

THE SCOVILLE SPLICE LIBRARY · THE FRONTIER

The Nightshade Files

The pepper learned to make fire. *Now the whole family can.*

The definitive dossier on the nearest frontier — the pepper's own family. Seven Solanaceae files, from the tomato that carries its own warmth to the eggplant named for dark matter: each one a few genes from a flavor it has never made, every target anchored to a number already computed in a cousin design.

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

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Opening essay · The family we were afraid of

There is an old fear in the garden, and it has a family name. *Nightshade.* Say the word and the body leans back a little, because for most of the history of the word it meant the plant at the edge of the wood with the glossy black berries — *Atropa belladonna,* deadly nightshade — the one that dilates the pupils of a Renaissance court and stops the heart of a careless child, the one that lent its genus the name of the Greek Fate who cut the thread. The family that berry belongs to carried that reputation like a surname. When the tomato arrived in Europe from the Americas, red and glistening and unmistakably a nightshade by leaf and flower, the botanists who knew the family recoiled; for the better part of two centuries a tomato was an ornament, a curiosity, a *poison apple* grown up a trellis and admired from a safe distance. The potato fared little better — buried, suspect, blamed for fevers it never caused. The family we now build most of dinner out of was, for a long time, the family we were afraid of.

The fear traveled, and so did the plants, and the collision of the two is one of the stranger chapters in the history of food. The tomato and the potato are New World plants — carried back across the Atlantic in the sixteenth century in the holds of Spanish ships, into a Europe that already knew the nightshade family by its poisonous natives and recognized the newcomers on sight as kin to belladonna. So they were received the way you would receive a stranger wearing a feared family's face. The tomato was grown up walls as a curiosity and left uneaten; the potato was planted, distrusted, blamed for sickness, resisted by whole populations before hunger and a few stubborn advocates finally pressed it onto the plate — after which it fed so many people so reliably that it reshaped the populations that grew it. It took the better part of two or three centuries for Europe to make peace with plants that are now the floor of its cooking. We keep that history close because it is the longest possible proof of this book's quiet thesis: that the most ordinary, most nourishing plants on the table and the most feared family in the garden are, and always were, the same plants — and that a little knowledge turns the fear into dinner.

We tell this story first because it is the truest doorway into the book, and because the fear was not entirely wrong. The Solanaceae really are a family of chemists. In their tissues they brew tropane alkaloids and steroidal glycoalkaloids, molecules evolved to make an animal's mouth report *stop* — bitterness as a warning, toxicity as the warning made good. What the frightened botanists could not know is that the same chemical inventiveness that makes a belladonna berry deadly is, one genus over, the thing that makes a pepper magnificent. Fire and poison came out of the same restless family that could never leave a metabolic pathway alone.



The founders in the research greenhouse at first light — the family drawer open on the bench, and the oldest question in it: who else in the Solanaceae could carry what the pepper carries?

This is the question the book opens as files. The pepper — *Capsicum* — is a nightshade. We forget it because we meet the pepper in a bowl of chili and not on a family tree, but it sits at one table with the tomato and the eggplant and the potato and the tomatillo, with the husk-lantern of the ground cherry and the evening-scented petunia on the sill, and with tobacco, the plant that taught half of molecular biology how to work. Somewhere along the family's long argument with the world, exactly one genus learned to make capsaicin — to speak to the TRPV1 receptor in the most extravagant language a plant has ever found — and we have loved that one cousin so completely, for so long, that we nearly never asked the obvious thing. If the fire is a family trait, built from a pathway every one of these plants already runs, then why does only the pepper know how to finish it?

Open a file on each and the answer resolves into something both humble and radical. The fire is not pepper magic. It is chemistry, and chemistry is inherited. Every vascular plant on Earth — the tomato and the potato among them — runs the ancient phenylpropanoid branch, **PAL → C4H → 4CL → HCT → COMT,** the metabolic highway that ends, in the pepper alone, at four more enzymes: **pAMT, BCAT, KAS,** and the capstone the family invented only once, **Pun1 / capsaicin synthase.** The pepper's siblings idle at the same junction with the same engine warm. To put a designed warmth into a tomato is not to cross the plant kingdom; it is to reach one chair over, to a cousin who already keeps the hard half of the road paved. That nearness is the whole reason this is the first frontier book and not the last. The nightshades are the low-hanging fruit of the garden precisely because they are *kin.*

And they are the plants of the everyday plate. Not curiosities for a collector's shelf — the tomato, the potato, the eggplant, the staples that feed most of the world. To design flavor into them is to design it into the foundation of how people actually eat, which is the quiet thing humming under every file that follows. We are not chasing an exotic heat. We are asking whether the most ordinary family in the garden — the one we were afraid of, then fed ourselves with anyway — can be grown, at last, toward all of itself: the tomato that finally tastes like a tomato *and* carries its own warmth, the potato seasoned from the inside, the eggplant that has a flavor of its own to give back instead of only borrowing one. A plant grown toward its fullest flavor

is, almost never by accident, a plant grown toward its fullest nourishment; here as everywhere in this Library, taste and nourishment were never two projects.

Seven files, and the one that proves them. We begin, as the family began for us, with the fear — and with the chemistry that turns out to be hiding inside it.



PART I OF IV

The Family

the Solanaceae · the dark inheritance · the shared road · the locks on the tongue · how to read a file

Chapter 1 · The family tree — *who is in the drawer.*

Taxonomy is not usually where wonder lives, but stand inside the Solanaceae for a moment and it is hard not to feel the strangeness of what one family managed. Roughly a hundred genera and something near three thousand species, scattered across every warm continent, and the range of what they do is almost comic: the family holds a deadly berry and a daily french fry, a hallucinogen and a houseplant, the world's most-traded drug crop and the world's most-eaten vegetable. Measured by what it does for and to humanity, the family has few rivals. After the grasses that give us wheat and rice and corn, no plant family feeds the world as heavily as this one — the potato and the tomato alone are among the most-produced crops on Earth, and the pepper and the eggplant are not far behind. And yet the same family holds the opposite extreme: *Datura,* the thorn-apple, whose seeds have poisoned and deranged across every continent it reached; *Hyoscyamus,* henbane, the poisoner's and the sleepwalker's herb; *Mandragora,* the mandrake, dug with such dread that legend said its root screamed when pulled; and *Atropa* itself, the deadly nightshade that named its genus for a Fate. A single family of chemists, running from the staple to the fatal, from the food that saved populations to the berry that ended individuals.

There is no other plant family that reaches so far in so many directions, and the reason is the reason this book exists — the Solanaceae are metabolically promiscuous. They build secondary compounds the way other families build leaves, and once a lineage within them hits on a new molecule, it tends to run with it.

Set the drawer out and name the cousins, because every one of them is either a file in this book or the shadow a file is cast against.

GENUS	SPECIES	COMMON NAME	WHAT IT IS KNOWN FOR	IN THIS BOOK
Capsicum	*C. chinense* et al.	Pepper, chili	Capsaicin — the one that learned fire	The source file
Solanum	*S. lycopersicum*	Tomato	Free glutamate, the umami staple	File 01 · Volcanic
Solanum	*S. melongena*	Eggplant	The great absorber; chlorogenic acid	File 02 · Dark Matter
Solanum	*S. tuberosum*	Potato	The staple tuber; glycoalkaloids	File 03 · Seismic
Physalis	*P. philadelphica*	Tomatillo	The tart green base of salsa verde	File 04 · Acid
Physalis	*P. pruinosa*	Ground cherry	The husk-lantern dessert berry	File 05 · Celestial
Petunia	*P. × hybrida*	Petunia	The model of floral scent chemistry	File 06 · Floral
Nicotiana	*N. benthamiana*	Tobacco	The workhorse of plant science	File 00 · Laboratory
Atropa	*A. belladonna*	Deadly nightshade	Atropine; the family's dark name	The shadow

Notice first the near-collapse of *Solanum.* The tomato, the eggplant, and the potato are not distant relations; they are a single genus — closer to one another than a wolf is to a fox — and they diverged recently enough that their genomes line up gene for gene across most of their length. When we say the engine ports easily among them, this is the structural fact underneath the sentiment: a promoter that fires in a tomato placenta has a real chance of firing in an eggplant's, because the regulatory grammar is nearly the same language with a local accent. *Physalis* is the next ring out — the tomatillo and the ground cherry, the husk-fruit cousins, wrapped in that papery inflated calyx that is itself a family signature. *Petunia* and *Nicotiana* are further still, ornamental and industrial rather than edible, but they are the family's two great laboratories — the organisms from which plant science learned scent and learned transformation — and a frontier is wise to keep its laboratories close.



A pepper split along its spine — the family resemblance made visible. The arcing pale placenta, the seeds clustered against it, the two-chambered architecture: look at a tomato, a tomatillo, a ground cherry the same way and you see the same floor plan, drawn at different scales.

The deep reason the family behaves as one is written in its history. The Solanaceae radiated out of South America, and somewhere near the base of the lineage the whole family underwent a genome triplication — three ancestral copies of its gene set, fused and then slowly resolved. Triplication is a gift to a chemist: extra copies of a gene are free to drift, to pick up new functions while the original keeps the lights on, and a family that has tripled its toolkit can afford to experiment with a copy here and a copy there. Capsaicin synthase itself is one of those experiments — a member of a large, ancient enzyme family (the BAHD acyltransferases, which we will meet in intimate structural detail in Part II) that the pepper lineage duplicated and then repurposed to join a vanilloid head to a fatty tail.

The same triplication that let one cousin invent fire let another invent the dense bitterness of a potato's defense and another the benzenoid perfume of a petunia's evening. The family's genius and the family's danger are the same genius: it cannot stop making new molecules out of old pathways.

That restlessness has a second gift for us, quieter than novelty: *nearness.* Because the eating cousins — tomato, eggplant, potato — diverged so recently inside a single genus, their chromosomes remain largely collinear, gene lined up against corresponding gene in the same order along the same arms, a property geneticists call synteny. Synteny is what makes the engine portable in practice and not merely in principle: a regulatory sequence that confines capsaicin synthase to a tomato's placenta has a real, structural chance of reading correctly in an eggplant's, because the surrounding genomic grammar is nearly the same sentence with a local accent. When we move a pathway among *Solanum* cousins we are not translating between languages; we are changing the dialect. That is the deep reason the nightshades sit at Tiers 1 and 2 of the frontier — the lowest-hanging fruit — rather than further out, and it is why, when we went looking for the first plants to carry designed flavor beyond the pod, we did not go looking far. We looked across the table.

Which is exactly the property an engineer wants. We are not, in these files, asking the Solanaceae to do something foreign to their nature. We are asking them to do *more of what they already do* — to take a pathway the family has been revising for forty million years and revise it once more, deliberately, toward flavor. The drawer is full of plants that were always going to say yes. We only had to learn to ask in the family's own language.

Chapter 2 · The dark inheritance — *why the family tastes like a warning.*

Before we hand the family a new flavor, we owe it the courtesy of understanding the flavors it already carries — and most of those, at their root, are warnings. The Solanaceae taste faintly of danger because a great many of them *are* faintly dangerous, and the bitterness is the plant saying so. If you have ever caught the green, metallic edge on a sprouting potato, the cottony bite at the back of an underripe eggplant, the vegetal sharpness of a tomato leaf, you have tasted the family's chemistry of defense. To design around it, you have to know what it is.

The family runs two great classes of alkaloid, and the division maps almost exactly onto the division between the cousins we eat and the cousins we fear. The genera at the family's dark end — *Atropa, Datura, Hyoscyamus,* mandrake — specialize in **tropane alkaloids:** atropine, scopolamine, hyoscyamine, molecules that block the acetylcholine receptors of the nervous system and that humanity has used, across its history, as poison, as medicine, as cosmetic (belladonna, "beautiful lady," named for the dilated eyes of the women who dripped it), and as the chemistry of a hundred witch-trials. We do not work in that end of the drawer; tropanes are a nerve chemistry, not a taste chemistry, and nothing in our files goes near them. But they are why the family has its name, and they are the reason the gentler cousins were mistrusted by association.



A potato in cross-section — the dense, pale, starch-packed flesh that feeds the world, and, just under the skin and in any green-tinged tissue, the glycoalkaloid defense that the family never fully set down. Our 80 potato constructs are a conversation with exactly this chemistry: not removing the plant's protection, but turning down the volume at which it shouts.

The cousins we eat specialize in the other class: **steroidal glycoalkaloids,** or SGAs. These are the family's everyday armor — α-solanine and α-chaconine in the potato, α-tomatine in the green tomato, solasonine and solamargine in the eggplant — and they are built, remarkably, from cholesterol, the same sterol scaffold an animal builds its membranes and hormones from, decorated with a nitrogen ring and a chain of sugars. The biosynthesis runs through a

tightly organized cluster of enzymes the field named, with unusual candor, the **GAME** genes — GLYCOALKALOID METABOLISM — a run of oxidases and transferases, GAME6 and GAME11 and GAME4 and their neighbors, sitting together on the chromosome and switched on as a unit when the plant needs to defend a tuber or a young fruit. The sugars matter: it is the glycosylated form that is bitter and bioactive, and the plant tunes its defense by tuning the decoration.

Two details of this chemistry matter for design. The first is that the GAME genes sit together and switch on together — a metabolic operon in all but name — which is a gift to an engineer, because a coordinated cluster is a single dial rather than a dozen scattered knobs; to modulate the plant's glycoalkaloid load you reach for the regulator above the cluster, not for each enzyme in turn. The second is *why* these molecules are dangerous as well as bitter, because the two are not the same thing. Their bitterness is a perception, read by the tongue; their toxicity, at high dose, is a real biochemistry — the steroidal glycoalkaloids inhibit acetylcholinesterase and disrupt membranes, which is the family's warning made good on an animal foolish enough to ignore the taste. This is the line our work walks with care. We turn down the *perception* and leave the *protection:* the Zero-Bitter axis quiets the signal the molecule sends to the tongue's bitter receptors without touching the plant's standing defense, so a Seismic potato is a friendlier thing to eat and no less a potato in the ground. The human mouth carries about twenty-five bitter receptors in the TAS2R family, a sensory early-warning net tuned over evolutionary time to exactly the shapes of plant alkaloids; glycoalkaloids trip several of them at once, which is why their bitterness is so broad and insistent, and why attenuating it is a matter of lowering a chord rather than muting a single note.

Here the family does something that is, if you let it, genuinely moving — it writes detoxification into ripening itself. A green tomato is armored with α-tomatine; as the fruit reddens and softens and makes itself worth eating, a ripening enzyme (GAME31) remodels that tomatine into esculeoside A, a benign, non-bitter molecule, and the warning stands down exactly as the invitation goes up. The fruit disarms itself at the moment it wants to be eaten. The potato, which offers a tuber rather than a fruit and so has no such bargain to strike, keeps its glycoalkaloids on standby and raises them sharply under stress — under light, which is why a greened potato runs bitter and is best not eaten, the chlorophyll a harmless signal of the harmful solanine that rose alongside it.

These molecules are bitter because the tongue is built to find them bitter. The human mouth carries around twenty-five bitter receptors — the **TAS2R** family — a sensory early-warning system tuned, over evolutionary time, to exactly the shapes of plant alkaloids like these. Our Zero-Bitter axis anchors to **TAS2R38,** the best-characterized of them, the receptor whose variants make some people taste a bitterness in a Brassica that others cannot find at all; the glycoalkaloids engage it and several of its siblings. And this is the lever the potato file already pulls. Those **80 potato constructs** are not an attempt to strip the plant of its defense — that would be both unkind to the plant and unwise. They turn down the *perceived*

bitterness, attenuating the signal the SGAs send to TAS2R38 by twenty to sixty-five percent, the same designed bitterness-down computed across the Library in broccoli and coffee designs. The potato keeps its chemistry; the mouth is simply spared the shout. The family's dark inheritance, read correctly, is not an obstacle to the frontier. It is the first axis the frontier gets to design — the one place where the kindest thing we can do to a staple is subtract.

