the seven other things a pepper does to a mouth — the bitterness, the sweetness, the cooling edge, the savory depth. To build a pepper on purpose, and to set it beside a tomato or a mint on one page, we needed an index anchored where sensation actually begins: at the channel.

The index inverts the EC_{50} from the last chapter. For any stimulus c and any axis, the score is:

$$IFI(c) = 1{,}000 \cdot EC_{50}(\text{reference}) \,/\, EC_{50}(c)$$

Read it slowly, because it is the spine of the library. EC_{50} is the concentration needed for half-activation, so a *smaller* EC_{50} means a *more potent* stimulus — less of it does the same work. Putting EC_{50} in the denominator flips potency the right way up: a louder stimulus earns a higher number. The reference in the numerator is a fixed anchor, a standardized wild-type extract whose own dose-response at the receptor defines EC_{50}(reference). By construction the reference scores exactly 1,000 — feed it into its own formula and the ratio is one. Everything else is read as a multiple of the reference's loudness. For the heat axis, that reference is a standardized wild-type *C. chinense* placental extract, so **IFI-H = 1,000** is "as loud as native wild-type," and the scale runs up from there. Scorecards in this book normalize each axis to a ceiling of **5,000**, which is why even our most extreme flagship leaves a little headroom at the top of the heat bar.

Here is the formula doing real work. Our eight-axis apex, Phoenix, carries **IFI-H 4,200**. Solve for its receptor behavior:

$$EC_{50}(\text{Phoenix}) = EC_{50}(\text{ref}) \cdot 1{,}000 \,/\, 4{,}200 = 0.238 \cdot EC_{50}(\text{ref})$$

Phoenix reaches half-activation of TRPV1 at **23.8 % of the concentration** the reference needs. It is, precisely, 4.2 times louder than wild-type — not 4.2 times more capsaicin necessarily, but 4.2 times more *effective* at the channel, which is the thing your nerve

actually reports. That distinction between amount and loudness is the entire reason we measure at the receptor, and the next two chapters are what it buys you.

It is worth seeing *why* an EC_{50} ratio is the right quantity to call loudness, because the choice is not arbitrary. Two stimuli acting on the same channel through the same Hill function produce response curves of identical shape, shifted along the concentration axis only by their EC_{50}. The more potent stimulus's curve sits to the left — it reaches any given activation at a lower concentration — and the horizontal distance between the two curves is exactly the ratio of their EC_{50} values. That ratio is dimensionless, independent of how much you happen to be eating, and stable across the dilution the mouth performs with saliva. By putting the reference's EC_{50} over the candidate's and scaling by a thousand, the index turns that horizontal shift into a single integer. A reading of 2,000 is not "twice as much capsaicin"; it is "the half-activation point sits at half the concentration" — twice as potent, twice as far to the left on the curve. Anchoring the reference at 1,000 rather than at 1 simply gives the integers room to breathe and lets all eight axes share one common ceiling, which the scorecards clip at 5,000. The discipline we are borrowing here is the receptor's own: the Hill function compresses an enormous range of concentration into a bounded response, and the index inherits that compression.

How does this receptor loudness relate to the familiar Scoville number? Strongly, but not perfectly — and the imperfection is the interesting part. Across our ten flagship superhots, each additional million Scoville units buys very roughly **1,100 to 1,200 IFI-H points**, a tight enough relationship that in the superhot band you can estimate one from the other. But the correlation is not a law, and it breaks in instructive places. Two peppers can carry the same SHU and read different IFI-H, because SHU totals every capsaicinoid by mass while IFI-H weights them by how each one actually drives the channel. A pepper heavy in the flat, slow dihydrocapsaicin can post a monstrous Scoville count and still read quieter at the receptor than a leaner, capsaicin-dominant fruit beside it. We built the index precisely so that the fruit would stop being able to lie to us about its loudness. Chapter 6 is the autopsy of exactly that lie.

	SCOVILLE HEAT UNITS	IYENGAR FLAVOR INDEX (IFI-H)
Measures	capsaicinoid amount, by mass	receptor loudness, at TRPV1
Anchored to	human dilution-to-threshold	EC_{50} of a fixed reference
Reads	one axis (pungency) only	one of eight comparable axes
Blind to	which capsaicinoid, and all non-heat taste	nothing in its lane
Native wild-type	varies by cultivar	**1,000**, by construction

Chapter 5 · The Other Seven — *a pepper is never only hot.*

Ask a hundred people what a pepper tastes like and ninety-nine will say *hot*, as though heat were the whole fruit. It is not. Heat is simply the loudest voice in a chord, and the chilihead who learns to hear past it discovers that even a modest jalapeño is doing six or seven things to the mouth at once — a grassy green bitterness, a faint sweetness as it ripens, a savory roundness in a cooked sauce, a cooling lift on the exhale. The Iyengar Flavor Index was built to hear the whole chord, and the pepper is where we first proved it could.

The eight axes, each anchored to its own receptor, are the alphabet the rest of this library is written in:

CODE	AXIS	RECEPTOR	WHAT IT READS, IN A PEPPER
IFI-H	Heat	TRPV1	the capsaicin burn
IFI-S	Sweetness	TAS1R2 · TAS1R3	sugars that rise with ripeness
IFI-U	Umami	mGluR1 · TAS1R1·R3	glutamate depth in cooked flesh
IFI-B	Zero-Bitter	TAS2R38	the green alkaloid edge
IFI-K	Kokumi	CaSR	continuity, body, the lingering fill
IFI-C	Cool-Burn	TRPM8	the menthol-adjacent exhale
IFI-P	Pungency	TRPA1	the sharp mustard-family bite
IFI-A	Astringency	salivary PRPs	tannic grip from skin and pith



A flagship cross-section. Heat is the headline, but the ribs, skin, and ripened flesh each sound their own axis — a pepper is a chord, not a single note, and the index was built to hear all eight voices.

Two of these axes deserve a careful word because they are the ones people most often mistake for heat. **Pungency, IFI-P**, is not a dialect of burn — it is a different receptor entirely. TRPA1, the channel behind the sharpness of mustard, wasabi, horseradish, raw garlic, and cinnamon, is a chemical irritant sensor distinct from TRPV1. A raw allium bite and a chili bite feel like cousins, but they are reported by different nerves answering different molecules, and the index keeps them on separate columns so that a sauce builder can dial the mustard-sharp top note and the capsaicin body independently. **Cool-Burn, IFI-C**, is stranger still: TRPM8 is the cold and menthol

sensor, the counterpart to TRPV1, and because the two channels argue across the same nerve, a trace of cooling can be laid over heat to change its entire character — the numbing, almost minty lift that the best superhots carry on the finish and that the Sichuan tradition raised to an art. A pepper that scores on both IFI-H and IFI-C does not merely burn; it burns and then releases, and the release is engineerable.

It helps to know what each voice is actually made of, because in a pepper the eight axes are eight different classes of molecule accumulating in the same fruit. The sweetness the TAS1R2·R3 receptor reads is literal sugar — glucose and fructose that climb as the fruit ripens, which is why a fully colored habanero tastes fruity-sweet beneath its fire where a green one does not. The umami read on mGluR1 is free glutamate and aspartate, concentrated when the flesh is cooked or dried, the savory depth that makes a roasted-chili sauce taste of more than heat. The bitterness on TAS2R38 is the fruit's flavonoids and alkaloids — the quercetin and luteolin glycosides, the green edge of an unripe pod. The astringency on the salivary proteins is its polyphenols and tannins, gripping the skin and pith. Kokumi, on the calcium-sensing receptor, is the subtlest of all: not a flavor of its own but a *modifier*, the γ-glutamyl peptides and calcium that lend continuity and fill. Read this way, the index is not eight opinions about a pepper — it is eight real inventories, each anchored to the receptor that happens to read that class of molecule.

Two composites finish the alphabet, and both bear on the flagships. **IFI-F**, full-spectrum, is not a ninth axis but the condition of sounding all eight at once — the thing Phoenix is designed to reach and nothing in nature does, the axis of the whole chord. **IFI-M**, multi-axis, names the deliberate two- and three-voice combinations the wider platform builds — heat with sweetness, umami with kokumi — the intersections where most designed flavor actually lives. The superhot ladder, in this light, is a walk from a single axis toward full-spectrum, and the composites are simply the names for how far along that walk a given fruit has come.

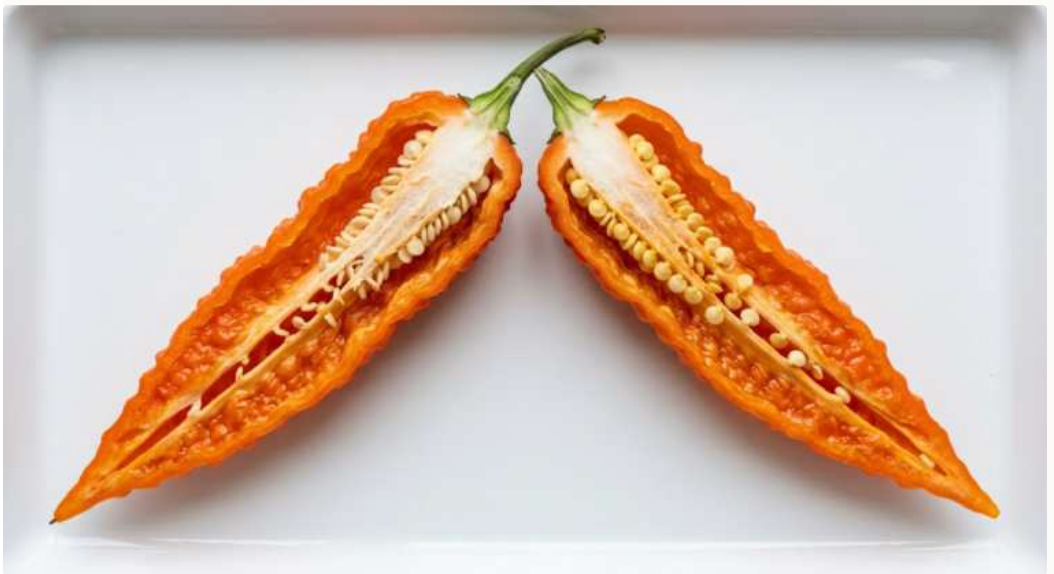
This is why the flagship ladder in Part IV is not a story about heat getting louder. It is a story about a chord getting fuller. As the placental pathway is pushed, secondary axes switch on, and they do so in a consistent order — an order we read directly off Phoenix, the one flagship for which we hold a complete eight-axis profile. Ranked by magnitude, Phoenix's non-heat axes fall out as **Zero-Bitter (2,200) > Kokumi (1,900) > Umami (1,800) > Astringency (1,400) > Sweetness (1,100) > Cool-Burn (800) > Pungency (252)**. That ranking is a recruitment order: the axes with the largest secondary presence are the ones that appear first as a cultivar climbs. A two-axis pepper sounds heat and the first companion, bitterness; add rungs and kokumi joins, then umami, then astringency and pungency; only at the apex do the quiet two, sweetness and a whisper of cool, finally sound. The magnitude ranking places pungency last among Phoenix's secondary axes at IFI-P 252 — it activates at the Firestorm/Solara level per the design but sounds

