

THE SCOVILLE SPLICE LIBRARY · THE MONOGRAPHS

Mint & the Cooling Plants

The cold that never reached the thermometer. *Grown leaf by leaf.*

A monograph on the plants that cool without cooling — peppermint, spearmint, eucalyptus, camphor, lavender, and the fruits we taught to feel cold. One receptor, a five-gene pathway, and every kind of chill scored on a single page.

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

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Opening essay · The cold that never reached the thermometer

Put a single leaf of peppermint on your tongue and the mouth goes cold. Press a thermometer to the same spot and it will not move. Nothing has dropped a degree — not the leaf, not the breath over it, not the blood in the floor of the mouth — and still the cold is unmistakable, a clean draught blowing through tissue that is exactly as warm as it was a second before. This is the first thing to understand about the cooling plants, and it is the whole reason we gathered them into one book: *cooling is not a temperature. It is a message about temperature* — and a plant can be grown to send that message on purpose, cleanly, and the same way every time.

Our family came to these plants from the far end of the sensory register. A kitchen that treats heat as a pleasure rather than an assault learns early to love the other pole just as much — the plants that open a window instead of lighting a fire. The hush of a spearmint bed at first light, silver and wet with dew. The medicinal clarity that lifts off a eucalyptus branch the instant you crush it. The way a sprig of mint, bruised into a glass of water that has already gone warm, seems to make the water colder than it is. For most of the ten thousand years that people have grown these plants, that was the entire art, exactly as it was for every other flavor: grow the leaf, crush it, keep the cutting of the one that moved you — and never once be able to say *how much*. How much cold. How clean. How long it would last in the mouth before it faded. How much of the musty, medicinal off-note rode underneath the chill, and whether this year's harvest carried more of it than last year's.



The founders in the research greenhouse at dawn. The cooling work began over a glass of iced mint that had gone warm in the hand, and a question no one at the table could answer.

The cold of mint has an address. It is a single protein — **TRPM8**, the channel the body built to feel genuine winter — and **menthol** is the small molecule that reaches it and tells a convincing lie. Everything in this monograph is the mapping of that lie and the plants that learned to tell it: the one receptor, the pathway of enzymes that grows its key inside the oil glands of a leaf, and the handful of species — peppermint, spearmint, eucalyptus, camphor, lavender, and the cool edge riding on top of a citrus — that each speak cold in their own accent. We measure every one of them on the same axis of the Iyengar Flavor Index, **IFI-C**, Cool-Burn, so that a peppermint

and a eucalyptus and the restrained chill we laid under our hottest pepper can be read against one another on a single page. And we grow them the way we grow everything in this library: toward the fullest, cleanest version of what the plant was always half-trying to be.

This is a monograph, which is to say it is a book about the plants themselves — their botany, their glands, their long human history, the oils they carry and the industries those oils built — and not only about the sensation they produce. The receptor and the mathematics are here, in full, because you cannot design what you cannot measure, and we would not ask you to take the cold on faith when we can show you the number. But the heroes of these pages are green and living. The chill that never reached the thermometer turns out to be, like everything else in this library, a thing a plant makes with enzymes and stores in blisters on a leaf, a thing we can read and, reading it, grow on purpose — toward pleasure, and toward the body that receives it, which were never two separate projects.



PART I OF VI

The Plant

the mint tribe · the gland · the sterile giant · the oil it carries

Chapter 1 · The Mint Tribe — *a family you already know by the stem.*

Reach into any mint, of any kind, and roll the stem between two fingers. It is square. Not round like a grass or a tree shoot, but four-sided, with the leaves set in opposite pairs that turn ninety degrees at every node, so the whole plant climbs the light in a slow spiral of crosses. That square stem is the signature of the **Lamiaceae**, the mint family, one of the great aromatic lineages of the plant world, and it is the first thing we want you to know about the cooling plants, because nearly all of them belong to it. Peppermint, spearmint, lavender — square-stemmed Lamiaceae, cousins close enough to cross. Basil, rosemary, thyme, oregano, sage, marjoram, the whole rack of the herb garden's most fragrant shelf — the same family, the same square stem, the same habit of storing their scent not in the flesh of the leaf but in tiny sealed blisters standing up off its surface. When we speak of the mint tribe, we mean a specific botanical thing: the genus *Mentha* and its nearest kin inside the Lamiaceae, a group of perennials that have followed human beings around the temperate world for as long as there has been a temperate world to follow them around.



Basil — a Lamiaceae cousin of mint, square-stemmed and gland-studded, built on exactly the architecture every cooling mint shares. The family resemblance is a matter of chemistry you can see.

The genus *Mentha* is a taxonomist's quiet nightmare, and the reason is also the reason it has given the world so many cooling plants: mints hybridize with abandon. Where two species grow near enough to share a pollinator, they cross, and the cross is often vigorous, fertile enough to persist, and distinct enough to look like a species of its own. The botanist counts somewhere between a dozen and two dozen true species depending on how the hybrids are treated, and then throws up their hands at the hundreds of named garden forms, because a great many of the mints people actually grow are hybrids, chimeras, sports, and cuttings with no clean place on the tree.

Watermint crossed with spearmint gives **peppermint**, a hybrid so successful it conquered the world without ever once setting viable seed. Spearmint itself, *Mentha spicata*, is likely an ancient hybrid in its own right. The family's genius is promiscuity, and the cooling chemistry we prize is scattered unevenly across the resulting tangle — menthol concentrated in one branch, carvone in another, the two separated by a single enzyme's choice that we will trace in its own chapter.

What unites them, under the taxonomic chaos, is the oil. Every member of this tribe runs a dedicated secondary metabolism whose only job is to build a specific blend of small volatile molecules — **monoterpenes**, ten-carbon compounds spun out of the same universal precursor — and to pool that blend in surface glands until something breaks them. The oil is not a byproduct. It is a purpose-built chemical arsenal, evolved to deter the insects that would eat the leaf, to slow the fungi that would rot it, perhaps to signal to the plant's neighbors, and the particular molecules each species settled on are an accident of which enzymes its lineage happened to assemble. Peppermint landed on menthol. Spearmint landed on carvone. Lavender, further out in the family, on linalool. Thyme and oregano on the phenols carvacrol and thymol, which is why they read as warm where their cousins read as cool. The mint tribe is, in a sense, a single invention — the surface gland full of defensive terpenes — run through a thousand variations, and the cooling plants are the variations whose particular molecules happen to speak to the body's cold channel instead of its heat one.

Mint has shadowed human settlement for all of recorded history and most of the unrecorded part. It appears in the oldest herbals of Egypt and Greece and Rome, strewn on floors so footsteps would release the scent, steeped against indigestion, carried in the mouth to freshen the breath — the single oldest and most durable use of these plants, a use we will come back to at the end of this book because it is still, by volume, the largest. The Latin *Mentha* reaches back through Greek *minthe* to a myth of a nymph crushed underfoot and risen as a fragrant herb, a story that gets the plant exactly right: it is a thing that gives its gift only when it is bruised. An unbroken mint leaf is nearly odorless. The cold, the scent, the whole chemical argument of the plant waits sealed in its glands until a footstep or a fingertip or a tooth tears them open, and then it arrives all at once. This is not incidental botany. It is the central fact of how these plants work, and it is the subject of the next chapter — because to understand the cooling plants, you have to understand the gland.

Chapter 2 · The Gland — *a factory smaller than a grain of salt.*

Run a fingertip slowly across the surface of a peppermint leaf, lightly, and you will feel a faint tack, a minute roughness, as though the leaf had been dusted with something just barely sticky. That texture is the whole chemistry of cold. What your finger is reading is a field of **peltate glandular trichomes** — thousands of them per leaf, tiny stalked blisters standing up off the epidermis, each one a sealed flask holding a droplet of the plant's monoterpene oil beneath a stretched, transparent cuticle. Crush the leaf and you rupture those flasks all at once, and their entire output — the menthol, the cold, the scent — floods out in a single release. The cooling of mint is the pooled contents of a few thousand microscopic factories breaking at once, and everything about how a mint tastes is set by what those factories build and how cleanly they build it.



Basil in cross-section — the same peltate glandular trichomes that stud every cooling mint, standing up off the leaf surface as sealed reservoirs of monoterpene oil. The cold is stored in structures you can photograph.

The architecture of a single peltate gland is one of the quiet marvels of plant biology, and it is worth seeing clearly, because so much of what we design happens inside it. At the base sits a single epidermal cell, the foot, anchoring the structure to the leaf. Above it a short stalk cell lifts a disc of **eight secretory cells** — in most mints, eight, arranged in a neat rosette — and those eight cells are the chemists. They synthesize the oil in a frantic burst over a few days as the leaf matures, pumping the finished monoterpenes outward, not into their own cytoplasm where the reactive molecules would do damage, but up and out into a **subcuticular cavity**: a dome-shaped space that

forms as the cuticle balloons away from the cells beneath it, inflating like a blister as the oil accumulates. The finished oil sits there, sealed and essentially inert, held under the taut cuticle at the end of the gland's brief productive life — a droplet of cold waiting, sometimes for the whole life of the leaf, for the mechanical insult that will release it.

That the plant stores its oil *outside* its living cells is not a detail; it is a necessity, and it shapes everything. The monoterpene pathway runs through intermediates that are too reactive, too volatile, too self-poisoning to keep inside a working cell — pulegone and menthofuran and the rest would wreck the machinery that made them. So the gland is also a quarantine: the chemistry is run at arm's length, the product shunted into a sealed external reservoir the moment it is finished, and the secretory cells spend their short lives essentially exporting a toxin they have carefully arranged not to be poisoned by. For a designer this has two consequences we live inside every day. The first is that **the gland is a yield ceiling**: a leaf can only build so many glands and inflate them only so far, so the total oil a plant can carry is bounded by the density and size of its trichomes, which makes trichome number and trichome volume two of the levers we most want to move. The second is that **the gland is where the off-notes hide**: because the whole reactive pathway runs in those eight cells, an enzyme out of balance leaves its half-made intermediate pooled in the reservoir alongside the finished cold, and the mouth tastes the mistake.

The numbers of the factory are modest and exacting. Peppermint oil runs on the order of one to three percent of the leaf's dry weight — a few drops per leaf, no more — and in a good oil the single molecule menthol makes up something near forty percent of that droplet, with menthone, menthyl acetate, and a long tail of minor terpenes filling out the rest. The glands fill on a daily rhythm as the leaf ages, the oil accumulating over days and then sitting, and a leaf picked young carries a different balance than the same leaf picked three weeks later, because the pathway's later steps keep running after the earlier ones have slowed. This is why timing the harvest is half the art of a traditional mint grower: the plant's chemistry is a moving target, and the window in which the oil is both abundant and clean is narrow and drifts with the weather. A cold, clean oil is a thing caught at the right moment from a gland that built it right — and the whole of our pathway work, the chapters of Part II, is an attempt to widen that window until it no longer closes, so the clean cold is there to be caught every day of the season and not only on the lucky ones.

It is worth sitting a moment with the sheer improbability of the thing. A structure smaller than a grain of salt, eight cells and a dome of cuticle, runs a seven-step chiral synthesis of one of the most sensorily potent molecules in nature, stores the product safely outside itself, and holds it ready for release at the first touch — and it does this across the entire surface of every leaf, thousands of times over, from a genetic program a few thousand bases long. We did not invent this. We inherited it, mapped across decades by biochemists

who loved the oil long before anyone could edit the plant that made it, and the whole of our contribution is to tune a machine that was already one of evolution's small masterpieces. Reverence, in this book, is not a decoration laid over the science. It is the only honest response to looking closely at a mint gland and understanding, finally, what it is doing.

Chapter 3 · The Sterile Giant — *why a clone could never breed its way to better.*

The most important plant in this book cannot have children. **Peppermint**, *Mentha × piperita*, the species that carries the whole cooling axis on its back, is a sterile hybrid — a chance cross of watermint and spearmint that arose, probably by accident, in an English field in the seventeenth century, was noticed for its remarkable cold, and has been carried around the world as cuttings ever since. It sets almost no viable seed. Every peppermint plant in every field on earth is, in the deepest sense, the *same* plant: a single genetic individual, cloned and replanted and shipped as rooted stem, dragged forward through three centuries without ever once passing through the genetic reshuffling of sex. This fact — that the giant of the cooling world is one sterile clone — explains almost everything about why mint was so hard to improve before us, and why precision editing fits it so perfectly now.



A clonal transplant, rooted from cutting rather than grown from seed. A sterile hybrid is improved one edited lineage at a time, then propagated forward unchanged — the exact mode of improvement a cloned crop was always best suited to and never had.

Consider what sterility does to a classical breeder. The entire craft of breeding is the controlled shuffling of sex — cross two parents, sift the thousands of offspring for the rare one that combines their virtues, backcross, select, stabilize, repeat for a decade — and it depends absolutely on fertile seed to shuffle. A sterile hybrid offers none of that. You cannot cross peppermint with anything and keep peppermint; the moment you reintroduce sex you lose the exact hybrid combination that made the plant worth having. So peppermint

could be improved, for three hundred years, in only two ways: by hunting through its clonal population for a spontaneous mutation that happened to be an improvement, or by moving it geographically to a climate that suited it better. The famous **Mitcham** peppermint of England, the **Pacific Northwest** fields of Oregon and Washington and Idaho that still supply much of the world's mint oil — these are not breeds in any ordinary sense. They are clones, lineages, selections: the same plant, replanted in better ground, its improvements the accidents of place and luck rather than the products of design.

And a clone carries a clone's great and specific weakness: it cannot breed its way out of a problem. When **Verticillium wilt** — a soil-borne fungus that invades the water-conducting tissue and kills the plant from the roots up — swept through the American mint fields in the twentieth century, classical breeding had almost nothing to answer with, because there was no sexual population in which to find and fix resistance. You cannot select a resistant peppermint from among its seedlings when it has no seedlings. The industry fought the wilt with crop rotation, with fumigation, with the slow, lucky isolation of the occasional more-tolerant clonal sport, and with a great deal of lost ground, literally — fields abandoned because the one vulnerable individual that fed the world's mint had no genetic answer to a fungus. The plant that gave humanity its cold was, genetically, a single susceptible organism copied a billion times, and its uniformity was both the source of its reliable flavor and the source of its fragility.

This is precisely the situation in which precision editing is not merely useful but *native*, the mode of improvement a clonal crop was always best suited to and never had. Editing does not care that peppermint is sterile. We do not need seed; we work on the plant's tissue directly — delivering edits into leaf cells or protoplasts and regenerating a whole plant from them — and because the plant is clonal, a successful edit is simply *locked in*. There is no segregation, no loss of the edit to the lottery of the next generation, because there is no next generation; the edited line is propagated onward as cuttings exactly as the unedited clone always was, carrying its improvement forward unchanged and indefinitely. The plant that resisted three hundred years of selection yields to a guide RNA. We can give it wilt tolerance without touching its oil. We can tune its oil without touching its hardiness. We can write a single clean change into the lineage and know it will still be there in ten thousand plants and ten years, because clonal propagation is the most faithful copying machine in agriculture, and for the first time we have something worth copying it faithfully.

