

THE SCOVILLE SPLICE LIBRARY · VOLUME XVII

Tea

One leaf. Green to black. *The grip, the broth, the bite — by number.*

The receptor-level account of the one plant behind green, white, oolong, and black — the catechins that grip the mouth, the theanine that feeds it, the caffeine that warns it — and the kitchen that proves all three dials in the cup.

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

Contents

01 Opening essay · One leaf, a thousand cups

02 Chapter 1 · The One Plant — everything, from Camellia sinensis.

03 Chapter 2 · The Three Voices — umami, the warning, and the grip.

04 Chapter 3 · The Number Under the Leaf — EC50, IFI, and how to read a tea.

05 Chapter 4 · The Cross-Linked Mouth — astringency, the touch we taste.

06 Chapter 5 · The Catechins, Named — six molecules and a galloyl group.

07 Chapter 6 · Building the Flavan-3-ol — the flavonoid branch, LAR and ANR.

08 Chapter 7 · The Galloyl Group — the ester that sets the bite.

09 Chapter 8 · Tuning the Grip — mean degree of polymerization, up and down.

10 Chapter 9 · The Brothy Green — theanine, glutamate, and mGluR1.

11 Chapter 10 · Theanine, at the Root — the amino acid the plant sends up.

12 Chapter 11 · Shade — the oldest way to move the ledger.

13 Chapter 12 · The Bitter Sentinel — caffeine, catechin, and TAS2R.

14 Chapter 13 · Caffeine, at the Enzyme — the methylxanthine route.

15 Chapter 14 · Attenuation, Not Amputation — 20–65%, and the forgiving cup.

16 Chapter 15 · Oxidation — one enzyme, a thousand teas.

17 Chapter 16 · The Styles, Read — white, green, oolong, black, dark.

18 Chapter 17 · Designing the Leaf — 280 constructs, four knobs.

19 Chapter 18 · Extraction, by Temperature — the EC50 story, in a pot.

20 Chapter 19 · Tea at the Table — the grip as an ingredient.

21 Chapter 20 · The Reference Readouts — every cup, scored; precision and the line.

22 Closing essay · The quiet cup

Opening essay · One leaf, a thousand cups

There is a pot on our table most evenings, and the leaves inside it — grassy and green some nights, dark and malty on others, pale gold when we want almost nothing at all — came every time from the same plant. Not the same *kind* of plant. The same species: *Camellia sinensis*, a glossy evergreen that, left alone on a hillside, would slowly become a small tree. Green tea and black tea are not two crops. They are one leaf met by two decisions. That has always been the quiet astonishment of tea to us — that the entire range of it lives folded inside a single plant, and is coaxed out, or held back, by what a person does in the hours after the leaf is picked.

We are a family of scientists, and tea is the plant we have spent the longest time with as drinkers before we ever brought it to the bench. We grew up at a table where the pot was the last thing cleared, where an argument could be settled or started over whether the second steep was better than the first, where someone always had an opinion about the water. One pair of hands in this family does the computing; the whole family does the growing and the steeping and the disagreeing. Tea came to our work the way most of our obsessions have — not as a problem to solve but as a pleasure we could not fully explain. Why did the shaded green taste of broth and the black of malt, when they were the same leaf? Why did the third cup grip harder than the first? We could feel the answers exactly. We could not, for the longest time, say *how much*.



The founders in the research greenhouse at first light — where most of our obsessions arrive before the kettle.

Inside that leaf, three families of molecules do almost all of the talking. The **catechins** — a set of flavan-3-ols, led by epigallocatechin gallate, EGCG — carry the bitterness and the astringent grip. **L-theanine**, an amino acid the plant builds in its roots and sends up to the bud, carries the brothy, savory depth that fine green tea is loved for. And **caffeine** carries a bitterness of its own and, as the cup cools, reaches out and binds the catechins into the faint haze tasters call *tea cream*. Every tea you have ever drunk is some arrangement of those three voices, plus the water and the time you gave them. The grower's whole craft, for ten thousand years, has been to move those three voices by hand and by season —

shade the field, pick younger, fire the leaf sooner, roll it harder — reading the result in the cup and never once able to say by *how much* the dial had turned.

This is the seventeenth book in a library built on a single idea: that a flavor can be measured — not described, *measured* — against the half-activation of the receptor it speaks to. The Iyengar Flavor Index assigns every taste a number anchored to EC_{50}, the concentration at which a stimulus drives its receptor to half of full response. Invert that against a fixed reference, scale by a thousand, and loudness becomes a score. Eight axes. Tea speaks loudly on three of them: **umami** through the receptor mGluR1, the attenuation of **bitterness** through TAS2R38, and **astringency** — tea's signature — through the proline-rich proteins of your own saliva. Three numbers, each anchored to a receptor rather than to a memory, so that a gyokuro grown under reed screens and a brisk lowland Assam can be read on the same page, in the same units, by anyone.

Tea is one of the forty-two host organisms our platform has validated, and there are **two hundred and eighty constructs** in its library today — two hundred and eighty engineered versions of this one leaf, each a different setting of the three voices, every one held to a batch-to-batch coefficient of variation at or under seven percent. We did not learn to measure tea to make it less wondrous. We learned because you cannot design what you cannot read, and we wanted to grow this leaf the way you would tend anything you love — toward the fullest it can be, carrying the most of what it should and the least of what it shouldn't. There is a quiet thing that hums under this whole book, the same thing that hums under the whole library: that food is something you give your body with intention, and that a leaf grown and steeped with care is a small daily act of that intention. We will never make a claim of it. We will only, at the end, say it plainly once and let it go.

Every one of those two hundred and eighty constructs began as a cup someone at our table could feel exactly and could not yet name. Let us begin where tea begins — with the one plant, and the two decisions.



PART I OF VI

The One Leaf

Camellia sinensis · the three voices · EC_{50} · how to read a tea

Chapter 1 · The One Plant — *everything, from Camellia sinensis.*

Two varieties of a single species do nearly all of the world's tea. *Camellia sinensis* var. *sinensis* is the small-leaf plant of the Chinese and Japanese hills — cold-hardy, slow-growing, high in the amino acid theanine, the native tongue of delicate greens and the elegant oolongs. *Camellia sinensis* var. *assamica* is the broad-leaf plant of the monsoon lowlands — vigorous, heat-loving, rich in catechin, the engine of brisk black tea. Same genus, same eight-axis machinery underneath, two very different starting balances of the three voices. Everything a tea house pours sits somewhere on the line between them: the high, cool, umami-forward restraint of a shaded *sinensis* green at one end, the deep, gripping, malt-heavy power of an *assamica* black at the other, and a whole addressable spectrum in between. The plant is a camellia, close kin to the ornamental ones that flower in winter gardens; it wants an acid soil, a humid air, a slope that drains, and a cool night to concentrate what the warm day builds. Left unpruned it becomes a tree; kept as a waist-high bush, plucked at "two leaves and a bud," it will give a tender flush every few weeks through the growing season for a hundred years.



Camellia sinensis — one evergreen leaf, and the whole range of tea folded inside it.

What makes the plant so unusually *workable* — from our bench's point of view — is that its flavor is almost entirely **secondary metabolism**. The catechins, the theanine, the caffeine, the volatile aromatics are not structural; they are not load-bearing for the plant's survival the way its cellulose and its sugars and its proteins are. They are the leaf's chemistry of defense and signal and nitrogen storage — molecules the plant makes to ward off insects, to store nitrogen through a lean season, to manage the light it drinks — and that is exactly the chemistry an index can read and a flux model can move without starving the plant of what it needs to live. When we talk about *designing a tea*, we are not rebuilding the leaf. We are

adjusting the ratio of a handful of molecules the leaf already knows, with great sophistication, how to make. This is the same reason pepper was a tractable first host and the same reason the phenylpropanoid branch — which, as we will see, feeds the catechins — has carried so much of this library: flavor so often lives in the non-essential, defensive, signaling periphery of a plant's metabolism, and the periphery is where an edit can reach without consequence to the whole.

A fact we will return to in every section of this book, because it governs the entire design space: **the catechins and the theanine are not independent.** The plant builds both from the same budget of carbon and nitrogen, and the budget is split by light. In bright sun — photosynthesis running hard, carbon abundant — the leaf routes more of that budget down the phenylpropanoid road toward the catechins, and the astringency climbs. Shade the plant, and the carbon supply narrows while the nitrogen stays; the amino acids, theanine chief among them, accumulate instead, and the umami climbs while the grip falls. Umami and astringency, on this one plant, are quite literally two ends of a single ledger. This is the first thing a grower ever learned to tune — the shaded green of gyokuro is nothing but this ledger pushed toward nitrogen — and it is the first thing we taught the Index to score. Hold the image of a ledger. It is the truest picture of the tea plant we know, and most of the chapters that follow are a way of learning to move its two columns on purpose.

Chapter 2 · The Three Voices — *umami, the warning, and the grip.*

Most plants in this library are loud on one axis and quiet on the rest. Pepper is heat with grace notes. Stevia is sweetness with a bitter tail we spent nine hundred constructs erasing. Tea is one of the small handful of organisms whose *interest* lives in a chord rather than a note — in the way three axes sound together — and the artistry of tea, from the grower's screen to the master blender's nose, is entirely the balance among them. A tea is not an astringency level, or a caffeine level. It is the relationship between three of our eight axes, and the ear for tea is the ear for that relationship.

Here are the three, each with the receptor it speaks to and the mechanism beneath it.

AXIS	NAME	RECEPTOR	WHAT TEA DOES HERE
IFI-U	Umami	mGluR1 / TAS1R1·TAS1R3	theanine and free glutamate deliver a brothy, savory depth — the "fed" taste of a fine green
IFI-B	Zero-Bitter	TAS2R family (anchored to TAS2R38)	caffeine and the galloylated catechins shout; the axis scores how much we *attenuate* that shout
IFI-A	Astringency	Salivary proline-rich proteins (PRPs)	catechins and their polymers cross-link and precipitate saliva's lubricants — the mouth grips and dries

Read the middle row twice, because it carries a subtlety that governs every scorecard in this book. **IFI-B is not a bitterness score. It is an attenuation score.** A high IFI-B does not mean a tea is bitter; it means the leaf is carrying our de-bittering machinery and the bitterness has been turned *down*, by the locked range of twenty to sixty-five percent. A raw, oversteeped, maximally bitter brew carrying no attenuation construct scores a *low* IFI-B. A designed green that keeps its grassy brightness but stops biting back when a distracted cup oversteeps by a minute scores a *high* one. The axis measures our mercy, not the leaf's severity — which is the single most common misreading of a tea scorecard, and worth flagging now so it never trips you later.



The leaf in isolation — the three voices are all here, in a few percent of the dry weight, waiting for water and time.

Umami is the savory pull of theanine and free glutamate finding mGluR1 and the TAS1R1·TAS1R3 heterodimer — the receptors that tell the body *here is nourishment, here is protein and broth*. It is what gives a shaded green its soft, almost oceanic depth, closer to a good dashi than to anything you expect from a leaf steeped in water. It is tea's quietest signature and its most underestimated one, and it is the axis most completely destroyed by careless brewing and most completely built by patient growing.

Bitterness is the catechins and the caffeine pressing on the TAS2R family — receptors evolution built as warnings, chemical smoke-detectors tuned to the alkaloids and phenolics that so often mean *poison* in a wild leaf. A little bitterness is backbone; it is half of why tea tastes of something rather than nothing. Too much is punishment, and it is the fault most people blame on themselves — *I must have steeped it too long* — when it is in fact a dial that can be set at the source.

Astringency is the grip — the drying, gathering, puckering sensation as tannins bind the proline-rich proteins that keep your mouth lubricated and pull them out of solution. It is tea's loud axis, the one the plant speaks most natively and the one this book is accented for: plum, the tannin colour. Controlled, it is the structure a great tea stands on and the reason a cup has a finish at all. Uncontrolled, it is the pucker that sends a pot down the sink. Until us, it was the one voice no grower could set on purpose. It is also, as the next chapter insists, the strangest of the three — because it is not, strictly, a taste at all.

Three voices, then: the broth, the warning, and the grip. The rest of the book is the biology of each, and the arithmetic that lets us read them. Let us earn the arithmetic first.

Chapter 3 · The Number Under the Leaf — *EC50, IFI, and how to read a tea.*

Everything in this library hangs from one formula, and it is worth writing out slowly, because once you have it a tea stops being a matter of opinion and becomes a matter of coordinates.

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

EC_{50} is the half-maximal effective concentration — the amount of a stimulus required to drive its receptor to half of its full response. It is the honest measure of *potency*, because it asks not "how much of this molecule is present" but "how little of it does the receptor need to hear it." A molecule with a low EC_{50} is loud: the receptor responds to a whisper. A molecule with a high EC_{50} is quiet: it takes a shout. The Index inverts the candidate's EC_{50} against a fixed reference's, so that *loudness* becomes the thing scored, and multiplies by a thousand to put ordinary flavors in a human-readable range. Per axis, we normalize to a maximum of **5,000**. A score of 1,000 means the candidate is exactly as loud as the reference. A score of 2,000 means it is twice as potent — the receptor reaches half-response at half the concentration.

Run it on astringency, tea's defining axis, so the arithmetic is concrete — and so you can see *why* the galloylated catechins grip hardest. The astringent EC_{50} is a precipitation threshold rather than a channel activation: the concentration of a reference tannin at which it half-saturates the precipitation of salivary proline-rich proteins, measured as the turbidity of the reaction. Suppose our reference tannin reaches that half-precipitation point at an EC_{50} of 1.0 millimolar. Now measure **epigallocatechin gallate** — EGCG, the galloylated catechin that dominates green tea — and find it half-precipitates the same proteins at 0.5 millimolar: it needs *half* the concentration, so it is *twice* as loud.

> IFI-A(EGCG) = 1,000 × (1.0 mM ÷ 0.5 mM) = **2,000.**

Now measure plain **epicatechin** — EC, the same molecule stripped of its galloyl group — and find it half-precipitates only at 2.0 millimolar: it needs twice the reference concentration, so it is half as loud.