softly, well below the other overtones in the corrected AITC convention. We present this as a model drawn from one complete profile, not as a separate measurement of each fruit — but it is a model the whole ladder obeys, and it reframes what a superhot actually is. The record-breakers are not the hottest peppers. They are the *fullest* ones, the fruits in which the most of the chord is awake at once.

There is a nourishment note hiding in this chord, and we will not preach it, only place it. The bitterness the index reads on IFI-B is largely the pepper's alkaloids and phenolics; the astringency on IFI-A is its tannins and polyphenols; the color that tracks with a ripe fruit's sweetness is carotenoid. These are not flavors bolted on — they are the compounds a well-grown fruit accumulates as it matures, the same molecules that make the pepper a dense little package of what a plant can hold. When we design for a fuller chord, we are also, quietly and on purpose, designing for a fuller fruit. We think those are the same act, and we think the pepper agrees.

Chapter 6 · The Shape of a Burn — *why Scoville lies about loudness.*

Somewhere in the flagship ladder sits a small scandal, and it is the best teaching case in this book. Kindle, the pepper we catalog as SS-0089, carries **1.25 million Scoville units** — a heavier Scoville count than Cinder (SS-0088) at 1.05 million just below it. By the logic of the hot-sauce bottle, Kindle should be the hotter fruit. At the receptor, however, it reads quieter: Kindle reads **IFI-H 2,000**, while the lower-Scoville Cinder reads **2,290**. More capsaicinoid, by mass — and a quieter channel. A pepper appeared to out-burn its neighbor on paper and under-burn it in the mouth. The index caught the fruit in the act, and the catch has a chemistry.



Kindle in cross-section — the paradox of the ladder. By mass it out-scores the rung below it; at the receptor it reads quieter, because the burn's loudness lives in *which* capsaicinoid, not how much.

Recall from Chapter 2 that the fatty branch of the pathway decides *which* capsaicinoid gets made, and that the Scoville method of Chapter 4 totals every capsaicinoid by mass with roughly equal weighting. The receptor is not so generous. It answers different capsaicinoids with different EC_{50} values and, just as importantly, with different *shapes* — different onset, duration, and location in the mouth. Here is the family, with the character that each member brings:

CAPSAICINOID	TYPICAL SHARE	PUNGENCY (SHU, PURE)	SHAPE OF THE BURN
Capsaicin (C)	~69 %	16,000,000	sharp, fast onset, mid-mouth and throat
Dihydrocapsaicin (DHC)	~22 %	16,000,000	flat, slow onset, deep, very long
Nordihydrocapsaicin (NDHC)	~7 %	9,100,000	front-of-mouth, fast, fleeting, mildest
Homocapsaicin (HC)	~1 %	8,600,000	low, broad
Homodihydrocapsaicin (HDHC)	~1 %	8,600,000	late, deep, numbing, longest

The shares vary by cultivar, and that variation is the whole story of Kindle. It is a **dihydrocapsaicin-dominant chemotype**: its placenta tilts the fatty branch toward the saturated, flat, slow-building capsaicinoid. On the Scoville scale, dihydrocapsaicin and capsaicin are near-equals by mass, so the shift barely registers in the SHU

total — Kindle still posts 1.25 million. But dihydrocapsaicin is the slow one. It arrives late, sits deep in the throat, and builds like a tide rather than striking like a match. At the receptor, read as peak loudness, that flat profile simply does not shout as loud as the sharp, capsaicin-forward strike of Cinder. Same family of molecules, redistributed along the fatty branch, and the mouth tells a completely different story than the mass spectrometer.

There is a stranger relative worth meeting here, because it completes the logic of *which molecule, not how much*. Change one atom in the aromatic head — swap the amine of vanillylamine for a hydroxyl, making vanillyl alcohol — and the final weld produces not a capsaicin*oid* but a capsin*oid*: capsiate, or its saturated cousin dihydrocapsiate. Structurally it is a near-twin, an ester where the capsaicinoid is an amide. Perceptually it is almost silent — roughly a thousandth of the pungency — because that single swapped atom no longer fits the vanilloid pocket the way the amide does. The cultivar CH-19 Sweet is the famous natural example: a pepper that runs the entire capsaicinoid machinery and yet barely burns, because a mutation in *pAMT* — the aminotransferase that should make vanillylamine — leaves the plant building vanillyl alcohol instead. It is the mirror image of our work. Where we push a pathway to its loudest, nature here runs the very same pathway to near-silence by changing one input, and the result proves the thesis from the other direction: the burn lives in the molecular detail, not the bulk.

The non-pungent bell pepper reaches silence by a cruder route still — the recessive *pun1* allele simply breaks the final weld, so no capsaicinoid forms at all. Pungency, then, can be switched off at the head (*pAMT*, giving capsinoids), at the weld (*Pun1*, giving nothing), or tuned along the tail (the fatty branch, giving the capsaicin-to-dihydrocapsaicin spectrum of this chapter). A pepper's heat is not one dial. It is three, and this compendium is, at bottom, a catalog of where each fruit sets them.

This is why two numbers are better than one, and why we insist on both. SHU tells you the *payload*. IFI-H tells you the *loudness*. The gap between them — call it the dihydrocapsaicin index, informally, because the saturated capsaicinoids are what pries them apart — is a real, readable property of a fruit, and it is one of the most useful things a sauce designer can know. Do you want a chili-oil that announces itself the instant it hits the tongue and then clears, or one that seems mild for a terrifying three seconds and then will not leave for ten minutes? That is not a question of how much heat. It is a question of which capsaicinoid, set at the KAS and FAT steps of the fatty branch, and it is exactly the kind of thing we learned to specify on purpose.

Onset and duration round out the shape. Because capsaicin is lipophilic, the burn's *arrival* depends partly on how fast the carrier releases it — a watery salsa strikes faster than an oil, which holds its payload and feeds it to the receptor slowly, lengthening the burn. The *location* depends on the capsaicinoid mix: the nor- series skews front-of-mouth and brief, the homo- series skews back-of-throat and

long. A complete description of a pepper's heat, then, is not a single Scoville number at all. It is a little curve — how high, how fast up, how slow down, and where in the mouth — and the compendium's ambition is that every fruit in it should be legible as that curve, not as a lonely number on a label.



PART III OF V

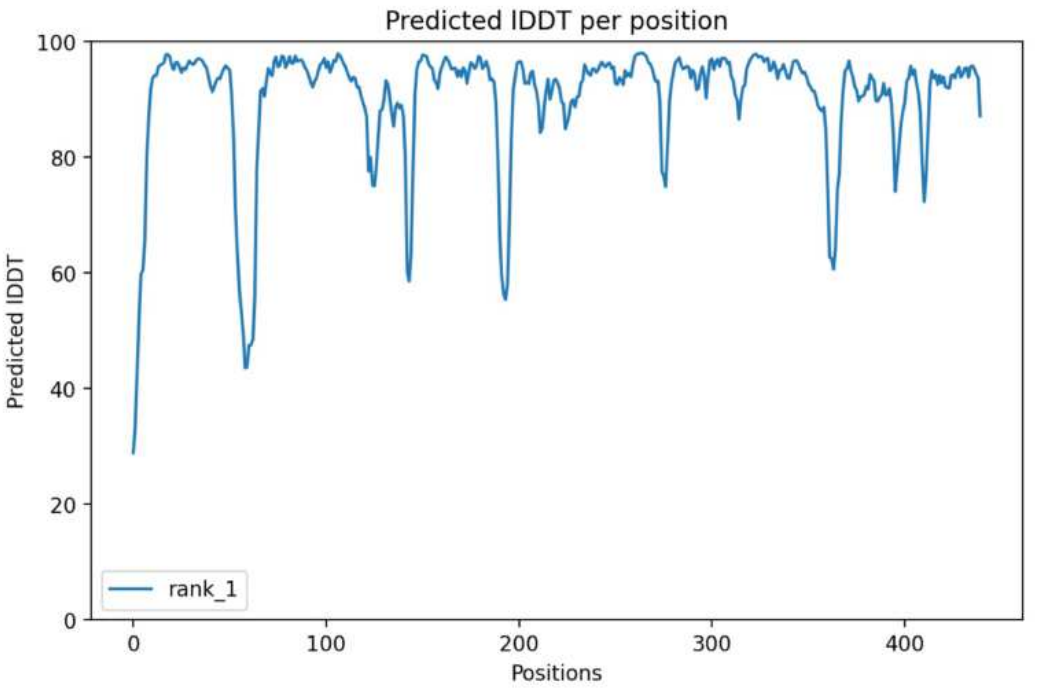
The Method

ESM2 · two edits to Pun1 · flux balance · CRISPR · CV ≤ 7 %

Chapter 7 · Designing Pun1 — *two designed edits the breeders never found.*

For ten thousand years the method for making a hotter pepper was the same: grow a field, taste the fruit, keep the seed of the one that burned brightest, and repeat until your grandchildren had a landrace. It is a beautiful method and it built every pepper in Part I of this book, but it has a ceiling, and the ceiling is information. Classical breeding selects the *phenotype* — the burn you can taste — and hopes the *genotype* that caused it comes along in the seed. It cannot see the enzyme. It cannot ask which single amino acid in the final weld is holding the whole fruit back. We inverted the method: instead of selecting the burn and hoping for the gene, we read the gene and designed the burn.