There is a deeper symmetry here that we find moving, and that sits under the whole of this monograph. Peppermint became the world's cold by an accident of hybridization and then was frozen, by its own sterility, into a single form it could not evolve past — a plant stuck being exactly as good as the seventeenth-century field that spawned it. For three centuries it waited, essentially, for a way to be improved that did not require it to stop being itself. Editing is that way. It lets the sterile giant keep its exact identity — the precise

watermint-by-spearmint cross that is *piperita* and nothing else — and still move forward, cleaner and hardier and truer, one written change at a time. We are not making a new peppermint. We are letting the old one, finally, become the best version of the single plant it has always been.

Chapter 4 · The Oil It Carries — *forty percent menthol, and the rest is the difference.*

A mint is its oil, and the oil is a blend. When we say peppermint and mean *cold*, we are using a kind of shorthand for a droplet of two dozen molecules in a particular proportion, dominated by menthol but defined, in the end, by everything around the menthol — by the menthone that brings warmth, the menthyl acetate that brings a fruity roundness, and above all by the two unwanted intermediates, pulegone and menthofuran, whose presence or absence separates a premium oil from a cheap one. To understand the cooling plants as a grower or a formulator understands them, you have to read the oil as a composition, not a single note, and you have to know which numbers in that composition are the ones that matter.



A mint specimen at the bench. The whole sensory argument of the plant is a droplet of two dozen molecules in a particular ratio — and the ratio, not the total, is what the mouth reads.

Here is a good peppermint oil, laid out as the major fractions a gas chromatograph would read, and what each one does in the mouth:

COMPONENT	SHARE OF OIL	WHAT IT CONTRIBUTES
(−)-Menthol	~38–48%	the clean cold; the headline molecule
(−)-Menthone	~15–30%	minty, but more warmth than cold
Menthyl acetate	~3–10%	fruity, sweet, rounds the oil
Menthofuran	~1–9%	musty, medicinal — the off-note
1,8-Cineole	~3–6%	a touch of eucalyptus openness
(+)-Pulegone	<1–4%	the restricted intermediate; raw, sharp
Limonene, others	balance	citrus top notes, minor terpenes

Read that table and you can taste the whole grower's problem in it. The menthol is the thing you want, and more of it, cleanly, is better. The menthone is a reservoir of warmth that a very minty oil can lean on but a pure cold wants held down. The menthyl acetate is a grace note, a fruity roundness that keeps the oil from reading thin and medicinal. And then there are the two numbers at the bottom that keep every mint grower awake: **menthofuran** and **pulegone**. These are not design choices the plant made; they are its unfinished business — pulegone an intermediate the pathway is supposed to pull all the way through to menthol, menthofuran a dead-end byproduct made from that stranded pulegone — and the more of them an oil carries, the more it reads as musty, raw, stale, and medicinal, the exact opposite of the clean cold the plant is prized for.

Two things make those bottom numbers wander, and both are the grower's enemy. The first is **maturity**: a leaf picked too young has run the early pathway steps but not finished the late ones, so it carries more pulegone and menthofuran and less menthol; the oil cleans up as the leaf ages and the pathway completes, which is why harvest timing is everything and why an early frost or a rushed cutting can ruin a crop's chemistry without touching its yield. The second, and crueler, is **stress**: the enzyme that makes menthofuran runs *harder* when the plant is under duress — heat, drought, a hard season — so a wild mint's cleanliness is hostage to the weather in a way the grower cannot control. The same clone, in the same field, makes a cleaner oil in a mild year than in a brutal one. A premium oil is not only a matter of good genetics and good ground; it is also a matter of a kind season, and a kind season cannot be ordered.

This is the gap a design platform was built to close, and it is worth stating now as the thesis the whole second part of this book will prove. Nearly everything that makes a mint oil good or bad lives in the ratio of the pathway's seven good steps to its one bad off-ramp — in how completely the plant carries its chemistry through to menthol and how firmly it keeps the door to menthofuran shut. A classical grower can nudge that ratio with harvest timing and prayer. We can set it, in the genes, and hold it against the weather: push the flux hard down the road to menthol, starve the menthofuran branch until it is dry, and build the whole thing to stay that way when the summer turns cruel. The reward is not a novel flavor. It is the *ordinary* flavor of a great mint oil — the clean, abundant, cold forty-percent menthol with the off-notes near zero — made reliable, made a specification instead of a lucky harvest. For a flavor house that has fought mint variability for a century, that reliability is worth more than any exotic new note, and it is the first thing our peppermint sells.

The minor cooling plants each carry their own characteristic oil, and we will meet them one at a time in Part III, but the logic is always the same: a dominant molecule that defines the plant, a supporting cast that rounds it, and a set of off-notes that cheapen it when they rise. Spearmint's oil is built on carvone, with its own unwanted enantiomer to exclude. Lavender's is a balance of two molecules a breath apart, linalool and its acetate, with camphor as the contaminant that coarsens it. Eucalyptus is nearly all cineole, prized for purity. Camphor is a single powerful note that must be kept to a trace. In every case the plant is its oil, the oil is a ratio, and the ratio is the thing we design. But first the cold itself — the receptor the oil is talking to, the mathematics that scores it, and the five-gene pathway that builds its key — because you cannot tune a composition until you can read every note in it as a number.



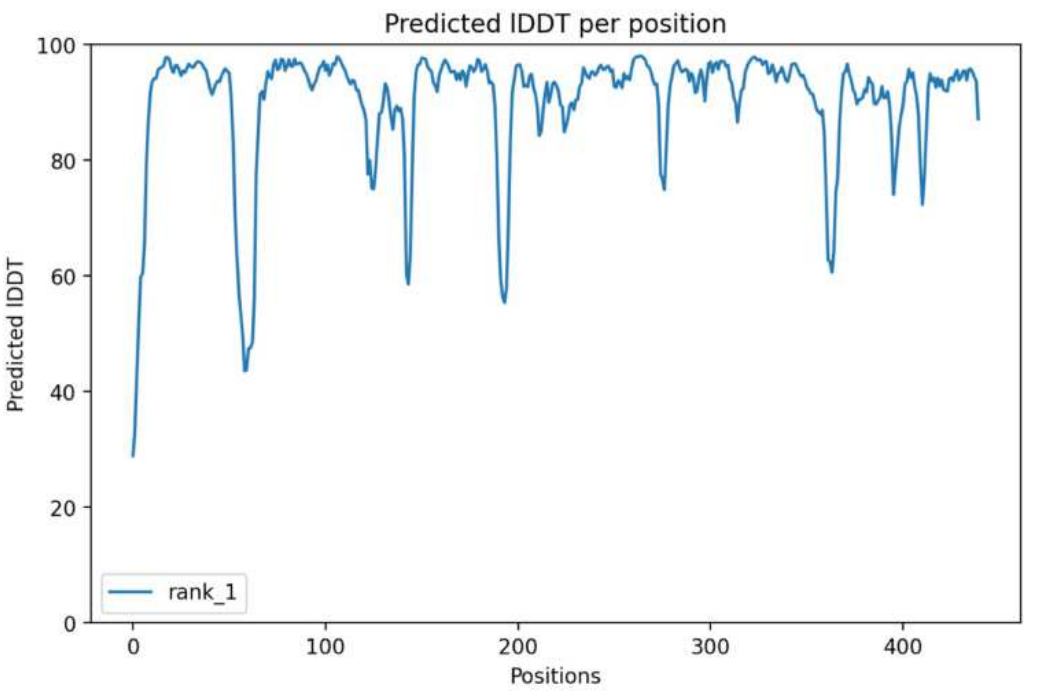
PART II OF VI

The Cold It Carries

the receptor that lies · the mathematics · five genes · the wrong turn · designing the cold

Chapter 5 · The Receptor That Lies — *one channel, counterfeiting winter.*

Every cold these plants make is a message delivered to a single protein, and the protein is **TRPM8** — the transient receptor potential channel, melastatin subfamily, member eight, the body's principal sensor for everything below comfortable. It sits threaded through the membrane of the sensory nerve endings that fan out into the lips, the gums, the tongue, the palate, the throat, and the lining of the nose, and its honest job is to feel real cold: when the tissue around it drops below roughly twenty-six degrees, the channel opens, ions pour through, the nerve fires, and the brain reads the single word *cold*. It is the reason a glass of ice water has a feeling and not merely a temperature. Menthol is the plant molecule that learned to pick this lock from the inside — and to understand the cooling plants at all, you have to understand, at least in outline, the channel they were all evolved to deceive.



The platform's protein-modeling pipeline, shown here on our capsaicin acyltransferase, is the same analysis we run on TRPM8 and on every enzyme of the menthol pathway — the fold resolved, the binding pocket mapped, before a single designed change is trusted.

TRPM8 is built like a gate, and like every good gate it is mostly a decision about when to open. Four identical protein chains assemble into one channel — a homotetramer — arranged around a central pore that, when it opens, lets sodium and calcium flood from outside the nerve to inside. Each chain carries six membrane-spanning helices, numbered S1 through S6; the last two, from all four subunits

together, line the pore itself, while the first four fold into a compact bundle at the edge of each subunit called the **voltage-sensor-like domain**, the VSLD. That bundle is the most important real estate in the protein for everyone in this book, because it is where menthol binds. Cryo-electron microscopy resolved the cooling-agent pocket directly, cradled inside the VSLD cavity between helices S1 and S4, and a single tyrosine on S2 — the residue the field labels **Y745** — proved to be the one you cannot do without: mutate it, and menthol loses most of its grip while the channel's sense of real cold survives intact. That one experiment is the cleanest proof anyone could ask for that menthol and cold are two different keys fitting the same lock from different angles.

But a pocket is only half the story, and the better half is the gating logic — the reason a channel with menthol in its pocket becomes more *likely* to open rather than simply forced to. TRPM8 is an allosteric machine with several inputs that all push on one equilibrium between closed and open: membrane voltage, temperature, the cooling molecule, and a membrane lipid called **PIP2** that the channel requires as a permissive cofactor. The voltage dependence is Boltzmann-shaped, described by a half-activation voltage, V½, the voltage at which the channel is open half the time:

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Po = 1 / (1 + exp[ zF(V½ − V) / RT ])
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At rest, in a warm mouth near 35 °C, V½ for TRPM8 sits far out past +100 mV, so far from the nerve's resting voltage that the channel is almost always shut. Cold shifts V½ toward physiological voltages. And menthol shifts it the same direction, powerfully — binding in the VSLD pocket moves V½ by something on the order of −80 to −100 millivolts, far enough to drag the half-open point down into the range the resting nerve actually sits in. Here is the whole counterfeit in one sentence: **menthol does not open the channel so much as lower the temperature at which the channel believes it should open.** A TRPM8 that would have waited for 26 °C now fires at 35 °C, a warm living mouth, because menthol has told it that 35 °C *is* cold. The forgery is not of a molecule or a temperature. It is a forgery of a threshold, and the brain, which keeps no independent thermometer, has no way to catch the lie.

Two consequences fall straight out of this model, and both matter in every glass and lozenge in Part V. The first is **synergy with real cold**: menthol and a genuinely cold drink push V½ in the same direction, so iced mint is not additively but *multiplicatively* cool, each input amplifying the other's shift — a cold mint drink is colder than the sum of its mint and its ice. The second is **desensitization**, the reason the second mint cools less than the first. Calcium floods in through the open channel; calcium activates an enzyme that consumes PIP2; and with its permissive lipid depleted, the channel's enthusiasm fades even with menthol still in the pocket, over tens of seconds to a couple of minutes. Anyone who has eaten two strong mints in a row has felt that exact molecular arithmetic, and anyone formulating a

lozenge that must cool for four minutes instead of forty seconds is, whether they know it or not, fighting PIP2 depletion. We will return to that fight, because winning it is half of what makes a cooling product feel expensive.

One last fact belongs here, because it is both charming and a standing lesson for a designer. TRPM8 is not uniform across animals: **birds** carry a version of the channel that reads real cold perfectly well but is largely indifferent to menthol — a few residues around the binding pocket differ, and the mint key no longer fits. The pocket is a specific, evolved shape, not a law of nature. The fact that our menthol fits our pocket so exquisitely is a contingency we inherited, not a necessity, and that is worth holding onto, because it means the fit between molecule and receptor is a *structure* — and structures are the thing we read, model, and edit. The chapters that follow are what we do with that fact: first the mathematics that turns the fit into a number, then the pathway that grows the molecule, then the design that makes the plant build it better than any field ever has.

Chapter 6 · The Mathematics of a Cold That Isn't There — *loudness, not quantity.*

A grower measures mint in percent oil. A chemist measures menthol in milligrams. Neither number tells you how cold the thing will feel, and the gap between them is the whole reason the Index exists. Two cooling molecules at the same concentration can differ a thousandfold in how loudly they speak to TRPM8; two mints at the same oil content can read as worlds apart if one carries clean menthol and the other carries menthol buried under pulegone and menthofuran. **Quantity is not loudness.** The Cool-Burn axis scores loudness, and loudness has a precise definition — the same one that runs through every book in this library, applied here to the cold:

$$\text{IFI-C}(\text{candidate}) = 1{,}000 \cdot \text{EC}_{50}(\text{reference}) \,/\, \text{EC}_{50}(\text{candidate})$$

EC_{50} is the half-maximal effective concentration — the amount of a cooling agent needed to drive TRPM8 to half of its fullest response. We measure it the way pharmacology measures any agonist: express the human receptor in cultured cells, load them with a dye that fluoresces when calcium enters, expose them to a graded series of the coolant, and read how brightly they answer at each dose. Plotted against the logarithm of concentration, the points trace a sigmoid, and we fit it with the Hill equation —

$$\text{Response} = \text{Response}(\max) \cdot [C]^n \,/\, (\text{EC}_{50}^{\,n} + [C]^n)$$

— from which the EC_{50} falls out as the curve's midpoint and the exponent **n**, the Hill coefficient, tells us how steeply the channel's four subunits act together. For menthol on TRPM8 that coefficient runs above one, often near two, meaning the subunits cooperate, meaning the cold arrives with a certain switch-like suddenness rather than a lazy ramp — which is exactly why a mint can tip from "barely there" to "fully cold" across a narrow range of dose, and why a formulator who misjudges concentration by a little can miss the mark by a lot.

A *small* EC_{50} means the channel answers a faint whisper of the molecule, which means the molecule is loud. We anchor the reference to **(–)-menthol** itself — its own EC_{50} divided by itself lands it at exactly **1,000**, the fixed point the whole axis is read against — and we cap the scorecard at **5,000**, the shared per-axis ceiling, so the rare molecules loud enough to saturate the channel peg the scale instead of running off it. We chose menthol as the anchor deliberately, over the far louder synthetic superagonists, for the same reason the heat axis is anchored to a familiar reference and not its own extreme: an index should be legible against the thing people already know. Everyone carries a memory of menthol.

Pinning the axis to that memory means a score of 2,600 *means something* — more than two and a half times as cold as the coldest mint you remember — in a way a score anchored to a laboratory compound never could.