> IFI-A(EC) = 1,000 × (1.0 mM ÷ 2.0 mM) = **500.**

There, in two lines of arithmetic, is the whole secret of tea's grip. The galloyl group — a single gallate ester hung on the flavanol — makes EGCG roughly four times as astringent as plain epicatechin, because it adds two extra binding faces that stack against the proline rings and clamp the saliva proteins harder. The *galloylated*

fraction of a tea's catechins is therefore the master dial of how hard it bites, and Chapter 7 is entirely about the one enzyme that sets it. Every scorecard you will read in this book is this arithmetic, run on a real leaf, for three receptors at once.

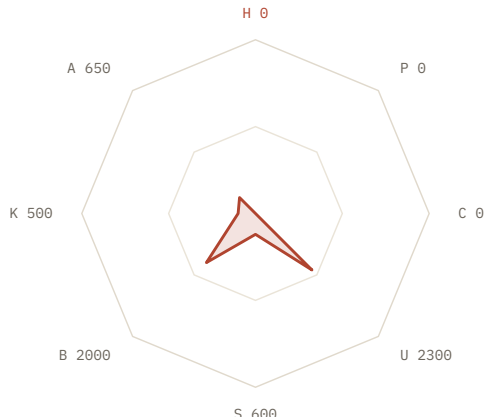


The leaf, halved — the flavanol cargo that grips the mouth is built and stored in tissue like this, a few percent of the dry weight and most of the character of the cup.

The bitter axis takes the same formula to the TAS2R family, with one honesty we owe you up front and will defend at length in Chapter 12: caffeine and the bitter catechins are read by a *chord* of bitter receptors — caffeine is a known agonist of TAS2R7, TAS2R10, TAS2R14, TAS2R43 and TAS2R46 — but for a clean, reproducible, genetically famous yardstick across all sixty-four books in this library, the Index *anchors* the Zero-Bitter axis to a single reference receptor, **TAS2R38**. TAS2R38 is the ruler, not the whole territory; when we report an IFI-B we report attenuation referenced to that standard and validated against the broader panel. And because IFI-B scores attenuation, not raw bitterness, its arithmetic is slightly different — we define the attenuation fraction directly, as the fraction of the integrated bitter response removed by an active construct, and map the locked 20–65% envelope onto the index. The umami axis takes the formula to mGluR1 and the TAS1R1·TAS1R3 heterodimer, where glutamate is the loud, low-EC_{50} partner and theanine is the abundant one that broadens and sustains the savory floor.

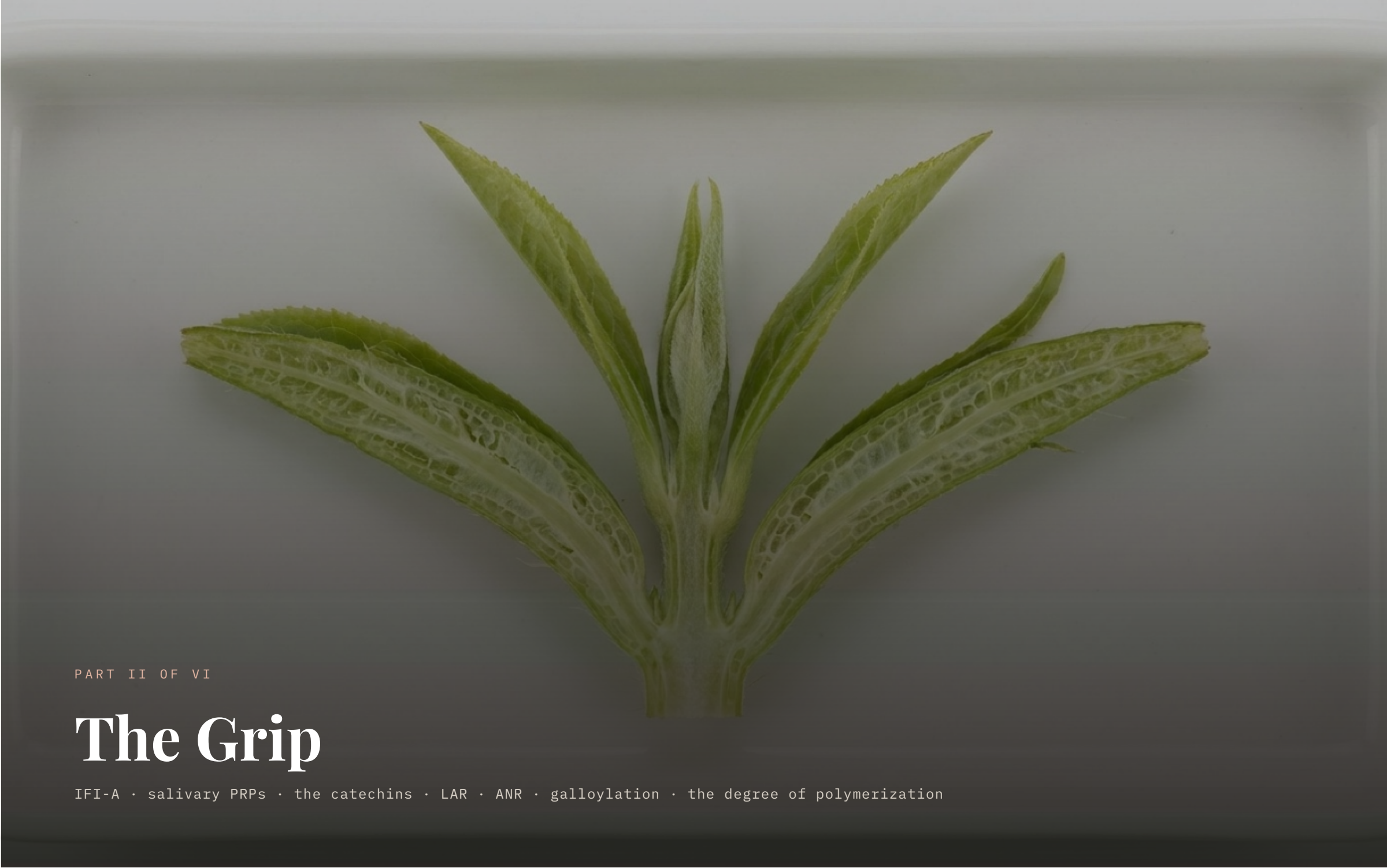
So a tea, fully read, is three numbers on a fixed scale, each one honest to the concentration at which a specific receptor hears a specific molecule — with the other five axes sitting quietly near zero, because a great tea, unlike our full-spectrum pepper, is an exercise in *restraint*. Here is the shape of the scorecard we will hang on every leaf and every cup in this book, shown across all eight axes as the Index requires. This one is a designed shade-grown green at its most umami-forward — the broth pulled high, the grip laid low, the bite softened, everything else held silent:

IFI PROFILE



IFI-H		0
IFI-P		0
IFI-C		0
IFI-U		2,300
IFI-S		600
IFI-B		2,000
IFI-K		500
IFI-A		650

Umami immense; astringency barely gripping; bitterness attenuated to a forgiving cup; a murmur of returning sweetness and a whisper of body underneath; heat, pungency, and cool-burn held completely silent. That is a fine gyokuro expressed as digits that mean something, and the rest of this book is the biology of how each digit is set. We begin with the loud one — the grip.



PART II OF VI

The Grip

IFI-A · salivary PRPs · the catechins · LAR · ANR · galloylation · the degree of polymerization

Chapter 4 · The Cross-Linked Mouth — *astringency, the touch we taste.*

Astringency is the one sensation in this entire index that is not, strictly, a *taste*. The other seven axes are chemoreception — a molecule keys a receptor and the nerve reports a quality. Astringency is **mechanoreception dressed as flavor**: there is no "astringency receptor" waiting on the tongue. Instead the tannins physically assault the lubrication of your mouth, and your brain reads the resulting friction as a flavor-like sensation. It is the strangest axis to measure and the most honest to feel, because your own saliva is the instrument, and it never lies to you about a tea.

Here is the mechanism, which is worth knowing exactly because every astringency edit in this book is aimed at one step of it. Your saliva is not merely water; it is a lubricant, and the molecules doing the lubricating are a family of **proline-rich proteins** — PRPs — along with the phosphoprotein statherin and the histatins: flexible, floppy, heavily glycosylated chains whose job is to coat the surfaces of your mouth and let your tongue glide frictionlessly over your palate and teeth. Tannins — the catechins and, more powerfully, their condensed polymers the proanthocyanidins — have a specific and ancient affinity for proline. Their phenolic hydroxyls hydrogen-bond to the carbonyls of the proline-rich backbone, and their flat aromatic faces stack against the pyrrolidine rings of the proline residues, and because each tannin polymer carries *many* such binding faces, a single tannin molecule can bridge *several* PRP molecules at once. The result is cross-linking: the lubricating proteins clump, aggregate, and precipitate out of solution. The film fails. For a few seconds, until fresh saliva rebuilds the layer, the raw surfaces of your mouth drag against one another, and that friction is reported as *dry, rough, puckering, gathering* — astringent.



Grape, halved — the organism where we first learned to sculpt tannin, 1,610 constructs deep. The ANR enzyme we tuned here for wine is the very one tea needs for its catechins.

Three consequences fall straight out of that mechanism, and each one is a design handle we will use.

Astringency is cumulative. Because it works by precipitating a *finite* pool of lubricating protein, each sip depletes the film a little more before saliva can fully restore it. A taste fades between sips; astringency *builds*. This is why the third cup of a strong tea grips harder than the first, why a tannic tea and a young tannic wine feel like cousins across completely different flavors, and why pacing and a plain-water palate-cleanser matter so much at a serious tasting. On the Index we score astringency against a standardized single-exposure precipitation assay, so the number is clean and reproducible — while knowing that the mouth will integrate it over a pot.

Astringency scales with polymer size, not just amount. A lone catechin monomer has only one or two binding faces and barely cross-links; it is mildly bitter and almost not astringent. A dimer grips noticeably. By the time you reach the longer proanthocyanidins — five, eight, ten flavanol units chained together — a single molecule can bridge a whole raft of PRPs, and the astringency is intense. So the astringent intensity of a tea tracks its **mean degree of polymerization**, its mDP, the average chain length of its condensed tannins, far more than its total phenolic content. *This is the master dial of amount*, and Chapter 8 is how we set it.

Astringency has sub-qualities — it is a console, not a slider. Galloylation, the gallate ester of Chapter 3's arithmetic, sharply increases PRP affinity and produces a harder, coarser, more aggressive grip; a heavily galloylated green bites in a way a lightly galloylated one never will. The balance between the 2,3-*trans* catechins and the 2,3-*cis* epicatechins subtly shapes the *quality* of the grip. And oxidation — the green-to-black transformation of Part V — converts the sharp, pointed catechin grip into the broad, soft, rounder grip of the theaflavins and thearubigins, a completely different astringent character from the same starting cargo. A tea's astringency is a specific setting across all of these: total tannin, mean chain length, galloylated fraction, stereochemistry, and oxidation state. A great tea is a coherent choice across the whole console; a bad one is a dial left wherever the weather happened to leave it.

This is why astringency, uniquely among our axes, is one we often tune *up*. Most of the library is about turning shouting axes down — heat, bitterness, the off-notes. Here, for the tea that wants structure, we frequently build a quiet grip *taller* and *better-made*: toward long, resolving, architectural polymers rather than crude green ones, toward the tannic backbone that makes a mouth water for the next sip. Tea taught us, more than any plant but grape, that astringency is not a fault to be minimized but a structure to be composed. Now the molecules themselves.

Chapter 5 · The Catechins, Named — *six molecules and a galloyl group.*

Tea is a textbook of flavan-3-ols, and if you learn six molecules and one chemical decoration you can read the grip of any cup. The catechins are built on a simple skeleton — two aromatic rings joined by a three-carbon bridge that carries a hydroxyl, the "3-ol" of flavan-3-ol — and they differ in two ways that set everything: how many hydroxyls decorate the B-ring, and whether a galloyl group is esterified onto the 3-position.

The six that matter, in rough order of how much they shape a green tea:

- **EGCG — epigallocatechin gallate.** The dominant catechin of green tea, often a majority of the total, and the single most important molecule in this book's loud axis. Trihydroxylated B-ring (the "gallo-"), *plus* a galloyl ester (the "gallate"). It is both the most abundant and, molecule for molecule, among the most astringent and most bitter of the set — the EGCG of Chapter 3's arithmetic, IFI-A around 2,000, the grip you feel when a green is oversteeped.
- **EGC — epigallocatechin.** The same trihydroxyl B-ring, but *no* galloyl group. Far gentler — a fraction of EGCG's grip — and abundant. The difference between EGC and EGCG is nothing but that one ester, and it is most of the difference between a soft green and a sharp one.
- **ECG — epicatechin gallate.** Dihydroxyl B-ring, *with* a galloyl group. Galloylated, so it grips hard; less abundant than EGCG but a real contributor to the bite.
- **EC — epicatechin.** Dihydroxyl B-ring, no galloyl. The gentle baseline monomer, IFI-A around 500 — present across the whole plant kingdom, the mildest of tea's catechins.
- **GC and C — gallocatechin and catechin.** The 2,3-*trans* stereoisomers of EGC and EC, made by a different enzyme branch (Chapter 6). Present in smaller amounts in most teas, more prominent in some, and important because their stereochemistry shapes the *quality* of the grip.



The leaf's phenolic cargo is built young and stored dense — the bud and first leaf carry the most catechin, which is why the finest plucks are also, untuned, the most gripping.

Read that list against one pattern and it collapses into something simple: **the galloylated catechins (EGCG, ECG) grip hardest; the ungalloylated ones (EGC, EC, GC, C) grip gently.** The galloyl group is the difference. It is why a tea's *galloylated fraction* — what share of its catechins carry that ester — is a cleaner predictor of perceived harshness than its total catechin content, and why the one enzyme that performs the galloylation (Chapter 7) is the highest-leverage single target in the entire tea astringency program. Lower the galloylated fraction and you soften the bite without stripping the tea of its phenolic cargo — the grip eases while the structure and the character stay. That is the move that buys what every blender has chased by feel for a thousand years: backbone without bitterness.