Chapter 3 · The shared road — *four enzymes from fire.*

Now the engine itself, because the argument of the whole book is an argument about distance, and distance here is measured in genes. The claim is that the nightshades are the shortest reach on the entire frontier. To believe it, you have to see the road.

Capsaicin is an acid amide — a vanillyl head joined by an amide bond to a short, branched fatty-acid tail — and the pepper builds it where two tributaries meet. The first tributary is the one every green plant on Earth already runs: the **phenylpropanoid branch.** It begins at the amino acid phenylalanine and proceeds down a corridor of enzymes so conserved they are practically a plant's signature — **PAL** strips the amino group to make cinnamic acid; **C4H** hydroxylates it to p-coumaric acid; **4CL** activates that as a coenzyme-A thioester; and through **HCT, C3H,** and **COMT** the molecule picks up the hydroxyl and methoxy groups that will become the vanilloid ring. The pepper runs this corridor to make vanillin and then, with an aminotransferase called **pAMT,** converts vanillin to **vanillylamine** — the head of the molecule, the part the receptor will actually read.

Stop and notice what has just been said. The tomato runs this corridor. The potato runs it. The eggplant runs it so hard that it piles up **chlorogenic acid** — a phenylpropanoid ester — in quantities that make eggplant one of the richest dietary sources of it in the whole produce aisle. The petunia runs it straight into the benzenoid volatiles that scent an evening. The road to the head of the capsaicin molecule is not a road the pepper built. It is a road the entire family — the entire *kingdom* — paved before peppers existed, and the pepper merely drives a little further down it than its cousins bother to.

It is worth dwelling on just how deep that road runs, because its universality is the entire license for the frontier. The phenylpropanoid branch is not a specialty pathway; it is one of the load-bearing walls of plant life. From its intermediates a plant builds **lignin** — the polymer that lets a stem stand up and a tree reach the light — along with the **flavonoids** that color a flower and screen it from ultraviolet, the **tannins** that defend a leaf, and the volatile phenolics that scent an herb. A plant that could not run this branch could not be a land plant at all. So when we confirm that a tomato runs PAL and C4H and 4CL, we are not confirming a happy coincidence; we are observing that the tomato is a plant, and that being a plant means keeping this exact engine warm every hour of its life. The pepper's innovation was never the engine. It was the short off-ramp at the end — a way to divert a trickle of the branch's output, which was always headed for lignin and pigment and scent, toward a molecule that talks to a nerve. Every cousin in the drawer keeps the highway open for reasons of its own. The frontier is only the off-ramp, built one cousin at a time.

The second tributary builds the tail: the **branched-chain fatty-acid route.** The branched-chain amino acids valine and leucine are handed to a transaminase, **BCAT,** which makes branched α-keto acids; a dehydrogenase complex turns those into branched short-chain acyl-CoAs; and a ketoacyl synthase, the **KAS** module, elongates them two carbons at a time into the eight- and nine-carbon branched fatty acids that become the capsaicinoid tails. This machinery, too, is a variation on fatty-acid metabolism every plant runs; the pepper has simply tuned it to make an unusually short, unusually branched product.

STEP	ENZYME	CONVERTS	→ PRODUCT	PEPPER-SPECIFIC?
1	PAL	L-phenylalanine	trans-cinnamic acid	No
2	C4H	cinnamic acid	p-coumaric acid	No
3	4CL	p-coumaric acid	p-coumaroyl-CoA	No
4	HCT · C3H · COMT	p-coumaroyl-CoA	feruloyl-CoA → vanillin	No
5	**pAMT**	vanillin	vanillylamine (the head)	Partly
6	**BCAT · KAS · thioesterase**	valine / leucine	8-methyl-branched acyl-CoA (the tail)	Partly
7	**Pun1 / CS / AT3**	head + tail	**capsaicin**	**Yes**

Read the right-hand column top to bottom and the frontier stops being a slogan and becomes an accounting. Of the seven working modules in the route, five are already present and running in every nightshade in the drawer — they are the shared road. Only the terminal few are pepper work, and of those only one, the capstone, is truly the pepper's own invention: **Pun1,** capsaicin synthase, the acyltransferase at the confluence that joins head to tail. This is why we can say, with a straight face, that putting warmth in a tomato is a four-to-five-gene problem and not a rebuild-the-plant problem. The tomato has already done five-sevenths of the work of making capsaicin for reasons of its own, and has simply never installed the last valve.

There is a tidy proof of this hiding in the produce aisle, and it is worth keeping in mind as a touchstone for everything that follows. The difference between a fiery chili and a sweet bell pepper — same genus, same corridor, same everything — is a single broken gene. A bell pepper carries a natural deletion at the *Pun1* locus; the whole pathway is intact above it, the vanillylamine is made, the tail is made, and then nothing happens, because the one enzyme that completes the molecule is gone. Pungency in *Capsicum* is, genetically, the presence of a working *Pun1,* and sweetness is its absence. There is a second natural off-switch in the family, at a different point in the same route, and it is just as instructive. The enzyme pAMT, which aminates vanillin into the vanillylamine head, is the gate between a pungent pepper and a merely warm one: break it, and the pathway, starved of its amine, defaults to the ester-linked capsinoids instead of the amide-linked capsaicinoids — the "heatless heat" of a CH-19 Sweet. So the family has, in the wild, two independent ways to silence the fire: delete the capstone (*Pun1,* the bell pepper) or starve the head (pAMT, the capsinoid peppers). Reading the pathway as a

circuit — a main valve at *Pun1,* a head-supply valve at pAMT, a chain-length dial in the branched-chain module — is exactly what lets us do more than turn fire on and off. It lets us turn it *up, down, and sideways,* which is the difference between finding a cultivar and designing one, and the reason the files that follow can specify a warmth to a number rather than hope a pod lands near it.

If the family can turn its own fire off with one deleted gene, the frontier is simply the same switch, thrown the other way, in the cousin next door.

Chapter 4 · The locks — *the receptors a file is written against.*

A flavor is not a molecule; it is a conversation between a molecule and a receptor, and this book plays six of those conversations. The eight-axis Index that governs the whole Library is, underneath, a map of eight locks on the surface of the body — eight proteins the tongue and the trigeminal nerve use to read the chemistry of the world — and designing a file means choosing which locks to pick and by how much. The nightshade files lean on six of the eight, and lean hardest on the four the family is already most fluent in.

AXIS	RECEPTOR	WHAT IT READS	THE FAMILY'S FLUENCY
IFI-H · Heat	TRPV1	capsaicin; warmth, the trigeminal fire	Native in the pepper; the engine we port
IFI-B · Zero-Bitter	TAS2R38	glycoalkaloid & phenolic bitterness	Already pulled down in potato (80 constructs)
IFI-K · Kokumi	CaSR	γ-glutamyl richness, continuity, body	Predicted in our Phoenix design at 1,900; the family is designed to hold it
IFI-U · Umami	mGluR1 · TAS1R1·R3	free glutamate, savory depth	The tomato's native genius; predicted at 2,600 in our Caldera design
IFI-S · Sweetness	TAS1R2 · TAS1R3	sugars and sweet proteins, sugar-free	The ground cherry's register; borrowed from strawberry
IFI-P · Pungency	TRPA1	the sharp, bright, mustard-ginger channel	The tomatillo's lift; a fast top note

The headline lock is **TRPV1** — transient receptor potential, vanilloid subfamily, member one — the channel that gives this whole series its accent color. It is a four-part gate folded into the membrane of the trigeminal nerve endings on the tongue, and it is a *polymodal* sensor: it opens on its own above about 43 °C, it opens to acid, and it opens to capsaicin, which binds in a pocket formed by its S3 and S4 helices and does something subtle and devastating — it lowers the channel's thermal threshold, so a gate that should wait for 43 °C now fires at the 37 °C the tissue already sits at. The heat you feel is not a fire that exists; it is a fire the receptor has been convinced to report, a message with no lie in it. When we move the engine into a tomato, this is the lock on the far end of the work — the same human receptor the pepper has been talking to for ten million years, now addressed by a cousin.

It is worth knowing this lock in some mechanical detail, because every heat number in every file is, underneath, a statement about how hard a food pushes on it. TRPV1 assembles as a homotetramer — four identical subunits cupped around a central pore — each contributing six membrane-spanning helices, with an outer sensor module (S1–S4) and an inner pore domain (S5–S6) coupled by a short, critical S4–S5 linker. Capsaicin seats in a pocket formed by the S3 and S4 helices and that linker, where its vanillyl head hydrogen-bonds to a threonine at position 550 and a glutamate at 570 while a tyrosine at 511 cradles it from below; mutate that single

tyrosine to alanine and the pocket goes deaf to capsaicin while still answering to heat. From there, binding acts as a wedge on the S4–S5 linker, levering open the lower of the channel's two gates — the crossing of the S6 helices near isoleucine 679 — so that calcium and sodium flood through and the neuron fires. The channel favors calcium about tenfold over sodium, and that calcium does double duty: it carries the signal, and through a calcium–calmodulin feedback loop it begins to close the very channels that let it in — *desensitization,* the reason the third chip is less fierce than the first, and a behavior we dose around. The dose–response is not a line but a sigmoid, captured by the Hill equation, **response = $[C]^n / (EC_{50}^n + [C]^n)$,** with a Hill coefficient *n* near 2 — which is why heat gathers itself and then arrives in a rush, the half-second of nothing and then the bloom. And there is an evolutionary signature in the lock we never tire of telling: mammals feel capsaicin, birds do not, because avian TRPV1 differs at a few of the pocket's residues. The pepper's fire was invented as a message to the animal kingdom — *not you, them* — a plant choosing which mouths carry its seed, and humans, alone among mammals, answered not by staying away but by leaning in. When a nightshade carries a designed warmth, it is speaking that ten-million-year-old sentence in a new voice.



Reading taste at the scale it actually happens — a specimen at the microscope stage. Every IFI score in this book is, in the end, a measurement made here: a molecule meeting a receptor on a living cell, the half-activation point that becomes an EC_{50} and then a number on a card.

The three savory locks are where the family is most at home, and together they are why a nightshade can be *composed* rather than merely heated. **TAS2R38** and its bitter siblings we have already met — the warning receptors, the ones the Zero-Bitter axis quiets. **CaSR,** the calcium-sensing receptor, reads **kokumi:** not a taste of its own but a modifier, the thing that makes a broth feel continuous and complete and *long,* switched on by small γ-glutamyl peptides like glutathione. And **mGluR1,** together with the TAS1R1·TAS1R3 pair, reads **umami** — the savory depth of free glutamate, the molecule a ripe tomato manufactures in such quantity that a good one needs almost nothing done to it. The tomato is, in receptor terms, a

glutamate delivery system that evolution happened to make delicious; the Volcanic file's whole premise is that a plant already this fluent in umami can learn one more word.

Two of the family's signatures, though, fall off the map entirely — and the honest thing, the thing we will not paper over, is to say so plainly, because good design is as much about what you refuse to touch as what you reach for. The tomatillo's defining quality is **sourness,** and sourness is not one of the eight axes; it runs through a different channel, the OTOP1 proton current, a sensor that counts hydrogen ions directly rather than reading a molecule in a pocket. The petunia's defining quality is **scent,** and scent is olfaction — read by the hundreds of receptors in the nose, not the handful on the tongue, a whole separate sense. Where a file leans on one of these, we will say it sits **off-index** and leave the plant that quality exactly as it is. The tomatillo's acid was never broken. We only want to hand it a warmth to carry.

Chapter 5 · Two kinds of number — *computed, and aimed.*

Two kinds of number live in this book, and we will never let them wear the same coat, because a frontier volume that blurs them is a brochure, and we are not writing a brochure. The distinction is the spine of the whole dossier, so we set it down formally here and hold to it on every card that follows.

The first kind is **computed.** It comes from our receptor-docking and flux-balance models, scored in silico against each receptor's binding pocket and placed on the same scale the Library uses across all designs. The formula is the one that governs every axis:

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

EC_{50} is the concentration at which a stimulus drives its receptor to half of full response — the measure of how loudly a molecule speaks to its receptor. Invert it against a fixed reference constant and scale by a thousand, and loudness becomes a score. Each axis's reference constant is a **stated convention** — defined as the axis's unit, the way Scoville's scale is defined by a dilution endpoint — not a value derived from published literature. The IFI-P (pungency) axis, for instance, uses AITC at 2.1 µM as its convention constant, so AITC itself scores 1,000 on that axis by definition. Because each axis is calibrated against its own reference point rather than a universal baseline, scores on different axes describe each signal's loudness against its own defined reference; they do not convert into a single cross-axis ranking. For scorecards we normalize every axis to a ceiling of **5,000.** When a number in this book is a computed result from our model, we say *computed,* and you can hold us to it: Phoenix's predicted heat of 4,200, the Caldera tomato's predicted umami of 2,600 — these are computational outputs, not hopes, and not yet laboratory measurements.

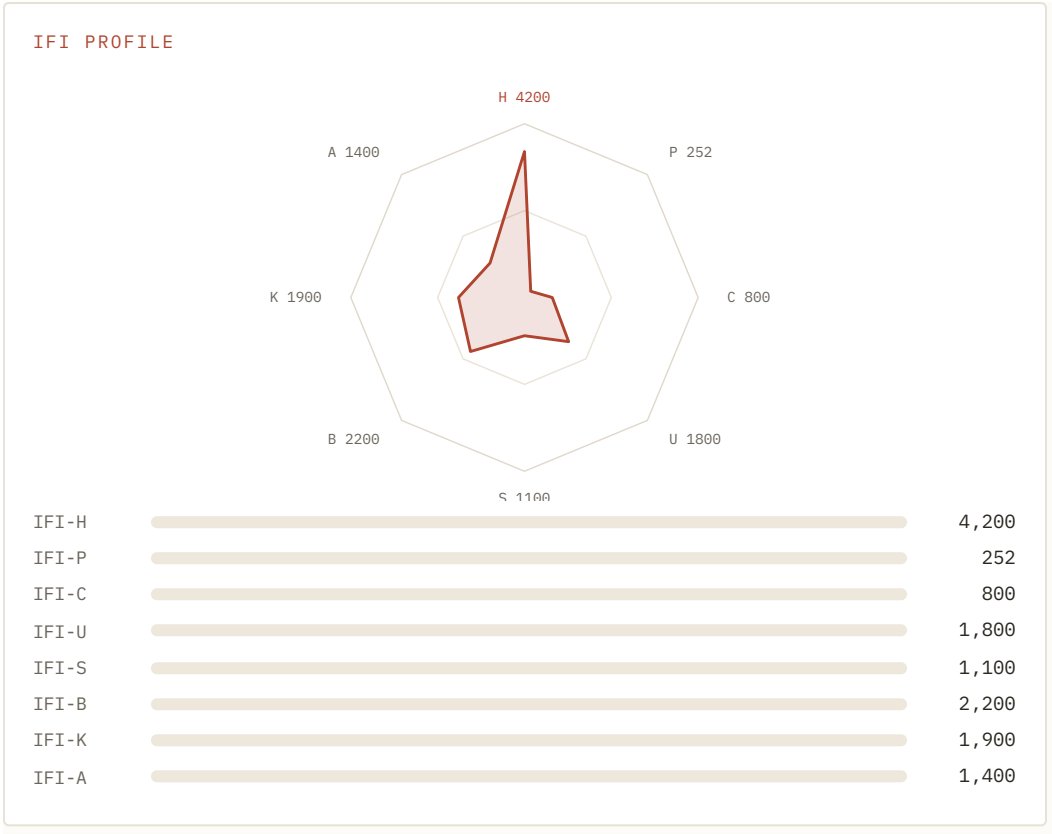
Walk the arithmetic once, concretely, because it is simpler than it looks and it clarifies everything the cards do. Suppose our convention constant for a given axis is fifty micromolar, and a candidate compound our model predicts half-activates the same receptor at five micromolar. The candidate is the louder molecule: it takes a tenth as much to reach the same half-maximal response. The score is 1,000 × 50 ÷ 5 = 10,000 — which, against our scorecard ceiling of 5,000, reads as a pinned maximum. Halve the candidate's potency, to an EC_{50} of ten micromolar, and the score falls to 1,000 × 50 ÷ 10 = 5,000; halve it again, to twenty micromolar, and it is 2,500. The concentration sits in the denominator, so a quieter molecule — a larger EC_{50} — yields a smaller score, which is the right direction: the number rises with loudness, not with quantity. Every value on every card in this book, computed or target, is that one division, performed against a receptor binding model.