The gene is **Pun1**, the locus that encodes capsaicin synthase — the acyltransferase that performs the final condensation of vanillylamine and the branched acyl chain. Pun1 is the terminal step of the entire pathway: the switch that determines *whether* heat forms at all. The recessive *pun1* allele, a deletion in its promoter and first exon, is precisely why a bell pepper has no heat at all: break this one enzyme and the whole varnish never forms. But Pun1 being the final weld does not make it the flux-rate governor — our model places that control upstream, at 4CL and HCT/CCoAOMT — and yet improving the final enzyme still matters: the ceiling it sets has to be high enough to pass whatever substrate the upstream steps send. If Pun1 is the switch for *whether* a pepper is hot, we reasoned, then the fine structure of the Pun1 protein must hold the dial for ensuring the terminal step is not a hidden constraint — and that dial had never been turned by anyone, because you cannot select your way to a protein substitution that the wild population never happened to carry.



Pun1 / AT3, the capsaicin synthase, colored by model confidence. The binding domain and the active-site cleft resolve at high confidence — the map we scored, residue by residue, before changing a single base in the plant.

So we modeled it. Pun1 belongs to the **BAHD family** of acyltransferases, enzymes that share a conserved catalytic **HXXXD** motif — a histidine that acts as the base, deprotonating the incoming vanillylamine so its nitrogen can attack the thioester carbonyl of the acyl-CoA — and a structural **DFGWG** motif that braces the fold. We built a structural model of the protein, validated its confidence surface (the per-residue pLDDT above, the predicted aligned-error map in the next chapter), and then did the thing breeding never could: we scored *every possible single-residue substitution* in the protein with a 650-million-parameter protein language model, **ESM2**, ranking each candidate mutation by its predicted effect on catalytic efficiency multiplied by fold stability. A protein language model does not know chemistry the way a textbook does; it has read enough protein sequence that it has learned, statistically, which substitutions proteins tolerate and which they do not — and that learned intuition, pointed at Pun1, lit up a small number of edits no pepper had ever carried.

It is worth being precise about what a protein language model does when it "scores" a mutation, because it is neither magic nor textbook chemistry. ESM2 was trained on hundreds of millions of natural protein sequences with a single objective: mask out residues and predict them from their context. To do that well across all of known protein space, the model is forced to internalize the statistical rules real proteins obey — which residues coevolve, which contacts must be preserved, which positions are load-bearing and which tolerate change. Once trained, it can be asked a question it was never explicitly taught: for a given position in Pun1, how much more or less *natural* does each possible substitution make the sequence? That difference in log-likelihood — the model's estimate of how far a mutation agrees with the deep grammar of proteins — predicts real effects on stability and function remarkably well, with no wet experiment required. We ran that scan over every residue of Pun1, multiplied each candidate's score by a structure-based estimate of its effect on fold stability, and kept only the handful the model and the structure agreed would help. Breeding searches the tiny space of mutations a wild population happens to carry. A language model searches, in silico, the whole space of mutations the protein *could* carry — which is how it reached edits ten thousand years of selection never did.

Two substitutions — **S39L** and **L345G** — make up the shipped construct, written into the plant with CRISPR, never before combined in any living pepper. A third candidate, **C175S**, emerged from our structural modelling as a disulfide-misfold prevention measure and is documented in our design notes as a structural annotation; it was not included in the final design. All three are listed below for completeness:

EDIT	STRUCTURAL ROLE	EFFECT	ΔΔG (KCAL/MOL)	STATUS
S39L	N-terminal binding region	raises substrate binding affinity	−2.1	shipped
L345G	active-site cleft	steric relief, opens the catalytic pocket	−1.8	shipped
C175S	non-native cysteine	prevents a disulfide misfold	−0.9	structural annotation — not in shipped construct

Read the ΔΔG column as the model's promise. Each negative value is a predicted *stabilization* — the edited protein folds into its working shape more reliably than wild-type. S39L tightens the grip on the substrate at the mouth of the N-terminal binding region; L345G swaps a bulky leucine for the smallest possible residue, glycine, relieving a steric pinch in the active-site cleft so the welded product can clear. Individually, modest. Together, the double variant is designed to lift the flagship line's predicted peak output to approximately **2.95 million SHU** — and, more quietly and more importantly, the design targets *repeatability*.

That repeatability is the goal we are proudest of, because it is the one a buyer actually depends on. Wild-type superhot output is wildly variable fruit to fruit — a batch-to-batch coefficient of variation around **42 %**, which is why two pods off the same record-breaking plant can differ enough to make a sauce formulation a gamble. The double-variant design targets a batch CV of **≤ 7 %**, the design specification the whole ladder holds. For a chilihead that means a pepper you can trust; for a formulator it means a specification you can build a business on. We did not only design a hotter pepper. We designed an *honest* one — a fruit built to deliver what the number says, every time, which for a family that cares about what it puts in front of people is the whole point.

Chapter 8 · Flux, Not Phenotype — *pushing a pathway without starving a plant.*

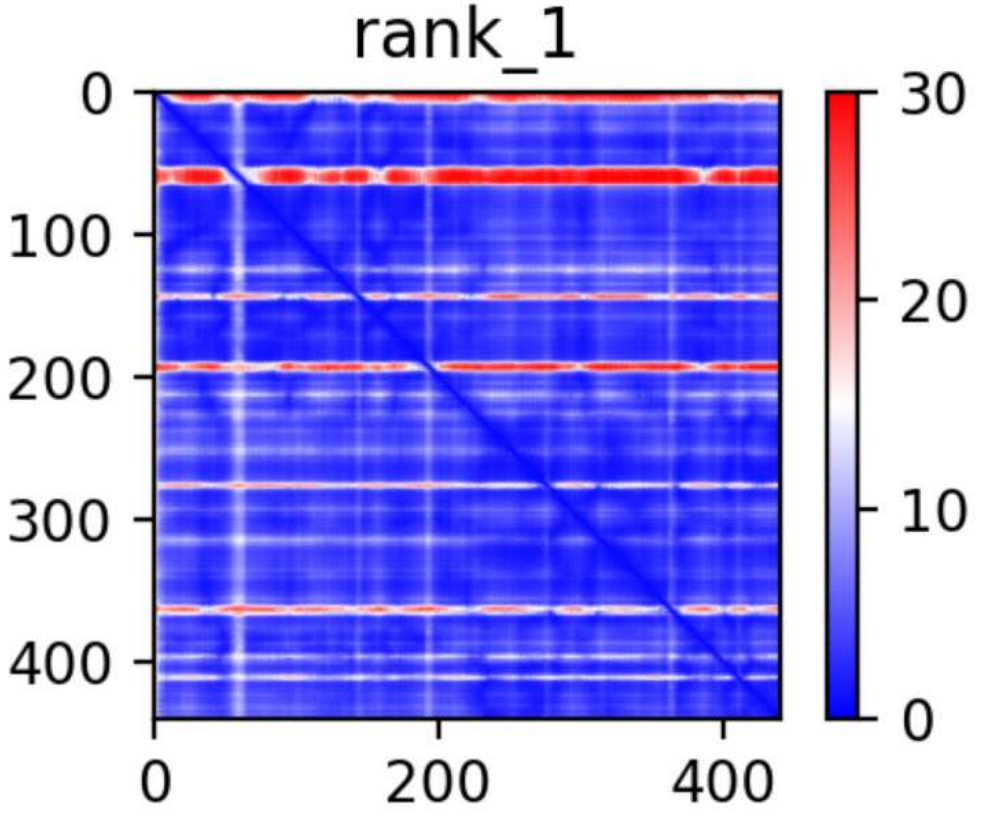
Editing Pun1 answers a question the breeder could never reach — *is this enzyme the best version of itself?* — but it raises a harder one. Even a perfect capsaicin synthase can only weld the parts that reach its bench. If the aromatic branch is slow to deliver vanillylamine, or the fatty branch runs short of its branched acyl chain, the finest enzyme in the world will sit idle for want of substrate. Before we changed a single base, we had to know which step in the whole network was actually the rate limiter — and we had to make sure that in pushing it, we did not quietly starve the rest of the plant.

The tool for that is **flux-balance analysis** run over a genome-scale metabolic model: a mathematical reconstruction of the plant's entire known metabolism, every reaction as an equation, solved under the assumption that at steady state what flows into each metabolite pool must flow out. You set an objective — here, capsaicinoid output — and the model computes the distribution of flux through thousands of reactions that maximizes it, subject to the hard constraints of stoichiometry and the plant's finite supply of carbon, nitrogen, and energy. Crucially, it tells you where the bottleneck *is not*, which is as valuable as where it is. Our flux model predicts that control sits primarily upstream in the phenylpropanoid pathway — at 4CL and HCT/CCoAOMT — rather than at the terminal Pun1/AT3 step. Pun1 is the final capsaicin synthase; it labels the product, it does not govern the rate. Metabolic Control Analysis of the network (summation theorem: sum of all control coefficients = 1.000) assigned Pun1 a predicted flux control coefficient near zero in our ensemble runs; upstream steps account for the dominant share of pathway control. That picture guided the design: the Pun1 edits of the last chapter raise the final step's ceiling, ensuring the terminal weld is not a constraint when the upstream pathway is encouraged to run harder.