Above the monomers sit the polymers — the **proanthocyanidins**, also called condensed tannins, built by the oxidative and enzymatic condensation of catechin units into chains. A dimer, a trimer, on up through the long ten-unit polymers: these are the molecules that bridge many PRPs at once and carry the intense end of the grip. Their average chain length is the mean degree of polymerization, the mDP of Chapter 4, and it is the amount dial to the galloylated fraction's quality dial. And there is one more phenolic family, born only when the leaf is oxidized: the **theaflavins** and **thearubigins** of black tea, made when the catechins are enzymatically coupled during oxidation. We meet them properly in Part V; for now, hold that black tea's grip is a *transformed* grip — the same catechin cargo rebuilt into larger, softer-gripping, differently-coloured molecules — not simply *more* or *less* grip than a green. The catechins are the clay. Oxidation is one of the hands that shapes it. The enzymes that build the clay in the first place are the other, and they are where design begins.

Chapter 6 · Building the Flavan-3-ol — *the flavonoid branch, LAR and ANR.*

To set a tea's grip at the source we have to reach into the enzymes that build the catechins, and the good news — the thing that makes tea a tractable host at all — is that those enzymes sit on the single most travelled road in this entire library. The flavan-3-ols come off the **flavonoid branch**, which comes off the **phenylpropanoid branch**, which is the universal aromatic-metabolism highway running in every vascular plant on earth. The shared trunk is the same one the capsaicin platform was built on and the same one every book in this library returns to: **PAL → C4H → 4CL** turns the amino acid phenylalanine into p-coumaroyl-CoA, and from there the branches diverge toward lignin, toward the flavonoids, toward the catechins of tea and the procyanidins of cacao and the tannins of grape. Five of our seven platform modules transfer unchanged to any genome we can sequence precisely because this trunk is universal; tea changes the terminal enzymes, not the road.

Here is the route, trunk to tannin, with the enzymes named and the intermediates in place. This is the pathway every astringency edit in this book acts upon.

STEP	SUBSTRATE → PRODUCT	ENZYME
trunk	L-phenylalanine → p-coumaroyl-CoA	PAL → C4H → 4CL
1	p-coumaroyl-CoA (+ 3 malonyl-CoA) → naringenin chalcone	CHS (chalcone synthase)
2	naringenin chalcone → naringenin	CHI (chalcone isomerase)
3	naringenin → dihydroflavonols	F3H, with F3′H / F3′5′H setting B-ring hydroxylation
4	dihydroflavonol → leucoanthocyanidin	DFR (dihydroflavonol-4-reductase)
5a	leucoanthocyanidin → **(+)-catechin / (+)-gallocatechin** (2,3-*trans*)	**LAR** (leucoanthocyanidin reductase)
5b	leucoanthocyanidin → anthocyanidin	ANS / LDOX
6	anthocyanidin → **(−)-epicatechin / (−)-epigallocatechin** (2,3-*cis*)	**ANR** (anthocyanidin reductase; the *BANYULS* enzyme)
7	catechin / epicatechin → **proanthocyanidins**	oxidative / enzymatic condensation and chain extension

Two enzymes carry the design, and they sit at step 5. **LAR** — leucoanthocyanidin reductase — makes the 2,3-*trans* catechins, catechin and gallocatechin. **ANR** — anthocyanidin reductase, encoded by the gene genetics first found in an *Arabidopsis* mutant and named *BANYULS* after the sweet tannic wine whose colour the mutant seed resembled — makes the 2,3-*cis* epicatechins, epicatechin and epigallocatechin, which are the dominant flavanols

of tea and the principal building blocks of its proanthocyanidins. The *ratio* of LAR flux to ANR flux sets the catechin-to-epicatechin balance, and therefore part of the *quality* of the grip — the *trans*-versus-*cis* character of Chapter 4's console. The *total* flux into step 7, together with whatever governs chain extension, sets the mean degree of polymerization — the *intensity* of the grip. Upstream, the choice at step 3 between F3′H and F3′5′H sets how many hydroxyls decorate the B-ring, which is the difference between the dihydroxylated catechins (EC, ECG) and the trihydroxylated ones (EGC, EGCG) — the "gallo-" that makes a catechin grippier before any galloyl ester is even added.

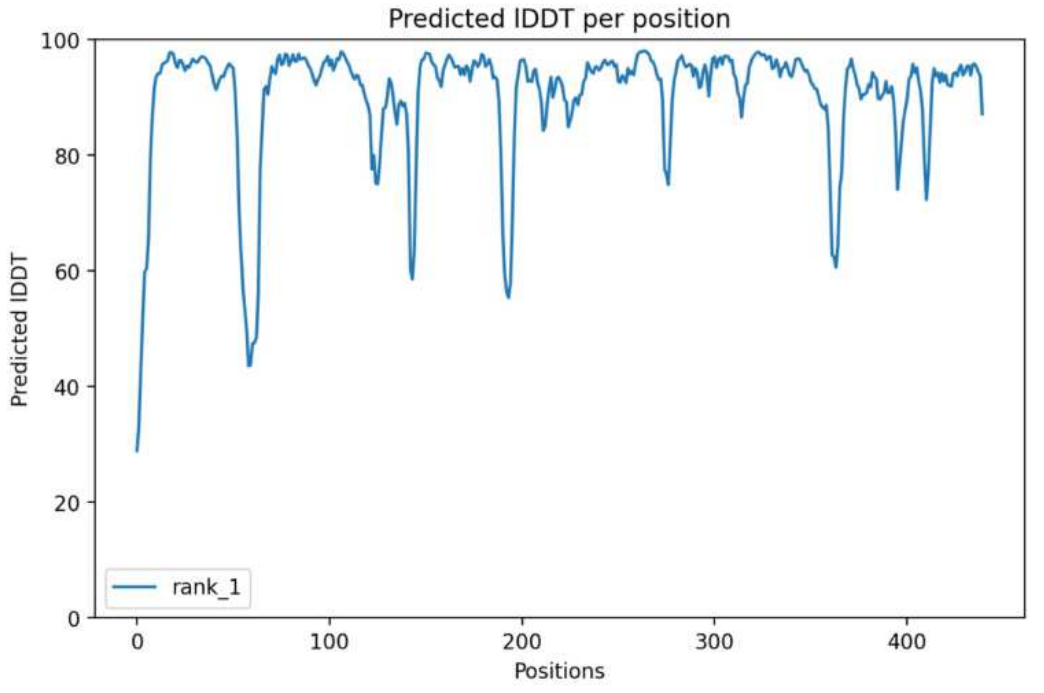


FIG. 6 — a platform fold model coloured by per-residue confidence (pLDDT); the rigid core and active-site cleft resolve at high confidence. This is the map an edit is designed onto — the method that first proved itself on the pepper acyltransferase, now read onto the tea reductases LAR and ANR.

So the astringent console, read as enzymes: F3′H / F3′5′H set the galloyl-ready hydroxylation; LAR and ANR set the *cis/trans* quality and, through their total throughput, feed the polymer pool; step 7's condensation sets the mean degree of polymerization. Every one of these is a flux we can model and a residue set we can edit. And every one of them we have edited before, in a sibling — because this exact node, the ANR/LAR branch of the flavonoid pathway, is where the astringent half of the **grape** library lives, sixteen hundred and ten constructs deep, tuned for wine. Grape and tea are the two great

tannin plants of this library, and they share an enzyme. What we learned to do to a grape's seed-coat procyanidins for a winemaker, we do to a leaf's catechins for a tea house. The clay is the same; only the hand and the vessel differ. But there is one enzyme tea has that grape leans on far less, and it is the single most important switch in tea's whole grip — the one that hangs the galloyl group.

Chapter 7 · The Galloyl Group — *the ester that sets the bite.*

If you could edit only one enzyme in the whole tea plant and had to buy the most control of the grip for your single edit, you would not touch LAR or ANR or the condensation. You would touch the enzyme that hangs the galloyl group onto the catechins — because, as the arithmetic of Chapter 3 showed, galloylation roughly quadruples a catechin's astringency, and the *galloylated fraction* is the cleanest single predictor of how harsh a tea feels. This chapter is that enzyme, and it is, we think, the most elegant target in the book.

The galloyl group is a gallate ester — gallic acid, a simple trihydroxybenzoic acid, esterified onto the 3-hydroxyl of a catechin. Gallic acid itself the plant draws from the shikimate pathway, branching off at 3-dehydroshikimate; a shikimate dehydrogenase with a side activity oxidizes it to gallate. But the catechin is not galloylated directly from free gallic acid. The plant runs a beautiful two-step, and the second step is the switch we want.

STEP	SUBSTRATE → PRODUCT	ENZYME
1	gallic acid + UDP-glucose → **β-glucogallin** (1-O-galloyl-β-D-glucose)	UGGT (UDP-glucose : galloyl-1-O-glucosyltransferase)
2	epicatechin / epigallocatechin + β-glucogallin → **ECG / EGCG** + glucose	**ECGT** (epicatechin : 1-O-galloyl-β-D-glucose O-galloyltransferase; an SCPL-IA acyltransferase)

Step 1 activates the gallate by hanging it on a glucose, making **β-glucogallin**, the plant's universal galloyl donor — the same activated donor that builds the hydrolyzable gallotannins of pomegranate and oak. Step 2 is the transfer: an enzyme called **ECGT**, a member of the **serine carboxypeptidase-like (SCPL) acyltransferase** family — the SCPL-IA clade — takes the galloyl group off β-glucogallin and esterifies it onto epigallocatechin to make EGCG, or onto epicatechin to make ECG, releasing the spent glucose. That single acyl transfer is what converts a gentle catechin into a hard-gripping one. **ECGT is the galloylation switch, and its flux is the galloylated fraction, and the galloylated fraction is the bite.**



Pomegranate — a different tannin chemistry (the hydrolyzable gallotannins), built from the same activated donor, β-glucogallin. 120 constructs; the galloyl chemistry we tuned here reads straight onto tea's catechins.

Notice why this is such a clean lever, and so much better than simply making *fewer* catechins. If you throttled the whole catechin pathway to soften a tea, you would lower the grip — but you would also strip the leaf of its entire phenolic cargo, flatten its character, and bank the spare carbon and nitrogen as who-knows-what. If instead you throttle *ECGT alone*, you leave the catechin pool almost untouched in *quantity* and shift it in *quality*: the leaf still makes its EGC and its EC, its full phenolic mass, but a smaller fraction of it carries the galloyl ester, so the same cargo grips far more gently. The tea keeps its body, its structure, its phenolic richness, its colour — and sheds the harsh edge. This is the difference between making a tea *weaker* and making it *softer*, and it is the whole reason an enzyme edit beats a blender's dilution. The SCPL family is also, happily, a well-characterized and editable class — these are serine-hydrolase-fold enzymes repurposed as acyltransferases, exactly the kind of compact, single-active-site target our structure-guided method reads well.

And we have run this galloyl chemistry before. **Pomegranate** — one hundred and twenty constructs — is built on hydrolyzable gallotannins that start from the very same β-glucogallin donor; tuning that galloyl flux is most of pomegranate's astringency work. The activated-gallate chemistry of step 1 is a shared primitive across the tannin plants, and ECGT's SCPL acyltransferase fold is kin to acyltransferases we have modeled across the platform. When we set out to soften a tea without hollowing it, ECGT is the first enzyme we reach for, and the galloylated fraction is the first number we move. Now let us see the whole grip set as a ladder — amount and quality together.

Chapter 8 · Tuning the Grip — *mean degree of polymerization, up and down.*

We have the sensation (Chapter 4), the molecules (Chapter 5), the pathway (Chapter 6), and the galloyl switch (Chapter 7). Now the composition: how we set a tea's grip to a chosen coordinate, and what the coordinates feel like in the mouth. The astringent axis has two master dials — the **galloylated fraction** (quality: how hard the grip bites) and the **mean degree of polymerization** (amount: how much there is to grip) — and a tea design is a choice of both, in service of a style.

There are two directions a design can go, and this is the axis where, unlike almost anywhere else in the library, we go *up* as often as down.

To soften a harsh tea — to take a green, aggressive, mouth-stripping grip and make it gentle without going flabby — we lower the galloylated fraction (throttle ECGT) and shift the polymer distribution shorter (modulate the condensation at step 7). The leaf keeps its phenolic mass and most of its character; the grip eases because the hardest-gripping molecules — the galloylated catechins and the long polymers — are the ones we have specifically reduced. The tea becomes forgiving without becoming bland. This is the move that widens a green's brewing window so a distracted cup cannot wreck it.

To give a flabby tea structure — to take a dull, sweet-leaning, characterless leaf and build it a backbone — we do the opposite: push flux toward longer, well-formed proanthocyanidins that grip with *architecture* rather than crudeness, a resolving astringency that makes the mouth water and gives a long finish. Astringency built *up*, toward structure, is what separates a serious tea from a soft one, and it is the move a connoisseur's style wants.

The whole axis calibrates against an mDP-and-galloylation ladder, because the sensation and the chemistry march together:

GRIP CHARACTER	GALLOYLATED FRACTION	MEAN DEGREE OF POLYMERIZATION	IFI-A
soft, barely gripping; a shaded green or a gentle white	low	~1–2 (monomer/dimer)	~600
gentle structure; mouth-watering, resolves fast	low–moderate	~2–3	~1,200
firm, architectural grip; a serious oolong or designed black	moderate	~4–5	~1,700
aggressive, slow-resolving; a brisk unmanaged black or oversteeped green	high	~6–10	~3,000+



Blueberry — a small, moderate astringency host, 120 constructs, built on the same salivary-PRP physics. A different fruit, the same grip chemistry; another rehearsal for the leaf.

Now the thing this book keeps insisting on: on the tea plant, the grip does not move alone, because of the carbon–nitrogen ledger of Chapter 1. Lower the catechin flux and you free carbon and nitrogen that the leaf will bank somewhere — and, left to its own logic, it often banks it as amino acids, theanine among them. So a thoughtful astringency edit that trims the galloylated, high-mDP end of the catechin pool tends to *raise the umami* as a side effect, pushing the leaf toward the shaded-green end of the ledger. This is the opposite of a problem; it is a gift the plant's own metabolism hands us, and it is exactly why the single most requested tea design — "a black with the body but half the grip and twice the broth" — is physically coherent rather than a contradiction. But it has to be *held*, not hoped for, which is why none of these edits is made by eye. The whole grip is set against a genome-scale flux-balance model that holds the catechin pool, the theanine pool, and the carbon budget at once, so that softening the grip raises the umami by the amount we chose rather than by whatever the weather would have handed us.