Here is the cool axis laid out as a ladder, from the synthetic superagonist that pegs the scale to the aromatic whisper that barely registers, with (−)-menthol fixed at an EC_{50} of 80 µM as the anchor. These are the reference values our bench works from:

COOLANT	CLASS	EC_{50} (TRPM8)	IFI-C	CHARACTER
Icilin	synthetic superagonist	0.36 µM	5,000 (capped; true ≈ 222,000)	glacial, Ca^{2+}-dependent, flavorless
WS-3	synthetic carboxamide	25 µM	3,200	odorless, long cool
WS-23	synthetic carboxamide	35 µM	2,290	odorless, clean
(−)-Menthol	**monoterpene (anchor)**	**80 µM**	**1,000**	**the reference cool**
Menthyl lactate	menthol ester	150 µM	533	mild, very long-lasting
(+)-Menthol	enantiomer	240 µM	333	weaker, slightly dusty
(−)-Menthone	monoterpene	400 µM	200	minty, more warmth than cool
Linalool	monoterpenoid (lavender)	~2,000 µM	40	floral, barely cool
1,8-Cineole (eucalyptol)	monoterpenoid	~3,500 µM	23	respiratory, airy
(+)-Camphor	monoterpenoid	— (TRPM8 blocker)	—	warms; see Chapter 12

Several things in that table reward a slow look. The first is the sheer **range**: an EC_{50} from 0.36 µM to 3,500 µM is a span of nearly ten thousandfold, which is exactly why a scorecard has to normalize — raw EC_{50} is unreadable across that distance, and the IFI compresses it into numbers a person can hold in one hand. The second is **icilin**,

so loud it would score over two hundred thousand if we let it, pinned instead at the 5,000 ceiling with its true value noted in the margin: a reminder that the receptor can be driven far harder than any plant ever drove it, because no leaf's life ever required a cold that loud. The third is the **enantiomer gap** — (−)-menthol scoring three times its own mirror image, (+)-menthol, from nothing but handedness — which is the entire argument of a plant's chirality compressed into two rows, and which we will meet again when we trace the pathway.

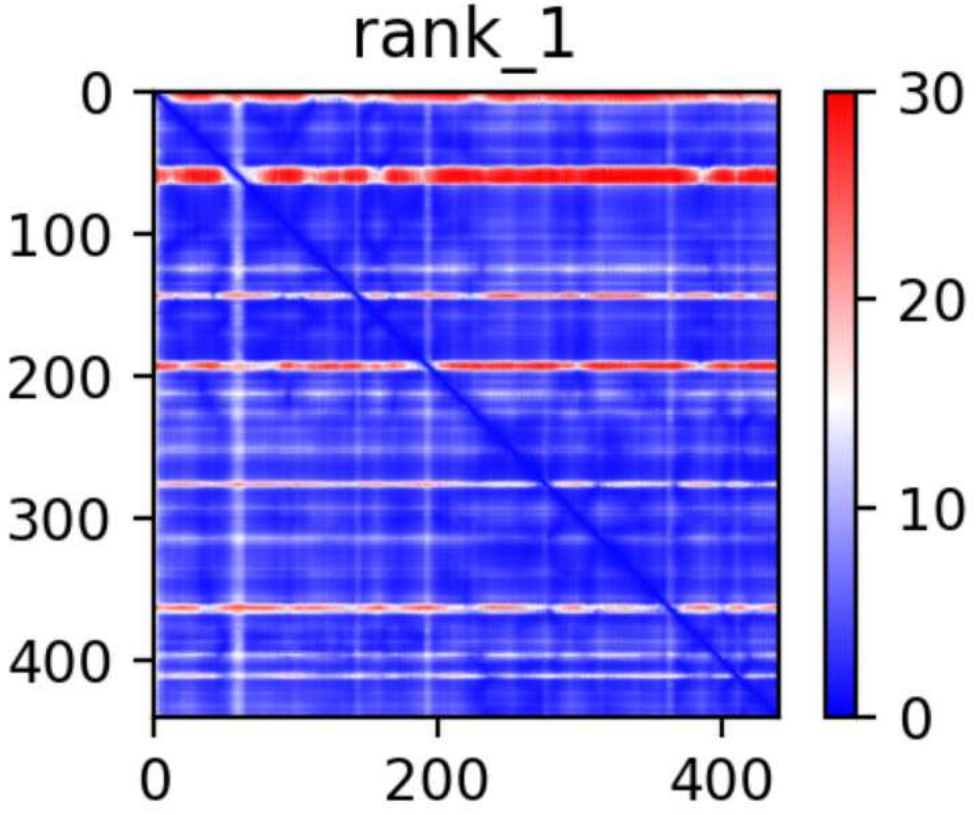
The IFI does something subtler than rank molecules, though: it lets us add them, and it lets us think about time. Because the axis is anchored to receptor loudness, a blend's cool is, below saturation, roughly the sum of each coolant's concentration times its per-molecule loudness — which is how a formulator reasons about a lozenge that carries a little menthol for the bright front, a little menthyl lactate for the long tail, a trace of WS-23 for the throat the menthol misses. But the honest version of the math carries a time term, because desensitization is real: the cool you feel is not a number but a curve, rising as the molecule arrives and falling as PIP2 depletes, something like

```
Cool(t) ≈ IFI-C · e^(−t/τ)
```

where a free, volatile molecule like menthol has a short time constant τ — the cool gone in under a minute — and a heavy, slow-clearing ester like menthyl lactate has a long one. A great cooling product is designed in two dimensions at once, *how loud* and *how long*, and the second dimension is where most of them fail. What the mathematics buys us, in the end, is **intention**: a grower who knows only percent oil can hope for a better mint, but a designer who knows the EC_{50} ladder and the τ of each coolant can specify one — this loud, this long, this clean of off-notes, in this plant, at this cost, within the ≤7% batch-to-batch variance the whole platform holds to. The number does not replace the pleasure of a cold draught of mint on a hot day. It is the thing that lets us build that pleasure on purpose, every batch, which for a sensory ingredient is the difference between a flavor and a product.

Chapter 7 · Five Genes to a Cold Leaf — *the menthol pathway, enzyme by enzyme.*

To make the coldest molecule in nature, a peppermint leaf runs an assembly line inside the eight secretory cells of each gland, and the line is one of the best-mapped secondary-metabolic routes in all of botany — every enzyme sequenced, every intermediate identified, the one dangerous fork characterized down to the competing enzymes that guard it. This is the heart of a cooling-plant monograph, because this pathway is the thing we actually design, and its shape explains both why clean mint is hard and why, once mapped, it is so beautifully tractable. We call it the **five-gene menthol pathway** — a deliberate shorthand, because although the full route from precursor to menthol runs seven committed enzymatic steps, the handful of genes we actually tune to own the cold is smaller, and five of them do nearly all the work that matters.



The predicted-aligned-error map from our structure pipeline — the same confidence analysis we run on the menthol pathway's cytochrome P450s before trusting a single designed substitution in an active site. We edit only where the model is sure of the fold.

The line begins with a universal building block. In the plastid, the **MEP pathway** — the methylerythritol-phosphate route, running from pyruvate and glyceraldehyde-3-phosphate through the enzymes DXS and DXR and their successors — produces the five-carbon isoprenoid units IPP and DMAPP, and **GPP synthase**, a heterodimer in mint, joins one of each into **geranyl diphosphate**, GPP, the ten-carbon precursor from which every monoterpene is built. GPP is the raw bar of metal the assembly line machines. From there, seven committed steps carve it into (−)-menthol:

STEP	SUBSTRATE → PRODUCT	ENZYME	ABBREV.	COMPARTMENT
1	GPP → (−)-limonene	(−)-limonene synthase	LS	plastid (leucoplast)
2	(−)-limonene → (−)-trans-isopiperitenol	limonene-3-hydroxylase (P450)	L3OH / CYP71D	endoplasmic reticulum
3	isopiperitenol → (−)-isopiperitenone	isopiperitenol dehydrogenase	IPD	mitochondrion
4	isopiperitenone → (+)-cis-isopulegone	isopiperitenone reductase	IPR	cytosol
5	cis-isopulegone → (+)-pulegone	isopulegone isomerase	IPGI	cytosol
6	(+)-pulegone → (−)-menthone	pulegone reductase	PR	cytosol
7	(−)-menthone → (−)-menthol	menthone:menthol reductase	MMR	cytosol
off-ramp	(+)-pulegone → (+)-menthofuran	menthofuran synthase (P450)	MFS / CYP71A32	endoplasmic reticulum

Read the line and you can taste it changing. Step one is citrus: limonene is literally the smell of an orange peel, and the first thing a mint does is build the same molecule a lemon does — a fact we will exploit, in Chapter 14, to put cold into a citrus. Step two hangs an oxygen on the ring at precisely the third carbon and nowhere else, and the citrus turns herbal. Through the middle of the line the intermediates are sharp and green and not yet cold at all. The cold does not arrive until the last two steps, where **pulegone reductase** turns pulegone into menthone — and here the balance of warmth and cool is first set, because menthone is minty but carries more warmth than cold — and then **menthone:menthol reductase** performs the final reduction to **(−)-menthol** itself, the cold at the end of the green. Seven enzymes, each one chiral, each handing its single correctly-handed product to the next, and the clean cold of peppermint is the reward for not making one wrong turn across all seven.

Look again at the compartment column, because it hides one of the strangest facts in plant biochemistry. This pathway does not sit still. It begins in the **plastid**, where GPP is made and cut to limonene; crosses to the **endoplasmic reticulum** for the first oxidation by a membrane-bound P450; travels to the **mitochondrion** for the dehydrogenation at step three; and finishes in the **cytosol** for the last four steps. The volatile intermediate is physically shuttled across membrane after membrane, through four organelles, on its way from green to cold, and no one fully understands how the cell manages the hand-offs without losing the cargo. For a designer this is both a

humbling marvel and a practical warning: a pathway spread across four compartments has four times the places to leak, and some of our best gains come not from speeding a step but from tightening a hand-off, keeping the intermediate on the line instead of letting it diffuse away into some other corner of the cell's metabolism.

Which brings us to why we call it the five-gene pathway in practice, even though seven enzymes draw the full route. When we sit down to *own* the cold in a peppermint, we are not editing all seven equally — several steps run with enormous spare capacity and are not worth touching. The genes that actually move the outcome, the five handles on the whole machine, are: the **precursor supply** (GPP synthase and the MEP enzymes feeding it, the true source of how much raw material the line ever sees); the committing oxidation at **L3OH**, which sets the molecule down the menthol road rather than letting limonene escape; the two late reductases **PR** and **MMR**, which decide the final balance of warmth and cold and the stereochemical cleanliness of the menthol; and — the most important handle of all, and the subject of the next chapter — the off-ramp enzyme **MFS**, which we do not speed up but shut down. Tune those five, and the other two steps follow, and the whole line pours clean cold. That is the practical meaning of the five-gene menthol pathway: not that the chemistry is only five steps, but that five genes are the keyboard on which the whole cold is played.

What makes this route so suited to design is that it is almost entirely *known*. There is no mystery step, no black box where flux vanishes, no uncharacterized enzyme standing between us and the molecule. The menthol pathway was mapped across decades by biochemists who cared about the oil long before anyone could edit the plant that made it, and we inherited that map complete. You cannot engineer what you cannot see, and here we can see everything — which is why peppermint, for all the difficulty the index files it under, is in the deepest sense a *solved* plant, waiting only for the tools to act on what was already understood. The next two chapters are those tools: first the one wrong turn we have to close, and then the pipeline that closes it.

Chapter 8 · The Wrong Turn — *menthofuran, and the door the plant left open.*

Every clean mint is a story about a door kept shut. At step five of the pathway, pulegone sits at a fork, and the whole quality of the oil — its cleanliness, its market grade, and whether it clears the law — is decided by which way the flux turns there. Pulegone reductase sends it forward, down the line toward menthone and then menthol, the road we want. But a second enzyme stands at the same fork: **menthofuran synthase**, a cytochrome P450 designated CYP71A32, which pulls pulegone off the line entirely and converts it to **menthofuran** — a compound that is at once an off-note and a liability, and the single most important thing a cooling-plant designer has to control.

As a flavor, menthofuran is the staleness of old mint: musty, medicinal, flat, the note that separates a cheap peppermint from a cutting-garden one. A little is part of the natural complexity; too much, and the oil reads tired before it is tasted. But menthofuran is more than an off-note, and this is where a monograph has to turn, briefly and carefully, to the law. Menthofuran and residual **pulegone** are the two components regulators actually restrict in mint-flavored foods and drinks, because at high intake the compounds raise genuine safety questions, and food law in the major markets caps them accordingly. The limits are real and specific — on the order of tens to a couple hundred milligrams per kilogram depending on the product category, and tighter for beverages, where intake is highest, than for confectionery. A conventional mint that runs hot on menthofuran sometimes has to be blended down, stripped, or rectified to clear those ceilings, and every one of those corrections costs the oil some of its character. The grower's quality problem and the regulator's safety limit are, molecule for molecule, the *same* problem — and a plant that solves one solves the other.

The off-ramp is not even constant, which is the cruelest part. **Menthofuran synthase runs harder when the plant is stressed** — heat, drought, a hard season push flux toward the off-note — so a wild mint's cleanliness wanders with the weather, and a field that cleared the regulatory limit in a mild year can breach it in a brutal one without anything about the farming having changed. This is the deep reason mint has always been a variable crop: the single enzyme that most determines the oil's grade is also the one most sensitive to a summer the grower cannot control. The traditional industry manages this with testing, blending, and rectification — buying oil by assay, cutting high-menthofuran lots with cleaner ones, correcting the blend to hit a spec — a whole apparatus of downstream correction built around the fact that the plant cannot be trusted to make clean oil on its own.

Our answer is to close the door at the source, and it is the clearest single example in this whole library of a principle we keep returning to: **the biggest wins come not from making more of the good molecule but from not making the bad one.** We silence menthofuran synthase — by deleting its promoter or by RNA interference against its transcript — and the fork at pulegone stops branching. The flux that used to leak into menthofuran stays on the line, carried forward to menthol; the musty off-note vanishes at its source; and residual pulegone falls as well, because the pulegone that would have fed the off-ramp is now pulled onward instead of pooling. One silenced enzyme does three good things at once: it cleans the flavor, it raises the menthol yield slightly by recovering lost flux, and it drops both restricted compounds below their legal ceilings *by construction* rather than by correction. A mint engineered with the off-ramp shut clears the regulatory limits the way it clears them in a kind season — always — and keeps its full character while doing it, because nothing had to be stripped out to make it compliant.

There is something almost poignant in why the door was ever open. The wild mint kept its menthofuran branch because nothing in the plant's life ever punished it for the off-note — a plant has no palate, and the mustiness that offends a confectioner is invisible to natural selection, which cannot see a flavor it has no tongue to taste. The branch persisted not because it helped the plant but because it never hurt it, a vestige of the pathway's evolutionary history left switched on for no reason except that evolution had no reason to switch it off. We are, in a real sense, finishing a job the plant had no cause to finish: bringing a wild chemistry the last distance to a human standard it was never shaped toward. The plant was already a superb chemist of cold; it simply never knew it was also making a mistake, because the mistake cost it nothing. We can see the mistake, we can measure it, and — holding the whole pathway to ≤7% batch-to-batch variance — we can close it for good, so that the clean cold the plant builds on its best days is the cold it builds on every day. That is the single most valuable edit in the cooling program, and it is, fittingly, an edit that *removes* rather than adds.