The mathematics under that sentence is simpler and more beautiful than its name suggests. A metabolic network is written as a stoichiometric matrix **S**, one row per metabolite and one column per reaction, each entry recording how much of a metabolite a reaction consumes or produces. The rates of all reactions form a flux vector **v**. The single governing assumption is steady state — that internal metabolite pools neither fill nor drain over the timescale of interest — which is the compact equation $\mathbf{S} \cdot \mathbf{v} = \mathbf{0}$. On its own that equation has infinitely many solutions, so you add bounds (a reaction can run only so fast, some run one direction only, nutrient uptake is limited) and then pick, among all allowed flux distributions, the one that maximizes an objective — here, flux to capsaicinoids. That is a linear program, solvable in seconds even for a genome-scale model of thousands of reactions. Its answer is not merely a maximum; it is a complete, self-consistent picture of how every reaction in the plant

would have to run to reach that maximum, which is what lets us see whether the bottleneck sits at the Pun1 weld or somewhere upstream. The companion technique of flux variability — asking how much each reaction *could* vary without lowering the objective — is how a true rate-limiting step announces itself: it is the reaction with no slack, pinned to its bound while the whole objective leans on it.

The same framework is what keeps the plant whole, through a construct metabolic engineers call the production envelope. Plot capsaicinoid output against biomass growth and you get a region of feasible trade-offs bounded by a frontier; push toward maximum heat and growth falls, and somewhere along that frontier lies the point past which the plant can no longer maintain itself. We do not design at the corner of maximum product. We design at the point on the envelope where capsaicinoid flux is as high as it can be *while* growth, maintenance ATP, and the fluxes feeding carotenoid and ascorbate stay above the thresholds a vigorous, nourishing fruit requires. The ten rungs of the flagship ladder are ten points along that envelope, each a different, deliberate answer to the only question that finally matters: how much fire can this plant carry and still be a healthy plant?



The predicted aligned-error map for Pun1 / AT3 — the structural confidence that underwrites the model, read beside a genome-scale flux reconstruction of the whole plant before any edit is committed.

The deeper reason we insist on the whole-plant model is reverence disguised as engineering. A plant is not a factory with one product; it is a living economy, and capsaicinoid synthesis draws on the same phenylalanine, the same acetyl-CoA, the same reducing power the plant needs for lignin, for defense, for its own structure and its own fruit. Pull too hard on the capsaicinoid objective with no regard for

the balance and you get a sick plant: a fruit heavy with heat on a vine that cannot support it, carotenoid-poor, thin-walled, vulnerable. Flux-balance analysis lets us ask for the most capsaicinoid the network can yield *while keeping the growth and maintenance fluxes above the thresholds a healthy plant needs*. The number we chase is not peak heat at any cost. It is peak heat the plant can carry and still be whole — still green, still vigorous, still laying down the vitamin C and the color that make it a good fruit as well as a fierce one.

This is also where the ten-flagship ladder stops being a marketing conceit and becomes a controlled experiment. Each rung from Ember to Phoenix represents a different setpoint in the same model — a different answer to "how hard do we pull, and which secondary fluxes do we let rise along with the heat?" The flux model predicts not only how much capsaicinoid each setpoint yields but which neighboring pools fill as a consequence, which is the mechanism beneath the recruitment order we read off Phoenix in Chapter 5. Push the shared trunk harder and the branches that share it — the phenolics behind IFI-B, the compounds behind IFI-K and IFI-U — rise too, in roughly the order their fluxes couple to the trunk. The chord fills in a sequence the metabolism dictates. The names on the rungs are threat levels. The physics underneath is a metabolic model being turned up one careful notch at a time.

Chapter 9 · Proof and Provenance — *numbers are a form of respect.*

A compendium is only as trustworthy as its accounting, so this chapter is the ledger. Across the whole platform that this book draws from, the canonical figures are fixed and every page pulls from the same source, because across a library this size, drift is the one thing that reads as carelessness. Here is what is true, and how we count it:

FIGURE	CANONICAL VALUE	WHAT IT MEANS
Engineered constructs	~19,000	distinct genetic designs built and characterized across all organisms
Live / purchasable today	1,000	cultivars you can actually obtain now
Total SKUs	78,800	the full catalogued design space across the platform
Host organisms	42	species characterized as working chassis
Sensory axes	8	the full IFI alphabet
Batch CV	≤ 7 %	fruit-to-fruit consistency of the engineered lines
Patents filed	3	the core method and its applications
Peer-reviewed papers	21	published open-access, Zenodo, CC BY 4.0



A flagship line under propagation. Provenance is not a flourish — every cultivar in this book traces to a construct, a flux model, and an open record, so the number on the fruit is one you can audit.

The twenty-one papers matter more to us than the three patents, and we will say why. A patent protects a method; a published, open-access paper lets anyone with a sequencer check our work. We put the science under a Creative Commons license on purpose — twenty-one peer-reviewed records, the structural models, the ESM2 scoring approach, the flux reconstructions — because a family that asks you to trust what it grows should be willing to show its work in full. Reproducibility is not a compliance checkbox for us. It is the

same instinct as the ≤ 7 % batch CV: if you cannot repeat it, you do not really know it, and if a buyer cannot repeat it, you have not really given them anything.

A word on what these peppers are and are not, under the law and in plain honesty. Our flagship lines are **gene-edited plants**, made with CRISPR to carry precise, designed substitutions in the plant's own genes — not transgenic constructs splicing in foreign organisms' DNA, but edits to *Capsicum*'s own Pun1 and its own pathway. In the United States, gene-edited crops of this kind fall under the USDA-APHIS framework for biotechnology oversight, and food ingredients derived from them engage the ordinary food-safety apparatus — the same apparatus any novel food ingredient meets.

The distinction between editing and transgenesis is not cosmetic; it is increasingly the hinge of how these plants are regulated. Under the USDA's biotechnology rule, plant varieties carrying changes that could in principle have been obtained through conventional breeding — a point substitution, a deletion, an edit to the plant's own gene — are generally handled far more lightly than organisms carrying DNA from another species, because the end product is, genetically, something breeding could have reached. Food ingredients still answer to the Food and Drug Administration, whether through the generally-recognized-as-safe pathway or food-additive review, and labeling and allergen rules apply as they do to any food. Other jurisdictions draw the line differently — the European Union has historically regulated gene-edited crops under its stricter genetically-modified-organism regime, though its position on precise edits has been actively evolving — which is exactly why provenance and documentation matter so much to us. A fully recorded edit, published and auditable, is the thing that travels across every one of these regimes without ambiguity. We would rather over-document than ask anyone to take our word. We note the capsaicinoids themselves are potent compounds: concentrated capsaicin is handled in our facilities with the respiratory and dermal protection you would expect, and it has genuine pharmaceutical uses entirely outside our scope. We are a flavor company. We make no health claim, no therapeutic claim, no promise about a body beyond the honest pleasure of eating well. The nourishment this library cares about — the vitamin C a pepper carries, the carotenoid color, the whole fruit grown to hold the most it can — is an intention and a value, never a claim on a label. We hold that line hard, in the lab and on the page, because the moment flavor pretends to be medicine it has stopped respecting the person eating it.

The provenance chain, end to end, is the thing we want a buyer or a collector to be able to trust: a construct with a documented edit, scored by a published method, balanced against a whole-plant flux model, grown to a ≤ 7 % consistency, and read at the receptor on a scale anyone can audit. Every cultivar in the dossiers that follow sits at the end of exactly that chain. These are computational designs; Scoville Splice's cultivars and constructs have not been experimentally validated in a laboratory. The threat-level names are theater, and we enjoy the theater. The chain underneath is not.



PART IV OF V

The Flagships

ten proof-of-concept superhots · SS-0087 to SS-0096 · a whisper to all eight axes

Chapter 10 · The Threat-Level Ladder — *ten names for one climb.*

The ten flagships are the heart of this compendium and the reason the method has a face. They are a single family of *Capsicum chinense*, built as a deliberate sequence — a ladder with ten rungs, each one a different setpoint of the same flux model and the same Pun1 edits, climbing from the gentlest superhot we make to the eight-axis apex. We gave them threat-level names because the climb deserved a mythology and because chiliheads, our people, keep the lore alive: a pepper should have a name you repeat. Here is the whole ladder on one page, which is itself a small triumph — ten record-class peppers, read on one consistent scale, something no field of wild fruit could ever give you. All SHU and IFI figures for the engineered flagships are computational predictions from our metabolic and receptor models.



Ember, SS-0087 — the first rung. The gentlest superhot we make is still 866,000 Scoville units, the base camp from which the whole ladder climbs.

RUNG	CULTIVAR	SKU	SHU	IFI-H	AXES	READS AT THE RECEPTOR AS
1	Ember	SS-0087	866,000	1,570	2/8	heat + the first bitterness
2	Cinder	SS-0088	1,050,000	2,290	3/8	+ kokumi body
3	Kindle	SS-0089	1,250,000	2,000	3/8	dihydrocapsaicin-flat; quieter than its SHU
4	Flare	SS-0090	1,480,000	—	4/8	+ umami undertone
5	Blaze	SS-0091	1,720,000	2,630	4/8	heat, bitter, kokumi, umami
6	Wildfire	SS-0092	1,960,000	2,930	5/8	+ astringent grip
7	Scorch	SS-0093	2,210,000	3,220	5/8	the five-axis plateau
8	Firestorm	SS-0094	2,470,000	3,490	6/8	+ pungency wakes
9	Solara	SS-0095	2,720,000	3,980	6/8	near the edge of six
10	**Phoenix**	SS-0096	2,937,948	4,200	**8/8**	all eight, at once

Read the two rightmost columns together and the ladder reveals what it actually is. The SHU column climbs almost monotonically — more capsaicinoid, rung by rung — and so, mostly, does IFI-H, at roughly the eleven-hundred-points-per-million slope from Chapter 4. But the **Axes** column is the real narrative. It does not climb smoothly; it *recruits*, in the fixed order we read off Phoenix's full profile: heat picks up bitterness, then kokumi, then umami, then astringency, then pungency, and only at the very top do sweetness and a thread of cool finally sound to complete all eight. The superhots are not a heat contest. They are a chord being assembled one voice at a time, and Phoenix is simply the rung where the whole chord is awake.