Here is one plant, read from the gentlest cup to the most gripping, with umami shown alongside precisely because on this leaf the two move against each other on a single ledger:

TEA	IFI-A · GRIP	IFI-U · BROTH
Gyokuro (shade-grown green)	650	2,300
Silver Needle (white)	850	750
Sencha (steamed green)	1,300	1,150
Oolong (mid-oxidation)	1,450	900
Keemun (Chinese black)	1,900	450
Assam, unmanaged (reference brisk)	3,200	400
Designed black (grip set, broth held)	**1,700**	**800**

Read the first and last rows together and you have the whole argument of the astringent half of this book. The designed black keeps the malt and the body of a full-oxidation tea but carries roughly half the grip of the unmanaged Assam — and twice the umami — because the catechin balance and the galloylated fraction were set in the field by the leaf's own enzymes, and the freed ledger was steered toward theanine, instead of all of it being left to the sun and the hour. The grip, finally, set on purpose. Now the other end of the ledger: the broth.



PART III OF VI

The Broth

IFI-U · mGluR1 · theanine · glutamate · the carbon–nitrogen ledger · shade

Chapter 9 · The Brothy Green — *theanine, glutamate, and mGluR1.*

Pour hot water on a fine gyokuro and the first thing that arrives is not green and not bitter but *savory* — a soft, round, brothy depth closer to dashi than to anything you expect from a leaf. People who meet it for the first time often cannot place it; it reads as *stock*, as *umami*, as the taste of being quietly fed, and it is the reason a cup of good shaded green can feel like nourishment in a way that a cup of coffee, for all its depth, never quite does. That savory depth is the umami axis, IFI-U, and it is tea's second great voice — quieter than the grip, easy to brew away, and, once you can read it, the surest mark of a tea grown with care.



Shiitake, halved — a umami neighbor, 80 constructs. The savory depth we build into a tea speaks to the same receptor a mushroom stock does, by a different molecule.

The mechanism is a two-molecule partnership. The loud partner is **glutamate** — free glutamic acid, the same amino acid that makes a good stock, a ripe tomato, and a well-aged cheese taste savory. Glutamate is a potent agonist of the umami receptors: the **TAS1R1·TAS1R3** heterodimer on the tongue and the metabotropic glutamate receptor **mGluR1**, a taste-variant of the same receptor family the brain uses for glutamate signaling. Its EC_{50} at those receptors is low — it is a loud molecule — so even the modest free-glutamate content of a fine green tea registers clearly. The abundant partner is **L-theanine**, which is, remarkably, an *ethylamide of glutamate* — glutamate with an ethyl group amidated onto its side-chain carboxyl — and it can make up a startling share of a shaded green's total free amino acids, sometimes approaching half. Theanine's own agonism at the umami receptors is gentler than glutamate's, but it is present in such quantity, and its structural kinship to glutamate is so close, that it broadens and sustains the savory floor — it is the body and the length of the brothy taste where glutamate is its sharp centre. Together they give the shaded green its characteristic savory roundness, and because both are amino acids rich in nitrogen, the whole umami voice of tea is, at bottom, a readout of how the plant has managed its nitrogen.

There is a classical umami multiplier we should name, because its *absence* shapes tea. In foods like dashi or a long meat stock, free glutamate is partnered with **5′-ribonucleotides** — IMP from the

bonito, GMP from the mushroom — and the nucleotides multiply the glutamate's effect severalfold at the TAS1R1·TAS1R3 receptor, an allosteric synergy that is why dashi tastes so much deeper than its glutamate alone would predict. Tea carries little of that nucleotide cargo, so its umami is *un-multiplied* — it is a pure amino-acid umami, glutamate and theanine without the ribonucleotide amplifier. That is part of why tea's savory depth is soft and clean rather than meaty and intense, and it is a lever we have deliberately left alone: a tea that tasted of multiplied dashi would be a novelty, not a tea. We build tea's umami the way the plant does — with the amino acids — and we let it stay the gentle, nourishing, un-amplified broth it has always been.

Chapter 10 · Theanine, at the Root — *the amino acid the plant sends up.*

To raise a tea's umami we have to understand where its theanine comes from, and the answer is one of the loveliest pieces of logistics in the plant kingdom: the leaf does not, mostly, make its own theanine. The **roots** do, and they ship it up.

Here is the biosynthesis, which is short and specific. Theanine is built from two precursors: **glutamate** and **ethylamine**. The ethylamine comes from the amino acid **alanine**, decarboxylated by **alanine decarboxylase (AlaDC)** — an enzyme that, interestingly, tea evolved specifically for this purpose, a close relative of serine decarboxylase recruited to make the ethylamine theanine needs. Then **theanine synthetase (TS)** — a glutamine-synthetase-like enzyme, CsTSI in the tea literature — condenses glutamate with ethylamine to form L-theanine, consuming ATP. Most of this happens in the roots, where the ethylamine is abundant; the finished theanine is then loaded into the xylem and transported up to the growing shoots and the youngest leaves, which is why the tender bud and first leaf — the finest pluck — are also the richest in theanine, and why the amino-acid depth of a tea is partly a function of how much of the plant's root-made theanine has reached the leaf you picked.



Soybean — a frontier umami-and-kokumi host, 360 constructs, another amino-acid-driven savory plant. The nitrogen chemistry that makes a soybean deep is kin to the one that makes a shaded green brothy.

Now the ledger again, in its full chemistry, because theanine is one end of it. In the growing leaf, theanine is not only a store of flavor — it is a store of *nitrogen*, and under light the plant draws on it. Bright sun drives photosynthesis, fills the leaf with carbon skeletons, and powers the phenylpropanoid and flavonoid pathways that build the catechins; under that same light, theanine is catabolized — its nitrogen released and reallocated, some of its carbon feeding toward the very catechin pathway that grips the mouth. So light

simultaneously *builds catechin* and *spends theanine*: the ledger tips toward the grip. Remove the light, and both halves of that reverse — catechin synthesis slows for want of carbon and the enzymes' light signals, and theanine, no longer catabolized, accumulates. Umami up, astringency down, from a single environmental lever. This is the metabolic truth beneath the grower's shade cloth, and it is the reason the two axes are not independent knobs but two readings of one balance.

Our umami edits work both ends. We can raise theanine *supply* by lifting flux through the AlaDC → theanine-synthetase route and easing theanine's light-driven catabolism, so the leaf accumulates more of it before the sun can route the budget elsewhere; and we can raise the *free glutamate* pool that is the loud umami partner. Done together, under the flux model that holds the carbon–nitrogen budget whole, the result reads on the Index as an IFI-U that a steamed sencha never reaches — and tastes, in the cup, like being quietly and deliberately fed. But the oldest version of this edit needs no gene at all. It needs a cloth, and three weeks of dark.

Chapter 11 · Shade — *the oldest way to move the ledger.*

Three or four weeks before harvest, a gyokuro field goes dark. The growers lay reed screens or black cloth over the rows and cut the incoming light by seventy, eighty, ninety percent, and the plant, starved of sun, does something precise and predictable: it slows its catechin synthesis and stops spending its theanine. Umami climbs. Astringency falls. The leaf, straining toward what little light remains, deepens to a near-black green thick with chlorophyll — which is why gyokuro and matcha leaf are so much darker than an open-grown sencha, and why they taste so much sweeter and brothier and less of grip. This is terroir as a dial. It is the oldest proof of the thing our whole platform rests on: that flavor is a flux you can move, and that moving it is agriculture, not alchemy.



The shaded leaf runs dark with chlorophyll and heavy with theanine — the carbon–nitrogen ledger pushed by hand toward nitrogen, three weeks under cloth.

We read shade now as exactly what it always was: a lever on the carbon–nitrogen ledger of Chapter 1, pushed by removing the carbon-driver. Everything the cloth does — catechin down, theanine up, the ledger toward nitrogen — is precisely what our theanine and galloyl edits do from the inside, which means the designed leaf can hold that ledger where shade would put it *without surrendering the yield that shade costs*. Shade is expensive: the plant grows slower under cloth, the harvest is smaller, the labor is real, and ninety percent less light is ninety percent less of the energy the plant lives on. A designed line can build like a shaded plant in open sunlight —

accumulating theanine and softening its galloylated grip while still drinking the full light it needs to yield — which is, in a sentence, the agricultural promise of the whole tea program: the gyokuro ledger at the sencha field's yield.

And yet we grow the shaded fields too, screens and all, and we mean to go on growing them. Partly because some of what the plant does under cloth we are still learning to say in numbers — the full aromatic consequence of three weeks of dark is more than theanine and catechin, and reverence, for us, includes knowing exactly what we have not finished measuring. And partly because the shaded field is where this whole way of thinking was born: a grower, centuries ago, noticing that a leaf grown dark tasted sweeter and gentler, and choosing to do it again. We are not the first engineers of this leaf. We are the ones who can finally read the gauge the shade cloth was always turning. Here is the cup that gauge was invented for.

Gyokuro, Cool and Slow

Serves 2 · three infusions · the cup we make when we want to taste the broth alone

The whole method is temperature. Keep the water low and the catechins stay locked in the leaf — their extraction is slow without heat — while the theanine and glutamate, soluble and willing, come out almost on their own. The first cup tastes of broth and sweet grass with barely a trace of grip. It is the EC_{50} story made drinkable: you are choosing a temperature at which umami wins the race to the water and astringency loses it.

You need

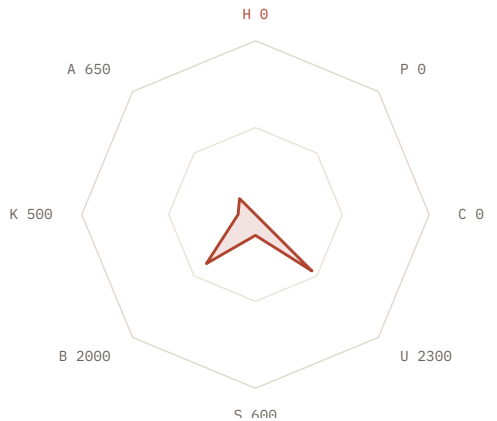
```
6   g      gyokuro (a shade-grown green, or a designed umami-forward
green)
120 ml     soft water, cooled to about 55 °C
           a small wide pot and three small cups
```

Make it

1. Cool just-boiled water by pouring it once between two cups — each pour drops it roughly ten degrees. You want it barely warm to a fingertip, near 55 °C. Hot water here would flood the catechins out and bury the broth under grip; the low temperature is not a nicety, it is the entire design.
2. Pour over the leaf and wait a full ninety seconds. Almost nothing will look as though it is happening. It is: the theanine and glutamate are diffusing out into the cool water while the galloylated catechins stay behind.
3. Pour out every last drop — the end of the pour is the sweetest and most concentrated. Then infuse twice more, a little hotter and a little shorter each time; the grip rises gently as it goes, so the three cups walk from pure broth toward structure. One leaf, three teas, set by heat.

IFI readout — first infusion

IFI PROFILE



IFI-H	0
IFI-P	0
IFI-C	0
IFI-U	2,300
IFI-S	600
IFI-B	2,000
IFI-K	500
IFI-A	650

At 55 °C the theanine and glutamate reach mGluR1's half-response long before the galloylated catechins extract, so the cup lands near IFI-U 2,300 and IFI-A 650 — the broth pulled forward, the grip left in the leaf, a faint *hui gan* sweetness returning after the swallow. The second and third infusions walk the astringency up on purpose. This is the single clearest demonstration in the book that extraction is an EC_{50} lever you hold in your own kettle.



PART IV OF VI

The Warning

IFI-B · TAS2R · caffeine · the methylxanthine route · attenuation, not amputation

Chapter 12 · The Bitter Sentinel — *caffeine, catechin, and TAS2R.*

Bitterness is the voice tea most often gets wrong, and the one most people blame on themselves — *I must have steeped it too long.* Usually they did; too hot or too long and the catechins and caffeine flood out together and press hard on the bitter receptors, and a cup that could have been lovely turns punishing. But the warning can be turned down at the source, and to turn it down cleanly we have to know precisely what we are turning down — which, as with every bitter plant in this library, turns out to be not one thing but a small committee of molecules keyed to a wide repertoire of receptors.



Coffee, halved — tea's bitter neighbor and the clearest twin of its caffeine problem. 40 constructs on the methylxanthine route; the grammar we proved here reads straight onto the leaf.

The committee's chair is **caffeine** — 1,3,7-trimethylxanthine, the same purine alkaloid that makes coffee bitter and cacao faintly so. Tea leaf carries a real load of it, often two to four percent of the dry weight in the tender shoots, more than many coffees by weight of leaf (though far less reaches a cup than reaches an espresso). Caffeine is a classic bitterant, and its bitterness is sharp and quick. Beneath it sit the **galloylated catechins** — EGCG and ECG again, the very molecules that carry the hard end of the astringent axis — which are *also* genuinely bitter, especially galloylated. This is the maddening coupling at the heart of tea, the exact one we met in cacao: **bitterness and astringency share a chemistry.** EGCG is both the grippiest and among the bitterest molecules in the leaf, so you cannot always lower one without touching the other. Caffeine, mercifully, is *not* astringent — it is pure bite — which is the first clue to where a clean de-bittering lever might be found: at the caffeine, not the catechin, wherever the design can spare the catechin's structure.