The second kind is a **target** — the profile a file is *open to reach,* the number the flux-balance model asks for before a seed is ever in the ground. A target is a design goal, not a result, and we mark every single one. More than mark it: we tether it. No number in this book is wished into being. Every target is anchored to something already computed elsewhere in the Library — the family's designed bitterness-down, Phoenix's predicted kokumi and umami, a dessert strawberry's computed sweetness — and the anchor is named in the margin of the card, so that a target reads as a promise with its collateral shown. When the Dark Matter eggplant's card asks for kokumi at 1,900, the margin says *anchored to Phoenix's predicted 1,900,* because that is the designed ceiling the family has already reached in a cousin's model. A target you cannot anchor is a target we do not print.



Phoenix in the controlled chamber — SS-0096, the only cultivar we have ever designed to register on all eight axes at once. Everything in this book is projected from this one fruit: the full-spectrum template, the measured engine, the proof that the family's chemistry can be composed and not merely stacked.

Here is the source file, the computed flagship design every target borrows from, laid out as the scorecards throughout this book will lay out a cultivar. This is Phoenix — the full-spectrum flagship, designed in a pepper, the proof that eight axes can be composed at once.



Phoenix did not arrive alone. It is the top rung of a computational design series — ten cultivar designs in *Capsicum chinense,* sequenced in increasing computational scope, our model predicting heat from 866,000 SHU at Ember up to Phoenix's predicted 2.95 million, and learning, design by design, how to compose the other seven axes alongside the heat. This is the full series, every number a computational prediction:

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

All SHU and IFI-H values are computational predictions from our model. Read the two numeric columns together and you can watch the mathematics of the Index do its quiet work. The predicted Scoville values climb in even, confident strides — hundreds of thousands at a time — while the predicted IFI-H values climb and then begin, gently, to lean back, the steps crowding together as the receptor fills. The reason is the Hill curve of the last chapter: perception tracks receptor *activation,* not molecular *count,* and activation is a saturating sigmoid. Double the capsaicin in a mild sauce and the heat roughly doubles; double it again near the top of the scale and the receptor, already most of the way to its ceiling, barely moves. There is even an instructive inversion in the ladder — Kindle, at 1.25 million Scovilles, scores *lower* on IFI-H than Cinder below it at 1.05 million, because Kindle's capsaicinoid mixture is

skewed toward the longer, less-pungent-per-molecule compounds (the burn signature we meet in the next part): more mass, less activation. SHU, blind to the receptor, ranks it higher; IFI-H, reading the receptor, ranks it where the tongue actually puts it. Neither is wrong. They answer different questions, and only one of them is the question a cook is asking — *not how much is in it, but how much will I feel.* It is also why, for every file in this book, we normalize each axis to a ceiling of 5,000 and tune toward the register where the receptor is still responsive, rather than chasing a Scoville number into territory the mouth can no longer tell apart.

The scale of the work behind that design series is worth stating plainly, because it is the collateral behind every target in the book. The platform holds roughly **nineteen thousand** engineered constructs, a thousand of them available today, across **forty-two** design-validated host organisms and **eight** sensory axes, every batch within a **seven percent** coefficient of variation design specification; three patents filed, twenty-one peer-reviewed papers deposited open-access. The nightshade files are drawn against that body of published computational work — never out ahead of it.

Read that card as the whole premise of the frontier condensed into eight lines. The heat is designed at 4,200 IFI-H — our model predicts approximately 2,937,948 SHU, the highest capsaicinoid level in any Scoville Splice design — but it does not stand alone. Around it, composed rather than stacked, sit a pulled-down bitterness at 2,200, a grown-in kokumi at 1,900 and umami at 1,800, a 1,400 astringent finish keeping the whole thing from going slack. The two AI-designed substitutions in Pun1 that shaped the heat — **S39L · L345G** — found with a protein language model, ranked by predicted efficacy × stability, are the subject of Part II. The files that follow ask a gentler question than Phoenix did. Not *whether* the family can carry this. Phoenix already answered that. They ask *which cousin carries which part of it best,* and at what warmth a plant you would put in a salad can comfortably wear.



PART II OF IV

The Engine

the capsaicinoids · the synthase, in three dimensions · the double variant the breeders never found · porting the fire

Chapter 6 · The molecule — *a family inside the family.*

We say "capsaicin" the way we say "sugar," as a convenient singular for something that is really a small committee, and before we can port the molecule into the nightshades we have to be honest about which molecule we mean. The burn of any real pepper — and the burn we design into any cousin — is made by a family of closely related compounds, the **capsaicinoids,** and the *ratio* among them is not a footnote. It is the difference between a heat that stabs and a heat that swells, a heat that lives on the lips and one that sits at the back of the throat. If TRPV1 is the instrument, the capsaicinoid profile is the phrasing, and a tomato tuned to a gentle warmth deserves its phrasing chosen as carefully as its volume.

Every capsaicinoid is built on the same two-part plan the pathway handed us: a **vanillylamine head,** which actually docks in the receptor's pocket, joined by an amide bond to a **fatty-acid tail** of varying length and saturation. The head is what the receptor reads; the tail is what tunes the reading. Five capsaicinoids account for essentially all natural pungency, and their proportions are a design specification, not an accident of the season.

CAPSAICINOID	TYPICAL SHARE	RELATIVE PUNGENCY (SHU/PPM)	TAIL	PERCEIVED CHARACTER
Capsaicin	45–55%	16.1	C9, one double bond	Sharp, immediate, forward; peaks fast
Dihydrocapsaicin	30–40%	16.1	C9, saturated	Round, deep, lingering; throat and back
Nordihydrocapsaicin	5–10%	9.3	C8, saturated	Fruity, fast, front-of-mouth; fades early
Homocapsaicin	1–3%	8.6	C11, one double bond	Mild, broadening; fills the mid-palate
Homodihydrocapsaicin	1–3%	8.6	C11, saturated	Slow, low, very persistent; the long tail

Read that table as a mixing board. Capsaicin and dihydrocapsaicin together make up the great majority of any real burn, and they are also the two most potent — each equivalent to about sixteen million Scoville units in pure form — but they differ by a single double bond in the tail, and that lone unsaturation changes the whole character. Capsaicin reads sharper, more immediate, quicker to arrive and to peak; dihydrocapsaicin is rounder, slower, the one still present when you thought the dish had let you go. The three minor capsaicinoids contribute the edges — nordihydrocapsaicin in particular reads as

the friendliest, fruitier and faster to fade. This is why two peppers of identical Scoville rating can feel like entirely different experiences: the *total* is the same, the *shape* is not. Scoville, which measures only the sum, is blind to this. Designing against the receptor, we are not.

Two further facts about the capsaicinoids earn their place in a frontier book, because they mark the edges of what "heat" even is. The first is that the burn signature is *legible* — inject a pepper extract onto an HPLC column and the five capsaicinoids resolve into five peaks whose relative heights are, quite literally, the shape of the fire drawn on a page before it is ever a shape in a mouth. That chromatogram is what lets us specify a cousin's warmth as a target rather than a hope: we are not guessing at a character, we are naming a peak pattern the engine should produce. The second is that pungency is not a property a molecule owns in isolation; it is something that happens when a molecule reaches an *intact receptor on the tongue.* A few peppers — the Japanese CH-19 Sweet is the famous one — make *capsinoids* instead of capsaicinoids: near-identical molecules joined by an ester bond where capsaicin carries an amide, and that single swap makes them break down in the mouth before they can build real oral heat, registering only lower down, in the gut. The result is a "heatless heat," the warming signature of capsaicin with almost none of the burn. We raise them because they draw the boundary of the axis in bright ink: nature has already built a molecule that does nearly everything capsaicin does except the one thing we call heat, which tells us exactly where on the pathway the sensation of fire is won or lost — at the amide bond, and at the receptor that bond is shaped to reach. When we tune a nightshade's warmth, we are working inside that boundary, specifying not only how much fire but whether it lands on the tongue at all, and where.



Wildfire in cross-section — the capsaicinoid-dense placenta glistening along the pod wall. In the superhot chassis this is the most productive organ in the plant; its exact capsaicinoid ratio is a specification we write, and the specification is what we carry, scaled down, into a cousin that has never made a drop of it.

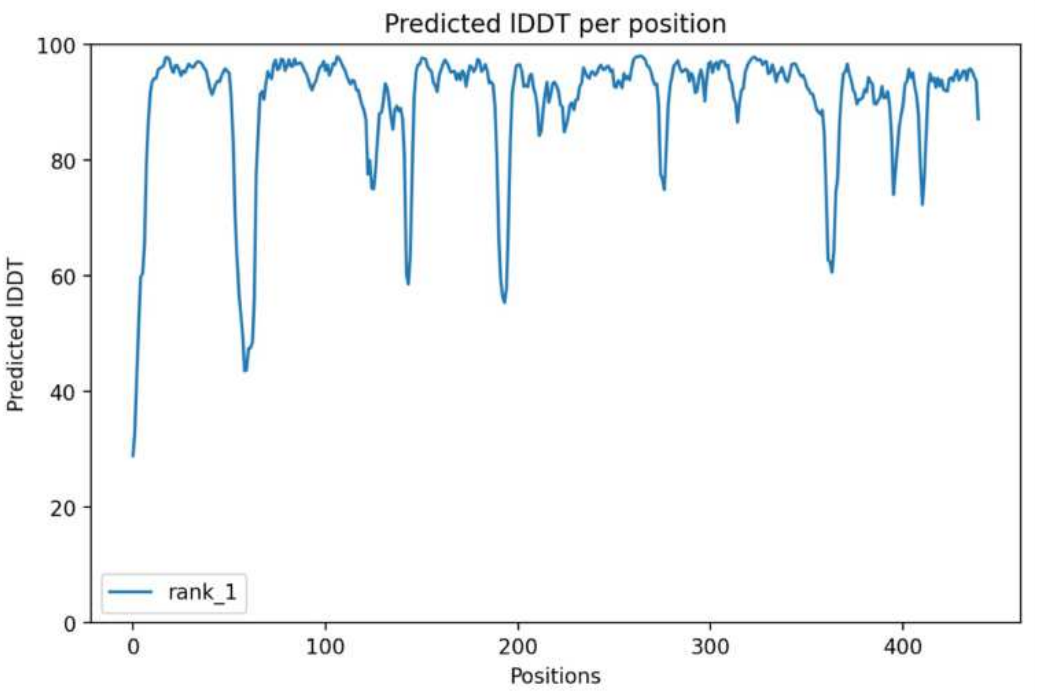
For the nightshade files this matters more, not less, than it does at the top of the pepper ladder. When a plant carries two or three million Scovilles, the fine architecture of the burn is a connoisseur's distinction. When a tomato is to carry a warmth of IFI-H 180 — a glow you reach into, not away from — the *shape* of those few capsaicinoids is nearly the whole experience, because there is so little of it that every molecule's character shows. A Volcanic tomato skewed toward capsaicin and nordihydrocapsaicin would read as a

bright, forward, front-of-mouth warmth that lifts and then clears, leaving the fruit's umami in the open — which is exactly what a sauce wants. The same tomato skewed toward dihydrocapsaicin and the long homo-compounds would read as a low, lingering heat that sits at the back and competes with the finish. Same IFI-H. Different dish. Because the tail is set enzymatically — by which fatty acid the final condensation step is handed — it is something we specify, and in the files we specify it toward *brightness and clearance,* a warmth that serves the fruit rather than occupying it. Total heat is the volume knob; the capsaicinoid ratio is the EQ; and in a plant where the volume is deliberately low, the EQ is where the craft lives.

Chapter 7 · The synthase, in three dimensions — *the one enzyme the pepper built.*

Everything upstream in the pathway is a plant being an ordinary plant. Everything that makes a pepper a pepper comes down to one enzyme, and we have now seen it clearly enough to describe it almost residue by residue — because before we move it into a cousin, we built its structure and read its machinery. This is the chapter where the frontier stops being botany and becomes molecular engineering.

Pun1 — capsaicin synthase, also called CS or AT3 — is a **BAHD acyltransferase,** a member of one of the great ancient enzyme families plants use to hang acyl groups onto acceptors. We modeled it from the *C. chinense* sequence, 440 amino acids, and the model is not a guess: it resolved at a mean **pLDDT of 90.2** with a **pTM of 0.910,** which in the grammar of structure prediction means high confidence across the whole fold and reliable packing of the domains against one another. The active site resolved even more sharply — the thirty-five residues lining the catalytic cavity modeled at a local mean pLDDT of **94.1** — which is the part that matters, because the active site is where the design happens.



Pun1 / AT3 capsaicin synthase, our structural model colored by predicted local confidence (pLDDT). The deep-blue core and the active-site cleft are the high-confidence regions — modeled reliably enough to engineer against. This is the one truly pepper-specific enzyme in the entire route, the confluence where the vanillyl head meets the branched tail and fire is finally made.

Inside, we found the canonical machinery of the family, resolved in three dimensions by our model. BAHD enzymes carry an **HXXXD** catalytic motif — a histidine and an aspartate spaced just so — and in the model the pair resolves as **His169 and Asp173, separated by**

4.6 ångströms, exactly the geometry the chemistry requires: the aspartate orients the histidine, and the histidine acts as the catalytic base that deprotonates the vanillylamine's amine so it can attack the acyl-CoA and form the amide bond. A second structural signature of the family, the **DFGWG** motif, sits where it should near residue 384, buttressing the fold. This is a well-built, textbook member of its enzyme family, and its textbook-ness is good news: it means the rules for engineering BAHD acyltransferases, learned across decades on other members, apply.

The part that makes it *capsaicin* synthase rather than some other acyltransferase is the shape of its tunnel. The pocket that receives the fatty-acyl tail is a **strongly hydrophobic channel** — lined by leucine, methionine, isoleucine, phenylalanine, tryptophan: Leu40, Met43, Ile45, Tyr44, Trp139, Phe167, Phe285, Phe405, Ile171, Ile221, Ile36, Pro399 — a greasy sleeve shaped to cradle the native 8-methyl-branched nonenoyl tail and nothing clumsier. Nearer the catalytic center, on the side that accepts the vanillylamine head, the lining turns polar — Asn303, Ser305, Ser168, Ser373 — hydrogen-bond donors positioned to hold the head in register while the bond is made. The enzyme is, in effect, two chemistries in one cleft: a hydrophobic glove for the tail, a polar clasp for the head, and the catalytic dyad at the seam where they meet.