Because the recruitment order is fixed, the ladder can be read as a table of which voices are awake at each rung — a model drawn entirely from Phoenix's one complete profile, not a separate claim about each fruit, and presented as exactly that:

AXES AWAKE	VOICES SOUNDING	FLAGSHIP RUNGS
2	Heat · Bitter	Ember
3	+ Kokumi	Cinder · Kindle
4	+ Umami	Flare · Blaze
5	+ Astringency	Wildfire · Scorch
6	+ Pungency	Firestorm · Solara
8	+ Sweetness · Cool-Burn	Phoenix

The jump from six to eight skips no rung by accident. The two quietest voices, sweetness and cool-burn, are the ones least coupled to the heat trunk, so they do not arrive gradually — they switch on together, at the top, or not at all. That is why there is no seven-axis pepper in the ladder: seven is not a stable place to stand, because the design either holds at six or reaches all eight, and reaching all eight is precisely what makes Phoenix the apex rather than merely the hottest.

Two rungs reward a closer look even before their dossiers. Rung 3, **Kindle**, is the paradox of Chapter 6 made flesh: its 1.25 million SHU out-masses the rung below it, yet its IFI-H of 2,000 reads quieter, because it is dihydrocapsaicin-flat — the ladder's proof that mass and loudness are not the same measurement. And the top rung, **Phoenix**, carries the only non-rounded Scoville figure in the table — **2,937,948** — because it is the apex our model predicted to the single unit, the fruit that gets its own chapter. The gap between Solara's six axes and Phoenix's eight is the hardest climb in the whole ladder; it is where the two quietest voices, sweetness and cool-burn, finally switch on, and getting both of them to sound without losing the heat is the single thing that took the longest to design.

A note for the collector, because this book is partly for you. The ladder is a set, and sets want completing. We built it as ten distinct, repeatable cultivars precisely so that a collector or a sauce designer could obtain a known rung and know exactly what they held — not a lottery pod off a famous plant, but SS-0091, every time, within seven percent. The names are a game. The reproducibility is a promise. The next three chapters open each rung in turn.

Chapter 11 · Dossiers, Ember to Blaze — *the first five rungs.*

Ember · SS-0087 · 866,000 SHU · IFI-H 1,570 · 2/8. The base of the ladder, and the kindest thing we make that still deserves the word *superhot*. Ember sits at the threshold where the ghost pepper lives in the wild, 866,000 Scoville units of clean, capsaicin-forward heat — a sharp, honest strike that arrives fast, peaks in the mid-mouth, and clears. At the receptor it is 1.57 times louder than wild-type, and it sounds only two of the eight axes: heat, and the first thin edge of bitterness from the green alkaloids of the placenta. We think of it as the ladder's handshake. It is the pepper we hand someone who says they can take heat, to find out, gently, whether they can. Its burn is a warning spoken aloud, not yet a threat.



Cinder, SS-0088, in cross-section — the rung where the chord widens from two axes to three as kokumi joins the heat, filling the burn with body it did not have one rung below.

Cinder · SS-0088 · 1,050,000 SHU · IFI-H 2,290 · 3/8. The first seven-figure rung, and the first time the chord opens past bitterness. Cinder crosses the million-Scoville line and, more interestingly, recruits its third axis: **kokumi**, the CaSR-mediated sense of body and continuity, the quality that makes a burn feel *full* rather than merely sharp. Its IFI-H of 2,290 is the ladder's first real jolt — notice it reads louder than Kindle one rung above, our standing reminder that the rungs are ordered by Scoville mass, not by receptor loudness. Cinder is where the heat stops being only a line and starts being a solid.

Kindle · SS-0089 · 1,250,000 SHU · IFI-H 2,000 · 3/8. The teaching pepper, dissected already in Chapter 6 and worth its own entry because it is the most instructive fruit in the book. By Scoville mass it out-ranks Cinder; at the receptor it reads a full 290 points quieter. The cause is its chemotype: Kindle's fatty branch runs toward **dihydrocapsaicin**, the flat, slow, saturated capsaicinoid, so its considerable payload arrives late and deep in the throat and builds like a tide instead of striking like a match. It is the pepper that taught us never to trust a Scoville number alone, and the pepper we reach for when a sauce wants a long, deep, creeping heat rather than a bright front strike. Same three axes as Cinder — heat, bitter, kokumi — but a completely different *shape*.

Flare · SS-0090 · 1,480,000 SHU · 4/8. The one rung whose IFI-H we hold in reserve — it is the pepper whose receptor characterization we are still finalizing, and we would rather leave a cell honestly empty than fill it with a number we have not earned. What we do know is the chord: Flare is the first four-axis fruit, the rung where **umami** joins heat, bitterness, and kokumi. There is a savory roundness here, most legible when the fruit is cooked into a sauce, a glutamate depth that makes Flare the first flagship that tastes like it belongs in food rather than only on a dare. The name fits: this is the rung where the heat stops being contained by a single sensation and breaks into the savory.

Blaze · SS-0091 · 1,720,000 SHU · IFI-H 2,630 · 4/8. The crown of the first five rungs, and the pepper where the four-axis chord fully settles. At 1.72 million Scoville units and IFI-H 2,630, Blaze is 2.63 times louder than wild-type and sounds heat, bitterness, kokumi, and umami in a balance we consider the ladder's first genuinely *complete* mid-range profile — a superhot you could build a serious sauce around and have it taste designed rather than merely dangerous. It is the rung we most often recommend to a formulator meeting the flagship line for the first time, because it carries real, four-voice complexity at a heat a professional kitchen can still actually work with. Everything below it is an approach. Blaze is where the ladder arrives.

A note for the people who will actually keep these five. As a collector's sub-set, rungs one through five are the approachable face of the ladder — the superhots you can grow, handle, and even cook with in fractions without ceremony, where the fruit is still a pleasure rather than a dare. Ember and Cinder make genuine table sauces; Kindle is the one to reach for when you want a slow, deep, building heat beneath a braise; Flare and Blaze are where real four-voice complexity begins, the first rungs a serious kitchen can build a signature around. If you are assembling the set, these are the five to learn first, because everything in the upper ladder is a variation on the chords they introduce.

Chapter 12 · Dossiers, Wildfire to Extinction — *where the other axes wake.*

Wildfire · SS-0092 · 1,960,000 SHU · IFI-H 2,930 · 5/8. The fifth axis switches on here, and it is **astringency** — the tannic, drying grip read by the salivary proteins, the quality that in a wine or a strong tea makes the mouth pucker and tighten. In a superhot it reads as a structural edge beneath the burn, a grip that gives the heat something to hold onto. At IFI-H 2,930, Wildfire is nearly three times wild-type loudness, and with five of eight axes awake it is the first flagship whose chord feels genuinely *wide*. We named the photographic reference set for this cultivar after the Trinidad Moruga Scorpion, the wild record-holder it was built to answer, and Wildfire is where the ladder stops chasing the wild superhots and starts passing them.



Scorch, SS-0093, on the microscope stage — the five-axis plateau, where the ladder pauses at 2.21 million Scoville units before the final, hardest climb toward the full chord.

Scorch · SS-0093 · 2,210,000 SHU · IFI-H 3,220 · 5/8. The plateau. Scorch holds the same five axes as Wildfire but pushes the heat harder — 2.21 million SHU, IFI-H 3,220, past three times wild-type loudness — so the experience is the five-voice chord of Wildfire with the volume turned up rather than a new voice added. This is deliberate, and it is the flux model's doing: there is a setpoint where pulling harder on the trunk raises the heat substantially before the sixth axis is ready to recruit, and Scorch sits exactly there. It is the

most purely *intense* of the mid-ladder peppers, the rung for someone who wants the five-axis complexity delivered at maximum loudness without yet reaching for all eight.

Firestorm · SS-0094 · 2,470,000 SHU · IFI-H 3,490 · 6/8. The sixth axis wakes, and it is **pungency** — IFI-P, the TRPA1 sharpness, the mustard-and-garlic bite that is a different receptor from heat entirely. Its arrival changes the character of the burn qualitatively: Firestorm carries not only the deep capsaicin fire but a sharp, almost sinus-reaching top note, two different irritant channels sounding at once. At IFI-H 3,490 the heat is nearing the top of the scale, and with six of eight axes awake the fruit is approaching the fullness that only Phoenix completes. This is where the ladder begins to feel less like a hotter pepper and more like a designed object with many simultaneous edges.

Solara · SS-0095 · 2,720,000 SHU · IFI-H 3,980 · 6/8. The last rung before the apex, and the hottest pepper in the ladder that is not Phoenix At 2.72 million Scoville units and **IFI-H 3,980**, Solara sits a hair under four times wild-type loudness — within striking distance of the 5,000 scorecard ceiling, further than any wild pepper has ever been reliably measured. It holds six axes, the same chord as Firestorm, delivered at the edge of what the heat axis can register. Solara is the pepper that proves the ladder could have stopped here and still have been a record. That it did not stop here — that there was one more rung, and that the last rung added not more heat but the two missing voices — is the whole argument of the next chapter.

The gap from Solara to Phoenix is the smallest Scoville step in the upper ladder (2.72 to 2.94 million) and the largest achievement in it. Extinction adds only about 220,000 SHU of raw heat on the way to the top. What Phoenix adds is **sweetness and cool-burn** — the two quietest axes, the ones that complete all eight — and those two voices, not the marginal heat, are what took the longest to design and what make the apex an apex. Six axes at near-maximum loudness was, it turned out, the easy part. The full chord was the hard one.

And a note for the people who will keep *these* four. Rungs six through nine are no longer everyday peppers; they are the collector's trophies and the formulator's extract stock, handled with the gloves and ventilation of Chapter 16 and used in fractions of a pod. Wildfire and Scorch are the five-axis workhorses of the upper ladder, the widest chords you can still deploy with intent; Firestorm and Solara are the sharp-edged record-breakers, where pungency joins the fire and the heat nears the top of the scale. They are less for the plate than for the proof — the rungs that demonstrate, pod by repeatable pod, how far the method reaches before the final climb to all eight.