Now the receptors, because "the bitter receptor" is really a bitter *switchboard*. Humans carry roughly twenty-five functional TAS2R bitter receptors — a deliberately promiscuous family, evolved to flag a vast chemical space of potential poisons with a small number of broadly tuned sensors. Caffeine is a known agonist of several — **TAS2R7, TAS2R10, TAS2R14, TAS2R43, TAS2R46** — and the bitter catechins engage an overlapping set. Our Index, for standardization

across all sixty-four books, *anchors* the Zero-Bitter axis to a single reference receptor, **TAS2R38**, the well-characterized sensor of the thiourea bitters PROP and PTC, because it gives a clean, reproducible, genetically famous yardstick against which every attenuation can be scored. We want to be scrupulous with you here, as the voice of this library requires: **TAS2R38 is the ruler, not the whole territory.** Tea's bitterness is read by a chord of TAS2Rs, and when we report an IFI-B we report attenuation referenced to the TAS2R38 standard and validated against the broader panel. Honesty about the instrument is part of the measurement. The lever, though — the thing that sets how much caffeine the leaf makes in the first place — lives upstream, at the enzymes, in a cascade tea shares almost word for word with its bitter neighbors.

Chapter 13 · Caffeine, at the Enzyme — *the methylxanthine route.*

Caffeine, like all the methylxanthines, is built by a short, elegant cascade of **N-methylations** — each step hanging a methyl group from S-adenosyl-L-methionine (SAM) onto a xanthine ring, run by a family of enzymes called the **SABATH N-methyltransferases**. It is the same chemistry, and nearly the same enzymes, that builds theobromine in cacao and caffeine in coffee; the three great caffeine-and-theobromine plants of this library converge on one tiny biosynthetic machine. Here is tea's version of it:

STEP	SUBSTRATE → PRODUCT	ENZYME	METHYL DONOR
1	xanthosine → 7-methylxanthosine	7-methylxanthosine synthase (TCS/SABATH)	SAM
2	7-methylxanthosine → 7-methylxanthine	N-methylnucleosidase (ribose cleaved)	–
3	7-methylxanthine → theobromine (3,7-dimethylxanthine)	theobromine synthase (SABATH)	SAM
4	theobromine → **caffeine** (1,3,7-trimethylxanthine)	**caffeine synthase (TCS1; SABATH)**	SAM

Read step 4 against what we said about cacao, because the contrast is the whole point. In cacao, the final methylation runs *weakly* — the tree methylates to theobromine and mostly stops, which is why cacao is a theobromine plant. In **tea**, the caffeine synthase **TCS1** is highly active, and the enzyme is in fact bifunctional, catalyzing both the theobromine step and the caffeine step — so tea drives the cascade all the way to caffeine. Tea is a *caffeine* plant because of which SABATH enzyme it stops at, exactly as cacao is a theobromine plant for the opposite reason. Tea's bitterness identity is, in a real sense, an enzyme's activity level — and an enzyme's activity level is precisely what a structure-guided, flux-checked edit sets.



Coffee, isolated — the methylxanthine twin. The caffeine-synthase edit we aim at the leaf, we applied to the bean: lower the agonist at its committed enzyme, by the computed amount, never to zero.

So the clean de-bittering lever for tea's sharp, non-astringent bitterness is **TCS1** — the caffeine synthase. Ease its activity and the leaf makes proportionally less caffeine, and the sharp quick bite falls, *without touching the galloylated catechins we are tuning*

separately on the astringent axis. This is the part of the bitter problem we can solve without any coupling cost at all, because caffeine and catechin are made on entirely different pathways: the methylxanthine cascade here and the flavonoid branch of Part II. For the *other* part of the bitterness — the galloylated catechins, which are bitter *and* astringent — we lean on the ECGT galloyl switch of Chapter 7, which lowers the galloylated fraction and so eases the catechin bitterness and the catechin grip together, by a shared and modeled amount. Two levers, two chemistries, one flux model holding both so that solving the bitterness never accidentally unsolves the broth or the structure.

We should say plainly what we do *not* do: we do not abolish the caffeine. A tea stripped entirely of caffeine is a decaffeinated tea, a legitimate product made by a different process (and a real option for a line), but it is not what the Zero-Bitter axis is for. The axis is for *attenuation* — taking a measured fraction of the bite off and leaving the character standing — and tea, like every bitter plant in this library, has a reason that the fraction has a ceiling.

Chapter 14 · Attenuation, Not Amputation — *20–65%, and the forgiving cup.*

The locked envelope of the Zero-Bitter axis — attenuation between twenty and sixty-five percent — is not a limit of our technique. It is a limit of our *taste*, written into the platform on purpose, and this short chapter is the argument for why the ceiling is a feature, in a cup where it is especially easy to go too far.

A little bitterness in tea is **backbone**. It is half of why a tea tastes of something — why a cup reads as *tea* rather than as faintly flavored water — and it is the counterweight the umami and the sweetness need to be interesting rather than cloying. A green tea with its bitterness amputated entirely is not an improved green; it is a thin, sweetish, characterless brew that has forgotten what it is. The best tea masters have always known this: they speak of bitterness as something to *balance*, to *place*, never to erase. The famous *hui gan* of a fine Chinese tea — the "returning sweetness" that blooms in the mouth a beat after you swallow — depends on a bitterness having been there first for the sweetness to return *against*. Take the bitterness away and you take the return with it.



Broccoli — one of the Brassica bitters, 380 constructs. A different bitterant entirely (glucosinolates), the identical attenuation grammar: lower the agonist at its source, by the measured amount, never past the point of hollowing.

So we clamp the axis. We take a fifth to two-thirds of the bite off — never more — and the design conversation is always *how much of the available mercy does this particular tea want*. A delicate white wants almost none; its faint bitterness is part of its fragile balance. A robust designed black that must survive a four-minute steep and a splash of boiling water wants a good deal. And a daily green for someone who tends to forget the cup on the counter wants most of it — not to make the tea bland, but to **widen the window in which it**

tastes like itself. This is, to us, the kindest kind of engineering, because it subtracts only the punishment and leaves the character: a designed green holds its grassy brightness and its structure but stops biting back when a distracted brewer oversteeps by a minute. For anyone who has ever ruined a good cup by walking away from it, that widened window is its own small mercy — a tea that forgives you.

This is the same grammar we have worked across nine bitter hosts, each a different molecule yielding to the same disciplined move. **Coffee** (40 constructs) carries the methylxanthine twin and attenuates by the same caffeine-synthase logic. **Broccoli** (380) and the broccoli-kale cross (280) carry glucosinolates; **grape** (1,610) carries phenolic bitters shared with its tannins; **hops** (80) the iso-α-acids of beer; **potato, orange, cabbage, kale, radish, rapeseed** their own bitter cargoes. Not one of them is tea, and every one is a rehearsal for it: read the receptor, model the flux, find the committed enzyme, turn it by the measured amount, stop before you hollow the thing out. Now the decision that takes the leaf from this careful chemistry to the thousand teas of the world — the one enzyme that splits green from black.



PART V OF VI

Green to Black

polyphenol oxidase · theaflavins · thearubigins · the styles · 280 constructs · the method

Chapter 15 · Oxidation — *one enzyme, a thousand teas.*

Here is the decision that splits the one leaf into a thousand teas, and it turns on a single enzyme. Inside a fresh, intact tea leaf, the catechins sit in one compartment — the vacuole — and an enzyme called **polyphenol oxidase (PPO)**, a copper-containing catechol oxidase, sits in another, kept rigorously apart. As long as the leaf is whole and alive, they never meet. Bruise the leaf — roll it, crush it, let it wither and break down at the cell walls — and the two compartments mix, and the PPO, together with a peroxidase (POD), meets the catechins in the presence of oxygen and goes to work.



The whole leaf holds its PPO and its catechins apart; bruise it and they meet, and the green begins, molecule by molecule, to turn.

What the PPO does is oxidize the catechins to **o-quinones** — reactive, electron-hungry molecules — which then couple to one another. Two trihydroxyl catechin quinones (from EGCG and EGC) couple and rearrange into a **theaflavin**: a bright orange-red pigment built on a benzotropolone core, and there are four main ones — theaflavin, theaflavin-3-gallate, theaflavin-3′-gallate, and theaflavin-3,3′-digallate, depending on which galloylated partners went in. Theaflavins carry the **briskness** and the bright coppery colour of a good black tea, and because the digallate still carries its galloyl groups, it still grips — but differently, a softer and broader grip than the sharp catechin it came from. Push the oxidation further and the theaflavins and remaining catechins polymerize into **thearubigins** — a large, brown, chemically heterogeneous family that nobody has fully characterized, which carry the **body**, the depth, the darkness, and much of the soft, round, mouth-filling grip of a fully oxidized tea. That whole cascade — catechin to theaflavin to thearubigin, green to orange-red to brown — is what the trade loosely calls *fermentation*, and it is not fermentation at all but **oxidation**. We keep the word precise, because the one tea that truly *is* fermented — pu-erh, worked by actual microbes — deserves not to be confused with the rest.

Where a grower *stops* that reaction is the style, and the stopping is done by heat — the **kill-green** step, *shaqing*. Steam the leaf (the Japanese way) or pan-fire it in a hot wok (the Chinese way) early,

within hours of plucking, and you denature the PPO — cook the enzyme dead — and lock the tea green: catechins intact, grip high and fresh and pointed, umami preserved, colour held. Let the oxidation run to completion before you fire the leaf and you get **black tea**: the catechins mostly spent into theaflavins and thearubigins, the raw pointed astringency transformed into malt and a rounder, heavier, broader grip, the colour gone to copper and mahogany. **Oolong** stops in the middle, anywhere its maker likes — a bruise of the leaf edges, a partial oxidation to ten or forty or sixty percent, then the kill-green — which is why oolong is the most varied style of all. Reading oxidation on the Index, you watch astringency *change character* rather than simply fall — from the sharp catechin grip of a green to the softer, broader tannin body of a black — while the umami quietly drains, because oxidation and the preceding wither spend the amino acids too. In the designed lines we tune the leaf's **PPO itself** — setting how much enzyme the leaf carries and therefore how far and how fast it is *able* to oxidize — so a tea reaches the oxidation a style wants reliably, with less of the final character left to the weather and the humid afternoon and the maker's nerve. The decision stays the maker's. We only make the leaf a more honest instrument to make it on.

Chapter 16 · The Styles, Read — *white, green, oolong, black, dark.*

With oxidation understood as a dial and the three axes understood as the readout, the whole family of tea styles resolves into coordinates on one map. Here is the family, read across its three loud axes — the grip, the broth, and the attenuated bite — as a single table, from the least handled leaf to the most transformed:

STYLE	PROCESSING	IFI-A · GRIP	IFI-U · BROTH	IFI-B · ATTENUATION	IN A PHRASE
White	withered, dried; no kill-green, no roll	850	750	~1,400	hay and melon; the leaf barely touched
Green (sencha)	kill-green early; catechins locked	1,300	1,150	~1,800	grassy, bright, pointed grip
Green (gyokuro / matcha)	shaded, then green-processed	650	2,300	~2,000	broth forward, grip laid down
Oolong	partial oxidation, often roasted	1,450	900	~1,900	floral to stone-fruit; the tunable middle
Black	full oxidation; theaflavins, thearubigins	1,700–3,200	400–800	~2,200	malt and body; the broad grip
Dark (pu-erh)	microbial post-fermentation	1,100	500	~2,400	earth, wood, the softened age

White tea is the least handled thing in the room — buds and young leaves withered in air and dried, no kill-green and no rolling, only the gentlest drift of edge-oxidation. What you taste is very nearly the leaf itself: hay, melon, a soft round grip, delicate to the point of shyness. It sits low on every axis at once, which is exactly its point, and it is the hardest style to improve without erasing. So we barely touch it — the only edit we trust on a white is the one that widens its forgiveness, a little bitterness attenuation so the long cool steep it wants cannot tip into grass. Some teas you design; this one you mostly protect.

Oolong is the whole spectrum of Chapter 15 compressed into one style, and so the most addressable tea there is. A green oolong kept near twenty percent oxidation reads floral and bright, the grip still crisp; a dark oolong taken past sixty and roasted over charcoal reads of stone fruit and caramel, the grip gone round and warm. Because oolong already lives in the middle of the ledger, it is where the designed PPO earns its keep most plainly — a leaf that reaches a chosen oxidation reliably lets a maker put the grip and body exactly where a house style wants them, batch after batch.

Pu-erh earns its own row because it is the one truly fermented tea — green or lightly processed leaf worked by real microbes (*Aspergillus* and a succession of others) over months or years, either slowly as it ages (*sheng*, raw) or quickly in a warm damp pile (*shou*, ripe). The

microbes transform the catechins and thearubigins further, into the earthy, woody, soft-gripping character of an aged dark tea. It is the tea most unlike the rest and the one where we tread most carefully, because its flavor is a living process, not a frozen one.

And **matcha** deserves a chapter's worth of attention in a paragraph, because it is the exception that proves the whole design argument. Every other tea is an *extraction* — you steep the leaf and drink what comes out, and the leaf itself goes to the compost, which means the brewing temperature is a lever you hold (Chapter 18). Matcha is the exception: shade-grown leaf, stone-ground to a powder finer than flour, whisked into water and drunk *whole*. You are not drinking what dissolved; you are drinking the leaf. Which means there is nothing to hold the catechins back, no cool-water trick, no leaving the grip behind in the pot — so a matcha's entire balance has to be built into the leaf *before* it is ever ground. This is the style where the designed leaf matters most, precisely because nothing is strained out: set the catechin balance a touch too high and a whisked bowl turns bitter and gripping with no way to fix it in the cup; set it right and matcha becomes what it is at its best — thick, sweet-edged, savory, a little oceanic, the whole plant in suspension.

Matcha, Whisked

Serves 1 · two minutes · the one tea you drink entire

You need

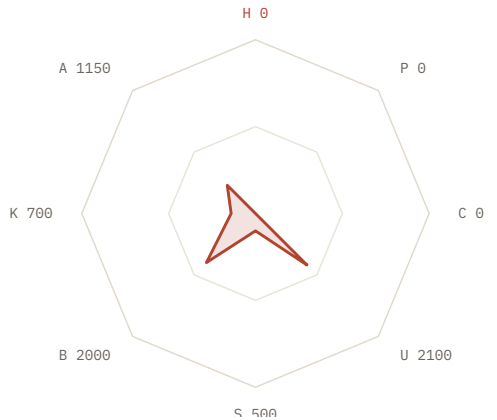
```
2   g     matcha (about one heaping bamboo scoop), sifted
70  ml    soft water, about 75 °C
          a wide bowl and a bamboo whisk
```

Make it

1. Sift the matcha into a warm, dry bowl — the lumps will not whisk out, so take them out first.
2. Add a little of the 75 °C water and whisk to a smooth paste, then the rest. Whisk briskly in a light W, wrist loose, until a fine even foam stands up across the surface. Not too hot: boiling water scalds the suspended leaf and pushes the grip and the bitterness forward.
3. Drink it soon and drink it all; the powder settles fast, and the last of the bowl is the sweetest.