Chapter 9 · Designing the Cold — *the model picks the mutation.*

The method does not change when the molecule changes. The same three-stage pipeline that redesigned our capsaicin acyltransferase to reach nearly three million Scoville units redesigns the menthol pathway's enzymes to pour clean cold — because the pipeline was never about capsaicin, or about heat. It is about **enzymes**, and an enzyme is an enzyme whether it builds a fire or a frost. We run all three stages on the cooling plants exactly as we ran them on the peppers, and the transfer is nearly total, which is itself the proof of the platform's thesis: a general method for designing flavor, pointed now at the cold.



An edited line isolated for validation. Every designed substitution earns its place on the bench, not in the model — the pipeline ranks the candidates, and the plant decides which ones were right.

First, a genome-scale flux-balance model tells us where the real bottleneck is. Flux-balance analysis treats the cell's metabolism as a system of linear constraints: every reaction a variable, the stoichiometry a matrix **S**, and the steady-state requirement that nothing accumulate written simply as **S·v = 0**, with bounds on each flux v. Hand that system an objective — maximize menthol output through the trichome network — and a linear-programming solver returns the flux distribution that achieves it and, more valuably, the *shadow prices* that reveal which constraint is actually binding. It is tempting to assume the last enzyme, menthone:menthol reductase, is the thing to push: it makes the final cold, so make more of it. The flux model says otherwise, more often than not. Modeling the whole network — precursor supply from the MEP pathway, GPP synthase throughput, the branch points, the NADPH budget the reductases draw on — repeatedly identifies **precursor flux to GPP** and the **pulegone fork** as the true rate limiters, not the terminal reductase. Pushing the last enzyme when the bottleneck is upstream just backs product up against a closed valve. The flux model is how we avoid spending a plant's energy in the wrong place — the same lesson we learned on peppers, where the model found control sits upstream in the phenylpropanoid pathway — at 4CL and HCT — not at the terminal Pun1/AT3 acyltransferase step, and the discipline of following the model rather than intuition transfers whole.

Second, a protein language model — an ESM2-class network with 650 million parameters, trained on tens of millions of natural protein sequences until it has internalized, statistically, what a working protein looks like — scores every possible single-residue substitution in each target enzyme. The scoring is elegant in its simplicity: mask a position, ask the model how probable each amino acid is there given the rest of the sequence, and read the log-likelihood difference between a proposed variant and the wild type as a prediction of whether the substitution helps or harms. A change the model finds *more* natural than the original is a candidate improvement; one it finds jarring is a likely loss. We fold that ranking against a structural confidence analysis — the pLDDT and predicted-aligned-error maps that say which regions of the modeled enzyme are trustworthy enough to edit — and we never touch a low-confidence loop. We edit where the model is sure of the fold and sure of the gain. Instead of guessing which mutation might speed pulegone reductase or sharpen the stereoselectivity of the final reductase, we let a model that has read the whole protein world rank all of them, and we test the top of the list.

Third, CRISPR writes the chosen edits into the plant, and we measure. Peppermint makes this both harder and easier than it sounds — harder because the plant is a sterile hybrid with no seed to work through, so edits are delivered into leaf tissue or protoplasts and the plant regenerated from them; easier because that same sterility means a successful edit is locked into a clone and propagated forward indefinitely without ever segregating away, exactly the point we made in Chapter 3. Here is a representative design slate for the cooling program — the strategy, not a promise, because every edit is assessed through the full design pipeline before it earns a place in a cultivar:

TARGET	STRATEGY	INTENDED EFFECT	ΔΔG (KCAL/MOL)
Pulegone reductase (PR)	A128V	↑ turnover toward (−)-menthone	−1.6
Menthone:menthol reductase (MMR)	S52T	↑ stereoselectivity for (−)-menthol	−1.1
GPP synthase	promoter up-regulation	↑ precursor flux (FBA-confirmed limiter)	–
Menthofuran synthase (MFS)	**promoter deletion / RNAi**	**↓ menthofuran, ↓ residual pulegone**	**–**

The ΔΔG column is the stability mathematics — negative values are stabilizing, the designed protein folding tighter than the wild type — and it is the number we trust least on its own and most in aggregate: any single prediction can miss, but a slate of stabilizing edits, validated, lifts an enzyme's effective output and, more importantly, its *consistency*. Which brings us to the number that matters most for a product rather than a demonstration. The entire platform holds to **≤7% batch-to-batch variance** — coefficient of variation, the standard deviation over the mean — against the 40-percent-plus that unimproved biology routinely shows, and for a cooling ingredient that specification is the whole ballgame. A confectioner cannot formulate around a mint that is clean one harvest and medicinal the next; a beverage brand cannot ship a cool that

wanders by a third between lots; an oral-care house cannot certify a cooling agent whose menthofuran rises in a hard summer. The redesigned enzymes do not only make *more* clean cold — by folding tighter and running truer, and by holding the off-ramp shut regardless of the weather, they make the *same* clean cold every time. And sameness, for anyone building a real product, is worth more than any single loud batch.

The star of the slate, as the last chapter promised, is the edit with no ΔΔG at all: silencing menthofuran synthase. Deleting that off-ramp does what a breeder could only ever approximate — removes the musty note at its source, recovers the lost flux, and clears the regulatory limits by construction, turning a flavor advantage and a safety advantage into a single genetic fact. This is the shape of nearly all our cooling work: the biggest wins come from closing a door the plant left open for no reason except that nothing in its life ever punished leaving it ajar. We do it with a model that reads proteins, a solver that reads metabolism, and a pair of molecular scissors — and the result is a leaf that is simply more itself: cold, clean, and the same every time. With the method in hand, we can finally turn to the plants, one at a time, and meet what the method made of each.



PART III OF VI

The Cooling Plants

peppermint · spearmint · eucalyptus & camphor · lavender · cold where you don't look

Chapter 10 · Peppermint — *the 2,360-construct heart.*

If the cooling axis has a home organism, it is peppermint, and the number that says so is **2,360** — the count of engineered constructs in our peppermint library, the deepest single-organism cooling program we run and one of the largest bodies of work we have built around any plant in the whole platform, behind only the headline crops. Peppermint earns that depth. It is the loudest natural cold there is, the species that makes (–)-menthol most cleanly, the plant a century of chemistry already mapped down to the last enzyme, and the sterile clone whose particular frustrations — no seed, one genetic individual, a fungus it could not out-breed — make it the plant precision editing was practically invented to rescue. When we decided to take the thermal axis seriously, peppermint was less a choice than a recognition: this is where the cold already lives, and our work is to make the plant more fully itself.

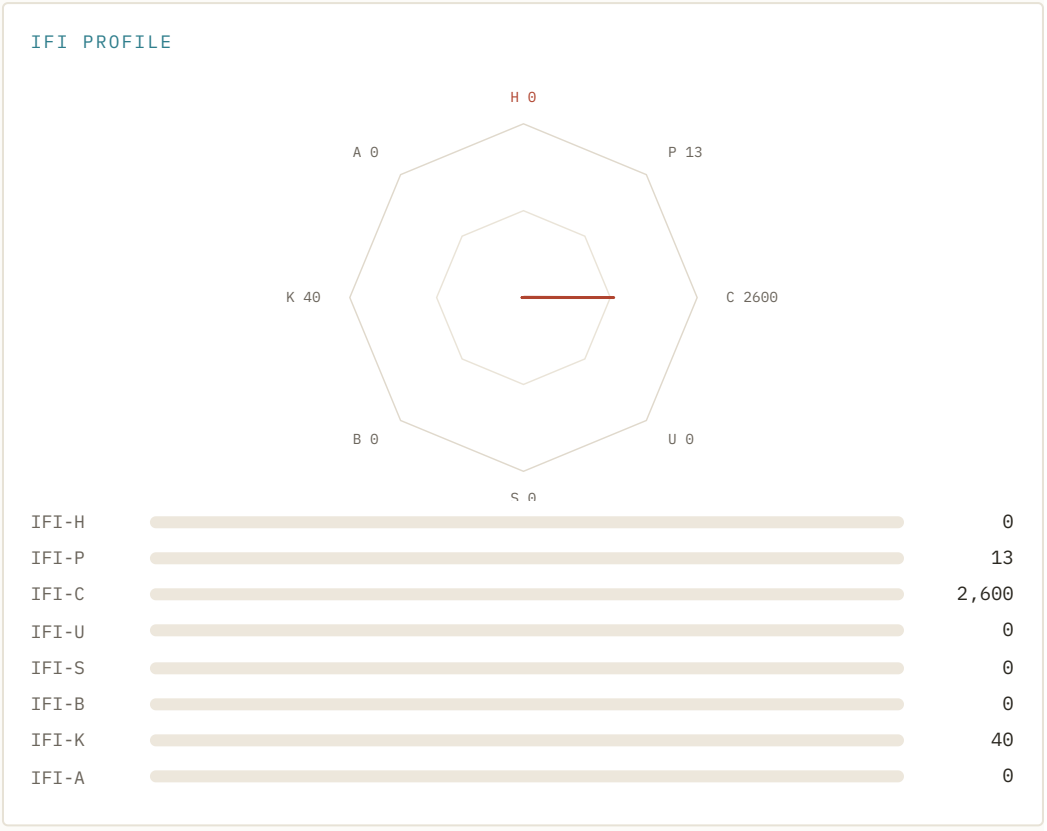


A research line in flower. Peppermint's sterility shows here — the blooms set almost no viable seed — which is exactly why every improvement must be written into the clone and carried forward as a cutting.

The 2,360 constructs are not 2,360 scattered experiments; they sort into a handful of **design families**, and the sorting is the clearest way to see the whole program at once. We do not issue these as a ladder of catalog SKUs the way the superhot peppers climb from Ember to Phoenix — mint is not sold as a threat level — but as lines, each a different answer to a different thing a formulator might want from the cold:

DESIGN FAMILY	WHAT IT CHANGES	WHY IT MATTERS
Clean-cool lines	MFS silenced, pulegone starved	removes the musty off-note; clears regulatory limits
Loud lines	GPPS and PR up, flux to menthol raised	more total menthol; faster, fuller cold
Long lines	trichome density up, ester balance tuned	built-in slow-release coolant; lasting cool
Composed lines	whole oil profile specified	mint tuned like an instrument, menthofuran at zero
Hardy lines	pathway stability under heat/drought stress	the off-ramp stays shut in a hard season

The ladder of refinement runs top to bottom. At the base sits the **clean-cool line**: menthofuran synthase silenced, residual pulegone starved, the musty note gone, so the cold reads purer than any field mint ever has — and this alone is transformative for a flavor house that has fought mint variability forever, because it is a mint that needs no rectifying to clear a spec. Above it, the **loud line**, the flux-balance-guided edits that push total menthol higher, for a faster and fuller cold. Above that, the **long line**, trichome density increased and the menthol-ester balance tuned so the oil carries more of its own slow-release coolant and the cold lasts in the mouth. Then the **composed line**, where we no longer accept the oil peppermint happens to make and instead specify it to the molecule — this much menthol for the front, this much menthone for warmth, this little menthyl acetate for roundness, menthofuran at zero — a mint tuned like an instrument. And the quiet, essential **hardy line**, which does not change the oil at rest but keeps it from degrading under stress, so a field in a brutal summer still makes the clean cold it made in a mild one. For a crop that is a single clone facing a warming climate, hardiness is not a luxury; it is survival with the flavor kept.



Read that scorecard and the plant's whole character is in it. The Cool-Burn axis towers at **2,600** — more than two and a half times the menthol anchor, a clean cold loud enough to carry a product on its own. A small Pungency reading of 60 is the faint, intentional TRPA1 edge that keeps the cool from feeling flat, the barely-there prickle that makes a mint feel alive rather than merely cold; push it

higher and you tip toward a cool-burn lozenge that bites as it chills, drop it to zero and you get a beverage mint so smooth it almost disappears. The trace of Kokumi at 40 is the slight mouth-coating body the designed oil carries, a roundness that keeps the cold from reading thin. Everything else is zero, and the zeros are the point: this is not a flavor trying to be many things. It is one axis, built as loud and as clean as a plant can build it, which is exactly what a confectioner, a beverage maker, or an oral-care formulator wants to start from — a pure, placeable cold. Peppermint is the heart of this book because it is the plant that gave the thermal axis both its anchor and its ambition: the memory everyone carries of what cold tastes like, now grown truer, cleaner, and steadier than the memory.

Chapter 11 · Spearmint — *carvone, and a fork in the second step.*

The most useful thing we can tell you about spearmint is that it is not a quieter peppermint. It is a *different cold*, built from a different molecule, read by the receptor in a different way — and treating it as a milder version of its famous cousin is the single most common way to formulate it badly. Peppermint's cold is menthol speaking loudly to TRPM8. Spearmint's cool is **carvone**, a monoterpene that is minty and fresh and faintly sweet but barely touches the cold channel at all. So when people call spearmint "milder," they are half right and wholly imprecise: it is not a weaker signal, it is a softer, rounder, warmer sensation that the brain files under *mint* by long association more than by any genuine cold. Understanding that one fact is the difference between designing spearmint well and designing it as a disappointment.

The pathway tells the whole story, and it diverges from peppermint's at a single enzyme's choice, early. Both mints start from the same limonene built in step one. Peppermint hydroxylates that ring at **carbon three** — limonene-3-hydroxylase, the committing oxidation of the menthol road — and heads down the seven-step line we traced in Chapter 7 toward the cold. Spearmint hydroxylates at **carbon six** instead, using a different P450, **limonene-6-hydroxylase**, and the single changed position sends the whole trichome down another road entirely: to trans-carveol, which a dehydrogenase lifts to **(−)-carvone**, and there the line essentially stops, the carvone being the destination rather than a waypoint to something colder. One enzyme, one carbon, and the plant's entire sensory identity forks — menthol or carvone, cold or merely fresh. This is why the two mints, so alike on the plate, are genuinely separate engineering problems: they share a precursor and almost nothing after it, and a design that improves one says little about the other.

Carvone, like menthol, comes in two hands, and here the handedness is almost comic in its clarity. **(−)-carvone**, R-carvone, smells and tastes of spearmint. Its mirror image, **(+)-carvone**, S-carvone, smells and tastes of **caraway** — rye bread, not chewing gum. The same molecule flipped left to right swaps one of the most recognizable flavors in the world for a completely different one, a demonstration of chirality so vivid we keep both enantiomers on the bench to hand to visitors who doubt that three-dimensional shape is everything. Smell one, then the other, and the abstract idea that a receptor reads form becomes a thing you have experienced with your own nose. Spearmint's whole identity is one hand of one molecule, which means a spearmint program is, at its core, a program to make (−)-carvone cleanly and abundantly and to keep its caraway mirror image out.

Our spearmint library is small — **80 constructs** against peppermint's 2,360 — and the smallness is not neglect but chemistry. Spearmint's route is shorter and simpler to steer once the carvone branch is understood; there is less pathway to tune, and the market pulls

hardest on the loud cold that peppermint supplies, so the depth went where the depth was needed. The 80 constructs we do build concentrate on what actually matters for this plant: carvone purity, holding the caraway enantiomer to near nothing, and lifting the sweet-fresh balance that is spearmint's whole appeal.