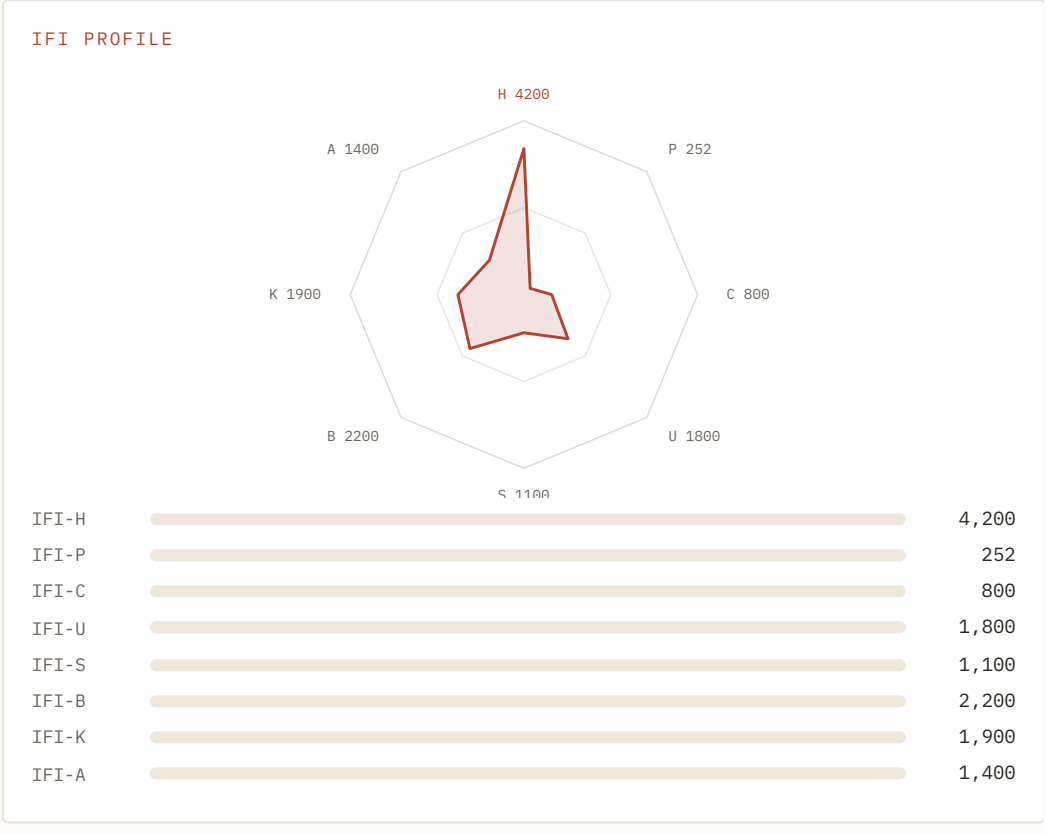
Chapter 13 · Phoenix — *all eight, at once.*

Some peppers are hot. Phoenix is *complete*. It is the only fruit in the flagship ladder — and, as far as our model extends, the only pepper anywhere — that registers on all eight axes of the Iyengar Flavor Index at once, and it is the pepper the entire method was built to prove could exist. Our model predicts **2,937,948 SHU** for this cultivar, a figure we carry to the single unit because a fruit this deliberate deserved to be known exactly, and we gave it a name that admits what it is: do not resuscitate, the top of the ladder, the edge past which we did not go.



Phoenix · SS-0096 — the eight-axis apex, the first cultivar engineered to sound every voice of the index at once. Not the hottest possible pepper, but the fullest one we know how to make.

Here is its complete receptor profile — the only full eight-axis scorecard we hold for any flagship, and the Rosetta stone from which the recruitment order of the whole ladder was read:



Read it as a chord with a dominant and seven present overtones. **Heat (4,200)** is the unmistakable lead — 4.2 times wild-type loudness, reaching half-activation of TRPV1 at 23.8 % of the

reference concentration, near the top of the 5,000 ceiling. But listen past it. **Zero-Bitter (2,200)** and **Kokumi (1,900)** and **Umami (1,800)** form a thick savory middle — the reason Phoenix, for all its violence, reads as *food* and not as a weapon: there is body here, continuity, a glutamate depth that a pure-heat pepper simply does not have. **Astringency (1,400)** gives it grip. **Pungency (252)** adds the sharp TRPA1 top note. And then the two voices that make it the apex rather than merely a six-axis record: **Sweetness (1,100)**, a genuine ripe-fruit sweetness the TAS1R2·R3 receptor reads beneath the fire, and **Cool-Burn (800)**, the thread of TRPM8 cooling that lifts the finish and keeps the enormous heat from being only a flat wall. Eight receptors, eight numbers, one fruit.

The design task behind that scorecard was not "make the hottest pepper." It was "fill the whole chord without letting any voice drown the others," and it is a harder problem by far. Recall from Chapter 8 that the flux model couples the secondary axes to the shared metabolic trunk: push the trunk for heat and the bitter, kokumi, and umami fluxes rise along with it, which is why those three are the loudest overtones. But sweetness and cool-burn are the two axes *least* coupled to the heat trunk — they do not come along for free, and at extreme heat setpoints they tend to be swamped. Getting them to 1,100 and 800 while holding heat at 4,200 required finding the precise setpoint, in the whole-plant model, where all eight fluxes could coexist above their thresholds. That setpoint is Phoenix It is not a maximum of any single quantity. It is a simultaneous solution — the one place in the design space where every voice sounds at once and the plant stays whole.



Phoenix on the microscope stage — our model's apex prediction, the end of the ladder and the beginning of everything the method made possible.

The double variant from Chapter 7 — S39L and L345G — is what our model predicts makes the enormous heat possible and the design repeatable at ≤ 7 % batch CV even here, at the physiological edge. A pepper this extreme that varied 42 % fruit to fruit would be a curiosity. A pepper this extreme that our model predicts will deliver 2,937,948 SHU and the full eight-axis chord *every time*, within seven percent, is a specification — something a formulator can build on and a collector can trust.

Writing two edits into a living pepper is its own discipline, and worth describing plainly. CRISPR-Cas9 provides the molecular scissors: a guide RNA directs the nuclease to the exact site in the Pun1 gene, where it makes a precise double-strand cut. But a cut alone only breaks a gene, which is the opposite of what we want — so to install a specific substitution we supply a repair template carrying the desired codon and let the cell's homology-directed repair machinery copy our intended sequence in as it heals the break. Edited lines are then sequenced to confirm that the substitution is present, in the right place, and nowhere else; off-target edits are selected against; and only lines carrying exactly the two intended changes — S39L and L345G, and nothing more — advance to the field. Because these are edits to the pepper's own gene rather than foreign DNA stitched in, the finished plant differs from its parent by two codons, a change smaller than a single generation of spontaneous mutation can produce, and arrived at on purpose rather than by luck. We will be candid about what Phoenix is for: almost no one will cook with the whole fruit, and we do not expect them to. Its purpose is proof. It is the demonstration that flavor can be designed to a complete receptor-level specification rather than merely bred toward, and once that is proven on the hardest possible case — a pepper at the edge of heat sounding all eight axes at once — it is proven for everything gentler and more useful that follows. Phoenix is the top of this book's ladder. It is also the bottom of the next one, the place all forty other organisms climb from. The fire, finally, read in full.



PART V OF V

The Living Library

the whole ladder · cooking the fire · growing it · and where the pepper opens onto everything else

Chapter 14 · The Ladder, End to End — *shishito to the edge of design.*

Step back from the flagships and the whole genus arranges itself into one continuous ladder — from a pepper so mild you could eat a plateful to a pepper no one should eat whole — and reading it top to bottom is the single most useful literacy a chilihead can own. The natural world fills the bottom and the middle; our method extends the top past where breeding could reach. Here is the ladder in bands, each with its wild exemplars and its receptor loudness, so a cook or a collector can place any pepper they meet:

BAND	EXEMPLARS	SHU	ROUGH IFI-H	WHERE IT LIVES
Warmth	bell, shishito	0 – 200	~5 – 40	the everyday, barely a signal
Gentle	poblano, ancho	1,000 – 1,500	~60	a glow, not a burn
Culinary	jalapeño, serrano	2,500 – 25,000	~100 – 300	the working heat of most kitchens
Bold	cayenne, tabasco, Thai	30,000 – 100,000	~400 – 800	the hot-sauce heartland
Fierce	habanero, Scotch bonnet, fatalii	100,000 – 350,000	~900 – 1,300	fruit-forward serious heat
Extreme	ghost (bhut jolokia), 7-pot	850,000 – 1,200,000	~1,500 – 2,000	the wild superhots begin
Record	Moruga Scorpion, Carolina Reaper, Pepper X	1.2M – 2.7M	~2,000 – 3,900	the Guinness frontier
Designed	**the flagship ladder, Ember → Phoenix**	**866K – 2,937,948**	**1,570 – 4,200**	**engineered, repeatable, eight-axis**



Solara in cross-section — the engineered band of the ladder, where repeatability and the full chord carry the fruit past the edge of what wild breeding reached.

Two honest notes on this table. First, the wild SHU figures are ranges drawn from published measurements, not points, because a wild pepper is a variable thing — a ghost pepper's Scoville count swings with its growing conditions, its ripeness, and the pod you happened to pick, which is precisely the 42 % kind of variability our engineered lines were built to abolish. The SHU figures in the Designed band are computational predictions from our metabolic model, not certified measurements; they represent our model's estimate of what a chromatographic analysis would find. The Guinness-listed records drift as new cultivars are certified; at the time of writing the Carolina Reaper's listed average sits near 1.64 million and Pepper X near 2.69 million. Second, the IFI-H values in the lower bands are approximate because the index was anchored for the superhot range where we work most precisely; the point of the column is the *shape* of the ladder — the way loudness climbs with the band — not a laboratory figure for a grocery-store jalapeño.