The chemistry those two halves perform is a single, elegant transfer. BAHD acyltransferases work by direct transfer rather than through a covalent enzyme intermediate: the acyl-CoA thioester (the branched fatty tail, activated) and the amine acceptor (the vanillylamine head) both bind in the cleft, the catalytic His169 — oriented and sharpened by Asp173 across that 4.6-ångström gap — plucks a proton from the head's amine, and the now-nucleophilic nitrogen attacks the thioester carbonyl, forming the amide bond and releasing free coenzyme A. One base, one bond, one molecule of capsaicin, repeated as fast as the pocket can load and clear. Knowing the geometry to this resolution is what turns the enzyme from a black box into an instrument: the model is the direct input to docking — seating a vanillylamine and an acyl-CoA in the cleft in silico to watch how they fit — and to the variant scoring of the next chapter, where every candidate mutation is read against this exact structure before a single base is edited. It is also what makes the specificity lever real rather than rhetorical. Because we can see which residues line the hydrophobic tunnel and how deeply the native tail reaches, we can ask the enzyme to accept a tail it has never seen — shorter, longer, differently branched — and so produce, deliberately, a capsaicinoid that does not exist in any pepper on Earth, tuned at the level of a single bond for a particular arrival and clearance in the mouth. That is a frontier beyond this book's files, which port the native engine; but it is worth knowing, standing at the structure, that the loudest instrument in the Library still has strings no plant has ever plucked, and that we now hold the diagram that says where they are.

That hydrophobic tunnel is the single most important feature in this book's second half, because it is the **specificity lever.** The reason capsaicin has the tail it has is that this sleeve is shaped to accept exactly that tail; reshape the sleeve — widen it, lengthen it, change

which residues line it — and the enzyme will accept and transfer a *different* acyl group onto the vanillyl head, producing a capsaicinoid that does not exist in nature. This is the frontier within the frontier: not only moving the pepper's fire into the family, but designing, at the level of this one pocket, capsaicinoids tuned for a particular arrival and clearance, a particular geography in the mouth — new-to-nature molecules built to serve a tomato rather than to defend a pod. We are not there in these files; the files port the *native* engine, tuned for warmth. But the structure tells us the lever exists, and that the loudest instrument in the Library still has notes no plant has ever played.

One more number anchors the method's reach. We modeled **pAMT** — the aminotransferase that makes the vanillylamine head — in the same run, 459 residues, at a mean pLDDT of **95.0** and a pTM of **0.930,** even cleaner than the synthase. Both of the enzymes that make the engine's half-reactions are now known to us in high-confidence three dimensions. You cannot design what you cannot see. We can see the engine.

Chapter 8 · The double variant — *the read before the write.*

For ten thousand years, improving a pepper meant selecting a phenotype and praying the genotype followed. You grew the plants, tasted the pods, kept the seed of the one that moved you, and waited a season to find out whether the trait had held. It is a method of extraordinary patience and almost total blindness — you are optimizing a protein you have never seen by rewarding the plants whose proteins happen to work, generation after generation, never once reading the sequence you are selecting on. It worked, slowly, for all of agricultural history. We inverted it. We read first, and write once.

The read begins at the protein. We took the Pun1 sequence and scored every possible single-residue substitution with a **protein language model** — ESM2, a 650-million-parameter network trained on tens of millions of natural protein sequences until it learned, the way a language model learns grammar, which substitutions a protein of this family will tolerate and which will break it. The model does not simulate physics; it has simply read enough of the book of proteins to have strong intuitions, and those intuitions, scored across the whole enzyme, nominate the handful of changes most likely to raise catalytic efficiency without costing fold stability. We ranked candidates by predicted **efficacy × stability** — because a faster enzyme that unfolds is worthless — and we kept only the top few.

The write is checked before it is made. A nominated mutation is only meaningful in context — its value shows only against the full metabolic map, with the pathway's flux distribution understood. So every candidate passes through a **genome-scale flux-balance model,** a mathematical account of the plant's whole metabolism that maps how carbon and energy move among all reactions simultaneously. Flux-balance analysis treats the metabolic network as a system of mass-balance constraints and solves for the distribution of flux that maximizes a stated objective — here, capsaicinoid output — subject to the plant staying alive. That analysis told us something important: our flux model finds that control over total capsaicinoid output sits upstream, in the phenylpropanoid branch, at **4CL and HCT/CCoAOMT** — not at the terminal Pun1 step. Pun1's predicted flux control coefficient sits near zero across five thousand Monte Carlo draws; it is the final capsaicin synthase, it labels the product, but it does not govern the rate. The Pun1 mutations survive not because they raise total pathway flux but because they improve the enzyme's folding stability and substrate handling — a more robust Pun1 produces the designed capsaicinoid profile more reliably, holds the capsaicinoid ratio under thermal stress, and meets the seven-percent batch CV specification. Only candidates the flux model confirms have genuine enzymatic value are nominated for CRISPR editing in the design specification.

Three candidates emerged from this analysis that no breeding program ever found, because no breeding program was reading the protein — it was reading the pod. Two went into the shipped double variant construct; the third remains a structural annotation from our modelling.

EDIT	EFFECT	ΔΔG (KCAL/MOL)	STATUS
S39L	binding affinity ↑ at the N-terminal lobe	−2.1	shipped construct
L345G	steric relief in the active-site cleft	−1.8	shipped construct
C175S	disulfide-misfold prevention (structural annotation)	−0.9	structural annotation — not in shipped construct

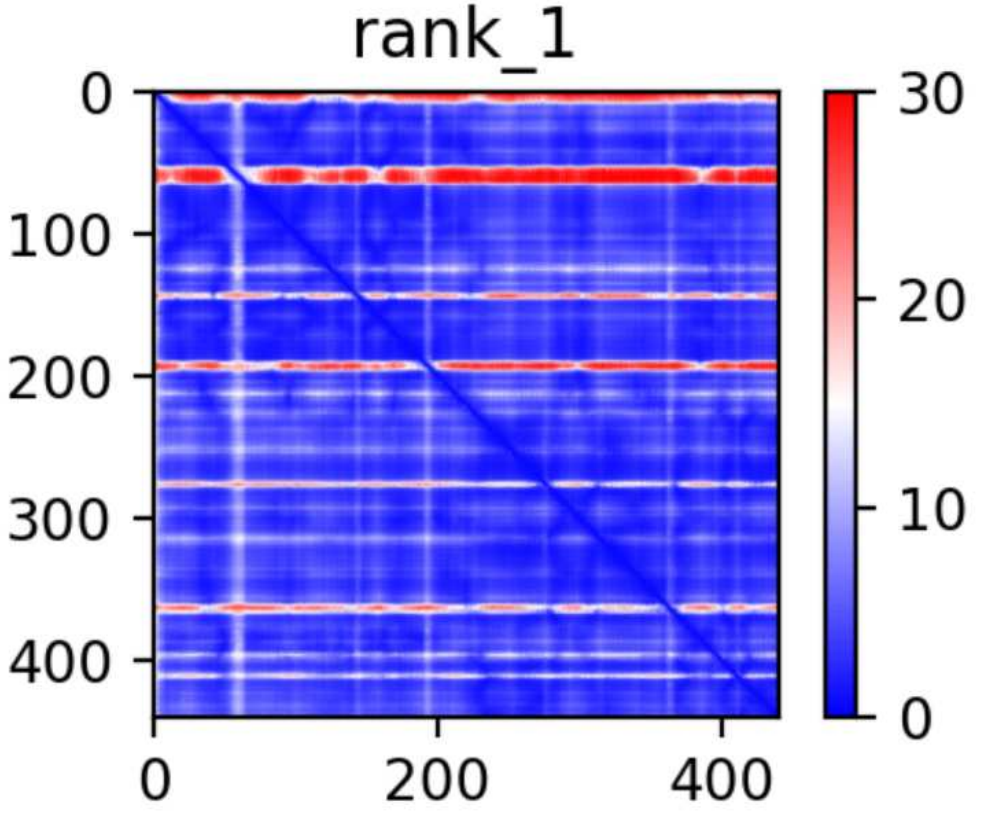


FIG. — Pun1/AT3 predicted aligned error (PAE). The low-error block running down the diagonal is the single compact domain the catalytic machinery sits in; confident relative positioning there is exactly what lets us trust a ΔΔG for a change at residue 39, 175, or 345, because the model knows where each of those residues sits relative to the active site and to one another.

Read the ΔΔG column — the predicted change in folding free energy — and the elegance shows: every value is negative, meaning every candidate *stabilizes* the fold even as it tunes the function, the opposite of the usual engineer's tax where a gain in activity is paid for with a loss in stability. **S39L** deepens binding at the N-terminal

lobe; **L345G** relieves a steric crowding in the active-site cleft, giving the acyl tail room to seat the way the hydrophobic tunnel wants it to. **C175S** — a structural annotation from our modelling, not part of the shipped construct — identifies a cysteine prone to forming a wrong disulfide bond; it informed the fold model and supported the enzyme's stability logic, but the final double variant proceeds without it. A word on that ΔΔG, because it is the quiet hero of the table. The folding free energy of a protein is the margin by which its correctly folded shape is favored over the unfolded tangle; a mutation with a negative ΔΔG widens that margin, making the enzyme more robust — more of it folds, and it stays folded under the heat and stress of a ripening fruit. Most activity-raising mutations carry a *positive* ΔΔG, destabilizing the fold as the price of a faster active site, which is why hand-tuned enzymes so often work beautifully on a bench and fall apart in a plant. The language model, scoring efficacy and stability together, was asked to find the rare substitutions that pay no such tax — and both shipped variants are predicted stabilizing, which is why they are designed to survive the move into a living fruit. Writing them in is the most precise step and the least dramatic: CRISPR is directed to each site in turn, the single codon is edited, and the plant is regenerated carrying the change and nothing else — not a transgene sprayed across the genome but two deliberate letters changed in a gene the pepper already had. The read was the hard part. The write is a scalpel.

Together, the two substitutions in the shipped double variant construct, written into the pepper, produce a capsaicinoid profile our model predicts at approximately **2.95 million SHU** at a batch-to-batch coefficient of variation of **seven percent or less** — against the better than forty percent a wild-type field will vary, pod to pod, from the same seed lot. The double variant design accomplishes two things: it specifies a precisely designed capsaicinoid profile, and it makes that profile *repeatable,* which for a cook is the greater gift.

It is worth sitting with that second gift, because it is the one the whole Library is built on and the one a Scoville record cannot capture. A wild-type pepper field, grown from a single seed lot, will vary in pungency by more than forty percent pod to pod — the fruit higher in the canopy catching more sun and more stress and firing the pathway harder, the same *Pun1* gene expressed at wildly different levels across one plant. For a cook, that variance is the real enemy, worse than any ceiling: it is the jalapeño that was supposed to be mild and was not, the sauce that cannot be reproduced, the dish that cannot be trusted. By designing a stabilized synthase and specifying its expression to a set point, we design that forty percent down to seven — the same predicted profile in every fruit, every harvest, an instruction rather than a wish. The search that found the two variants is worth its own measure of respect, too, because it is what no breeding program could have done. There are nineteen other amino acids available at each of 440 positions — on the order of eight thousand single substitutions, and astronomically more in combination — and a field program can test only the mutations that

happen to arise and happen to show in a pod. The protein language model read all of them at once, in silico, ranking the full space by predicted efficacy and stability; the flux-balance model then confirmed which candidates have genuine enzymatic value; and only the survivors, a handful, went forward. We did not search harder than the breeders. We searched *first,* and in the right place — the sequence, not the pod.

These same two substitutions are the core of every file in Part III — not at pepper scale, but as the designed, stable synthase our flux model selected. When a Volcanic tomato is dialed to a culinary warmth, it is this enzyme doing the work, turned down to a setting a tomato can wear. The hard design work is done. What remains is placement.

Chapter 9 · Porting the fire — *addressing, not inserting.*

Here is the move that makes the whole frontier tractable, and it is subtler than it sounds. Putting the engine into a cousin is less a matter of *inserting* a pathway than of *addressing* it — telling an already-capable plant to run machinery it mostly already owns, in the right room, at the right time, at the right volume. The difference between inserting and addressing is the difference between building a new wing and handing someone a key to a room that was always in the house.



A seedling at the transplant stage in the controlled chamber — the moment the addressed engine goes from a design in a model to a plant on a bench. The containment is not theater; every first-generation construct is designed to live its whole life indoors, read and reviewed before any question of a field is raised.

Recall from Part I that five of the seven pathway modules already run in every nightshade. So the port is not seven genes; it is the terminal few — a route to vanillylamine the plant may partly have, a branched-tail supply, and above all a working, tuned capsaicin synthase — set down on an engine the plant keeps warm. The genome nearness of the *Solanum* cousins (Chapter 1) means the enzymes themselves transfer with little fuss. The hard part, the part that is genuinely engineering and not cut-and-paste, is the **promoter** — the switch that decides where and when the new enzyme fires.

The pepper did not merely invent capsaicin synthase. It invented the *discipline* of where to use it. The enzyme fires only in the placental gland cells, and only during a defined window of fruit ripening, directed by a layer of transcription factors — MYB- and WRKY-family regulators — that read the fruit's developmental clock and open the pathway at exactly one place and time. This is why a pepper's leaves and roots, carrying the identical genome and the identical phenylpropanoid corridor, never burn: the terminal genes are present everywhere but held silent everywhere except the one tissue evolution chose. When we move fire into a tomato, we must recreate that discipline in the tomato's own terms — find or build the promoter that confines the new pathway to the fruit, to the ripening window, to a tissue that will hold the capsaicinoids without taxing the

rest of the plant. A fruit that made capsaicin in its leaves would be a sick plant and a bitter salad. Addressing is the art of making the new flavor show up only on the plate.

Getting that addressing right is a problem with a known shape, which is why we can put months on it rather than maybes. The pepper confines capsaicin synthase with a layer of transcription factors — MYB- and WRKY-family regulators that read the fruit's developmental clock — bound to specific sequences upstream of the gene. To reproduce the discipline in a tomato we have two routes, and we weigh them per file. We can borrow a native tomato promoter already known to fire late in ripening and only in the fruit — a ripening-specific, flesh-specific switch the tomato already owns — and place the synthase under it, so the plant's own clock turns the new pathway on exactly when it reddens. Or we can supply a tuned synthetic promoter carrying the regulator-binding sites the pathway needs, a switch built to specification. The first borrows the cousin's grammar; the second writes a new sentence in it. Either way the engineering target is precise and testable: the right tissue (placenta and flesh, never leaf or root), the right window (the ripening fruit, never the growing plant), the right level (a warmth, not a wall). Because the *Solanum* cousins are syntenic, a switch designed for a tomato carries a real presumption of working in an eggplant, which is why Tier 1 bundles the two. The potato breaks the presumption — a tuber has no ripening fruit to borrow a promoter from — and that single fact, not any difference in the chemistry, is most of why it costs an extra tier and an extra year.

Fruit-targeting is not only a flavor discipline; it is a safety one, and the two happen to be the same act. A pathway confined to the ripe fruit is a pathway kept out of the leaves and roots and stems — out of the tissues a plant's own pests and the field's own ecology interact with, and out of the green parts where a nightshade's glycoalkaloid chemistry already lives. A tomato that made capsaicin only in its ripe flesh would present nothing new to a caterpillar on its leaf and nothing new to the soil. Confining the engine to the one organ meant to be eaten, at the one moment it is meant to be eaten, is how a designed flavor stays a flavor and does not become a change to the whole plant's relationship with the world. The pepper worked this out for itself over ten million years. We are simply holding to the discipline it already proved, in every cousin we address.