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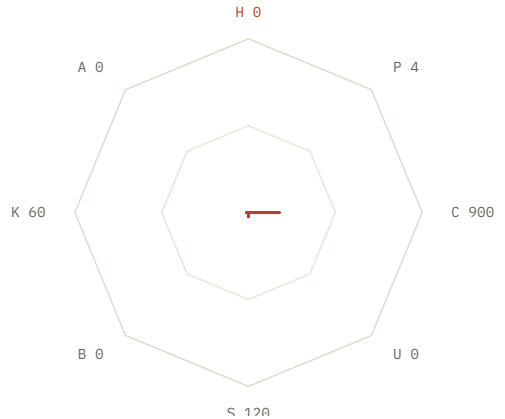


IFI-H	0
IFI-P	4
IFI-C	900
IFI-U	0
IFI-S	120
IFI-B	0
IFI-K	60
IFI-A	0

The scorecard tells the honest story, and we will not inflate a number to flatter a plant. Cool-Burn reads **900** — real and present but well below peppermint's 2,600, because carvone simply does not drive TRPM8 the way menthol does. But look at the Sweetness reading of 120, which peppermint's card does not carry: spearmint's carvone brings a genuine sweet-fresh roundness, and that roundness is the reason spearmint owns the gum and the toothpaste aimed at everyone who finds peppermint too sharp, too cold, too medicinal. Spearmint is the cool for someone who does not actually want to be *cold* — who wants fresh, clean, sweet-edged, gentle, the long exhale rather than the clean shock. That is a very large someone, and designing for them means resisting the temptation to make spearmint louder on the wrong axis. The best spearmint is not a colder spearmint; it is a cleaner, rounder, truer carvone, with the caraway held to zero and the sweetness allowed to sing. It is a plant whose virtue is restraint, which makes it a quiet pleasure to design and an easy one to ruin by overreaching.

Chapter 12 · Eucalyptus & Camphor — *the medicinal edge, and the cool that warms.*

There is a kind of cold that opens the chest, clears the nose, carries a whisper of the medicinal — the cool of a eucalyptus steam, a camphor rub, a strong herbal lozenge — and it comes from two plants that approach cold from opposite directions and meet in the middle. One cools genuinely but faintly, through volatility more than loudness. The other does not cool at all, in the strict sense, and yet reads as the most medicinal cool of them all. Together **eucalyptus** and **camphor** define the airy, respiratory, medicinal corner of the thermal axis, and they are among the subtlest design problems we work — and the two that most reward knowing the receptor precisely, because neither one behaves the way a naive reading of the word "cooling" would predict.



Ginger's warm chemistry — gingerols and shogaols speaking to the warm channels. Knowing the warm side precisely is how we keep it out of a cool that should stay clean, and how we fold it in when, as with camphor, a cool is supposed to turn.

Eucalyptus makes **1,8-cineole**, properly called eucalyptol, the molecule that *is* the smell of a eucalyptus grove, built in a single step by cineole synthase cyclizing GPP into a bicyclic ether. Its loudness on TRPM8 is low — an IFI-C near 23, near the bottom of the ladder — and yet its cooling effect feels far larger than that number, and the reason is one of the most instructive facts on the whole axis: **coverage can matter as much as loudness.** Cineole is intensely volatile; it lifts off into the nasal passage and the upper throat and

floods the trigeminal field of the entire airway, producing a cooling *openness*, a sense of breath moving more freely, that owes as much to how much sensory surface it touches as to how hard it drives any single receptor. This is the eucalyptus paradox in our framework: a quiet molecule that feels loud because it reaches so much of the mouth and airway at once. Our eucalyptus program — **80 constructs** — is therefore less about driving cineole's receptor loudness up, which hits a low ceiling anyway, than about tuning the oil's volatility and purity so the characteristic open, clean, respiratory cool arrives without the harsh camphoraceous and turpentine top notes that wild eucalyptus oils so often carry. A cleaner cineole, a calmer top note, a eucalyptus that opens the breath without scratching it.

Camphor is the stranger of the two and, pharmacologically, the one that teaches the most, because camphor is the plant that proves the axis is not a one-way street. It reads to nearly everyone as cooling — the aromatic chill of a chest rub, the medicinal coolness of a liniment — and yet it is mostly a *warming* molecule: an agonist of **TRPV3**, the skin and mouth's gentle warm sensor, and at the same time a mild *blocker* of TRPM8, the cold channel itself. TRPV3 answers warmth in the comfortable 32–39 °C band and, unusually, *sensitizes* with repeated exposure rather than desensitizing, so camphor's warmth can build across successive tastes where menthol's cold fades. Camphor's "cool," in other words, is a sensory illusion assembled from sharpness, volatility, and warmth rather than from any genuine cold signal — a vivid reminder that the mouth's thermal report is a composite the brain puts together, and that a clever molecule can counterfeit the composite without ever touching the channel you would expect. The molecule is made in the camphor laurel, *Cinnamomum camphora*, down a short terpene branch — GPP cyclized to bornyl diphosphate, hydrolyzed to borneol, oxidized to camphor — three steps to one of the most distinctive aromatic molecules in the plant world.

Our camphor library is the smallest cooling program we run — **40 constructs** — and it exists not because camphor is a volume flavor but because camphor is a *tool*: the one plant-made molecule that lets us put a warming, medicinal depth underneath a cooling impression, the paradox of this axis grown in a leaf. A winter lozenge, a warming balm-flavored confection, a cold that should carry an undertow of heat — camphor supplies what no pure coolant can. Designing it is almost entirely a study in restraint, because camphor is powerful and, overdone, genuinely unpleasant, flooding a formulation and reading as harsh and medicinal; the art is a trace, placed exactly. Lay the five cooling plants of the core palette side by side and the shape of the region comes clear:

PLANT	CONSTRUCTS	KEY MOLECULE	RECEPTOR ACTION	CHARACTER
Peppermint	2,360	(−)-menthol	TRPM8 agonist (loud)	clean cold
Spearmint	80	(−)-carvone	weak TRPM8	fresh, sweet
Lavender	160	linalool	very weak TRPM8	floral calm
Eucalyptus	80	1,8-cineole	weak TRPM8, volatile	respiratory open
Camphor	40	camphor	TRPV3 agonist, TRPM8 blocker	warm medicinal

No single plant *is* the cool; the cool is a region, and these five plants are the points we have learned to grow within it — peppermint the loud cold at the center, spearmint the sweet-fresh variation, eucalyptus the airy openness at one edge, lavender the floral calm at another, and camphor the warm paradox at the far side, where cool turns back into warmth. The palette is small on purpose. Mastery of a small palette, understood to the enzyme and the receptor, is worth more than a large one half-known, and these five plants are enough to place a product almost anywhere a person has ever wanted the cold to live — and a few places no one has tasted yet, which is the chapter after next.

Chapter 13 · Lavender — *calm you can taste, and a promise we will not make.*

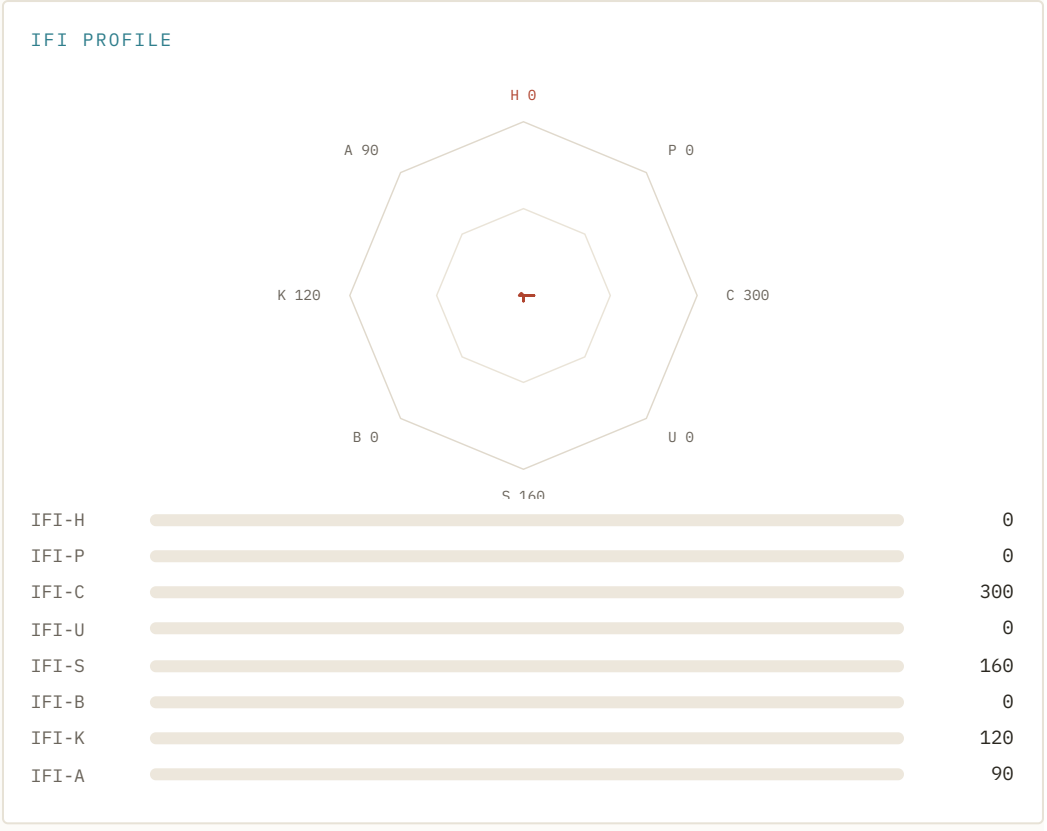
Lavender is the quietest plant in this book and, in some ways, the most interesting, because its cool is barely a cool at all in the receptor sense and yet unmistakably cooling to anyone who has tasted it. The explanation is a lesson the thermal axis keeps teaching: the mouth's sense of cool is a composite the brain assembles from several streams — the cold channel, the nose, the body's whole sense of ease — and a molecule can lower that composite without ever raising its voice to TRPM8. Lavender's **linalool** registers near an IFI-C of 40, a faint touch on the cold channel, but the sensation it produces reads as a cool *calm*, an aromatic coolness that arrives as much through scent and the sense of a settled room as through any thermal nerve. Lavender cools the way a shaded room cools: not by dropping a temperature but by changing the whole mood of the air.



A dewed morning — the quiet, settled coolness lavender trades in. Its chill is not the clean shock of menthol but the implied cool of shade, of cool linen, of a still room at the end of a day.

Our lavender library is **160 constructs** — more than any of the other minor cooling plants, and the number is a measure of how fine the plant's margin is, not how loud it can be made. Lavender's value is precision, not volume, because a loud lavender is an unpleasant lavender. The oil is a blend dominated by two molecules that are chemically a single breath apart: **linalool**, a free alcohol, and **linalyl acetate**, that same alcohol capped with an acetate ester. The ratio between those two is the entire character of the plant. Too much

free linalool and it turns sharp, almost soapy, the harsh edge of a cheap lavender soap; too much acetate and it goes flat and sweetly dull; the beautiful lavender, the one that reads as clean floral calm, holds a particular balance between them — a balance that varies wildly between species and seasons. Fine lavender, *Lavandula angustifolia*, holds a graceful ratio and almost no camphor. Its coarser cousin spike lavender and the vigorous commercial hybrid lavandin both carry more camphor and a rougher, more medicinal profile — cheaper to grow, harder to love. A breeder chases the fine balance across years of selection and never quite fixes it against the weather. We specify it: holding the linalool-to-acetate ratio to a chosen value and the camphor contamination to near zero, at ≤7% variance, so that every harvest reads the same calm, the same cool, the same soft floral a perfumer or a confectioner or a tea blender can build on without hedging against the vintage.



The scorecard is a portrait of restraint, and it is worth reading as a *chord* rather than a note. Cool-Burn at **300** — modest, honest, a floral coolness and not a cold. Sweetness at 160 and Kokumi at 120 give lavender its roundness and its gentle body, the soft fullness that keeps it from reading thin; a faint Astringency at 90 is the slight dryness that keeps it from cloying. There is no single towering axis here, and that is the whole point of lavender: it is a *composition*, a balanced small chord rather than a loud single note. A plant whose value is in its proportion rewards a design platform more than almost

any other, because where peppermint asks us to make one axis enormous, lavender asks us to make five small axes sit in a particular, unwavering relationship — the harder problem, and the one precision serves best. A loud plant forgives a clumsy hand; a balanced one does not, and lavender is where the discipline of ≤7% stops being a specification and becomes the difference between a flavor and a mess.

This is also the chapter where the ethos of the whole library comes nearest the surface, and where we have to be most careful with our words. Lavender has carried associations of calm and rest for as long as people have grown it — strewn in linen, tucked under pillows, steeped at the end of a hard day — and we honor those associations, because they are real to the people who hold them, and a cup of lavender tea in the quiet of an evening is a genuine kindness someone gives themselves. But we make no claim on anyone's nervous system. We do not say lavender calms; we say lavender *tastes and smells of calm*, that it produces a cool floral sensation the mind has long associated with ease, and that we have learned to make that sensation clean and constant. The distinction is not legal hair-splitting. It is respect — for the reader, who deserves a flavor and not a false promise, and for the plant, which is remarkable enough as a flavor that it needs no medicine draped over it. The nourishment this library cares about lives in the intention behind a thing grown well, never in a claim about what it will do to a body. Lavender, of all the cooling plants, is where that line is thinnest and where we hold it hardest.

Chapter 14 · Cold Where You Don't Look — *citrus, cucumber, and the cool that moves.*

The most quietly radical thing a design platform does is move a sensation into a plant that never had it. Capsaicin out of peppers and into a tomato; menthol's logic out of mint and into a fruit. The thermal axis is where this gets strangest and most delightful, because cool is a sensation people associate with a very short list of plants — mint, mostly — and the moment you put a genuine, clean cold into something that has no business being cold, you have made a thing the world has never tasted. This chapter is about cold where you do not look for it, and about the two plants that taught us the most about reaching it: the orange and the cucumber.

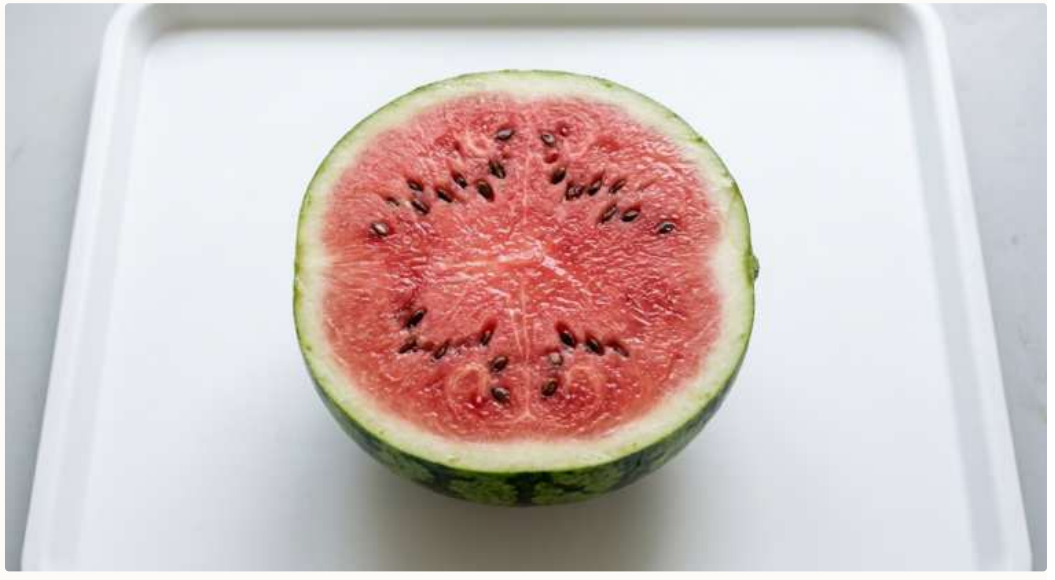


An orange in cross-section. Citrus already runs the hardest part of the cooling pathway — it makes limonene in quantity in its oil glands — and lacks only the handful of downstream steps that would carry a slice of it toward a cold molecule.