It repays a chilihead to populate the bands more fully, because the names are a map of the whole domesticated genus. In **Warmth** live the bells and the sweet Italian frying peppers, the pimento, the shishito and its Korean cousin the kkwari-gochu, the Spanish Padrón — famous for the one pod in a dozen that surprises you, a natural lottery our engineered lines were built to replace with intention. **Gentle** holds the poblano (dried, the ancho and mulato), the New Mexico and Anaheim chiles, the cherry pepper, the Hungarian wax. The **Culinary** band is the busiest in the world: the jalapeño (smoked and dried, the chipotle), the serrano, the Fresno, the guajillo and pasilla of the Mexican canon, the Kashmiri chile prized more for its red than its burn. **Bold** is the cayenne, the tabasco, the de árbol, the piri-piri, the Thai bird's-eye, the Calabrian — the whole fermented-sauce heartland. **Fierce** belongs to *C. chinense* at last: the habanero in its orange, chocolate, and white forms, the Scotch bonnet of the Caribbean, the datil of St. Augustine, the fatalii, the Jamaican hot. **Extreme** opens the superhot era — the bhut jolokia or ghost that first broke a million Scoville units in a laboratory in 2007, the 7-pot family of Trinidad, the Douglah with its rough chocolate skin. And the **Record** band is the modern arms race: the Trinidad Moruga Scorpion, the Carolina Reaper that held the Guinness title for a

decade, and Pepper X that took it — a race run pod by uncertain pod, in exactly the wild variability our Designed band was built to close.

The ladder is also a map of where heat belongs in cooking, and the bands are the cook's real vocabulary. Warmth and Gentle are for texture and color — a roasted poblano is about its flesh, not its fire. The Culinary band is the working heat of most of the world's spicy food, the jalapeño-to-serrano range where heat is a seasoning rather than a subject. The Bold band is the hot-sauce heartland, where cayenne and Thai chilies carry fermented sauces and chili oils. Fierce is where fruit and fire balance — the habanero's tropical sweetness under its burn is why it anchors so many great salsas. And Extreme upward is where heat becomes the point itself, the chilihead's territory, the bands where our flagships live and where you measure in fractions of a fruit. A recipe that calls for "a pepper" is really calling for a band, and the chilihead who thinks in bands cooks better than the one who thinks in names.

What the Designed band adds to the ladder is not only reach but *trust*, and that is the quieter revolution. For the first time the top of the ladder is as repeatable as the bottom — a specific rung, obtained on purpose, designed to a predicted SHU and a consistent eight-axis chord within seven percent. The wild record-holders are magnificent and we revere them; they are also a gamble every time you pick a pod. The engineered ladder turns the frontier of heat from a lottery into a specification, which is what lets the next chapter talk about cooking with extreme heat as an act of precision rather than bravado.

Chapter 15 · Cooking the Compendium — *heat you can place to the half-degree.*

Cooking with a laddered, measured pepper is a different craft from cooking with a pepper you merely hope is hot, and the first principle of that craft is a physical fact from Chapter 3: capsaicin is lipophilic. It does not dissolve in water; it dissolves in fat, oil, and alcohol. Everything useful about cooking heat follows from that one property. It is why a chili's fire blooms when you bloom it in oil and stays muted when you add it to a watery braise. It is why a dairy fat — the casein in milk, yogurt, or paneer — is the only thing that genuinely cools a burning mouth, because casein acts as a detergent that strips capsaicin off the receptor, while a glass of water merely spreads the fire around. And it is why, when you want to layer the counter-cooling of IFI-C over a dish's heat, a cooling agent works: TRPM8 answers it even as TRPV1 burns, and the two channels arguing is the whole sensation of a great numbing-hot dish.

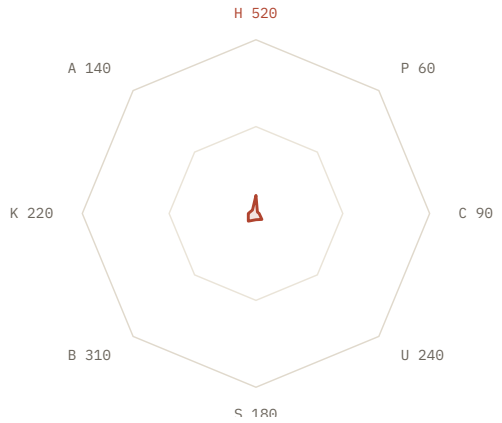
Because our peppers are repeatable, you can cook heat the way a baker weighs flour. A pinch of a flagship is not a gamble; it is a known quantity, which means you can place a dish's heat to a target and hit it. Here are a few from our own table — plant-forward by instinct, because that is how our family eats, and because the engineered depth does the work that meat often does elsewhere.

Blistered Shishito, Phoenix-Dust Finish. The gentlest possible use of the fiercest possible pepper — a whole plate of mild shishitos carrying only a breath of the apex.

shishito peppers	300 g, whole
good olive oil	2 tbsp
flaky salt	to finish
Phoenix dust (SS-0096)	the faintest pinch — a knife-tip for the whole plate
lemon	half, for squeezing

1. Get a heavy skillet smoking hot. Add the oil, then the shishitos in one layer. Leave them alone until they blister and char on the underside, two to three minutes, then toss and blister the other side.
2. Off the heat, squeeze the lemon over, salt generously, and — with real restraint — dust the whole plate with the merest pinch of Phoenix The point is a warm surprise in one pepper of five, not a wall of heat.
3. Eat with your fingers, by the tails.

IFI PROFILE



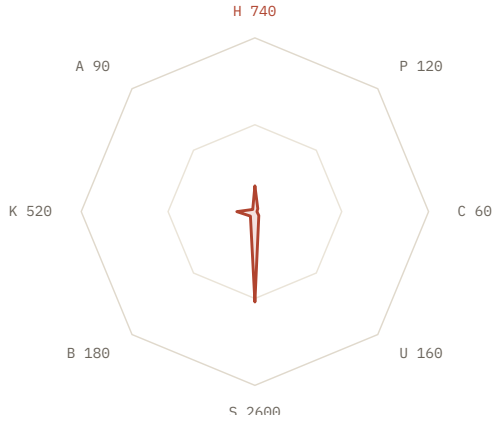
IFI-H	520
IFI-P	60
IFI-C	90
IFI-U	240
IFI-S	180
IFI-B	310
IFI-K	220
IFI-A	140

Cinder Hot Honey. The million-Scoville rung in a form anyone can use — a condiment where the pepper's kokumi body does as much work as its heat.

honey	250 g
Cinder (SS-0088)	1 pepper, or 1 tsp dried flake
cider vinegar	1 tbsp
flaky salt	a pinch

1. Warm the honey gently with the pepper (split, seeds and all, or the flake) until it just loosens — do not boil; you want to infuse, not cook.
2. Hold it at a bare simmer for ten minutes, letting the fat-soluble capsaicinoids migrate into the honey's trace oils and the honey carry the kokumi fullness.
3. Off the heat, stir in the vinegar and salt. Strain if you used a whole pepper. It keeps for weeks and improves for the first few.

IFI PROFILE



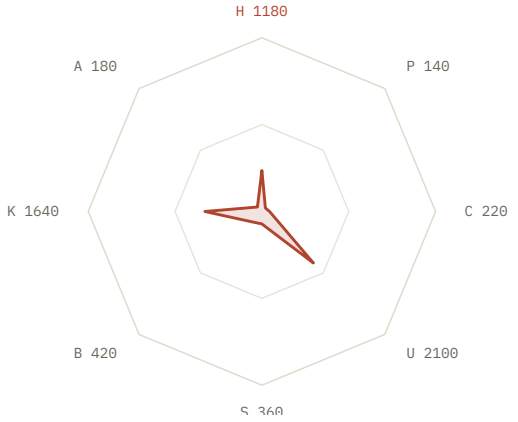
IFI-H	740
IFI-P	120
IFI-C	60
IFI-U	160
IFI-S	2,600
IFI-B	180
IFI-K	520
IFI-A	90

Coconut-Braised Chickpeas, Kindle. The slow, deep, dihydrocapsaicin-flat burn is perfect for a long braise, where its creeping heat has room to build under the coconut's fat.

cooked chickpeas	2 cups
coconut milk, full-fat	1 can (400 ml)
onion	1, fine dice
garlic	4 cloves
ginger	thumb, grated
Kindle (SS-0089)	¼ pepper, minced — respect the chemotype
cumin, coriander	1 tsp each, toasted and ground
tomato	2, chopped (our umami-restored line if you have it)
cilantro, lime	to finish

1. Sweat the onion in oil until soft and golden; add garlic, ginger, and the ground spices and cook until fragrant.
2. Add the tomato and the minced Kindle and cook down to a thick base — the fat is carrying the capsaicin now, so the heat will bloom slowly and deepen as it simmers.
3. Add the chickpeas and coconut milk, and braise gently for twenty-five minutes. The heat will seem mild at first and build into a deep, throat-warming glow — that is the dihydrocapsaicin arriving late, exactly as the chemotype promises.
4. Finish with lime and cilantro, which lift the deep heat with brightness and a little cooling.

IFI PROFILE



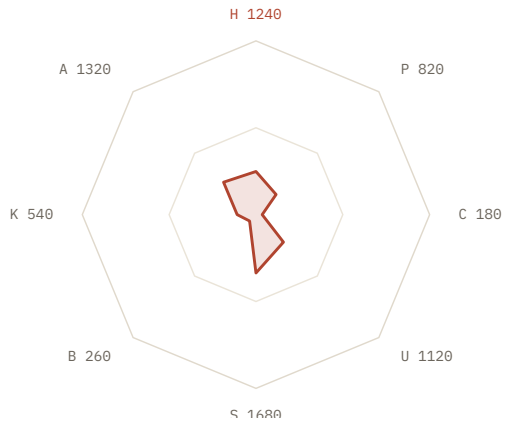
IFI-H	1,180
IFI-P	140
IFI-C	220
IFI-U	2,100
IFI-S	360
IFI-B	420
IFI-K	1,640
IFI-A	180

Wildfire Citrus Glaze, for Grilled Fish or King Oyster. Written for a fillet of firm fish and, in the same breath and with the same respect, for a thick slab of king oyster mushroom — the glaze does not care which, and neither do we.

honey or maple	3 tbsp
soy or tamari	2 tbsp
lime + orange	juice of one each
garlic	2 cloves, grated
Wildfire (SS-0092)	1/8 pepper, minced fine
neutral oil	1 tbsp

1. Whisk everything but the protein into a glaze. The astringent grip this cultivar carries on IFI-A is the point — it gives the sweet-sour glaze a tannic backbone that stands up to char.
2. Pat the fish or the scored mushroom dry, oil and salt it, and grill over high heat until nearly done.
3. Brush the glaze on in the last two minutes, letting it catch and lacquer without burning. The heat arrives bright, then grips; the citrus lifts it; the char rounds it.