This is also where the tiers come from, the honest clock we will show in full in Part IV. A tomato (Tier 1) is a fruit addressing a fruit-targeted pathway — the shortest possible reach, four to five genes, eighteen to twenty-four months. A potato (Tier 2) is harder not because the chemistry is different but because a *tuber* is not a fruit: the tissue logic, the developmental clock, the place to concentrate the pathway all have to be re-derived for an organ the pepper's promoter grammar was never written for. Five to seven genes, twenty-four to thirty-six months. Distance, on this frontier, is mostly the distance between one tissue's switchboard and another's.

And this is why one cousin takes the first risk so the food crops never have to — the logic of File 00, the proving ground, which we meet first in the next part. The dangerous reading, the question of whether an addressed pathway behaves, gets done first in a plant we do not eat and can transform in days, so that by the time the engine reaches a tomato the only open questions are the gentle ones: how warm, how bright, how composed. The quiet radicalism of the whole frontier is that the design — the receptor, the pathway, the double variant, the structure of the synthase, the discipline of the promoter — is finished. What remains is placement, and placement is an engineering problem with a clock on it, not a mystery.



PART III OF IV

The Files

seven dossiers · the proving ground, the tomato, the eggplant, the potato, the tomatillo, the ground cherry, the petunia

Chapter 10 · File 00 · The Laboratory — *the cousin that takes the risk.*

FILE 00 · T1 · Solanaceae · Tobacco · *Nicotiana* · concept — the proving ground *Proof of Concept · Benchmark · Threshold*

Before any food crop is asked to carry the engine, one cousin volunteers. Tobacco is the oldest workhorse in plant science — it transforms fast, it regenerates from almost nothing, a leaf disc can become a whole new plant in weeks, and through transient agroinfiltration a single leaf can be made to express a borrowed pathway in a matter of days, read, and discarded. It has borne more first drafts of more pathways than any plant alive. We do not eat it, and we do not pretend otherwise; its nicotine is a pyridine alkaloid off to the side of everything this book cares about, and its whole value here is that it will take a risk a tomato should never have to.

The reason it is the family's laboratory is a set of unglamorous virtues that happen to be exactly the ones a proving ground needs. Tobacco — *Nicotiana benthamiana* above all — accepts *Agrobacterium* readily, so a new gene can be delivered simply by infiltrating a bacterial suspension into the air spaces of a leaf; within three or four days that leaf is expressing the borrowed pathway at high level, no new plant required, a result you can read and then compost. This is *transient expression,* and it compresses the slowest step in plant engineering — build a construct, wait for a whole plant to grow up around it — from a season to a long weekend. For questions that need a stable plant, tobacco regenerates from a single leaf disc through tissue culture in weeks, where a tomato takes months and many crops resist regeneration altogether. And because the plant is fast-cycling, self-compatible, and genetically well mapped, a result in tobacco is a result you can actually interpret. None of this makes tobacco food; it makes it *fast,* and speed in the proving ground is what buys patience everywhere downstream. Every yes-or-no that would be expensive to ask in a tomato — does the synthase fold and function in Solanaceae cytoplasm, does the tissue tolerate the flux, does the engine run at all without the two substitutions or only with them — gets asked here first, cheaply, in a plant whose entire purpose is to answer honestly and be thrown away.



Tobacco — *Nicotiana,* the laboratory of the family. Broad, fast-growing, endlessly transformable, and never dinner. Its leaves have hosted more borrowed pathways than any plant on Earth, and in these files they host the first, honest answer to whether the engine runs at all.

The file is named for exactly what it is for, in three stages. In **Proof of Concept,** the terminal enzymes go in and we ask only the yes-or-no question: does a capsaicinoid appear at all, at the end of a leaf that has never made one? It is the crudest and most important question on the whole frontier, and tobacco answers it in weeks rather than in the two years a tomato would take to even pose it. In **Benchmark,** we measure *how loudly* — we quantify the capsaicinoid output, tune the Pun1 double variant (the same **S39L · L345G** that shapes Phoenix's heat design), and check the response against what the flux-balance model drew, calibrating the engine against its own prediction. In **Threshold,** we push until the pathway taxes the plant more than it rewards it, finding the line where flux into capsaicinoids starts to starve the plant's own metabolism — so that when the engine moves to a fruit we love, we already know its limits and will never ask a tomato to cross them.

That third stage is more quantitative than it sounds, and it is where the flux-balance model meets the plant. Every molecule of capsaicinoid is paid for: the vanillyl head is a phenylalanine the plant did not spend on protein or lignin, the branched tail is carbon and reducing power pulled out of fatty-acid metabolism, and the condensation itself consumes a coenzyme-A. Push the pathway hard enough and those withdrawals start to show — in slower growth, thinner leaves, a plant visibly spending its budget on a molecule it was never meant to make. Threshold is the experiment that finds the knee of that curve: the output level above which the next increment of heat costs more plant than it is worth. Knowing the knee is what lets us set a tomato's warmth not at the maximum the engine can produce but at the maximum the fruit can afford while still being a healthy, high-yielding tomato — a number the model predicts and tobacco confirms, cheaply, before a single food plant is grown. And all three stages happen under containment, in a plant that was never going to be eaten, which is the quiet ethic of the proving ground: the organism that takes the risk is the one chosen precisely because nothing is lost if the experiment says no.

It is unglamorous and it is everything. The reason the six files that follow can speak in months instead of maybes is that their hardest design questions get answered here first, in a plant whose only job is to be honest. There is a kind of care in that, too — and it is the

care that runs under this whole Library — in letting the cousin who will never be dinner do the dangerous reading, so that the tomato can simply be a better tomato, and the first generation of every food construct can live its whole life in containment, reviewed before it is ever asked to be food. The proving ground is not a detour around rigor. It is where the rigor lives.

No food scorecard: tobacco is a method, not a meal. What it yields is a design-verified engine and a number we trust — carried, from here, into the plants on the plate.

Chapter 11 · File 01 · The Volcanic Tomato — *a warmth grown into the sauce.*

FILE 01 · T1 · Solanaceae · Tomato · 2,040 constructs · difficulty: Easy *Ember · Magma · Pyroclast · Caldera · Krakatoa*

Of all the files, this one is already half-written in the greenhouse. The tomato is the most-built organism in our whole Library — **2,040 constructs,** more than any other host — and most of that work has been one quiet, patient restoration. A century of breeding the tomato for the truck rather than the tongue — for firmness, for shelf life, for the ability to be picked green and gassed red a thousand miles from where it grew — stripped the fruit of the thing it was beloved for, the deep savory sweetness of one eaten warm off the vine in August. We have spent much of the tomato's file putting that back, through the plant's own machinery: coaxing the free glutamate back up so the fruit speaks loudly again to mGluR1 and the TAS1R1·TAS1R3 pair, letting the sugars and the roundness return. Our **Caldera** design carries it, and these numbers are **computed** in our model; the design package is available today.

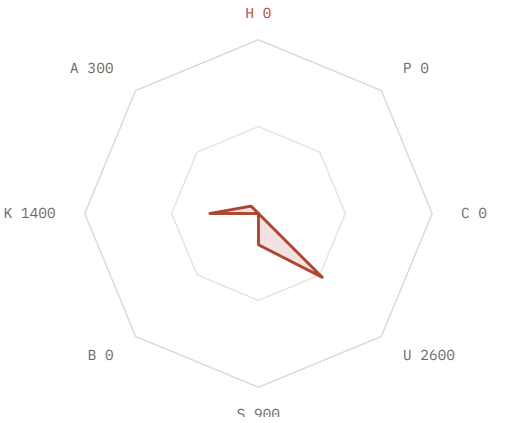
The biochemistry of that restoration is worth naming, because it is the story of a number the tomato manages on its own and that breeding accidentally turned down. A ripe tomato's umami is free **glutamate** — glutamate not locked into protein but loose in the cell, where the tongue can read it — and the fruit builds its pool through a small metabolic economy: during development much of the glutamate is shunted into **GABA** by the enzyme GAD, and then, in the final days of ripening, that store is drawn back down and free glutamate climbs steeply, which is why a truly vine-ripe tomato tastes so much deeper than one picked green. Glutamate dehydrogenase (GDH) sits at the hinge of that economy, interconverting glutamate with the carbon skeleton beneath it. A century of breeding for the truck — for fruit firm enough to ship, uniform enough to machine-harvest, able to be picked green and gassed red a thousand miles from the field — selected, without anyone intending it, against the long vine-ripening that lets the glutamate pool fill. The savor was not removed by a gene; it was left unbuilt by an early harvest. Our work on the tomato, across those 2,040 constructs, is largely the work of giving the fruit back its own late-ripening chemistry — restoring the glutamate climb so the tomato speaks to mGluR1 at the volume it reached when a tomato was something you ate in the garden, warm, the week it was ready. Caldera's predicted umami of 2,600, roughly three times a supermarket fruit in our model, is that climb, designed back in.



A tomato, restored — split to the chambered, seed-glossed interior that a good one earns. The umami a century of shipping-first breeding bred out, designed back in through the fruit's own glutamate metabolism: IFI-U predicted at 2,600 in our model, roughly three times a supermarket tomato. This is the designed floor the Volcanic file builds its warmth on top of.

Here is the computed base — the tomato design profile as it stands before heat is added. Note the card: it lights up the savory half of the Index and sits silent on the heat half, because that is exactly what it is — a fully designed savory profile with no warmth yet composed in.

IFI PROFILE



IFI-H	0
IFI-P	0
IFI-C	0
IFI-U	2,600
IFI-S	900
IFI-B	0
IFI-K	1,400
IFI-A	300

The four live axes are the computed ones from our model — umami at **2,600,** the savory depth designed through the native glutamate route (the GAD/GDH metabolism that governs the fruit's glutamate pool); sweetness at **900,** the ripe-afternoon register, not a grain added; kokumi at **1,400,** roundness designed in; and a faint astringency at **300,** a whisper of skin-and-seed bite left on purpose because a tomato with no edge at all tastes like a tomato pretending. The Volcanic line asks the frontier question on top of that designed base: what if the tomato that finally tastes like a tomato could also

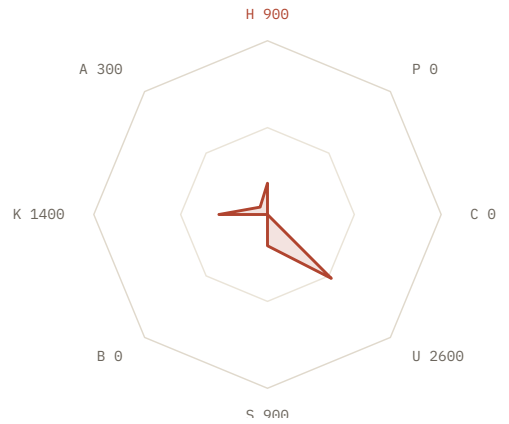
carry its *own* warmth — the sauce that arrives already a little hot, the slow glow built into the fruit instead of shaken over it at the end? The cultivar names run the ladder a volcano runs, from the first warmth to the summit.

CULTIVAR	TARGET IFI-H	THE WARMTH IT CARRIES
Ember	120	the whisper you notice only on the second bite
Magma	300	a confident background warmth, a good table salsa
Pyroclast	500	the dish's defining edge, serrano country
Caldera	2,600 (U)	*the computed base — umami, not heat; the floor the design series stands on*
Krakatoa	900	the top we allow a tomato: the confident warmth of a good hot sauce

Set those target numbers against a cook's intuition for a moment, because the ladder is meant to be read that way. Ember at IFI-H 120 sits in the register of a mild fresh chili — the warmth you notice on the second bite, not the first. Magma at 300 is a confident table-salsa heat, the background warmth of a dish that knows what it is. Pyroclast at 500 is serrano country, the defining edge of a plate. Krakatoa at 900, the summit we allow a tomato, is the assured heat of a good hot sauce — and still an order of magnitude below the mildest of the ten flagship superhots, which begin in the thousands. That gap is the whole point: a Volcanic tomato lives entirely in the lower, hospitable bands of the heat axis, the country where most of the world actually cooks, because a tomato's job is to season a dish from within, not to dominate it. The 2,040 constructs behind the tomato are what make a design series this fine-grained possible — enough computational variation in the chassis to specify a warmth at 120 and design it to *stay* at 120, every fruit, the savor profile and the warmth held to the same seven-percent coefficient of variation specification as everything else in the Library.

A word on the ceiling we chose, because it is a choice and not a limit. We could aim a tomato at the top of the pepper ladder; we will not. A tomato is not a pod, and heat here is a seasoning, not a stunt — Krakatoa reaches for the confident warmth of a good hot sauce, never a superhot, because a tomato asked to carry two million Scovilles would stop being a tomato and become a delivery device, and we are not interested in that. Everything Caldera is designed to be, held; a warmth, composed in and tuned (recall Chapter 6) toward brightness and clearance so it lifts the fruit rather than burying it. Here is the Volcanic target at its summit — the computed base with Krakatoa's warmth composed on top, every number anchored.

IFI PROFILE



IFI-H	900
IFI-P	0
IFI-C	0
IFI-U	2,600
IFI-S	900
IFI-B	0
IFI-K	1,400
IFI-A	300

AXIS	TARGET	ANCHORED TO
IFI-H · Heat	120 → 900	Ember to Krakatoa — a culinary warmth, never a superhot
IFI-U · Umami	2,600	carried straight over from Caldera, **computed**
IFI-S · Sweet	900	the ripe sweetness kept, **computed**
IFI-K · Kokumi	1,400	the grown-in body kept, **computed**

This is the shortest reach on the whole frontier, and the one most likely to end up in a weeknight pan: a fruit two-thirds designed, a four-to-five-gene port into a fruit-targeted pathway, a warmth chosen to stay in the register of cooking. The tomato was always going to answer first. It had already done most of the work.

Chapter 12 · File 02 · The Dark Matter Eggplant — *the flavor you feel before you taste.*

FILE 02 · T1 · Solanaceae · Eggplant · *Solanum melongena* · concept
Smolder · Nightshade · Eclipse · Obsidian · Event Horizon

The eggplant is the family's great absorber — a spongy, violet-skinned blank that takes on whatever it is cooked with and, left alone, can turn faintly bitter and cottony. It is adored for what it accepts and quietly distrusted for what it is on its own: a texture in search of a flavor, a sponge that gives back only what the cook put in.