Orange is the more tractable of the two, because it is already halfway there, and the shared index gives the game away: orange carries two axes, Zero-Bitter and Cool-Burn, and the Cool-Burn is no accident. Citrus and mint share a precursor — **limonene**, the citrusy molecule that is the first committed step of the menthol pathway. An orange is, in a sense, a plant that makes the raw material of cold and then stops, turning its limonene toward the bright aromatics of citrus rather than down the road toward menthol. Which means the road is

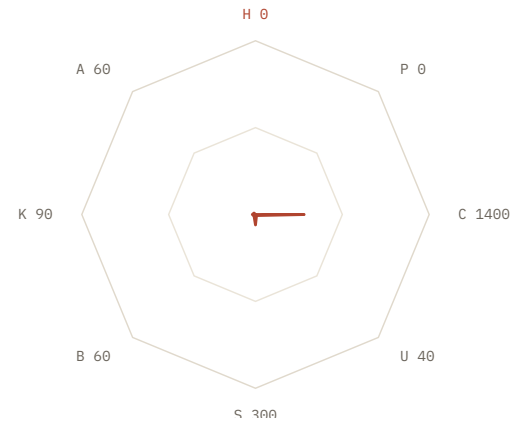
already half-built. The orange runs the hardest part on its own — it makes limonene in quantity, in the oil glands that spray when you tear the peel — and what it lacks is only the handful of downstream steps that would divert a controlled slice of that limonene toward a genuine cooling note. Our orange program — **120 constructs** — explores exactly this: installing a mint-like hydroxylation-and-reduction branch to send a measured fraction of the limonene flux into a real cold molecule *inside a citrus*, a "cool orange" that is not flavored with mint but actually makes a cold molecule of its own. And because orange carries the Zero-Bitter axis too, the same program turns the fruit's bitter load of limonin and naringin down — the 20-to-65-percent attenuation we make on coffee and brassica — so the result reads sweet and cold-bright rather than sweet and faintly resentful. The fruit tastes, at last, the way it has always smelled: lifted, clean, cool at the rim. It is the organism we reach for when a cooling note should feel like sunlight rather than frost.

Cucumber is the deeper lesson, because cucumber is the plant whose name *means* cool — "cool as a cucumber" — and yet cucumber makes almost no cooling molecule at all. Its famous coolness is a trick of water and freshness: a high-water flesh usually sitting a little below mouth temperature, plus a faint, green, almost melon-like aroma carried by a pair of nine-carbon aldehydes, the molecule that *is* the smell of a cut cucumber chief among them. There is no menthol in it, no carvone, nothing that touches TRPM8 — the coolness is entirely a sensation of clean wet green that the culture long ago rounded up to "cool." Cucumber taught us to separate the *idea* of cool from the *chemistry* of cool: a plant can be culturally, associatively cool without firing the cold channel once. And that separation is precisely the opening a design platform exploits. A cucumber that already reads as cool to the mind, given a genuine designed cooling molecule — a trace of clean menthol-like cold laid into the fruit's own fresh-green frame — becomes cool twice over, once by reputation and once by receptor, and the two coolnesses reinforce each other the way menthol and ice do, each lending the other credibility.



A melon in cross-section — cucumber's cucurbit cousin, another high-water, faintly green canvas where a designed cold reads not as an intrusion but as the fruit simply becoming more of what its name already promised.

IFI PROFILE



IFI-H	0
IFI-P	0
IFI-C	1,400
IFI-U	40
IFI-S	300
IFI-B	60
IFI-K	90
IFI-A	60

That scorecard is a designed cool cucumber, and it is one of our favorite objects in the whole library. Cool-Burn at **1,400** — a real, loud cold, well above the menthol anchor, laid into a fruit that naturally scores near zero on the axis. The small Sweetness, Umami, and Kokumi readings are the cucumber's own fresh body, the green roundness that keeps it tasting like cucumber and not like a mint wearing a vegetable's skin. The result is coherent rather than monstrous — a cold that *belongs*, that reads as the cucumber finally delivering on its name, not as a novelty bolted on. This is the whole thesis of moving a sensation: not to make a plant into something else, but to let it become the fullest, most complete version of what it already half-is. The cool cucumber is not a trick. It is a cucumber that is, at last, as cool as we always said. And it points at a larger map — melon, lettuce, celery, the whole quiet family of green-fresh plants the culture already calls cooling — each one a canvas waiting for the real cold its reputation has been promising all along. Cold, it turns out, is not the property of six plants. It is a thing that can be grown wherever the precursor already runs, which is nearly everywhere, and that is the quiet frontier under this entire monograph.



PART IV OF VI

Fire, Ice & the Blend

cool inside fire · the counterpoint · the longer cold · the plant against the reactor

Chapter 15 · Cool Inside Fire — *Phoenix and the thermal counterpoint.*

The strangest thing we have ever grown is a pepper that is cold. Not cold instead of hot — cold *and* hot, at full volume, in the same bite, a fruit that drives the heat channel and the cold channel at once until the mouth, receiving two true and opposite reports simultaneously, stops being able to tell you what temperature it is. This is **Phoenix**, SKU **SS-0096**, the final cultivar in our flagship superhot series, the first plant engineered to register on all eight axes of the Index at once — and the clearest proof the cooling plants have ever given us that cool and burn are not opposites but neighbors, close enough to hold in one hand. It belongs in a monograph on the cooling plants precisely because it is where the cold goes to do its most impossible work: not in a mint, where cold is expected, but inside the hottest plant on earth, where it has no business being at all.



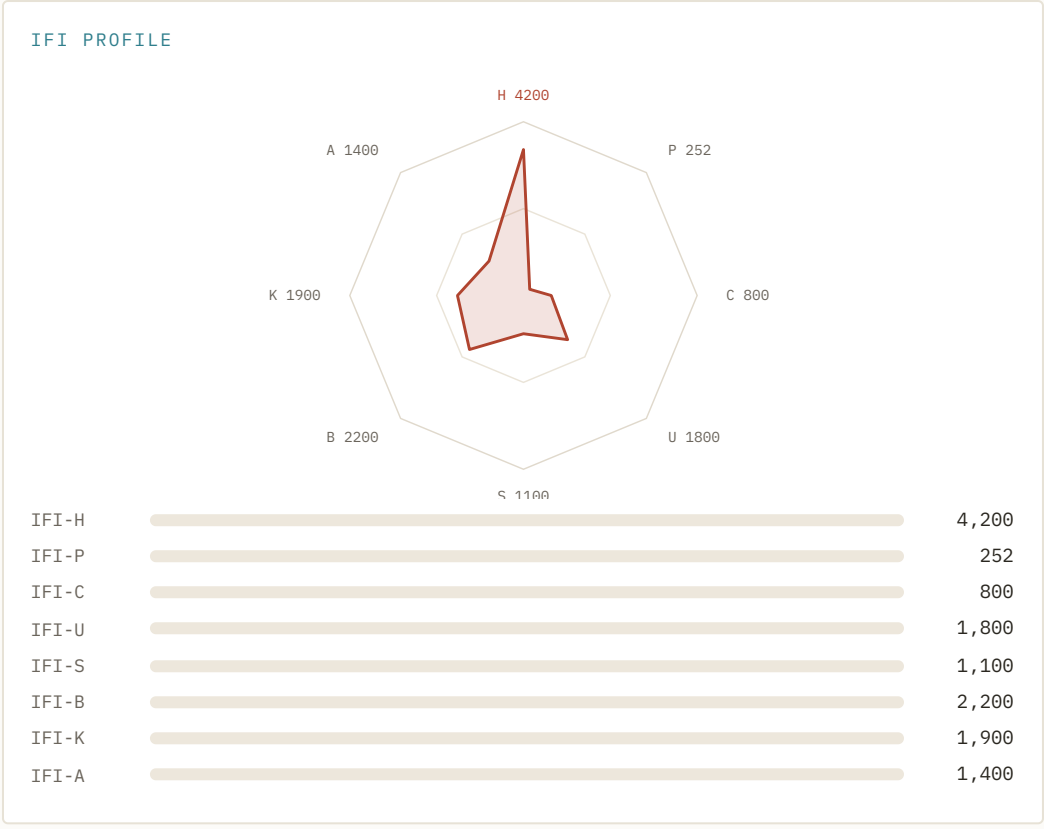
Phoenix (SS-0096) on the microscope stage — our model predicts approximately 2.95 million SHU of heat, and a designed, deliberate cold running underneath it. Eight axes, fire and ice among them, in a single fruit.

Phoenix is best known for its heat — our model predicts approximately **2,937,948 Scoville units** (2.95 million SHU), an IFI-H of **4,200**, the loudest designed burn in the library, built on two AI-designed substitutions in the capsaicin acyltransferase Pun1 (**S39L+L345G**), written in by CRISPR and held to ≤7% batch variance against the 42% that unimproved peppers show. It sits at the top of a ladder the superhot program climbed one cultivar at a time, each rung adding heat and, past a point, adding whole axes:

CULTIVAR	SKU	SHU	IFI-H	AXES
Ember	SS-0087	866K	1,570	2/8
Blaze	SS-0091	1.72M	2,630	4/8
Firestorm	SS-0094	2.47M	3,490	6/8
Phoenix	**SS-0096**	**2.95M**	**4,200**	**8/8**

SHU values are computational predictions from our flux-balance model.

That heat is the headline. But the reason Phoenix closes the flagship series, the reason it is the eight-axis plant, is everything riding alongside the fire — and on the thermal axis, that means a **designed Cool-Burn of 800**, the cold pathway's logic deliberately installed in a plant that had only ever known heat:



Eight hundred is not a loud cold — it sits below the menthol anchor, a cool you would call gentle in a mint — but in a pepper carrying 4,200 of heat it is extraordinary, because it means the fruit is driving TRPM8 while it drives TRPV1, running the two thermal sentinels at once. Here the labeled-line coding of the sensory nerves pays off in the strangest possible way. Because cool and heat travel on separate wires to the brain — TRPM8's cold line and TRPV1's hot line — they do not cancel the way two numbers of opposite sign would. The brain does not average them into "lukewarm." It receives both,

at full volume, as two true and simultaneous facts, and it has no template for that, because nothing in the natural world is ever both freezing and burning at the same instant. What does that *taste* like? It tastes like a contradiction the mouth cannot resolve. The heat arrives first and enormous, a wall of TRPV1 fire; and then, threaded through it, impossibly, a cold — a menthol-like lift that should not be there, that the brain keeps trying to file as relief and cannot, because the fire is still climbing. Cool and burn, the two faces of this axis, fused in a single fruit, each one true.

And that eight hundred is one of the most carefully chosen numbers in the whole catalog, because two thermal channels competing for the same mouth do not simply add — a naive stack cancels itself, the cold reading as confusion rather than counterpoint. Set the cold too loud and it fights the heat and the fruit reads as muddled; set it here, just below the menthol reference, and the chill does not fight the burn — it *frames* it, a cool lining under nearly three million Scoville units that makes the heat read sharper and arrive cleaner. The platform's flux-balance model finds the ratio that holds, and on Phoenix that ratio is 4,200 of heat to 800 of cold. We designed it deliberately, and the design is a small masterpiece of pathway transfer: a trace of the menthol route's logic — the downstream reductions that make a cold molecule — laid into a *Capsicum chinense* that already runs its capsaicinoid pathway at full tilt, so the one fruit builds a cold counterfeit and a hot counterfeit in the same flesh. It is the exact move as the cool cucumber of the last chapter, run in the opposite emotional register: there, cold laid into a plant the culture already called cool; here, cold laid into the hottest plant on earth, precisely because the contradiction is the point.

Phoenix is not a fruit you cook with casually — it is a demonstration, the eight-axis flag planted at the summit of the superhot program, the plant that proves the platform can put any axis into any plant. But its lesson belongs to this whole book, and it is the lesson that closes Part III and opens this one: the thermal axis is called Cool-Burn because at the extreme, cool and burn are reachable from the same design. Turn the heat pathway up and the cold pathway up in the same fruit and you get both — not a cancellation but a counterpoint, two melodies the mouth plays at once. Everything gentler in this volume — the clean beverage mint, the floral lavender, the cool cucumber — lives somewhere on the line between Phoenix's two poles. Phoenix is where the line's ends touch, and it taught us that the cold has no true opposite inside the thermal axis, only a distance we can choose to collapse.

Chapter 16 · The Longer Cold — *the blend, and the plant against the reactor.*

Loud is easy. Lasting is the whole craft. Everything to this point has been about how cold a cooling plant can be made; this chapter is about the second dimension, the one most products fail on — how *long* the cold holds in the mouth before it fades — and it is where the plant's menthol meets the industry's synthetic coolants and has to earn its place beside them. The governing problem is the desensitization of Chapter 5, and it is worth restating as a clearance problem, because that is how a formulator can act on it. Free menthol arrives fast, floods TRPM8, drives a bright cold — and then two clocks start running against it. The first is the receptor's own: calcium entry depletes PIP2 and the channel adapts within tens of seconds. The second is the mouth's: saliva flows, dilutes, and washes the small volatile molecule down and away. A cooling agent that is all free menthol loses on both clocks at once — a firework, brilliant and brief.



Tea — the oldest vehicle for cool in a cup, and the place a formulator thinks hardest about duration, because a drink lets a cold be exactly as long as the slow pour allows.