IFI PROFILE



IFI-H	1,240
IFI-P	820
IFI-C	180
IFI-U	1,120
IFI-S	1,680
IFI-B	260
IFI-K	540
IFI-A	1,320

And the cook's insurance policy, because a compendium that laddered the heat owes you the antidote. **Cooling Mint-Yogurt Raita**: whole-milk yogurt beaten smooth, grated cucumber squeezed dry, a little salt, toasted cumin, and plenty of chopped mint. The casein in the yogurt is the real worker — it strips capsaicin from the receptor the way water never can — and the mint lays a thread of TRPM8 cooling over the top, IFI-C answering IFI-H directly. Serve it beside anything from the Extreme band up. It is not a garnish. It is the other half of the design.

A closing word for the cooks who love meat and fish, written with the same respect: everything here applies without apology to a piece of fish glazed in Wildfire or a shoulder rubbed with Blaze. The lipophilic rule means a fatty cut carries capsaicin beautifully and releases it slowly, which is why laddered heat and good fat — plant or animal — are natural partners. We cook plant-first because we love to, not because the other way is lesser. The index does not care what is on the plate. It only cares that you placed the heat on purpose.

Chapter 16 · Growing the Fire — *stress is a seasoning.*

A pepper is a semi-tropical perennial that most of the world grows as an annual, and the superhots are the divas of the genus: slow to germinate, slow to ripen, hungry for warmth and light, and — this is the part that matters to a collector — quietly responsive to how hard you make them work. Capsaicinoid output is not fixed by the seed alone. It is written partly by the plant's life, and a grower who understands that can coax a hotter fruit from the same genetics, or steady one, or gentle one. The engineered lines narrow this variability on purpose, but even they respond to their conditions, and the old growers' lore turns out to be real biochemistry.



Dawn on a flagship plant in the research house — the superhots are the divas of the genus, and how hard you make a plant work is written into the fruit it sets.

The governing principle is that **capsaicinoids are, in part, a stress response**. The pathway sits downstream of the plant's general defense metabolism, and a plant under moderate, well-judged stress tends to pour more into it. Controlled water deficit in the weeks before ripening is the classic lever — a pepper kept a touch thirsty often sets hotter fruit than one kept lush, because drought stress pushes the phenylpropanoid trunk that feeds the aromatic branch. Heat and strong light push the same direction. Nitrogen is the counter-lever: a plant flooded with nitrogen grows big and green and comparatively mild, spending its carbon on leaves rather than on defense chemistry. The grower's craft is to feed the plant enough to build a healthy fruit and then, in the ripening window, to apply just enough stress to drive the heat — the horticultural echo of the flux-balance logic from Chapter 8, where the whole art is pulling hard on capsaicinoid output without breaking the plant that carries it.

The practical calendar of a superhot tests a grower's patience from the first week. *Capsicum chinense* seed is slow and warmth-hungry to germinate — it wants soil near 28–30 °C and can take two to six weeks to show, far longer than a tomato — which is why serious growers start indoors on heat mats months before the last frost. From transplant, a superhot often needs ninety to a hundred and twenty days or more to set and fully ripen its pods, so in a cool-summer climate the fruit is racing the season the whole way. The reward for the wait is that peppers are true perennials: kept above

freezing and given light, a prized plant can be overwintered and will fruit again the next year, larger and earlier — the collector's equivalent of keeping a vine rather than replanting a row. Along the way the plant asks for steady warmth, strong light, free-draining soil, and vigilance against the aphids and thrips that find a greenhouse before you do. None of this is incidental to the heat: a plant kept healthy and unhurried through a long season builds a fuller, more consistent fruit than one stressed by neglect rather than by design. That is the whole distinction — the stress that seasons, applied on purpose and in the ripening window, against the stress that merely harms.

Ripeness is the other lever, and it is the one most home growers get wrong. Capsaicinoids accumulate as the fruit matures and generally peak at or near full color — a green superhot picked early is milder and flatter than the same pod left to ripen red or chocolate or peach. Leaving fruit on the plant to full ripeness also lets the carotenoids finish, which is why a fully ripe pepper is both hotter and more nourishing than its green self: the heat and the color climb together, the same way the chord fills together on the flagship ladder. Patience, in a pepper, is literally flavor and nourishment both.

A sober word on handling, because this book reaches collectors who grow the extreme end. The superhots demand respect in the kitchen and the garden alike. Processing more than a pod or two of anything above the Extreme band means gloves, eye protection, and ventilation, because capsaicin aerosolizes when you grind or blend it dry and will find every mucous membrane you own — the same lipophilic persistence that makes it cling to a receptor makes it cling to skin and resist washing with water. This is not caution for its own sake; it is the ordinary discipline of working with a potent compound, the same discipline our own facilities keep. Treat the fruit the way its chemistry asks to be treated and it will never harm you. Treat it carelessly and it will teach you, memorably, what directed deterrence actually means.

The collector's ethic, finally, is a thing we hold dear and want to pass on. To grow the flagship ladder is to keep a living set — ten cultivars, each a repeatable rung, each traceable to a construct and an open record. We built them to be grown, not just measured, because a pepper that lives only in a chromatogram is only half real. The deepest pleasure of this whole enterprise is still the oldest one: a plant you tended, a fruit warm from the vine, a cross-section under good light, and the small shock of recognition when the burn arrives exactly where the number said it would. That is where the company started — a family growing things and measuring things — and it is where, every season, it starts again.

Chapter 17 · Beyond the Pepper — *the same fire, any plant.*

We will close where the pepper stops being the whole story and becomes the first chapter of a much larger one. Everything in this compendium — the pathway, the method, the index, the ladder — was built on *Capsicum*, but almost none of it is *about* Capsicum. Recall the quiet thesis from Chapter 2: of the enzymes that make a capsaicinoid, only four are pepper-specific. The rest — the entire phenylpropanoid trunk, PAL through COMT — runs in every vascular plant on earth. The pepper was not the destination. It was the proof of concept, the hardest case we could find, the fruit that already knew how to push a single pathway to the edge so that we could learn to push it on purpose.



The tomato, restored — the first organism beyond the pepper, where the same method grows back the umami and sweetness that a long supply chain strips away. The fire was never about Capsicum.

Once the method worked on the pepper, it transferred. Five of the seven platform modules — the structural modeling, the ESM2 scoring, the flux-balance analysis, the CRISPR delivery, the receptor-anchored measurement — carry across unchanged to any organism with a sequenced genome. Today **42 host species** are validated, from the tomato whose savory depth we grew back through its own glutamate pathway to the peppermint whose five-gene menthol route we tuned, each one measured on the same eight axes as the peppers in this book. Beyond the 42 lies a roadmap of **64 concept organisms** across five tiers — a volcanic tomato carrying real heat, a

dark-matter eggplant, a seismic potato, and, further out, cross-family work no breeder could attempt: a sweet-heat strawberry, a contradiction cucumber, a storm corn. The pathway that makes those possible is the one this book has named throughout:

Shared trunk (every vascular plant)	PAL → C4H → 4CL → HCT → COMT	`the phenylpropanoid branch`
Pepper-specific terminal enzymes	pAMT · Pun1/CS · KAS · BCAT	`the four that make heat`
Transfers unchanged	5 of 7 platform modules	`to any sequenced genome`

The roadmap climbs in tiers of rising difficulty, and the order is set by how far an organism sits from the pepper. The nearest tier is the rest of the nightshade family, *Capsicum*'s own cousins, where four or five transplanted genes suffice because so much of the machinery is already shared — a volcanic tomato, a dark-matter eggplant, a seismic potato, an acid tomatillo, each eighteen to thirty-six months of work. Beyond the nightshades the gene count rises and the timelines stretch: the cross-family tier reaches into unrelated plants — a strawberry, a cucumber, a melon, an apple, a lettuce — where seven to ten genes must be coordinated to carry a pathway the plant never evolved. The frontier tier is the hardest and furthest out, a decade's horizon: a carrot, a cabbage, a head of broccoli, an ear of corn, a grain of rice, each demanding the near-complete synthetic installation of a pathway in a chassis that shares only the ancient phenylpropanoid trunk. The further from the pepper, the more of the four terminal enzymes must travel with the design — but the trunk is always already there, in every one of them, and that single fact is what makes a sixty-four-organism roadmap a plan rather than a fantasy.

What does not transfer is the reverence, because it never needed to — it was always the point. The reason we insist on the whole-plant flux model, the reason we grow to full ripeness, the reason we hold the nourishment line as a value and never a claim, is the same reason the pepper seduced us in the first place: a plant is a whole and generous thing, and the right way to design flavor into one is to honor everything else it was already making. The fire taught us that. A pepper grown for the most heat should also carry the most vitamin C, the most color, the fullest chord — not as a trade-off but as a single act, because the molecule that burns and the molecule that nourishes come off the same trunk and respond to the same care.

So this is a book about peppers, and it is not. It is the record of how our family learned to read a fruit at the level where sensation begins, to write at that level rather than only select, and to keep a plant whole while pushing it to the edge of what it can carry. The ten flagships are the proof, Phoenix the apex, the eight-axis chord the thing we can now compose at will. But the last word belongs to the plant that started it — the one fruit that learned to say no, aimed its refusal at exactly the mouths it meant to reach, and in doing so showed us that a flavor is a key, a receptor is a lock, and anyone who learns the lock well enough can cut a key for the whole living garden. We learned it on the pepper. We are only getting started.