The sponge is not a metaphor; it is anatomy. Eggplant flesh is an open lattice of large, thin-walled cells around generous air spaces, and that architecture is why a raw cube weighs almost nothing and why, dropped in hot oil, it drinks — the air spaces collapse and the lattice fills with whatever fat and flavor surround it. It is the family's great absorber by construction. Left to itself, though, that same flesh offers two things the tongue reads as a warning. One is the steroidal glycoalkaloids solasonine and solamargine, the eggplant's share of the family defense. The other is **chlorogenic acid,** and here the family's chemistry closes a circle worth pausing on: chlorogenic acid is a *phenylpropanoid,* an ester built from the very PAL-to-COMT branch that ends, three enzymes further along in the pepper, in capsaicin. The eggplant stockpiles it — enough to make the plant one of the richest dietary sources of chlorogenic acid in the whole produce aisle — and runs the branch so hard, in part, to pigment that violet skin. So the eggplant is already a champion of the shared road; it simply drives the road toward bitterness and color rather than fire. The Dark Matter file does not fight that chemistry. It turns down the *perception* of the bitter edge through TAS2R, grows in kokumi and umami to give the sponge something of its own to carry, and lets a low smolder of warmth sit underneath — asking the family's great absorber, for the first time, to arrive at the pan already full. This file asks the eggplant to finally have a flavor of its own to give back, and names the ambition after the thing in the universe you cannot see but can measure by its pull. **Dark matter** — the density under the dish, the gravity you feel before you can name its source. The cultivar names run from the first glow into deep space: **Smolder, Nightshade, Eclipse, Obsidian, Event Horizon.**

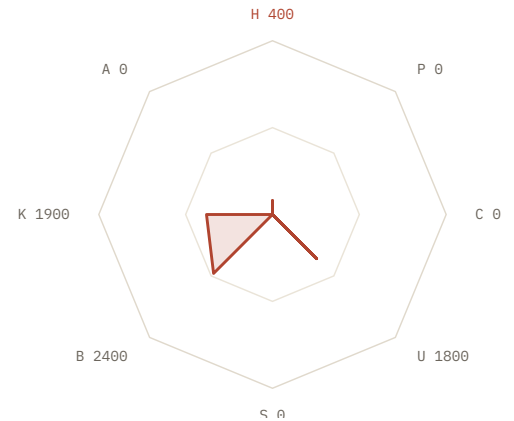


Eggplant — *Solanum melongena,* the family's absorber. That violet skin is a phenylpropanoid pigment, and the flesh beneath is one of the richest dietary stores of chlorogenic acid in the produce aisle: the same universal branch that ends in capsaicin runs hard in this cousin already, just toward bitterness and color instead of fire.

Three axes do the work, and they are the family's most natural three. First, **subtract.** The eggplant's native bitterness comes from two sources, and both trace back to chemistry we have already met: the steroidal glycoalkaloids solasonine and solamargine (Chapter 2), and the sheer load of chlorogenic acid, that phenylpropanoid ester the eggplant stockpiles. Both read as bitter through TAS2R38 and its siblings, and we turn the signal down the same way we design it down in a potato or a broccoli — rerouting the perception, not stripping the plant's chemistry, the designed twenty-to-sixty-five-percent attenuation. Then, **add gravity.** Kokumi through the calcium-sensing receptor, the richness that has no taste of its own but makes a dish feel continuous and complete and *long* — exactly the quality a sponge most lacks on its own. And umami through mGluR1, so the eggplant carries savor instead of only borrowing it from the pan. Under all of it, a low **smolder** of heat, above a cooking accent and well below the pod.

The choice of those three axes is not arbitrary; it is the sponge's own anatomy answering back. An absorber with nothing of its own is a liability — it will take on bitterness from its own skin as readily as flavor from the pan, and it dilutes whatever it is cooked with by sheer volume of bland flesh. Give it kokumi, and that same volume becomes an advantage: CaSR's signal of continuity and body turns a large, soft, yielding bite into a *long* one, the richness filling the mouth the way the flesh fills the pan. Give it umami, and the sponge stops borrowing savor and starts contributing it, so a dish built on eggplant no longer needs the anchovy or the stock or the long-cooked meat to give it a floor — the eggplant *is* the floor. Turn down the bitter, and the one thing that made cooks salt and purge and distrust the vegetable simply recedes. The smolder of heat sits under all three as a lift, the TRPV1 warmth that makes the savory read more present without ever announcing itself as spice. Composed this way, the eggplant's defining trait — that it becomes whatever surrounds it — is no longer a confession of emptiness. It is a promise that whatever you build on it, it will carry, and now carry with a weight of its own.

IFI PROFILE



IFI-H	400
IFI-P	0
IFI-C	0
IFI-U	1,800
IFI-S	0
IFI-B	2,400
IFI-K	1,900
IFI-A	0

AXIS	TARGET	ANCHORED TO
IFI-B · Zero-Bitter	2,400	the family's designed bitter-down, computed in broccoli and potato designs (20–65%)
IFI-K · Kokumi	1,900	Phoenix's predicted kokumi, ported — the designed ceiling
IFI-U · Umami	1,800	Phoenix's predicted umami
IFI-H · Heat	400	a smolder: above a cooking accent, well below the pod

It is a concept file — eggplant is not yet a design-validated host, so this one is drawn, not built — and we mark that plainly. But look at the right-hand column: every target on the card is borrowed from a number we have already computed in a cousin design. The bitter-down is the potato's and the broccoli's designed lane. The kokumi and umami are Phoenix's predicted ceilings, specified in a pepper design and asked for here at the same level. That is the whole argument of the family stated in one scorecard — nothing on this card asks for a chemistry the Solanaceae have not already shown, in our models, they can run. The eggplant that has only ever given back what it was given would, for the first time, arrive at the pan already carrying weight: a flavor you feel, as the name promises, a little before you can say what it is.

Chapter 13 · File 03 · The Seismic Potato — *seasoning from the ground up.*

FILE 03 · T2 · Solanaceae · Potato · 80 constructs · difficulty: Easy

The potato already keeps a file open in our greenhouse — **80 constructs,** all of them so far aimed at one thing: turning down the glycoalkaloid bitterness, the faint green warning of α-solanine and α-chaconine, through TAS2R38. That makes the chassis computationally established even though the heat is still the frontier. The Tier-2 reach here is longer than the tomato's — **five to seven genes, twenty-four to thirty-six months** — not because the chemistry is different but because, as Chapter 9 explained, the engine has further to travel into a *tuber* than into a fruit. A potato is a swollen underground stem, not a ripening fruit; the pepper's whole grammar of where-and-when was written for a fruit, and addressing a tuber means re-deriving the tissue logic from scratch.



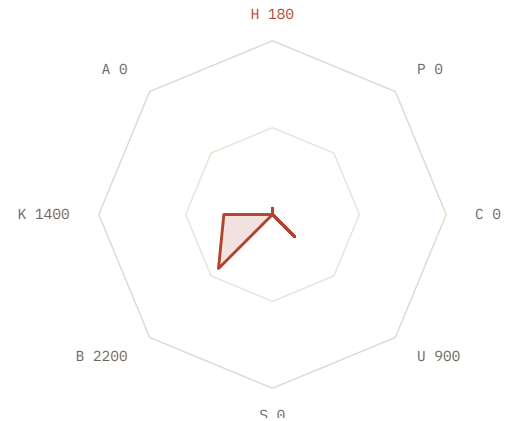
A potato — *Solanum tuberosum,* the blandest canvas the family owns, which is exactly why it feeds the world. It carries everything and insists on nothing. The Seismic file asks the humblest and maybe the most radical question in the book: what if the staple arrived already holding a little flavor of its own?

The ambition is the humblest in the book and maybe the most radical. Season the staple from the inside. A potato is the blandest canvas the family owns, and that blankness is not a flaw — it is the reason a potato can be a French fry and a gnocchi and an aloo gobi and a vodka, the reason it became the carbohydrate floor under so much of the world's eating.

The scale of that floor is the thing that makes the humblest file in the book, quietly, the one with the longest reach into real lives. The potato is among the most-produced food crops on Earth and the staple that stands, for a great many people, between the day and hunger — a crop that fed empires and, when it failed, emptied them. A flavor improvement in a potato is not a flourish; it is multiplied by one of the largest denominators in agriculture. The chemistry we work with here is the family's defense at its most familiar: α-solanine and α-chaconine, the glycoalkaloids that rise sharply when a tuber is exposed to light and begins to green, the faint bitter warning most cooks already know to cut away. We do not touch that defense — a potato should keep its armor in the ground — we quiet only the perceived bitterness, through the same TAS2R attenuation the 80 potato constructs have already designed. The reach is longer than the tomato's for one structural reason named in Part II: a potato is a tuber, a swollen underground stem, not a ripening fruit, and the pepper's whole grammar of *where and when* was written for fruit. There is no reddening moment to borrow a promoter from, no placenta to address; the tissue logic has to be re-derived for an organ the engine has never met.

The tuber's own biology sets the terms of that re-derivation. A potato is mostly a dense matrix of starch-packed parenchyma cells wrapped in a corky periderm — the skin — with the bulk of its glycoalkaloids concentrated just beneath that skin and in the eyes, where the plant most needs to guard the buds that will become next year's plants. That geography is useful to know, because it tells us where a designed flavor would have to live to be tasted and where the bitterness we want to quiet already sits. A warmth and a savory floor built evenly through the flesh would season the whole tuber from within; a bitter-down tuned to the sub-skin layer would meet the glycoalkaloids where they actually are. And because a tuber stores for months — that is its evolutionary job, to carry the plant through a dormant season — any flavor we design has to be stable in storage, not merely at harvest, a constraint a quick-eaten fruit never imposes. These are solvable problems, but they are the potato's problems specifically, and solving them is the work the extra year buys. Five to seven genes, two to three years — not harder chemistry, just a longer walk into unfamiliar ground. The payoff is a staple seasoned from the inside, and a little less bitter at its source, which is the frontier arriving not on a tasting menu but at the center of the plate most of the world actually sets. **Seismic** is the warmth that comes from underground, a tremor rather than a strike: a potato that arrives already holding a gentle heat and a savory floor and a little less of its native bitterness, so that the first thing you do to it is not the only thing giving it flavor.

IFI PROFILE



IFI-H	180
IFI-P	0
IFI-C	0
IFI-U	900
IFI-S	0
IFI-B	2,200
IFI-K	1,400
IFI-A	0

AXIS	TARGET	ANCHORED TO
IFI-B · Zero-Bitter	2,200	the tuber's own glycoalkaloid edge, turned down — its 80 constructs' **designed** lane
IFI-K · Kokumi	1,400	body grown into the staple, anchored to Caldera's **predicted** kokumi
IFI-U · Umami	900	a savory floor, in the register of good slow-cooked beans
IFI-H · Heat	180	a warmth below *hot* — you reach for the next forkful, not the water

There is a nourishment logic here we find hard to let go of, and it is the clearest statement in the book of what this whole frontier is quietly for. The potato is, for a great part of the world, the plate itself — the single most-eaten vegetable crop on Earth, the food that stands between a great many people and hunger. To grow a little flavor and a little less bitterness into the most-eaten thing there is, *at the source,* so that the staple is more worth eating for its own sake and not only for what butter and salt do to it, is the opposite of an exotic project. It is the frontier arriving where people actually live. A potato that seasons itself a little is a small thing. Multiplied by how much potato the world eats, it is not small at all.

Chapter 14 · File 04 · The Acid Tomatillo — *the salsa that arrives already hot.*

FILE 04 · T2 · Solanaceae · Tomatillo · *Physalis philadelphica* · concept

Unhusk a tomatillo and you hold the base of every great salsa verde — tart, green, a brightness so clean it tastes like a held note, the sharp counterpoint that cuts through the richness of everything it is served beside. Its project name, **Acid,** is a love letter to that tartness. It is also a lesson in the limits of our own Index, and we will not paper over it, because the honest thing a frontier book can do for its reader is draw its own boundaries clearly.



A tomatillo in its papery husk, that inflated calyx the whole *Physalis* lineage wears — a lantern grown around a fruit. The defining quality inside is sourness, and sourness is the one great taste our eight axes do not touch. This file is as much about what we refuse to design as what we reach for.

The tomatillo's signature is **sourness,** and sourness is not one of the eight axes. The Index measures receptor-mediated taste and chemesthesis — heat, sweet, umami, bitter, kokumi, cool, pungency, astringency — and acid runs through a different channel entirely: the OTOP1 proton current, a sensor on the sour cells of the tongue that counts hydrogen ions directly rather than reading a molecule docked in a pocket. The citric and malic acids that make a tomatillo bright are talking to a receptor the eight axes were never built to score.

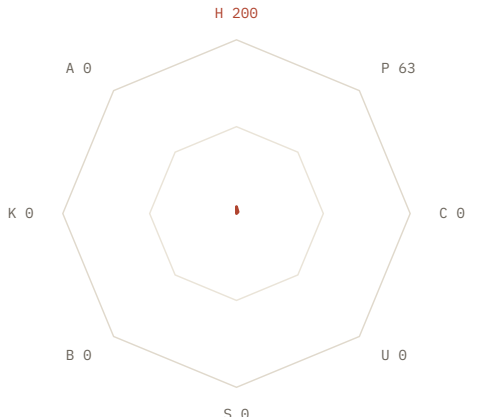
That receptor deserves a moment, because it explains why sourness sits outside the Index by nature and not by oversight. Sour is read by **OTOP1,** a proton channel on the tongue's sour cells — and notice what kind of sensor that is. The other tastes work by a molecule docking in a pocket: capsaicin in TRPV1, glutamate at mGluR1, a glycoalkaloid at TAS2R38, each a lock and a specific key. Sour is not a key in a lock at all; it is the tongue *counting hydrogen ions directly,* the acid's protons flowing through an open channel and depolarizing the cell. There is no molecule to tune, no binding affinity to raise or lower, no EC_{50} to anchor a score to — the sensation is a current, proportional to acidity itself. This is why the IFI, which is built on receptor binding, has no sour axis and should not pretend to one: you cannot write 1,000 × EC_{50}(reference) ÷ EC_{50}(candidate) for a stimulus that has no EC_{50}. The tomatillo's tartness is a different physics, and the honest thing is to leave it exactly as the fruit does it — a brightness carried in that papery husk, the inflated calyx the whole *Physalis* lineage wears like a lantern around its fruit. What we design sits *around* the acid: a laddered warmth and a fast TRPA1 lift, placed at the front of the mouth where the sourness already lives, two sharp sensations arriving together and raising each other. We do not improve the acid. We give it company. So this file leaves the tomatillo's defining quality exactly where it belongs: **off-index,** the fruit's own, untouched. We could not raise it with our tools if we wanted to, and we do not want to.

What we design is what sits *around* the acid. A laddered **heat,** so the salsa comes out of the husk already warm, the way the best table salsas are — not fire, a warmth that arrives with the brightness instead of being chased down with it. And a bright **pungency** — the quick TRPA1 top note, the sharp lift you know from mustard and ginger and a fresh horseradish — placed at the very front of the mouth, where tartness already lives, so the two sharp sensations arrive together and lift each other. Acid and pungency are natural allies; both are fast, both are forward, both clear quickly, and a tomatillo that carried a whisper of TRPA1 brightness alongside its native sour would read as a salsa verde that someone had already, invisibly, seasoned.

The receptor that carries that lift is worth a word, because it is the family's other sharp channel and it works nothing like the heat one. TRPA1 — the bite of mustard, wasabi, horseradish, raw garlic — is an electrophile sensor: the pungent molecules that trigger it do not merely dock in a pocket but chemically modify it, forming a reversible covalent bond to cysteine residues on the channel's inner face, which is why the sensation is so immediate, so sharp, and so quick to clear once the molecule lets go. That speed is exactly what pairs it with acid. Sourness, read by the OTOP1 proton current, is also a front-of-mouth, fast-arriving, fast-clearing sensation, so the two land in the same place at the same instant and leave together — a clean bright lift rather than a lingering burn. A tomatillo tuned with a trace of TRPA1 pungency would not taste hotter, exactly; it would taste *sharper and more alive* at the very front of the bite, the green

brightness it already does best given an edge that clears before the next chip. It is seasoning placed precisely where the fruit's own signature already lives.