IFI readout — the bowl

IFI PROFILE



IFI-H	0
IFI-P	0
IFI-C	0
IFI-U	2,100
IFI-S	500
IFI-B	2,000
IFI-K	700
IFI-A	1,150

The umami is high — the whole shaded leaf, nothing left behind — and the grip, at IFI-A 1,150, is higher than the gyokuro's, because you are drinking the catechins you would have left in a gyokuro's pot. That is why the balance *must* be set in the field: the bowl cannot fix it. There is real body here too, IFI-K 700 — the suspended leaf itself, a genuine weight — and a sweet edge that answers the grip. Matcha is the design argument on a whisk.

Chapter 17 · Designing the Leaf — *280 constructs, four knobs.*

Everything the field does by shade and bruise and fire, the pathway can do by flux, and this chapter is how. Tea's flavor molecules come off the branches we have now walked end to end — the phenylpropanoid trunk **PAL → C4H → 4CL → HCT → COMT** running in every vascular plant, then the flavonoid route to the catechins through LAR and ANR, the galloylation through ECGT, the theanine arriving from the roots, the caffeine from the SABATH cascade, the oxidation waiting in the PPO. Read as design, the whole leaf comes down to **four knobs**:

1. **The catechin flux and polymer length** (LAR/ANR and the step-7 condensation) — the *amount* of grip and bitterness, the mean degree of polymerization.
2. **The galloylated fraction** (ECGT) — the *quality* of the grip, how hard it bites.
3. **The theanine and glutamate pool** (AlaDC, theanine synthetase, and the glutamate supply) — the umami.
4. **The PPO** — how far and how fast the leaf will oxidize, green to black.

Set those four, against the ledger that binds them, and you have set the tea.

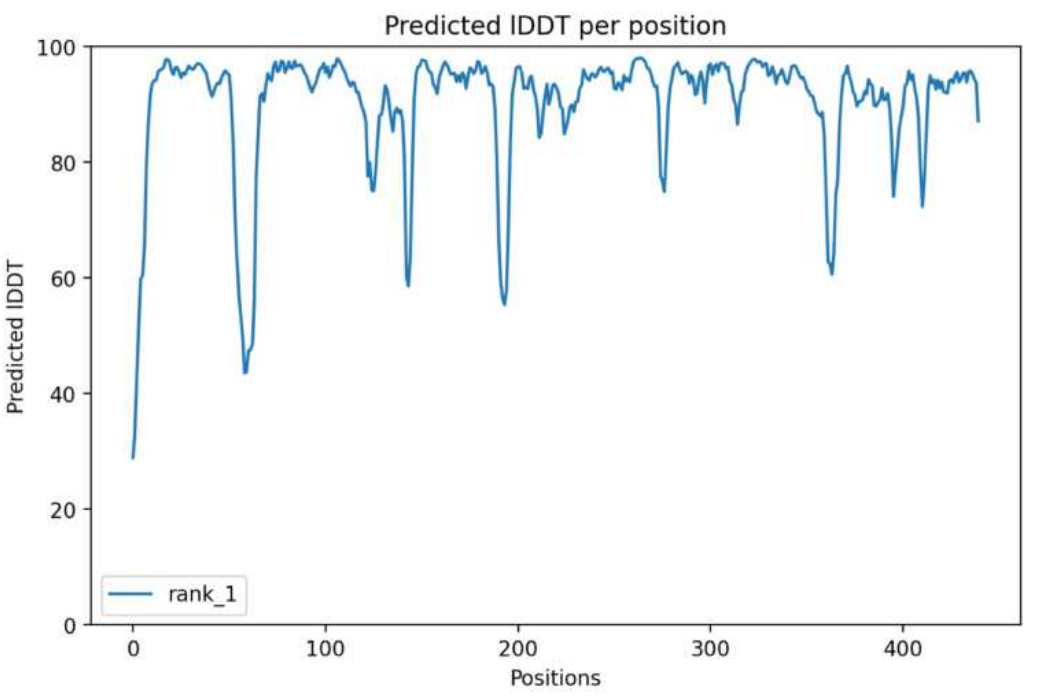


FIG. 17 — the method, made visible: a platform fold model coloured by per-residue confidence. We score every single-residue substitution of a target enzyme for catalytic effect and fold stability, confirm it is the true control point in a flux model, and write only the survivors. The method is the pepper's; the targets are the leaf's reductases, the galloyl transferase, the caffeine synthase.

We find the settings the way we find all of them, in a four-movement pipeline that is organism-agnostic by construction. **First, the structure:** for each target — LAR, ANR, ECGT, TCS1, PPO — we build a high-confidence structural model with a folding network and read it for the rigid scaffold, the flexible active-site loops, and where the substrate and cofactor sit. **Second, the language model:** we score

every possible single-residue substitution with an ESM2-class protein language model, a 650-million-parameter network trained on the grammar of millions of natural proteins, and combine its evolutionary-plausibility score with an explicit **ΔΔG** fold-stability calculation. The product — catalytic plausibility × stability — ranks the entire mutational landscape of the enzyme, turning a combinatorial impossibility into a shortlist a human can reason about. For a de-gripping or de-bittering edit we hunt substitutions that *throttle* an enzyme's throughput in a controlled, partial way — a tunable loss of function, not a knockout. **Third, the flux check:** a throttled enzyme is useless if it is not the step that controls the outcome, so we confirm in a genome-scale flux-balance model that the target is a true control point, that moving it shifts the axis by the amount we want, and — critically for tea — that it does not starve a pathway we care about or push the carbon–nitrogen ledger somewhere unintended. This is where the ledger is *enforced*: the model warns us if a galloyl edit would collaterally flatten the umami, so the two axes are solved as one coupled system. **Fourth, the write:** the surviving edits are written into the genome with CRISPR, precise substitutions at the residues the model named, and then the plant is grown and the design is profiled — the catechin and galloylation profile by chromatography, the theanine and glutamate by amino-acid analysis, the caffeine by mass spectrometry, the whole eight-axis reading by the Index.

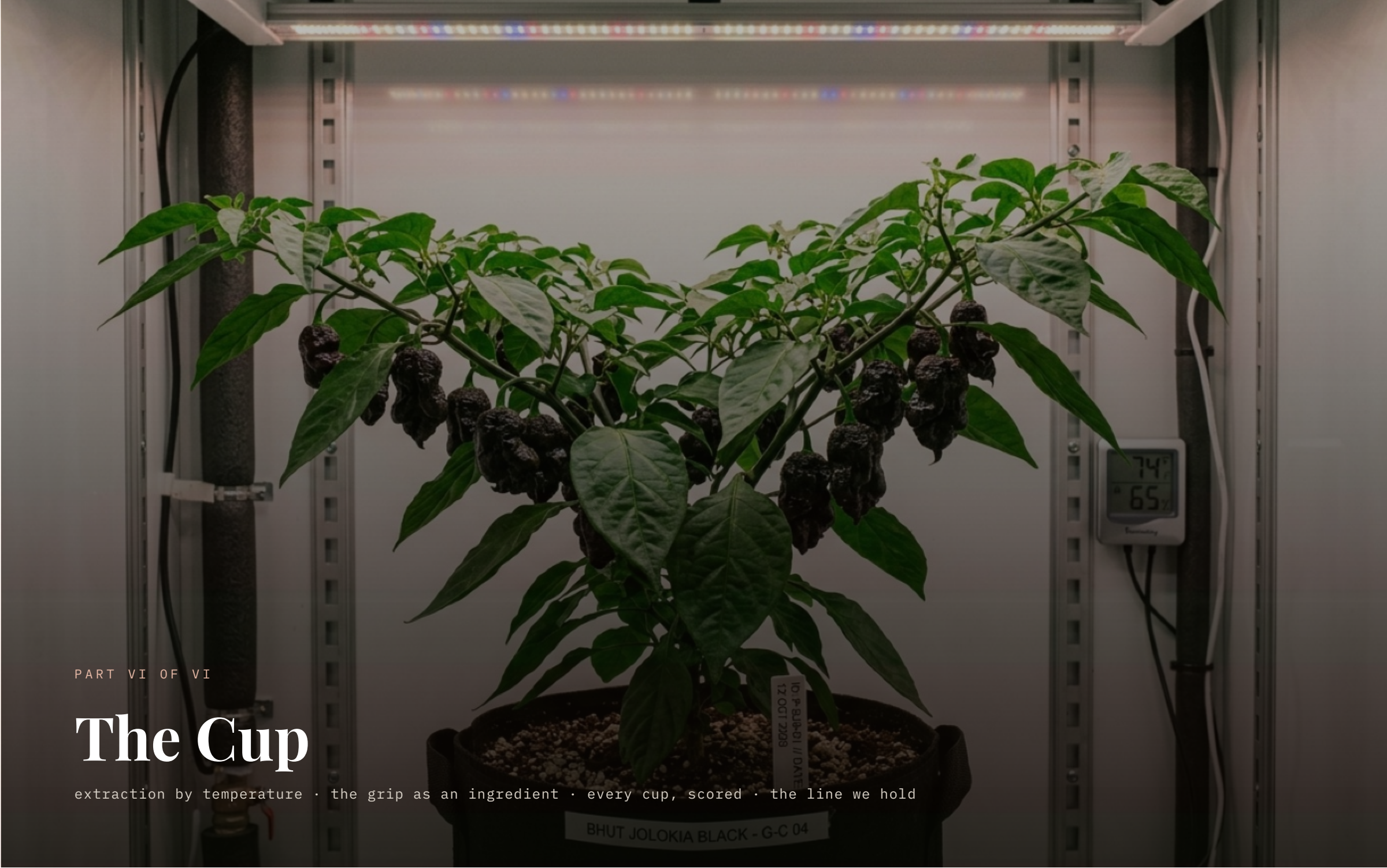
The output of this pipeline, for a tea astringency-and-bitterness edit, looks like a short table of candidate substitutions on the galloyl transferase and the reductases — the model's top-ranked edits for a controlled throttle. We present these as exactly what they are: **predicted design targets**, the calculation we write and then profile in the growing plant, and the ΔΔG values are the model's predicted fold-stability change (negative is stabilizing). The intent in each case is a partial, tunable modulation, not an abolition.

TARGET ENZYME	CANDIDATE EDIT	PREDICTED EFFECT	PREDICTED ΔΔG (KCAL/MOL)
ECGT (galloyl transferase)	active-site margin substitution	lowers galloylated fraction ~30%; grip softens, cargo kept	−1.3
ANR (epicatechin branch)	catalytic-loop substitution	shifts *cis/trans* balance; tunes grip quality	−0.9
TCS1 (caffeine synthase)	SAM-pocket margin substitution	throttles caffeine flux ~25%; sharp bite eased	−1.1
Theanine synthetase	expression-ward stabilizing substitution	lifts theanine pool; broth up	−1.6

Compare these, for *method* and not for target, with the two substitutions that founded this company: the Pun1 double variant **S39L (ΔΔG −2.1) and L345G (−1.8)** — a design our model predicts at approximately 2.95 million SHU — at a batch-to-batch coefficient of variation of **≤ 7%**, against 42% in conventionally bred material. Two substitutions no breeder ever found by phenotype — because you cannot select your way to a specific combination of two residues across a protein; you have to *read* them off the model and *write*

them in. The tea edits above are the same kind of object, a small legible set of residue changes ranked out of an impossible space, aimed at different enzymes toward gentler ends.

Two hundred and eighty constructs later, the discipline shows up exactly where a tea house feels it. These molecules trade against one another on the ledger — pull the catechin flux down naïvely and the plant banks the spare budget as something you did not ask for — and the flux model is the thing that finds the ratios that *hold*, so a softened grip arrives with a lifted broth rather than a hollowed leaf. And the number that matters as much as the mean is the CV: a tea house that approves a leaf at IFI-A 1,700 in spring must receive IFI-A 1,700 in autumn, this harvest and the next. On a plant this famously sensitive to its own weather — where two fields on one hillside give two different teas, where a single humid afternoon can move a batch — a batch-to-batch CV at or under seven percent is not a nicety. It is its own kind of craft, and on tea it may be the most valuable thing the platform makes: not a louder leaf, but a *reliable* one.



PART VI OF VI

The Cup

extraction by temperature · the grip as an ingredient · every cup, scored · the line we hold

Chapter 18 · Extraction, by Temperature — *the EC50 story, in a pot.*

The reward for all the biology is that a drinker, with no laboratory at all, holds one of the most powerful levers in this book: **temperature**. Brewing is extraction, and extraction is selective, and the selection is governed by the same EC_{50} logic that governs the whole Index — because the three voices do not leave the leaf at the same rate, and heat sets the race.

Theanine and glutamate are small, soluble, and willing; they diffuse out of the leaf readily even in cool water. The galloylated catechins and the caffeine are larger and more reluctant; they extract far faster as the water heats. So the *temperature of the water* is a dial that trades umami against grip and bite directly. Cool water pulls the broth forward and leaves the grip behind; hot water floods everything out at once, grip and bite and all. This is why a gyokuro is brewed near 55 °C and a black tea near boiling — not tradition for tradition's sake, but a precise exploitation of the different EC_{50}s and extraction rates of the three voices, run in the drinker's own kettle. Everything the designed leaf does at the enzyme, the brewer can *also* do, more coarsely, at the thermometer — and on a designed leaf the two compound, so a grip already set low barely registers under a cool steep, and you reach the most forgiving cup in the whole book from the least effort.

The clearest case of all is cold.