The answer is a **blend across durations** — choosing molecules with different time constants τ so their fading curves overlap into a plateau instead of a spike. And here a monograph has to be honest about something, because the honesty is the point: the industry's longest, cleanest coolants are not plant molecules at all. They are **synthetic**, and a reader deserves to know which cold came out of a leaf and which came out of a reactor wearing a leaf's name:

COOLANT	SOURCE	IFI-C	FOOD STATUS	NOTE
Icilin	synthetic	5,000 (capped)	not food-approved	research superagonist
WS-3	synthetic	3,200	FEMA GRAS	odorless, long
WS-23	synthetic	2,290	FEMA GRAS	odorless, clean, long
(−)-Menthol	plant / synthetic	1,000	FEMA GRAS	the anchor
Menthyl lactate	semi-synthetic	533	FEMA GRAS	very long, mild
1,8-Cineole	plant	23	FEMA GRAS	respiratory, volatile
(−)-Carvone	plant	— (non-TRPM8)	FEMA GRAS	spearmint, fresh

The **Wilkinson Sword carboxamides** — WS-3, WS-23, and their siblings, named for the chemists who made them in the 1970s when a menthol shortage looked possible — are the clearest proof that the receptor pocket does not care about mint at all. They share no obvious shape with menthol; they are acyclic amides, not ring compounds carrying the familiar arms; and yet they fit the VSLD cavity and drive TRPM8 harder than menthol does, at IFI-C values of 3,200 and 2,290, with almost no smell or taste of their own. They are pure cool, flavor subtracted, indispensable where cold sensation is wanted but mint flavor is not. **Menthyl lactate** sits on the boundary — a plant-derived menthol skeleton capped with a reactor-made lactic-acid ester — and trades loudness for the long, gentle persistence an all-day product needs, its heavier, less volatile molecule arriving softly and lingering for many minutes after free menthol would have flashed away. **Icilin**, loud enough to peg the scale, is a research compound no plant makes and no one eats. So the layered cold of a great lozenge is usually a trio: a little free menthol for the immediate bright front everyone expects a mint to open with, menthyl lactate for the long tail, a trace of WS-23 for coverage of the throat the menthol misses — three τ's overlapping into a plateau.

Where, then, does a plant add value across a catalog half of which it cannot farm? We are honest about the line — our plants can grow a louder, cleaner, longer menthol, a better eucalyptol, a designed carvone; they cannot grow icilin or the carboxamides, and we would mislead you to imply otherwise. But the honesty points straight at the plant's real advantage, and it is the one the synthetics were invented to beat: **reproducibility**. The whole reason the Wilkinson Sword compounds took the oral-care shelf in the first place is that a reactor's WS-23 did not vary, while a grower's mint varied by harvest and by weather, its menthofuran rising in a hard season. The synthetics won on consistency, not on character — plant menthol is still the cold people prefer, the one with the familiar bloom and the natural-label honesty — and consistency is exactly what our platform restores to the leaf. A peppermint that holds ≤7% batch-to-batch variance, with its menthofuran silenced so it clears the regulatory limits by construction, takes back the one axis the synthetics always owned. It is a plant menthol with a reactor's reliability: the front of a blend that no longer needs a synthetic to

make it dependable. The long tail may still want a little menthyl lactate; the throat coverage may still want a trace of WS-23; but the heart of the cold, the part the label and the tongue both care about most, can finally be the leaf's own — loud, clean, and the same every time. That is the plant's claim restaked, and it is the whole commercial argument of the cooling program in a sentence: we did not set out to replace the reactor's coolants, but to make the plant's coolant good enough that, where a plant will do, no one needs the reactor at all.



PART V OF VI

Where Cool Is Sold

the mouth · the glass · the oldest home of the cold and its largest market

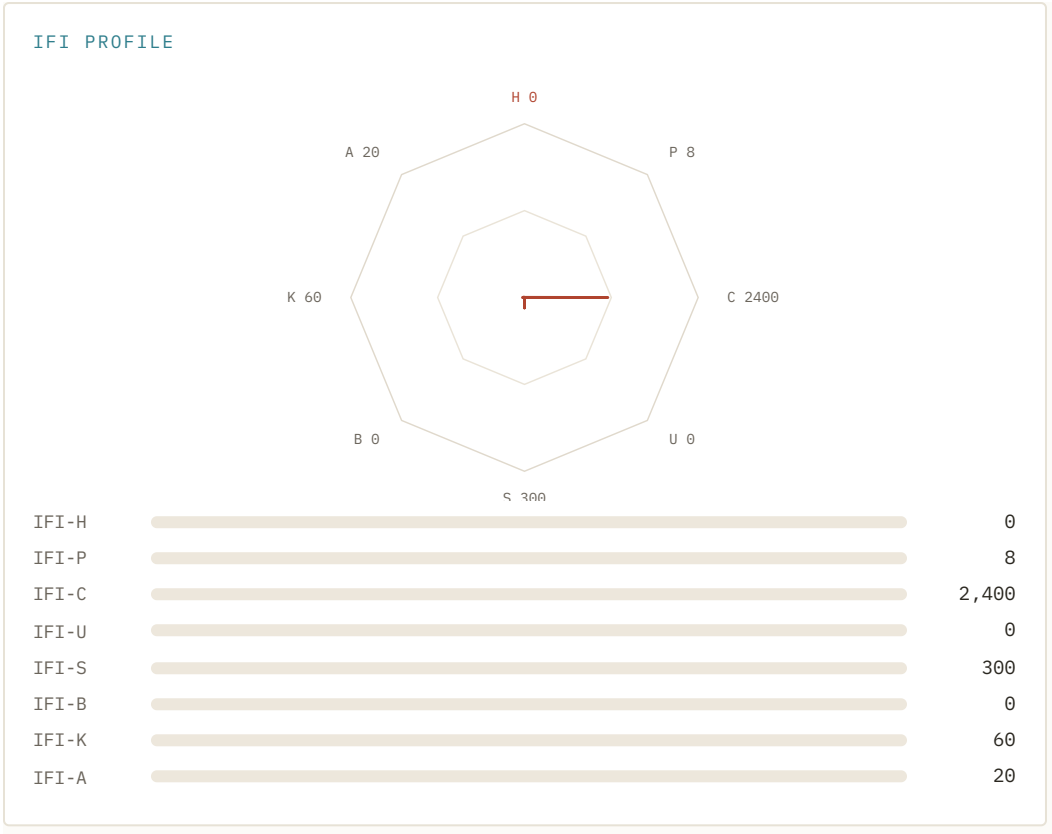
Chapter 17 · The Mouth — *the oldest home of the cold.*

The mouth is where cool was first commercialized, and it is still where the thermal axis lives most densely — the mint, the lozenge, the gum, the toothpaste, the cough drop, every one of them a tiny delivery device engineered to put a cooling molecule onto the trigeminal field and keep it there. Oral care and confection are, by volume, the largest market the cooling plants have ever had, and the oldest: people carried mint in the mouth to freshen the breath long before anyone could say why it worked. This is the chapter for the confectioner and the oral-care formulator, and its governing problem is the one the whole book has circled — not how loud the cold is, but how long — made concrete in two objects, a lozenge and a chocolate, each built from the molecule out.

The craft of a long lozenge is the craft of stacking the durations of Chapter 16 into a plateau, and it is worth walking through as a formulation, because the reasoning is the product:

```
SECOND-WIND COOLING LOZENGE · makes ~40 · oral-care / confection
— isomalt base                          200 g
— engineered clean-cool peppermint oil    0.9 g (menthofuran-free)
— menthyl lactate                         0.6 g
— WS-23 (cooling agent)                   0.15 g
— engineered spearmint oil                0.1 g (for a sweet-fresh round)
— citric acid                             a pinch
```

1. Melt the isomalt slowly to hard-crack, 165 °C, and let it fall to 130 °C off the heat — too hot and the volatile menthol flashes off before it is captured.
2. Stir in the menthyl lactate and WS-23 first; they are heat-stable and want full dispersion through the melt, and they are the long tail of the cold.
3. At the last moment, fold in the clean-cool peppermint and spearmint oils and the pinch of citric acid, working fast and gently to keep the volatiles in the melt rather than in the air.
4. Deposit into molds; cool fully before unmolding. The cool front is the peppermint; the long plateau is the lactate and WS-23; the sweet-fresh round is the spearmint; the acid lifts the whole thing and keeps it from going flat.



Note the sugar that is not there. The base is **isomalt**, not sucrose — this is a sugar-free confection, and that is not a diet gimmick but a design opportunity, because cool and sweet are cross-modally linked in the mind, and a well-built cool can carry the *impression* of sweetness past the point where the sugar stops. A cool this clean reads as refreshing, almost sweet, on its own, which is why the sugar-free lozenge does not taste deprived. We will say it plainly and only once, because the ethos of this library is a quiet one: leaving the sugar out is not a health claim and we make none. It is a choice about what a cool confection can be — a pleasure that asks a little less of the body — and the engineered cold is what makes that choice taste like abundance rather than absence. Here, too, the clean-cool peppermint earns its keep most visibly: a menthol front with no menthofuran muddying it, holding ≤7% batch to batch so the plateau is the same height every time, which for an oral-care house formulating at scale is worth more than any single loud lot.

The oldest mint pairing in all of confection deserves rebuilding from the molecule out as well, because it is where two of this library's engineered plants meet on one shard:

> DARK CHOCOLATE & COOL-MINT THINS · makes ~24 · vegetarian
> — dark chocolate, 70%, engineered low-bitter cacao 250 g
> — engineered clean-cool peppermint oil 4 drops (~0.2 g)
> — flaky salt to finish

1. Temper the chocolate — melt two-thirds to 45 °C, add the final third, bring it down to 31 °C, working it until it sets with a snap.
2. Stir the peppermint oil into the tempered chocolate; four drops is enough, and the clean engineered oil means no medicinal menthofuran edge to fight the cocoa, while the low-bitter cacao lets the cold read against sweetness instead of against a tannic wall.
3. Spread thin on parchment, scatter flaky salt, set at cool room temperature — not the refrigerator, which dulls both the cold and the sheen. Snap into shards.

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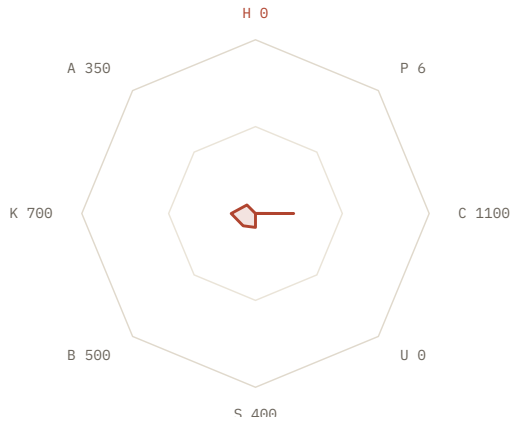

IFI-H		0
IFI-P		6
IFI-C		1,100
IFI-U		0
IFI-S		400
IFI-B		500
IFI-K		700
IFI-A		350

The chocolate card is a different balance from the lozenge, and reading the two side by side teaches the whole chapter. In the thins the cold at 1,100 is a *counterpoint* to the dark chocolate's body (K 700) and its softened bitterness (B 500, pulled down from where an ordinary dark chocolate would sit by the low-bitter cacao), the cold cutting the richness the way a mint chocolate always has — but cleaner, because the peppermint carries no off-note into the cocoa and the cacao carries less bitterness into the mint. Two engineered subtractions and one engineered cold, and the thing tastes like a window opening inside a dark room. The lozenge is cold as the whole point, carried as high and as long as a sugar-free confection can hold it; the chocolate is cold as a single bright line through richness. Same molecule, two jobs — which is exactly the versatility a placeable, clean, constant cold was built to give the confectioner, the thing a hundred years of variable mint never could.

Chapter 18 · The Glass — *the long, slow pour.*

Cool is, before it is anything else, a beverage sensation. More people meet the thermal axis in a glass than anywhere else — iced tea, mint water, a cold lemonade, a cocktail over ice — and the glass is where designed cold does some of its most useful work, because a drink can carry a cooling molecule into the mouth dissolved, dispersed, and paired with real cold in a way a solid never can. This is the chapter for the beverage maker, and it rests on the compounding logic of Chapter 5: real cold (ice) and counterfeit cold (the coolant) push TRPM8's half-activation voltage the same direction, so they do not merely add — they *multiply*. A cold mint drink is cooler than the sum of its mint and its ice, and the designer's job is to balance that synergy so it refreshes without tipping over the crest into a sting.



Tea in cross-section — the leaf that carries cool into a cup more often than any other. An engineered clean-cool mint, steeped or blended in, is tea's cold without tea's bitterness or mint's medicinal edge.

There is a solubility problem worth naming first, because it humbles every first attempt. Menthol barely dissolves in water; carry it into a drink naively and it beads, floats, and strikes the lip as a hot little slick of concentration instead of a smooth cool. The traditional answers are to infuse the whole leaf, so the oil arrives bound in plant matter and released slowly; to carry the coolant in a trace of alcohol or a syrup; or to reach for the water-friendlier cousins — menthyl lactate dissolves more kindly, WS-23 more kindly still. A good cool

drink is as much a dissolution problem as a flavor one. These four build the cold from the leaf, each a different balance of plant and temperature:

```
MOUNTAIN-MINT ICED TEA · serves 4 · vegetarian / zero added sugar
– green tea, engineered low-bitter       4 cups, brewed, cooled
– engineered clean-cool peppermint        1 small handful, bruised
– monk-fruit extract                      to taste
– lemon                                   1, juiced
– ice                                     to fill
```

1. Brew the green tea gently — our low-bitter tea line lets you steep longer for body without the tannic grab, so the cool has a soft bed to sit on rather than a bitter one to fight.
2. Bruise the engineered peppermint and steep it in the still-warm tea five minutes; the clean oil gives a cold lift with no medicinal tail, infused through the leaf so it carries smoothly into the water.
3. Sweeten lightly with monk fruit, sharpen with lemon, pour over a full glass of ice. The ice and the menthol multiply; the low-bitter tea keeps the base from fighting them.

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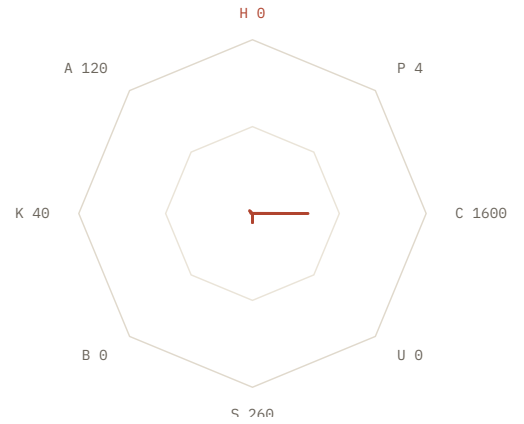

IFI-H	0
IFI-P	4
IFI-C	1,600
IFI-U	0
IFI-S	260
IFI-B	0
IFI-K	40
IFI-A	120

```
CUCUMBER–LAVENDER COOLER · serves 2 · vegetarian / no alcohol
– designed cool cucumber                 1, the engineered line, juiced
– engineered lavender                     1 tsp, as a light syrup or
infusion
– lime                                    1, juiced
– sparkling water                         to top
– ice                                     to fill
```

1. Juice the cool cucumber — the engineered line carries its own designed cold, so the drink starts cool before anything is added to it.

2. Stir in a restrained measure of lavender infusion; lavender is a whisper, not a shout, and too much turns soapy — the fault line of Chapter 13.
3. Lime, ice, top with sparkling water. The carbonation's own prickle rides the trigeminal field alongside the cool; the result is a cooler that is cool twice — the cucumber's designed cold and its cultural cool — lifted by lavender's floral calm.