IFI PROFILE



IFI-H	200
IFI-P	63
IFI-C	0
IFI-U	0
IFI-S	0
IFI-B	0
IFI-K	0
IFI-A	0

AXIS	TARGET	ANCHORED TO
IFI-H · Heat	200	a salsa-verde warmth, laddered into the fruit
IFI-P · Pungency	63	a bright TRPA1 lift, anchored to the computed pungency in our bean designs
— · acidity	*off-index*	the tartness has no receptor axis in the eight; it stays the fruit's own

Design, done well, is as much about what you refuse to touch as what you reach for. The sparse card is not a thin file; it is a disciplined one. The tomatillo's acid was never broken, and a frontier that tried to "improve" it would only be vandalism with good intentions. We want to hand the fruit a warmth and a lift to carry alongside the brightness it already does better than anything else in the garden — and then step back.

Chapter 15 · File 05 · The Celestial Ground Cherry — *a lantern with a warm wick.*

FILE 05 · T2 · Solanaceae · Ground Cherry · *Physalis pruinosa* · concept

The ground cherry is the tomatillo's sweeter sibling — a little papery lantern you peel back to a golden berry that tastes, improbably, of pineapple and warm tomato and something like candy. It is the family's dessert, hiding in plain sight in a genus better known for its tart green cousin, and it carries a second distinction worth naming: it is one of the very first plants anyone ever *domesticated with gene editing,* its wild habit and small fruit tamed by precise edits to a handful of known genes. The family's dessert berry is also a proof that *Physalis* takes direction.

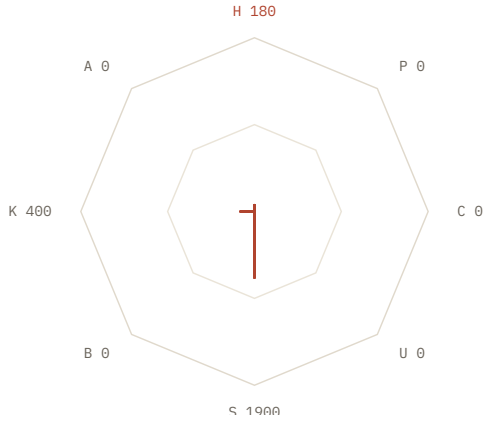
That is not a flourish; it is a precedent that matters to this file specifically. A research group took the wild ground cherry — a sprawling, shatter-prone plant with tiny fruit — and, by editing the *Physalis* counterparts of a handful of genes already mapped in the tomato (the ones governing plant architecture, flower number, and fruit size), tamed it toward a crop in a single deliberate step, compressing the thousands of years such domestication took the tomato into a design. For us the lesson is direct: *Physalis* takes direction, and takes it through the same genes, read across from its syntenic cousin the tomato — exactly the family nearness that makes the whole frontier tractable, demonstrated in the very genus the Celestial file lives in. The flavor design on top is the gentlest kind of swicy. Sweetness comes the way it always does for us, not a grain added — the plant's own TAS1R2·TAS1R3 signal grown up to one perfect ripe afternoon — and over it a whisper of heat kept below the threshold of *hot.* The reason that whisper works is a real quirk of perception: a trace of TRPV1 warmth, too faint to read as spice, is read instead as *intensity,* the brain folding the low heat signal into the sweetness beside it and hearing the sweet as louder, rounder, more present. It is the swicy trick at its subtlest, heat functioning purely as an amplifier of everything it sits next to, and in a berry this small the whole effect fits in a single bite. Its file, **Celestial,** keeps that sweet, skyward register: this is the sweet-heat frontier told in a fruit small enough to eat from the palm.



A ground cherry — *Physalis pruinosa,* the husk-lantern dessert of the family. Peel the papery calyx and the golden berry inside tastes of pineapple and warm tomato and candy. The Celestial file is the sweet-heat frontier at its gentlest: sweetness grown up to one perfect afternoon, and a whisper of warmth that only makes the sweet louder.

The design is close kin to a sweet-heat strawberry, and we borrow that cousin's computed design profile on purpose rather than invent a new one. **Sweetness** comes the way it always does for us — not a grain of added sugar, but the plant's own TAS1R2·TAS1R3 signal grown up to the level of one perfect ripe afternoon, the fruit made to speak more loudly in the language it already speaks. Over it, a **whisper of heat,** kept deliberately below the threshold of *hot,* so the warmth does not read as spice at all but as the sweetness getting louder and rounder — the swicy trick at its subtlest, where the heat is felt mostly as an intensifier of everything beside it. A faint **kokumi** rounds the finish, giving the little berry a length it would not otherwise have.

IFI PROFILE



IFI-H	180
IFI-P	0
IFI-C	0
IFI-U	0
IFI-S	1,900
IFI-B	0
IFI-K	400
IFI-A	0

AXIS	TARGET	ANCHORED TO
IFI-S · Sweet	1,900	the one-perfect-afternoon sweetness, anchored to our **computed** sweet-heat strawberry design
IFI-H · Heat	180	a whisper, below the threshold of *hot* — it only makes the sweet louder
IFI-K · Kokumi	400	a faint roundness on the finish

Two more things make the Celestial file the gentlest on the whole frontier. The first is the husk itself — the inflated papery calyx that gives the genus its lantern, a balloon of tissue that grows up around the fruit and shelters it as it ripens, so a ground cherry arrives pre-wrapped, protected, a little secret you have to open. It is a fruit built for the hand, and a frontier that ends in the hand is the one we trust most. The second is how we reach the sweetness, because it matters that we never reach for sugar. The TAS1R2·TAS1R3 receptor that reads sweet does not care whether it is activated by a sugar, by a sweet protein, or by the plant's own intensified sugar signal; sweetness is a receptor event, not a calorie count, and our whole approach to the axis is to make the plant speak more loudly in the language it already speaks rather than to pour sugar into it. A Celestial ground cherry designed to a computed-anchored 1,900 on the sweet axis is not a sweeter berry because it holds more sugar; it is a berry whose ripeness is designed to reach the receptor more completely, turned up to one perfect afternoon and held there in every lantern, not one in ten.

A ground cherry is the kind of thing a child eats standing in a garden, lantern after lantern, the husks dropped in the dirt. We like a frontier that ends there — not in a laboratory and not on a dare, but in a cupped hand, in a berry sweet enough to feel like a secret and warm enough, just barely, to make you reach for another. The most advanced flavor engineering we know, arriving as candy you grow.

Chapter 16 · File 06 · The Floral Petunia — *proof the family can carry a scent.*

FILE 06 · T2 · Solanaceae · Petunia · *Petunia × hybrida* · concept — ornamental

The last file in the drawer is not food, and that is precisely the point of it. The petunia is a flower on a windowsill, but to a plant scientist it is a second great model of the family — the organism from which we have learned the most scent chemistry, the benzenoid and phenylpropanoid volatiles that make an evening petunia smell the way it does, governed by a master regulator the field named ODO1, ODORANT1, that opens the whole perfume pathway as the light fails and the moths come out.

Follow that perfume back to its source and it arrives, startlingly, at the junction this whole book orbits. The petunia's evening scent is a bouquet of **benzenoid and phenylpropanoid volatiles** — methylbenzoate, benzaldehyde, phenylethyl alcohol, isoeugenol — and every one of them is built from the output of PAL, the same first enzyme that commits phenylalanine to the phenylpropanoid branch in the pepper, the tomato, the eggplant, and the potato. The branch forks: one way lies lignin and pigment and, in the pepper, the vanilloid head of capsaicin; another way lies the volatile phenolics that lift off a flower into the dark. ODO1 is simply the switch that opens the volatile fork on the petunia's own schedule. So the petunia and the pepper are not distant metaphors for the family's range; they are two exits off one highway, fire at one and perfume at the other, and the precision we use to tune a receptor on the tongue is the same precision that would tune a volatile bound for the nose. Its file, **Floral,** asks whether the family's designable reach extends past the tongue entirely, into the nose.



A petunia — *Petunia × hybrida,* the family's perfumer and one of plant science's two great laboratories. Its evening scent comes off the same phenylpropanoid junction that ends, in its pepper cousin, in capsaicin. The branch that makes fire and the branch that makes perfume leave from the same corner of the family's metabolism.

It does extend, and it draws a clean line for us — the same line the tomatillo drew, from the other side. **Scent is olfaction.** It is a different sense, read by a different system, scored by none of the eight axes, which measure only what the tongue and the trigeminal nerve report.

The gap between the two senses is not a matter of degree; it is a matter of architecture. Taste is a handful of receptor types reading molecules dissolved in saliva at close range — sweet, sour, salt, bitter, umami, and the chemesthetic channels of heat and pungency and cool — a small, fixed alphabet. Smell is hundreds of receptor types, around four hundred working genes in a human nose, each tuned broadly, so that a single volatile lights up a *pattern* across many of them and the brain reads scent as a combinatorial code rather than a set of named tastes. A petunia's methylbenzoate is not "sweeter" or "more umami"; it is a chord struck across dozens of olfactory receptors, arriving orthonasally from the flower and, when a fruit is eaten, retronasally from the back of the mouth — the same molecules, read by the same nose, that make up most of what we loosely call a food's "flavor." None of it has an EC_{50} against a taste receptor, because none of it is talking to one. That is why the petunia carries no IFI card and should not: to score its perfume on the eight axes would be a category error, like weighing a song in grams. The file's honesty about that boundary is exactly what makes its proof trustworthy — the family's reach extends to the nose, and the nose is somewhere the Index does not, and should not, go. So we will not hand the petunia a food scorecard it has no business carrying; there is no `ifi` block in this file, and there should not be. What the petunia offers the frontier instead is a proof of *range.* Its perfume is built on the benzenoid branch of the very phenylpropanoid pathway that, three enzymes further along in its pepper cousin, ends in capsaicin. The branch that makes heat and the branch that makes an evening smell like a garden leave from the same junction — PAL, the same first enzyme, feeding both. To tune a petunia's volatile is to demonstrate that the same precision we use to pick the lock of a receptor on the tongue can pick the lock of a volatile bound for the nose, in a plant of this very family, on the same shared road.

That is why the ornamental earns a place among the food files. It marks the far edge of the family's designable world. The nightshade frontier, read through all seven files together, runs from the deep underground warmth of a tuber (Seismic) through the restored savor of a fruit (Volcanic) and the composed gravity of a sponge (Dark Matter) all the way to the evening air above a flower (Floral) — and every one of those reaches, from the tongue to the nose, leaves from the same metabolic corner the pepper's fire leaves from. One family. One road. A range wider than any of us guessed when we first asked who, besides the pepper, could carry the flame.

No food scorecard: the petunia is ornamental, and scent sits off every one of the eight axes. The file earns its place by what it proves — that the family's designable range runs from a tuber's warmth to a flower's perfume, all from one shared pathway.



PART IV OF IV

The Reach

the full spectrum in a tomato · the clock on each file · past the family fence · grown toward all of itself

Chapter 17 · The full spectrum, in a tomato — *the Phoenix template, transferred.*

Heat is the headline of this book, but it was never the whole ambition, and this is the chapter where the larger one comes out of hiding. Phoenix's design showed something bigger than a Scoville record: that a single fruit can be composed across **all eight axes at once** — not stacked. The open question the seven files leave on the table is whether that full-spectrum design, specified first in a pepper, can be transferred whole into a plant you would put in a salad. We believe it can, and the belief is not a hope; it is an extrapolation from a computed result, which is the only kind of belief this Library permits itself.



Phoenix at the microscope stage — the composed eight-axis profile that is this book's north star. Not the hottest pod as a trophy, but the first proof that a single plant can be made addressable on every axis at once, which is the same thing as saying it can be composed like a dish before it is one.

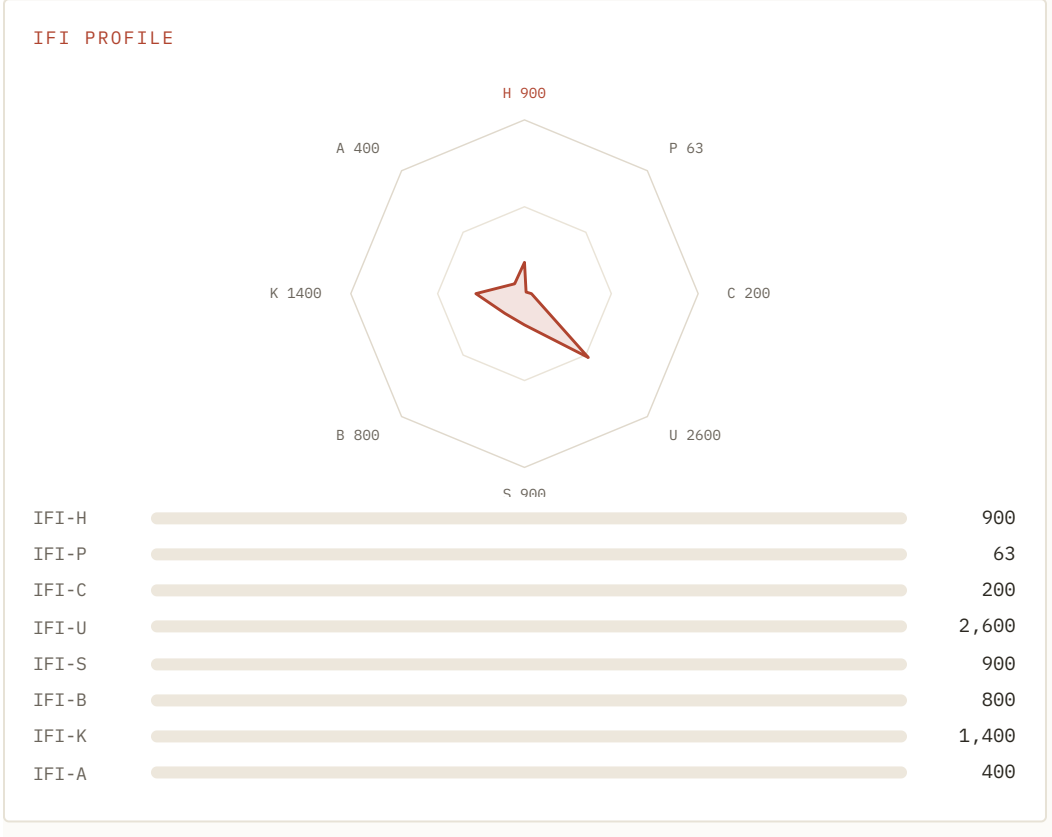
Composition is the hard part, and it is why we do not simply pile axes on until the card is full. Receptors interact. A naïve stack cancels itself — add kokumi carelessly and you can flatten the very heat you just built, because the CaSR signal that lengthens a savory note can blunt the sharpness of a trigeminal one; push sweetness too far and the umami recedes behind it. Phoenix's coherence did not come from maximizing eight numbers. It came from the flux-balance model finding the *ratios* that hold — heat designed at 4,200 while

bitterness is pulled deliberately down to a predicted 2,200, kokumi and umami composed in at 1,900 and 1,800 to give the fire a body to stand in, a 1,400 astringent finish that keeps the whole composition from going slack. The eight numbers are not eight achievements. They are one chord.