Overnight Cold Brew, Green

Serves 4 · eight hours, almost all of it unattended

Steep a green tea in cold water overnight and the catechins and caffeine, slow to leave the leaf without heat, mostly stay put — while the theanine, soluble and willing, comes out anyway. The cup that results is sweet, soft, barely gripping, and lower in caffeine than any hot brew of the same leaf: a tea that tastes as though it were designed for gentleness, made gentle by nothing but time and cold.

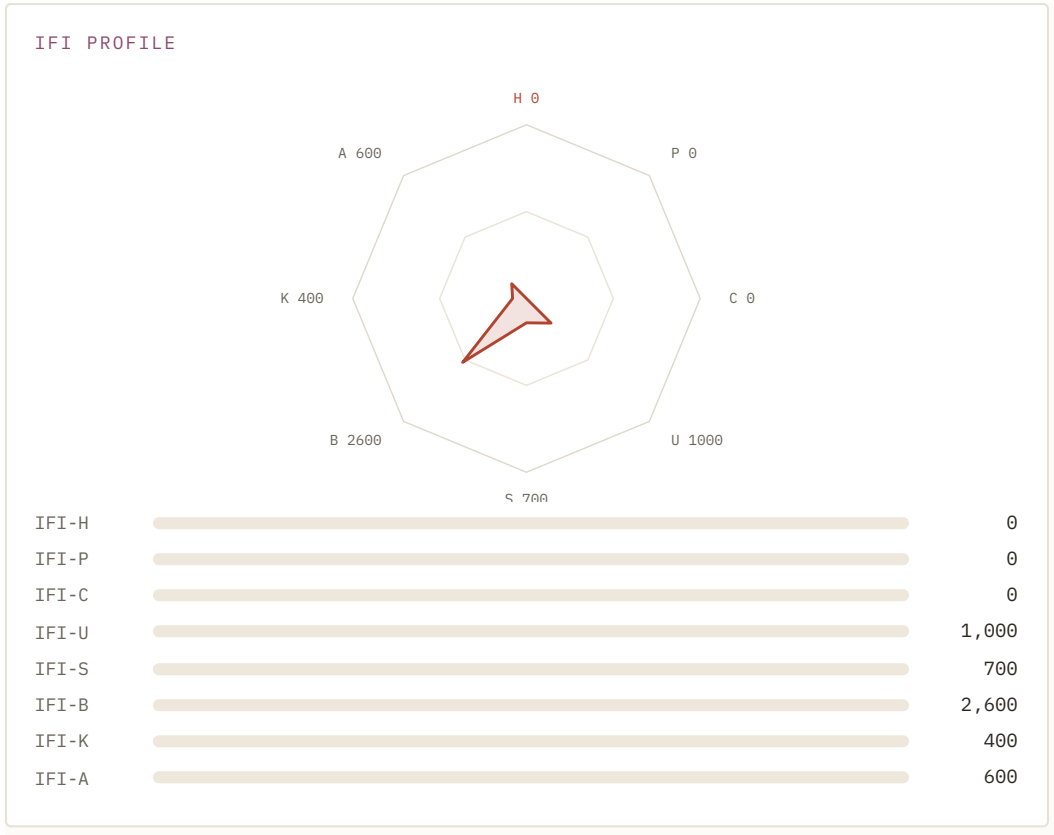
You need

```
10  g     green tea (sencha, or a designed green)
1   L     cold soft water
          a jar and a refrigerator
```

Make it

1. Put the leaf and the cold water in a jar. Do not heat anything. Stir once.
2. Cover and leave it in the refrigerator eight hours, or overnight.
3. Strain and drink cold. It keeps a day; after that the grip slowly wakes up as the last catechins find their way out.

IFI readout — the cold cup



Nothing about the leaf changed; you simply chose a temperature at which umami wins the race to the water and astringency and caffeine lose it. The grip sits at IFI-A 600, the broth at IFI-U 1,000, and the attenuation reads high because so little caffeine extracted at all. It is the EC_{50} story made drinkable, and on a designed green the effect only deepens.

A Proper Black, With or Without Milk

Serves 2 · four minutes · the everyday cup, read honestly

Black tea is the leaf run all the way to the end of its oxidation — the sharp catechin grip spent into the malt and body of theaflavins and thearubigins, the colour gone to copper, the astringency broad instead of pointed. It is the tea built to stand up to things: to boiling water, to morning, to milk. And milk is where black tea's chemistry rhymes with the whole Index, because the casein proteins in milk bind the tea's tannins exactly as your own salivary proteins do — so the milk intercepts the grip before your mouth ever feels it, and the cup goes soft and round. Astringency, met and quieted by a protein, on purpose.

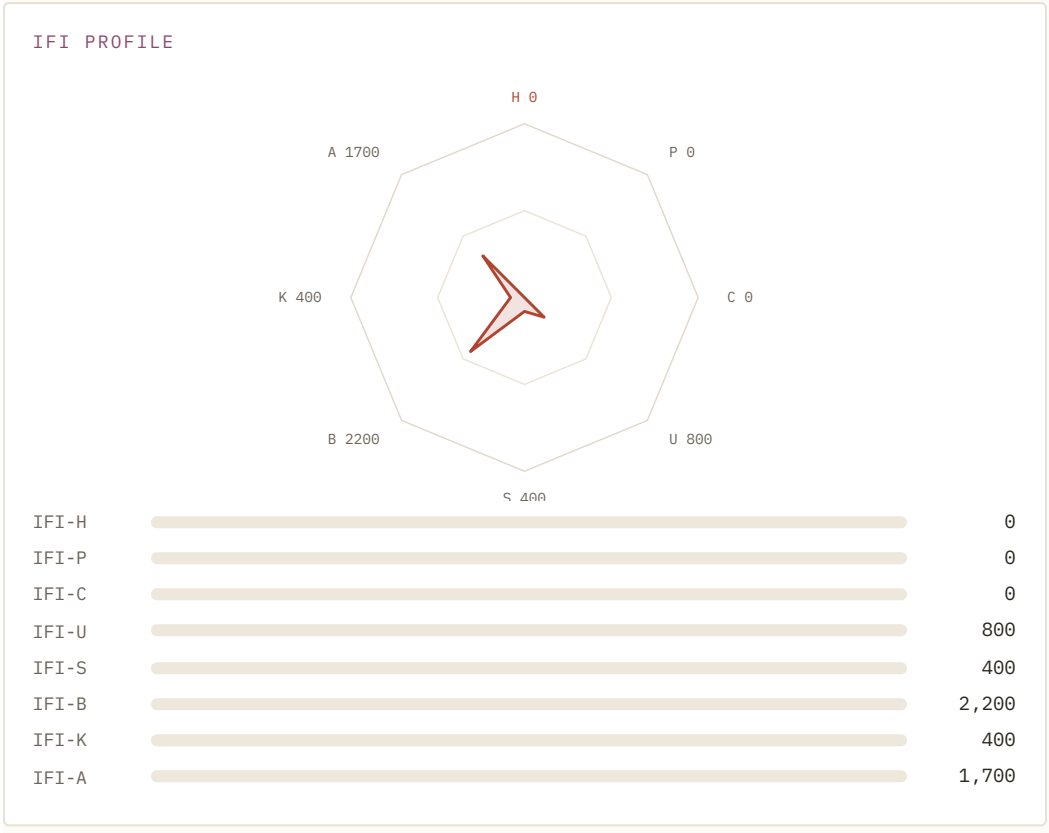
You need

```
5   g      designed black tea (or a good broken-leaf black)
300 ml     water, full boil
30  ml     whole milk, optional, cold
```

Make it

1. Warm the pot. Add the leaf, pour the water at a hard boil, and steep four minutes — black tea wants the heat a green would hate, because its grip is already broad and its amino acids already spent, so there is no delicate broth to scorch.
2. Strain completely. Taste it black first: the grip should read as *structure*, not as a pull you want to wash away.
3. If you take milk, add it to the cup, not the pot, and pour the tea onto it. The casein meets the tannin on contact and the cup turns round before your first sip.

IFI readout — the cup, black, then with milk



Black, the designed cup reads IFI-A 1,700 — structured, not punishing — and IFI-U 800, twice the broth of an unmanaged Assam because the ledger was steered in the field. Add the milk and only two numbers move: the grip falls toward 1,000 as the casein binds the tannins, and the body (IFI-K) rises toward 900 as the milk adds its own soft weight. The tea itself is unchanged in the cup; your mouth simply meets less of its grip. A designed black is a tea that no longer *needs* the rescue — it takes milk gracefully and is just as good without it.

Chapter 19 · Tea at the Table — *the grip as an ingredient.*

There is a reason tea follows a rich meal and sits beside a buttery pastry: **astringency cuts fat.** The same tannins that grip your salivary proteins also cut through the coating of cream and oil, clearing the mouth and resetting it for the next bite. It is the oldest pairing logic there is — it is why a dim-sum table runs on pots of tea, why a tannic black answers a scone and clotted cream, why green tea follows the fattiest sushi — and it is just IFI-A doing in the mouth what it was always going to do, except that now we can *aim* it. A tea whose grip is set to a known number is a tea you can pair like an ingredient rather than a guess, and a leaf is an ingredient in far more than a cup. We cook plant-first, as this whole library does, and where a dish is better for dairy or an egg we reach for them without apology and treat them with the same care as the leaf.



Grape again — the tannin cousin on the plate as well as in the glass. The grip-against-fat logic that pairs a red wine with a rich dish is the same IFI-A mechanism that pairs a tea with one.

Matcha and Cream, the Grip Against the Fat

Serves 4 · ten minutes · a pairing that proves the mechanism

The clearest demonstration is also the simplest: let a measured grip meet a measured richness and watch them finish each other.

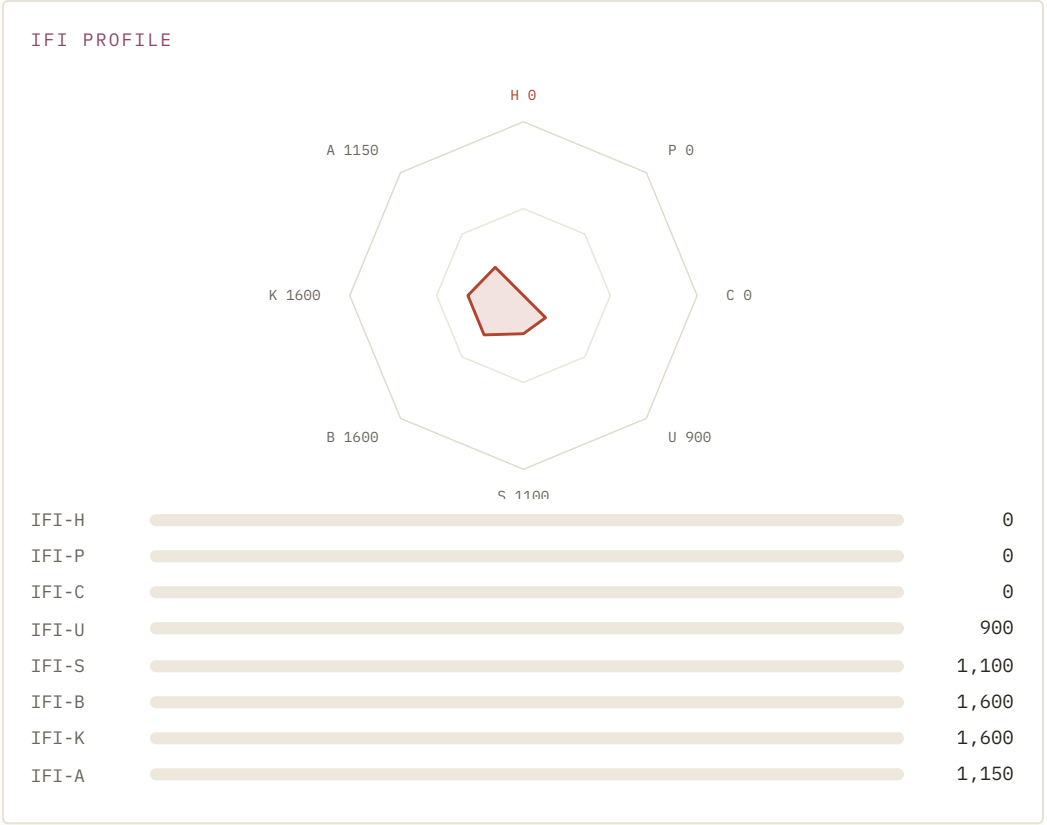
You need

200	g	cold whipping cream
2	tbsp	honey (or a spoon of designed-stevia syrup, Stevia-S)
4	g	matcha, sifted
		a pinch of flaky salt

Make it

1. Whip the cream soft with the honey — stop while it still slumps.
2. Sift half the matcha into the cream and fold once, barely, so it streaks green and white.
3. Spoon into four small cups. Dust the rest of the matcha over the top and finish with the smallest pinch of salt.
4. Eat slowly. Notice how each spoonful's richness is gone by the time you reach for the next — the grip clearing it, the salt lifting the sweet.

IFI readout — the finished spoonful



The pleasure here is a balance, not a flavor: the astringency and the fat are each at their best because the other is there. The IFI-K 1,600 is the cream — the fat we mean to cut; the IFI-A 1,150 is the matcha's grip, doing the cutting; the IFI-U 900 is the savory undertone that keeps it from cloying. That is the whole argument of this book, on a spoon.

Tea-Smoked Eggs and Mushrooms

Serves 4 · forty minutes · the leaf as smoke

Tea leaves thrown onto heat smoulder into a fragrant, faintly bitter smoke that carries the catechins' character onto whatever sits above them — a technique Chinese kitchens have used for centuries on duck and egg. Here it is vegetarian-first, over jammy eggs and meaty mushrooms, with a measured black tea so the smoke reads as structure and perfume rather than ash. The same smoke rises just as kindly under a fillet of fish, made with the same care and no less respect.