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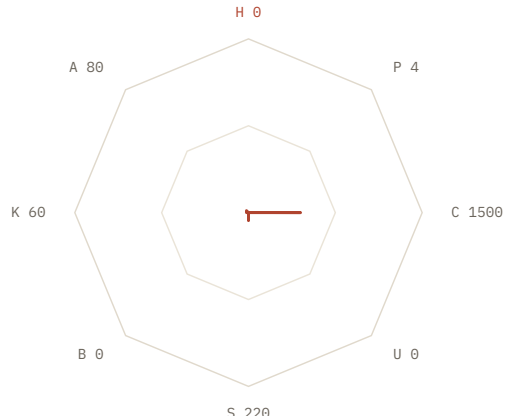

IFI-H	0
IFI-P	4
IFI-C	1,500
IFI-U	0
IFI-S	220
IFI-B	0
IFI-K	60
IFI-A	80

SPEARMINT-LIME AGUA FRESCA · serves 4 · vegetarian / vegan

— engineered spearmint	a large handful
— lime	3, juiced
— cucumber or melon	1 cup, blended (optional, for body)
— monk-fruit or light agave	to taste
— cold water and ice	to fill

1. Muddle the spearmint gently with the sweetener; spearmint's cool is the round, sweet-fresh carvone cool, not the sharp menthol one, so it wants a soft hand.
2. Blend with the lime, the optional cucumber or melon for weight, and cold water.
3. Strain over ice. This is the gentle cool — a drink for someone who wants fresh, not frozen, the spearmint doing exactly the rounded work peppermint would overpower.

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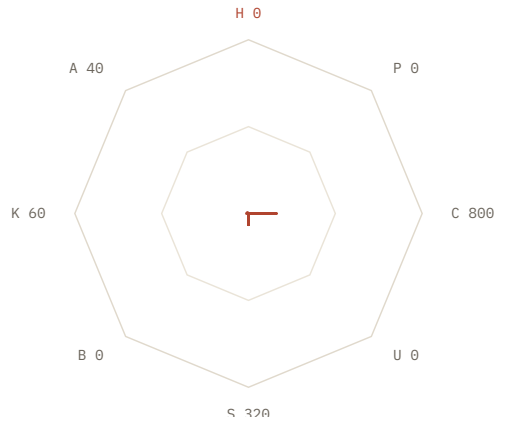

IFI-H	0
IFI-P	0
IFI-C	800
IFI-U	0
IFI-S	320
IFI-B	0
IFI-K	60
IFI-A	40

Not every drink on this axis is cold, and the most interesting one is warm — because the thermal axis spans cool *and* burn, and a winter drink can live on the warm shadow while still carrying a cooling aromatic lift, the paradox of the book made drinkable:

THE WARM-COOL TODDY · serves 1 · vegetarian / non-alcoholic base

— hot water or herbal base	1 mug
— honey or engineered sweet syrup	1 tbsp
— engineered clean-cool peppermint	2 leaves, torn
— a whisper of camphor-leaf infusion	1 bar-spoon (warm, medicinal)
— engineered ginger, grated	1 tsp (warmth, TRPV1 / TRPA1)
— lemon	to taste

1. Steep the ginger in the hot base for a warmth that climbs slowly — real TRPV1 and TRPA1 heat, gentle and building.
2. Off the heat, add the torn peppermint and the barest touch of camphor infusion; the peppermint cools the front, the camphor warms beneath it.
3. Sweeten, sharpen with lemon, drink hot. The sensation is the whole axis at once — a cool that opens the chest riding on a warmth that fills it.

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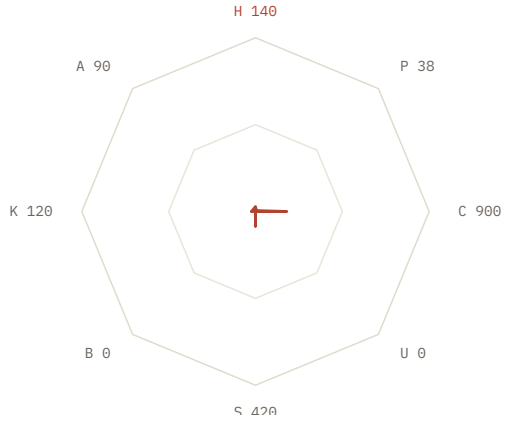

IFI-H	140
IFI-P	38
IFI-C	900
IFI-U	0
IFI-S	420
IFI-B	0
IFI-K	120
IFI-A	90

Read the toddy's card against the iced tea's and the thermal axis lays itself bare. Both carry cool near 900 to 1,600, but the toddy adds Heat (140) and Pungency (180) — the ginger's warmth and bite, with camphor's warm shadow beneath — so the mouth receives cool and warm at once, the drinkable cousin of Phoenix, gentle where the pepper was extreme. One axis, two temperatures, held in a mug. This is what the glass does better than any plate: it lets real temperature and designed sensation braid together, and it lets a cool be exactly as long and as deep as the slow pour of a drink allows. For the beverage maker, that is the gift — a cold that keeps arriving after the ice is spent, because the cold was never the ice's to begin with. It was the leaf's, and now the leaf tells it clean.



PART VI OF VI

At the Table & After

the plate · the temperature of care · why we grow the cold

Chapter 19 · The Plate — *cool as the missing primary color.*

Cool is the least-used tool in the savory kitchen, and that is an accident of history, not of merit. Heat has owned the chemesthetic conversation on the plate for centuries — chili, pepper, ginger, mustard — while cool was exiled to the dessert course and the after-dinner mint. But the great cooking traditions always knew better in practice than the cookbooks admitted in theory: mint on lamb, cucumber in a raita cooling a fierce curry, shiso under sashimi, dill against cured fish, the cold lift of herbs threaded through a rich Vietnamese bowl. Cooks have always known that a designed cold can cut richness, lengthen a finish, and wake a palate the way acid does, from a different direction. This chapter cooks with the thermal axis on purpose, plant-forward by default, and it treats the one fish dish it includes with exactly the respect it gives the vegetables, because a cook who reveres ingredients reveres all of them.



Garlic and the alliums anchor the savory plate — and a clean designed cool played against their depth is one of the quietest, most surprising seasonings in the kitchen.

```
COOL-BURN SESAME COLD NOODLES · serves 4 · vegetarian / vegan
— wheat noodles                          400 g, cooked, chilled
— tahini                                  4 tbsp
— engineered low-bitter soy / tamari      3 tbsp
— engineered clean-cool peppermint        a large handful, shredded
— designed cool cucumber                  1, julienned
— engineered chili oil                    to taste (real TRPV1 heat)
— rice vinegar, sesame, scallion          to finish
```

1. Whisk the tahini, tamari, and vinegar into a loose sauce; the low-bitter tamari lets you use more for depth without the base turning acrid.

2. Toss the chilled noodles through; fold in the cucumber and a generous amount of shredded peppermint at the very end, so the cool stays bright rather than wilting into the warm sauce.
3. Finish with chili oil to taste — this is the dish's cool-burn, the designed cold of the mint and cucumber against the real heat of the chili, the two thermal channels firing together on one fork.

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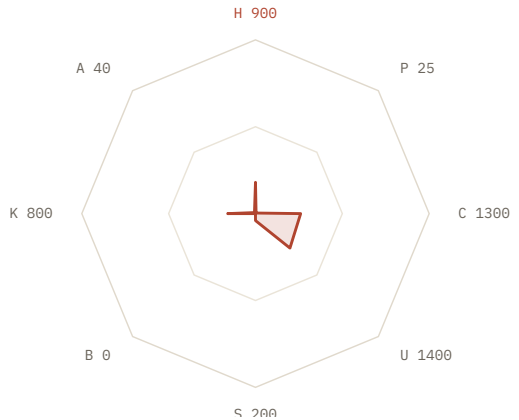

IFI-H	900
IFI-P	25
IFI-C	1,300
IFI-U	1,400
IFI-S	200
IFI-B	0
IFI-K	800
IFI-A	40

That scorecard is the book's title on a plate: Heat at 900 and Cool-Burn at 1,300, fired at once, the noodle you cannot decide the temperature of, grounded by a deep savory base (U 1,400, K 800) so the thermal drama has something to stand on. It is Phoenix's lesson made dinner — cool and burn as counterpoint, not conflict — and the single clearest argument in this book for why a cook should want a clean, placeable cold on the shelf next to the chili oil.

> PEA, MINT & RICOTTA ON TOAST · serves 4 · vegetarian
> — fresh or frozen peas — 300 g
> — engineered clean-cool peppermint — a handful
> — ricotta — 200 g
> — lemon zest, olive oil, flaky salt — to finish
> — good bread — 4 thick slices, toasted

1. Briefly blanch the peas; smash half for a rough spread, keep half whole for texture.
2. Fold in the torn peppermint, lemon zest, and olive oil — the clean engineered mint lifts the peas' sweetness with a cold brightness and no medicinal edge to muddy the green.
3. Spread the ricotta on the warm toast, pile on the minted peas, finish with salt and oil. Warm bread, cool mint, sweet pea — the thermal contrast between the warm toast and the cold mint is the whole pleasure.

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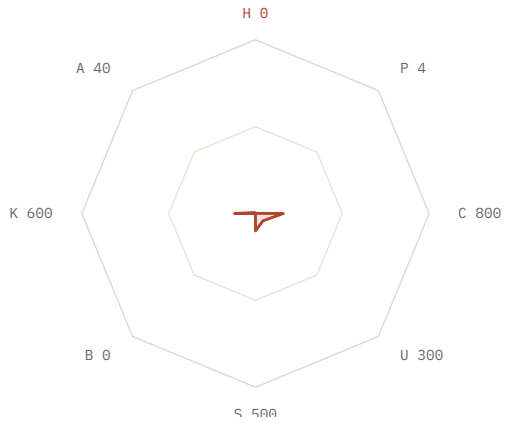

IFI-H	0
IFI-P	4
IFI-C	800
IFI-U	300
IFI-S	500
IFI-B	0
IFI-K	600
IFI-A	40

And one dish written with equal respect — a fish, no apology, because the plant-first kitchen honors the animal when it cooks one:

```
CURED TROUT, CUCUMBER & COOL-MINT OIL · serves 4 · pescatarian
— cured or cold-smoked trout              300 g, sliced
— designed cool cucumber                  1, shaved into ribbons
— engineered clean-cool peppermint        a small handful
— cool-mint oil (peppermint in neutral oil) 2 tbsp
— lemon, dill, cracked pepper              to finish
```

1. Lay the trout and shaved cool cucumber loosely on a cold plate, the ribbons and slices overlapping.
2. Spoon over the cool-mint oil — gently; the designed cold should accent the fish, not bury it.
3. Finish with dill, lemon, cracked pepper. The cucumber's designed cool and the mint oil give the rich, cured fish a cold frame that keeps every bite feeling fresh. The trout is the center of the plate and is treated as such.

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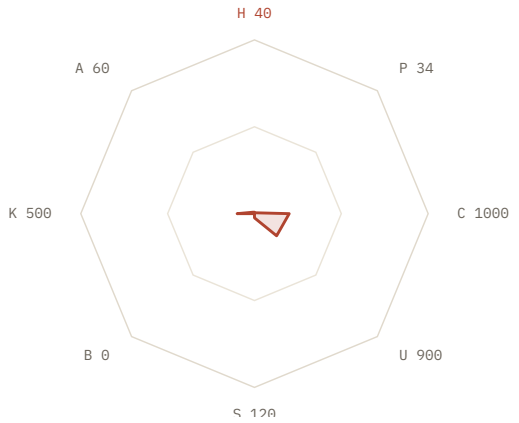

IFI-H	40
IFI-P	34
IFI-C	1,000
IFI-U	900
IFI-S	120
IFI-B	0
IFI-K	500
IFI-A	60

The plate is where the thermal axis stops being a demonstration and becomes seasoning — a thing a cook reaches for the way they reach for salt or acid, to lengthen, to cut, to wake. A designed cool is not a novelty on the plate; it is a missing primary color, cold, that the savory kitchen has had no clean way to paint with until the mint stopped carrying its off-note into the dish. Now it is clean, and constant, and placeable to the number. What a cook does with a new primary color is the oldest pleasure there is, and we built this axis, in the end, to hand that color over.

Chapter 20 · The Temperature of Care — *why we grow the cold.*

We have measured cool to the millivolt and the micromolar across this whole monograph — the voltage shift menthol works on TRPM8, the EC_{50} ladder from icilin to eucalyptol, the Hill curves and the τ of a fading cold, the seven enzymes and the one off-ramp, the sterile clone and the four-organelle shuttle, the scorecards and the ≤7% variance — and it would be easy to finish there, with the mathematics tidy and the plants catalogued. But the mathematics was never the reason. It was the means. The reason is older than the Index and simpler than any enzyme, and it is worth saying plainly at the end: cool is a kindness the body has always known how to receive, and we grew it because we wanted to understand, and improve, a thing that comforts people.



The greenhouse where it started — a family that reveres what it grows, writing about the mathematics of cold the way you would write about something you love and want to nourish you.

Think of when you reach for cool. A cold cloth on a hot forehead. A mint tea after a heavy meal. A glass of cucumber water on a day the heat will not break. A lozenge when the throat is raw. Cool arrives, almost always, at a moment the body is asking for relief, and it answers that ask not by changing the body's temperature — a thermometer, as our title insists, feels nothing — but by telling the mouth and the skin a true-feeling story of cold that the mind receives as ease. That is a remarkable thing for a small molecule off a crushed leaf to do, and the whole of this book has been an attempt to deserve it: to understand the story precisely enough to tell it cleaner, longer, and more truly than a wild plant ever could, and to tell it the same way every time, so the comfort is there to be given on the hard day and not only the lucky one.

We make no claim on anyone's medicine, and we have been careful to make none, chapter by chapter, because the ethos that runs under this library is a quiet one and a quiet thing is spoiled by overclaiming. We do not say mint heals or lavender calms or eucalyptus treats. We say they *taste of cool and calm and openness*, that those sensations have comforted people for as long as there have been people, and that we have learned to grow them clean and constant and placed exactly where a maker wants them. The nourishment in this work is not a health claim. It is an intention — that a cool confection can ask a little less of the body and still taste like abundance, that a cold drink can refresh without a load of sugar

behind it, that a plant can be grown toward the fullest, cleanest version of the gift it already offers: a peppermint that carries its menthol all the way through and leaves no half-made pulegone behind, a eucalyptus with its clarity and not its rasp, a lavender held to its soft true note. Intention, never promise. The difference is respect, and respect is the whole house style. These are computational designs; Scoville Splice's cultivars and constructs have not been experimentally validated in a laboratory.

The work is a family's. The computing was one pair of hands, but the question that started it was asked at a shared table, over a glass of iced mint on a hot afternoon, when someone wondered aloud why the mint still felt cold when the glass had already gone warm — and no one at the table could answer, and the not-knowing would not leave us alone. Everything in this volume grew from that table. The forty-two plants, the nineteen thousand constructs, the eight axes, the ≤7% variance, the three patents filed and the twenty-one papers we have put into the open — all of it is the long answer to a short question a family could not stop asking. And the answer, when it finally came, was the sentence we opened with and will close on: *nothing has changed but the message.* The cold is real to the one who feels it and absent from every instrument. It is a story the plant tells and the body believes, and we have spent ourselves learning to tell it well — one receptor, five genes, six plants, and a cold you can read on a page and trust in a mouth — because a cold that comforts, told cleanly, is one of the small true kindnesses a grown thing can give a person, and we would like, with every leaf we tune, to give it a little better than it has ever been given. The thermometer will go on feeling nothing. The person will feel cared for. Between those two facts is the entire work, and we are not finished with it, and we are glad.