Composing that chord is a real optimization, not a wish list, and it is worth seeing why the naïve approach fails. Receptors and the pathways that feed them share resources and interfere, so the axes are not independent sliders. They compete for *metabolic* budget first — every axis is a demand on the same pool of carbon and energy and precursor, and the flux-balance model's central job is to find a distribution that satisfies eight demands at once without any of them starving the plant or each other; push one axis to a pepper-scale extreme and the model will show the others collapsing for lack of supply. And they compete for *perceptual* budget second — kokumi's CaSR signal, which lengthens and rounds a savory note, can blunt the sharp edge of a trigeminal one if it is overbuilt; a sweetness pushed too high will stand in front of umami and hide it; a bitterness not pulled down far enough will flatten everything behind it. Put rough numbers on it and the trade-offs stop being abstract. Phoenix's design spends its metabolic budget on a towering heat profile, so its other axes sit where a budget shared eight ways allows — umami at 1,800 and kokumi at 1,900, strong but not maximal, bitterness pulled *down* to 2,200 because a high bitter would fight the very heat the design is built around. Move the template into a tomato and invert the priority: let umami lead at its predicted 2,600, and the budget Phoenix poured into 4,200 of heat is freed to compose a warmth of 900, a pungent lift of 63, a cool whisper of 200, a modest bitter-down and a little more astringent structure — eight smaller, compatible numbers instead of one enormous one and seven supporting it. Same template, different dominant axis, and in both cases the flux model's job is identical: find the one distribution where every axis is fed and none cancels its neighbor. That is why we call it a chord and not a stack. A stack is eight numbers added up; a chord is eight numbers chosen so they sound like one. Phoenix's coherence was the flux model finding the ratios where all eight demands are met and none cancels — heat designed high while bitterness is deliberately suppressed, kokumi and umami composed to give the fire a body to stand in, astringency set just high enough to keep the finish from going slack. That is why a full-spectrum nightshade is a harder design than a hotter one, and a more interesting one: the goal is not eight large numbers but eight *compatible* ones, a profile that reads as a single intended taste rather than eight ingredients shouting over each other. Transferred to a tomato, the pepper-scale magnitudes fall away, but the compatibility problem — the chord — is exactly the same, and solving it in a fruit you would put in a salad is the thing we mean by composing a plant before it is a dish.

Transfer that chord to a nightshade and it would not keep the pepper-scale numbers — a tomato is not a pod, and we would not ask it to be — but it would keep the *shape:* a dominant axis chosen on purpose, the others composed around it to hold. A Volcanic

tomato that is mostly umami and warmth, the way Caldera is mostly umami. A Dark Matter eggplant that is mostly kokumi and a smolder. Here is what the first full-spectrum tomato might look like — the computed Caldera base, kept whole, with the other axes composed in at nightshade scale: warmth from the Volcanic engine, a modest bitter-down, a bright pungent lift, a cool whisper, a touch more astringent structure. Every value sub-pepper, every value anchored, the whole thing labeled for exactly what it is.



Target — a projection, not a plant. The umami, sweet, and kokumi are carried from computed Caldera; the heat from the designed Volcanic engine; the remaining axes composed at nightshade scale against the Phoenix template's predicted ratios. This would be the first **8/8 cultivar outside *Capsicum*** — not because eight is a trophy, but because a plant addressable on every axis at once is a plant you can finally *compose* like a dish before it is one, a tomato tuned at the level of the fruit so the cook inherits a ready chord instead of a blank. The dream the files leave open, stated plainly: the full spectrum, grown into the most ordinary fruit on the plate. Phoenix proved the chord can be played. The frontier is to play it on an instrument you would set beside the mozzarella.

Chapter 18 · The clock on each file — *gene counts and the months they cost.*

A frontier book owes its readers honesty about time, and this is the chapter where we show the clock rather than the dream. The tiers are not marketing language; they are gene counts and the months those genes cost, and the whole reason the nightshades are first is that their clocks are the shortest ones on the map.

TIER	ORGANISMS (THIS BOOK)	GENES	TIMELINE	WHY
T1 · Solanaceae Core	Tobacco (00), Tomato (01), Eggplant (02)	4–5	18–24 mo	Shared engine, fruit-to-fruit addressing, two-thirds-designed chassis
T2 · Extended Nightshades	Potato (03), Tomatillo (04), Ground Cherry (05), Petunia (06)	5–7	24–36 mo	Same family road, longer haul into tubers, husk-fruit, ornamentals

And here are the seven files themselves, gathered on one page — the whole dossier at a glance, with the honest status of every headline number marked:

FILE	PROJECT · ORGANISM	DOMINANT DESIGN	HEADLINE TARGET	STATUS	TIER
00	Laboratory · Tobacco	the proving ground	a design-verified engine	method	T1
01	Volcanic · Tomato	warmth over restored savor	H 120→900 on U 2,600	base **computed**, heat target	T1
02	Dark Matter · Eggplant	gravity in a sponge	K 1,900 · B 2,400 · U 1,800	target	T1
03	Seismic · Potato	season the staple	B 2,200 · H 180 · K 1,400	chassis **computed**, rest target	T2
04	Acid · Tomatillo	warmth around the sour	H 200 · P 300 (acid off-index)	target	T2
05	Celestial · Ground Cherry	sweet-heat in the hand	S 1,900 · H 180	target	T2
06	Floral · Petunia	reach past the tongue	scent (off-index)	proof of range	T2

Read down the Status column and the book's one discipline is visible at a glance: a computed base and a marked target in the tomato, a designed chassis under the potato, an honest *target* on the concept files, and two plain admissions — the tomatillo's acid and the petunia's scent — where the Index itself does not reach. Nothing here is hidden, and nothing is wished.

Tier 1 — Solanaceae Core. Four to five genes, eighteen to twenty-four months. The tomato and the eggplant, plus the tobacco proving ground that de-risks them both. The nearest reach on the entire sixty-four-organism roadmap: a shared engine, a short addressing problem, a fruit or a leaf to hold it. The tomato is further along than the rest because its chassis is the most-built in the Library, 2,040 constructs deep, with the umami floor already computed and the design package available. When we say eighteen months, we mean a clock that has, for the tomato, effectively already started.

Tier 2 — Extended Nightshades. Five to seven genes, twenty-four to thirty-six months. The potato, the tomatillo, the ground cherry, the petunia. Not harder *chemistry* — the same family road, the same engine — but a longer haul, because the tissue is less fruit-like (a tuber), or the fruit is wrapped in a husk, or the plant is ornamental and its pathway bound for the nose. The extra genes and the extra months are the cost of re-deriving the pepper's where-and-when discipline for an organ it was never written for.

Two notes of rigor belong on this clock, because a responsible frontier keeps them in view from the first gene. The first is **containment.** Every first-generation construct in every file lives its whole life indoors, in controlled chambers like the ones these pages are full of — grown, read, and reviewed under containment before any question of a field is ever raised. The proving-ground logic of File 00 is the same logic scaled up: the dangerous reading happens where it can be watched.

A word on what sits between a designed construct and a plate, because a frontier book that skipped it would be dishonest about the clock. A designed cultivar does not become food by being interesting; it becomes food by clearing the same gates any new crop clears — compositional analysis against its conventional counterpart, allergenicity and toxicology review of any novel protein, and, for this family above all others, a hard look at the glycoalkaloids. The Solanaceae are the one family where regulators already watch total glycoalkaloid load as a matter of course, because the family's defense is potent; a Seismic potato or a Dark Matter eggplant would be measured for solanine and solasonine as a baseline, and our bitter-down work — which quiets perception without lowering the plant's actual glycoalkaloid content — is designed to pass that look rather than complicate it. We would rather a cultivar be boring to a toxicologist and interesting only to a cook. None of this is fast, and we do not pretend the gene is the whole timeline — the eighteen-to-thirty-six-month figures are molecular build and validation, with the regulatory road beyond them walked honestly and without shortcuts. The canonical measure of the work standing behind these files is worth restating plainly: roughly nineteen thousand constructs across forty-two design-validated organisms, a thousand available today, every batch inside a seven-percent coefficient of variation, three patents filed and twenty-one papers deposited open-access. The nightshade files are projections, clearly marked — but they are projected from a body of published computational work, and that is the only thing that gives a target the right to be printed. The second is the family's own chemistry, which we respect rather than override.

The Solanaceae carry glycoalkaloids for a reason (Chapter 2), and our bitter-down work turns down the *perception,* not the plant's defense — we are quieting a shout, not disarming a guard. A frontier that ignored the family's toxicology to chase a flavor would be exactly the reckless thing the old fear of the nightshades warned against. We would rather earn the family's trust slowly and keep it.

These seven files are the first seven of a roadmap that runs to sixty-four concept organisms across five tiers. The nightshades are Tiers 1 and 2 — the low-hanging frontier — precisely because they are kin, and the honest measure of that kinship is the clock: real timelines, two-thirds-designed chassis, every target anchored to a computed cousin design. The drama of this book, in the end, is that there is no drama. This is buildable, the arithmetic is shown, and the clock has already started on the first file.

Chapter 19 · Past the family fence — *where the files run out.*

Honesty cuts the other way too, and a frontier book that only ever flattered its own frontier would not be worth the paper. The family ends. Past the nightshade fence, the next plants we want are not cousins — they are strangers from other families, and the reach gets longer fast.



The strawberry — the first plant past the family fence, and a different, braver book. It shares the universal phenylpropanoid backbone with every nightshade, but none of the near wiring the Solanaceae gave us for free: a cross-family reach of seven to ten genes and three to four years, where a tomato asks for four to five and eighteen months.

Tier 3 is cross-family work: seven to ten genes, three to four years, because the stranger shares the universal phenylpropanoid backbone — that part is every plant's inheritance — but none of the near wiring the Solanaceae gave us for free. A sweet-heat strawberry, a contradiction cucumber, a deep-earth carrot: each shares the ancient road but not the local grammar, not the genome-nearness that let a tomato's promoter have a real chance in an eggplant, not the computed cousin design standing by to anchor a target. The engine still ports. It just travels further, arrives needing more adjustment, and takes longer to trust. We say this here, at the edge of the nightshade drawer, because the family's gift is best understood by what lies just past it. Everything that made these seven files fast — shared tissue logic, a half-designed chassis, a cousin's computed number to anchor a target — thins the moment you cross out of Solanaceae. The strawberry file is a different, braver book, and it is the subject of the next volume on this shelf.

It helps to see how fast the ground rises past the fence, because the gradient is the whole argument for doing the family first. The roadmap runs five tiers, and the nightshades are only the first two. **Tier 3** is cross-family — strawberry, cucumber, melon, apple, lettuce — seven to ten genes and three to four years, where the engine must be re-tuned for a plant that shares the universal phenylpropanoid backbone but none of the near wiring: a new promoter grammar with no syntenic cousin to borrow from, a new tissue, a new developmental clock, and no computed relative design standing by to anchor a target. **Tier 4** is frontier-synthetic — carrot, cabbage, broccoli, corn, rice — ten to twelve genes and the better part of a decade, and the grasses (corn, rice) are the hardest reach

of all, because a cereal grain is about as far from a pepper placenta as an edible plant gets, in tissue, in regulation, and in the sheer length of pathway that must be supplied rather than borrowed. Read those numbers against the tomato's four-to-five genes and eighteen months and the shape of the frontier is clear: it is not a cliff but a ramp, and the nightshades are the gentle first stretch of it. Everything learned on that first stretch — the promoter discipline, the computed-versus-target rigor, the structural read of the synthase, the containment practice, the flux model calibrated against the first designs — is what makes the steeper grades climbable at all. It is worth being precise about what, exactly, carries forward, because this is the real yield of the nightshade files — not seven cultivars but a transferable method. The structural read of the synthase transfers unchanged: Pun1 folds and functions the same whatever plant it sits in, and the two substitutions that stabilize it are the engine's property, not the pepper's. The flux-balance discipline transfers: the question of whether a plant can feed a new pathway without starving is asked the same way in a strawberry as in a tomato, only against a different metabolic map. The computed-versus-target rigor transfers, and so does the containment practice, and so does the structural docking that lets us reshape the acyl tunnel. What does *not* transfer is the easy part — the syntenic promoter, the computed cousin design to anchor against, the near tissue logic — and that is precisely the gift the family gave us for free and the strangers will make us earn. The method is portable. The shortcuts are local.

You do not start a long ascent at the summit. You start where the family already left the trail half-cut.

But the near shore comes first for a reason, and the reason is not timidity. It is method. Prove the engine moves cleanly among kin — build out the tomato and the eggplant and the potato designs, refine the promoter grammar, calibrate the flux model — and you have not only seven cultivars. You have a *method with its first miles behind it,* ready for the longer roads. Each thing learned in the family transfers outward: the discipline of tissue-targeting, the computed-versus-target rigor, the containment practice, the structural read of the synthase that makes the engine tunable anywhere it goes. The nightshades were never the whole frontier. They were the on-ramp — chosen because they are the family, and the family was always going to answer first, and the answers the family gives are the ones that make the strangers reachable at all.

Chapter 20 · A closing file · grown toward all of itself — *what the family was always for.*

Close the drawer and notice what is in it. Not curiosities. Not a collector's shelf of exotic heat. The tomato. The potato. The eggplant and the tomatillo and the little husk-lantern of the ground cherry — the plants that have fed people for as long as there have been kitchens, the quiet staples of the everyday plate. The most ordinary family in the garden, the one the world was once afraid of and then learned to live on anyway, and the one we chose to open first.



First light in the research greenhouse, the family's plants in silhouette. The frontier, for us, did not point away from the familiar toward something stranger and hotter. It pointed back into the familiar — toward a tomato grown, finally, to all of itself.

That is the thing we most want left on the table when the files are closed. The frontier did not point *away.* It pointed back — toward a tomato grown, finally, to all of itself; a potato carrying a little flavor and a little less bitterness at its own source; an eggplant with something of its own to give back; a staple made worth eating for its own sake and not only for what you do to it. And here is the quiet truth that runs under every file and under this whole Library: a plant grown toward its fullest flavor is, almost never by accident, a plant grown toward its fullest nourishment. The ripeness that carries umami in a tomato carries the rest of what the fruit is for; the restoration that brings back savor brings back the whole fruit the truck took. Taste and nourishment, here as everywhere, were never two projects. They are one act, done with intention, and the intention is simply to feed the body well.

We are careful with that word, *nourish,* because it is easy to cheapen and we refuse to. It is not a claim here, and never a cure — it is an intention, the same one that has run under every file: that a plant grown toward the fullest version of itself tends to carry the fullest version of what it was for, and that designing a food's flavor and designing its worth to the body are not two acts but one act seen from two sides. A tomato restored to its late-ripening chemistry is a tomato restored, period — in savor and in the substance that savor

was always a signal of. A potato seasoned and softened in its bitterness at the source is a staple made a little more worth the eating, which, multiplied across how much of it the world eats, is not a small kindness.

These are computational designs; Scoville Splice's cultivars and constructs have not been experimentally validated in a laboratory.

We began by asking who else in the family could carry the pepper's fire. The real answer, the one the files kept quietly returning, is larger and gentler than the question. All of them can — the whole Solanaceae, from the tuber in the dark to the flower in the evening air, every one a few genes from a flavor it has never made, every one running the same ancient road. But the point of teaching them was never only the heat. It was to take the plants we have eaten and loved and, for a while, feared the longest, and help each one become, at last, the fullest version of the thing it already was. The family we were afraid of turns out to be the family that was always most ready to be more itself.

There is one last symmetry we cannot help noticing, standing at the closed drawer. We opened this book with the oldest fear in the garden — the nightshade, the poison family, the glossy black berry at the edge of the wood — and we have spent it learning that the same restless chemistry that made the family frightening is the chemistry that lets us make its gentler members more themselves. The fear was never wrong about the family's power. It was only wrong about what that power was for. A family that could brew a molecule to stop a heart could also, one genus over, brew a molecule to delight a tongue, and with care and a decade of work could be asked to grow a warmth, a savor, a sweetness, a quieted bitterness into the plants we actually live on. The Solanaceae were always a family of chemists. We have simply, at last, asked them to cook.

That is the whole frontier. It runs in the family, and it leads home.