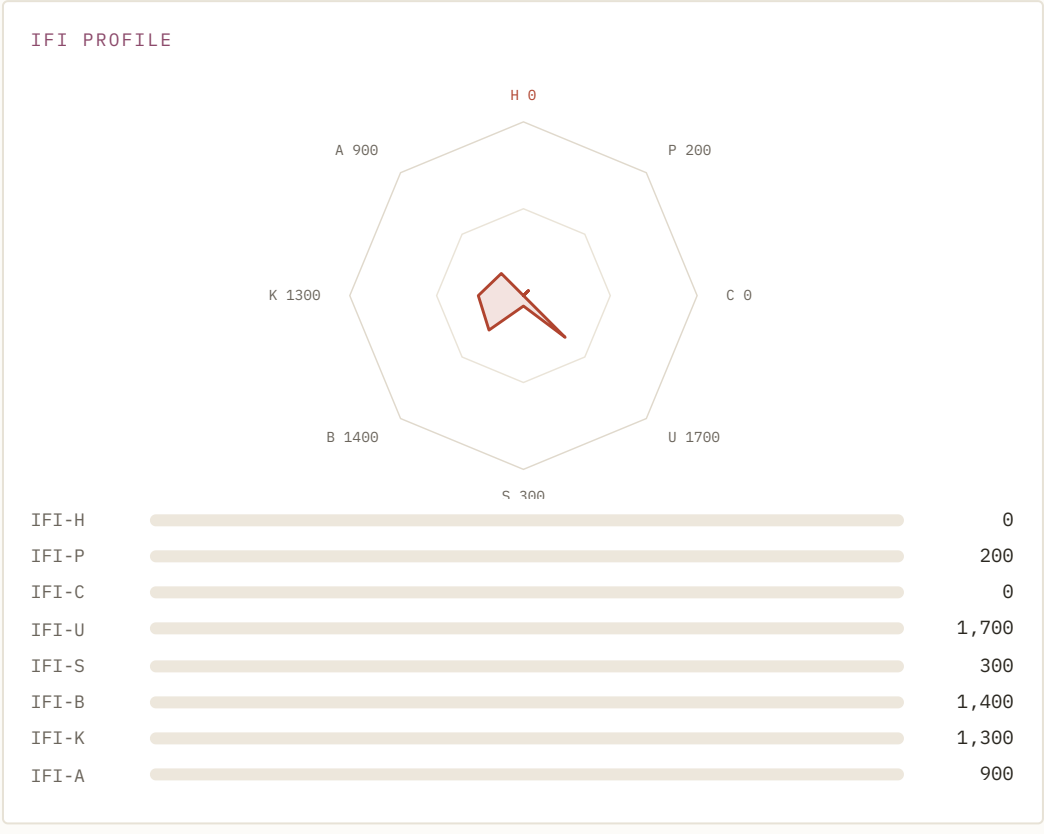
You need

6	eggs, soft-boiled 7 minutes and peeled
250 g	king oyster or shiitake mushrooms, thick-sliced
40 g	black tea leaves (a robust designed black, or Keemun)
60 g	raw rice
40 g	brown sugar
2	star anise, a strip of orange peel
	soy or tamari, and a little toasted sesame oil, to finish

Make it

1. Line a wok and its lid with foil. Scatter the rice, sugar, tea, star anise, and orange peel across the bottom — this is the smoking bed; the sugar and rice carry the heat, the tea carries the aroma.
2. Set a rack above the bed. Lay the eggs and mushrooms on it. Put the wok on high until the bed begins to smoke, then cover tightly and turn to medium.
3. Smoke 12–15 minutes — the eggs will burnish amber, the mushrooms will soften and take the perfume deep. Kill the heat and let them sit, covered, five minutes more.
4. Slice the eggs; dress everything with a little soy and sesame oil. Serve warm over rice or greens. The tea reads here exactly as it reads in a cup — a structured grip and a faint bitterness — only now it is perfume and seasoning, cutting the egg's richness from the outside in.

IFI readout — a dressed plate



The umami here is high — the mushrooms and the soy, savory on their own account — and the tea's grip (IFI-A 900) threads through the whole dish, cutting the egg yolk and the oil the way it would cut

cream in a cup. A faint pungency from the star anise and a real body from the mushrooms round it. Astringency, finally, as a *flavor you cook with*.

Cold-Steep Sencha and Stone Fruit

Serves 4 · fifteen minutes plus a cold steep · the grip beside the sweet

A cold-steeped green poured over ripe summer fruit — the tea's soft grip and clean umami framing the fruit's sugar and acid, no cooking, almost no work. The least handled dessert in the book, and a direct taste of the EC_{50} lever: the cold steep leaves the grip low so the fruit leads.

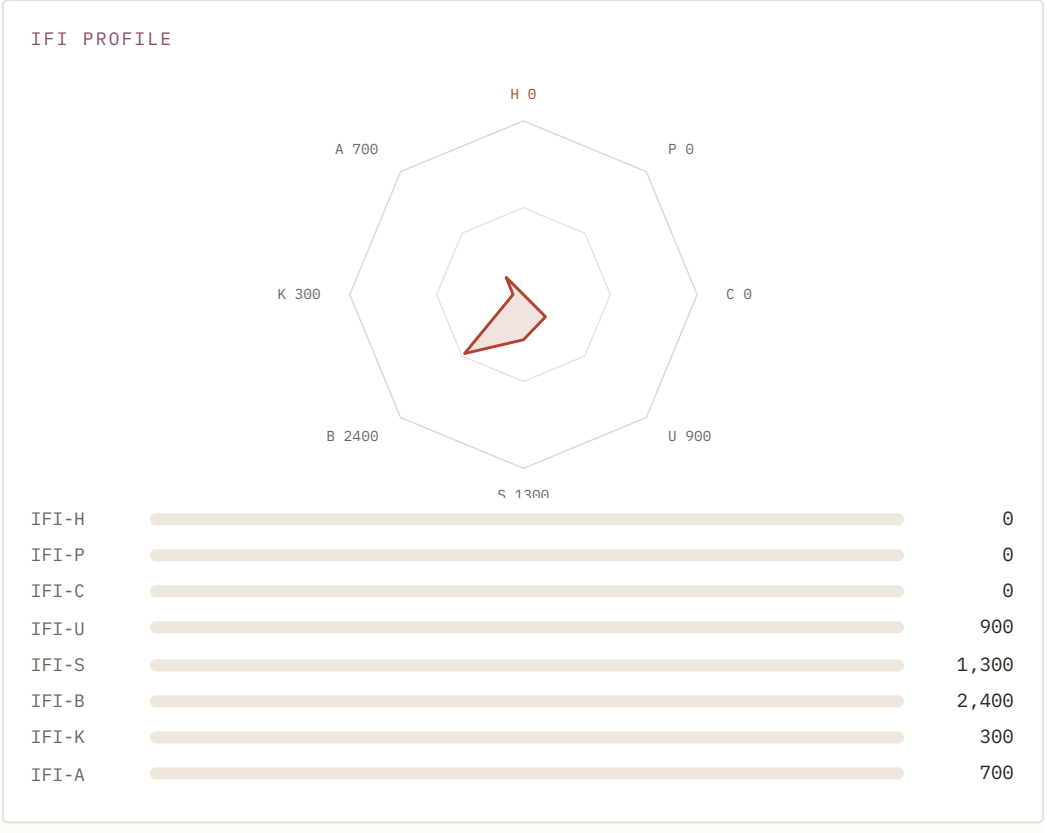
You need

400	ml	cold-steep sencha (from Chapter 18), strong
3		ripe peaches or nectarines, sliced
1	tbsp	honey or stevia syrup (Stevia-S), if the fruit needs it
		a few mint leaves; a squeeze of lemon

Make it

1. Make the cold-steep sencha strong — 15 g to 400 ml, overnight — so its gentle grip can hold its own beside the fruit.
2. Toss the sliced stone fruit with the lemon and, only if it needs it, the honey. Let it sit ten minutes to weep a little syrup.
3. Divide the fruit among bowls and pour the cold tea over to not quite cover. Tear mint across the top.
4. Eat cool. The tea's grip resets the palate between each sweet, soft bite of fruit — the same fat-and-sugar-cutting job it does after a rich meal, here cutting the fruit's own lushness so each piece tastes as bright as the first.

IFI readout — a bowl



Sweetness leads (the fruit), the grip sits low and clean behind it (IFI-A 700, the cold steep), the broth hums underneath (IFI-U 900), and the attenuation is high because almost no caffeine or hard catechin

came out in the cold. A dessert that is really a lesson: the grip, set gently, makes the sweet taste sweeter by clearing the way for it each time.

Chapter 20 · The Reference Readouts — *every cup, scored; precision and the line.*

We will close the working part of the book the way we close every monograph: with the readouts gathered in one place, so the whole leaf can be read at a glance and taken to a bench or a tasting table and *checked*. Everything below is the arithmetic of Chapter 3, run on a real leaf, for three receptors — the grip, the broth, the attenuated bite — with the other five axes held near silent, because that silence is the design.

TEA / CUP	IFI-U	IFI-B	IFI-A	IFI-K	THE DESIGN IN A PHRASE
Gyokuro, cool & slow (1st)	2,300	2,000	650	500	broth alone, grip left in the leaf
Matcha, whisked	2,100	2,000	1,150	700	the whole leaf, balance set in the field
Sencha, hot	1,150	1,800	1,300	300	grassy, bright, pointed
Silver Needle (white)	750	1,400	850	300	barely touched; protect, don't design
Oolong, mid-oxidation	900	1,900	1,450	500	the tunable middle
Designed black, hot	800	2,200	1,700	400	malt and body, grip set
Designed black, with milk	800	2,200	1,000	900	casein binds the tannin
Cold brew, green	1,000	2,600	600	400	gentleness from cold alone
Assam, unmanaged (reference)	400	—	3,200	300	the grip the weather handed it

Read down the astringency column and you can watch the whole thesis: from the gyokuro's 650 to the unmanaged Assam's 3,200, one plant covers nearly the entire range of the axis, and the designed black sits at 1,700 *on purpose* — malt and body kept, grip halved, broth doubled — where the unmanaged leaf sits at 3,200 by

accident. That gap, 3,200 down to 1,700, is the difference between the grip the sun handed the leaf and the grip we set at the enzyme. It is the whole company, in one column.

A word on precision, because it is the quiet product. None of these numbers is worth anything if it is not *repeatable*. The headline of a designed tea is not that it is gentler or brothier than a wild one — a single lucky harvest can be that. The headline is the **CV ≤ 7%**: that the leaf which reads IFI-A 1,700 in spring reads 1,700 in autumn, this field and the next, this year and the next, so a tea house can build a house style on a number instead of chasing a moving target through every humid afternoon of the season. Tea is perhaps the most weather-sensitive flavor crop there is; reproducibility, on tea, is the most valuable thing the platform makes.

And a word on the line we hold, plainly, because a book about engineering a food owes its reader clarity. On the technology: precise gene edits — changing a handful of the plant's own residues on its own enzymes — sit in a different regulatory conversation from inserting foreign genes, and frameworks reflect that unevenly across jurisdictions; we design to be honest about *what* was changed, and any novel protein is assessed for safety and allergenicity as a matter of course, with tea's own well-known caffeine and compound profile unchanged by tuning its native enzymes. On labeling: where a modification leaves detectable modified genetic material, it is disclosed as the law requires, and we treat clear labeling as a feature of a thing we are proud of, not a burden to minimize. On caffeine specifically: a tea's caffeine content is a number drinkers have a real stake in, and we state it; an eased-caffeine line is labeled for what it is, and a true decaffeinated tea is a separate process we do not conflate with attenuation. And on the firmest line of all — **the words.** Tea's compounds are much studied and much hyped, and we will not translate that study into a health claim. We do not say that this leaf cures, prevents, treats, calms, or detoxifies anything. The theanine's famous quiet is the subject of the closing essay, and we will name it there exactly as what it is — a thing we feel and do not measure and will not sell. Everything past that is for a doctor to say, not a tea grower, and not us. These are computational designs; Scoville Splice's cultivars and constructs have not been experimentally validated in a laboratory.

Closing essay · The quiet cup

Of everything we grow, tea is the plant we most often reach for not to be impressed but to be settled. A cup at the end of a long day asks very little and gives a particular kind of attention back — an awake, unhurried calm that fine green tea has been quietly famous for across every culture that has ever drunk it. We know the molecule most often credited with it: theanine, the same brothy amino acid that carries the umami, which readily crosses into the body and is associated, in the way these things are loosely associated, with that settled alertness. We measure theanine's umami precisely, to a number, on mGluR1. We do not measure the calm, and we would not want to make a claim of it. We only know that it is real, that it has sat at our table for as long as we have had one, and that some of what a plant gives you lives, rightly, outside the reach of the Index. Reverence, for us, has always included knowing what we have chosen not to measure.



The greenhouse at dusk — the family's last walk of the day, the work put down, the leaves left to grow.

Here is the thing this leaf keeps teaching us, and it is the opposite of what people expect from a company that designs flavor: the design was never about *adding*. A great tea is three voices in balance and five held silent — the restraint is the art, the subtraction is the craft, and the grip, set with care, is what holds the whole cup together instead of turning on you. Everywhere else in this library we are mostly turning shouting axes down, or building a quiet one up to a thing it never was. On tea we are doing something gentler and, we think, truer to the plant: we are reading a ledger the leaf has always kept between its broth and its grip, and setting it, on purpose, where

a shaded hillside and a patient master would have set it by hand and by luck — and then holding it there, every batch, so that what reaches you is the leaf as its best growers always meant it, made reliable.

And the quiet thing that hums under the whole book can be said once now, plainly, and then let go. We think a great deal, as a family, about growing food to hold the most it can and preparing it to keep what it holds. Tea is one of the oldest things people drink on purpose for something other than thirst — a daily, deliberate, small act of care, a pot made and shared and lingered over. Most of what makes a tea good is the leaf grown toward the fullest and clearest version of itself and steeped with a little attention; most of what ruins one is haste. We will not tell you what the leaf does in your body. We will only say that it is an act of care to grow a plant toward the most of what it should carry and the least of what it shouldn't, and to steep it slowly, and to pour it for someone you are glad to sit with. That is not a claim. It is an intention, and it is the oldest one at our table.

One leaf. Green to black. The grip, the broth, the bite — read, at last, by number. And still, after everything, a cup of tea, poured for someone, at the end of the day.