

THE SCOVILLE SPLICE LIBRARY · CRAFT & SCIENCE

The Grower's Guide

The design is already in the seed. *Now grow it.*

The definitive manual for growing what we designed — seed to harvest, under lights or open sky — and bringing every axis of the profile all the way to the number on the card.

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

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Opening essay · What a grower actually grows

A seed does not look like a decided thing. A pepper's is no larger than a comma, pale and dry in the palm, giving away nothing. And yet by the time one reaches a grower's hand the hardest part of its flavor is already written. The pathway is in. The receptors it will one day move are already chosen. What a grower grows is not the flavor itself — the flavor was engineered, gene by gene, before the seed was ever packed. What a grower grows is *how much of it arrives.*

That is a gentler job than it sounds, and a more exacting one. Every number in this library — the heat that towers at IFI-H 4,200, the umami we grew back into a tomato, the cool that was never in a plant until we wrote it there — begins as a ceiling, not a promise. The design specifies what the fruit is *built* to reach. The field decides how close it comes. A plant started cold, starved of light, over-fed and under-stressed carries the same genome and still surrenders half its profile to the compost. The same seed, read correctly and grown with attention, hands you the fruit the design intended, with the number on the card and the taste to match.



The founders walking the research greenhouse at first light — the oldest instrument in the whole operation is a person who knows when a plant is thirsty.

Consider where the pathway actually begins. The branch we engineered into every one of these plants — **PAL → C4H → 4CL → HCT → COMT**, the phenylpropanoid route that runs through every vascular plant on earth, and then the four terminal enzymes that make a pepper a pepper, **pAMT · Pun1/CS · KAS · BCAT** — does not run on its own schedule. Its first gate, **PAL** (phenylalanine ammonia-lyase), is switched by light and by stress. Which means the grower standing in the greenhouse at dawn, deciding when to pull back the water and when to let the sun in hard, has a hand on the first enzyme of the sequence we designed. We wrote the pathway. The weather, and you, turn it on.

This is a family that has grown things for longer than it has edited them. The computing was one pair of hands; the beds, the trays, the long warm wait over a flat of slow seed — that was all of us, and it is the oldest part of the work. So this is not a manual written down at growers from a laboratory. It is written across the bench to you, from people who still believe the most important instrument in the whole operation is a person who knows when a plant is thirsty.

A word on what this guide assumes, and how it is built. It assumes you are growing a **licensed line** — one of the 42 host organisms, from a library of some 19,500 product packages backed by roughly 225 distinct construct designs, 1,000 of the packages live and purchasable today. It assumes you care about the number, because a formulator downstream is holding us to a **batch coefficient of variation at or under 7%**, and that promise is kept or broken in your field, not in ours. And it assumes the thing every good grower has always assumed: that food grown with attention is better food, in every sense of the word, than food hurried to a truck.

The twenty-two chapters move in the order a season moves. Part I is the blueprint — what is actually in the seed, and the mathematics of how a design becomes a dose. Part II is propagation, seed to seedling to clone. Part III is the six great levers — light, water, root, nutrition, air, and stress — the variables through which a grower actually moves the number. Part IV walks the season itself, flower to placenta to ripening to harvest. Part V is the systems you grow inside, field and glass and water, and the living defense that keeps a crop clean. Part VI tours the rest of the library, because a pepper is only the first of forty-two crops. And Part VII is the promise: the consistency a formulator buys, the post-harvest care that preserves it, and the stewardship that carries a line forward. We will come back, at the very end, to the quiet thing that runs under all of it — because it turns out to be the whole point.



PART I OF VII

The Living Blueprint

the design is in the seed · the field decides the dose

Chapter 1 · The Seed — *true to type.*

Begin with the thing itself. The seed we ship is the genome we designed, stabilized — the CRISPR edits written into the line are heritable and fixed, so the two Pun1 substitutions that make Phoenix's heat possible, **S39L · L345G**, come up in every plant from every seed, generation after generation, with none of the drift that ten thousand years of open pollination left in the older crops. That stability is the quiet luxury of the whole program. The grower is not gambling on which seedling threw the trait. Every one carries it.

To understand why that matters, hold two seeds side by side in your mind. A heritage chile landrace is a cloud of genotypes wearing one name — selected by hand over centuries, but never fixed, so a field of it is a field of near-cousins, some hotter, some milder, some that bolt and some that sulk. A designed line is a point, not a cloud. The edit is in the germline; it segregates as a stable allele; the population you sow is, to the limits of biology, the same plant repeated. The variation you will see in your field is therefore almost entirely *environmental* — which is the best possible news, because environment is the one thing a grower can actually steer. There is a tidy way to state it that the whole book rests on: the phenotype you harvest, P, is the sum of genotype and environment and their interaction, **P = G + E + G×E.** We have made G a constant. Everything left to manage is E.



A single stabilized specimen under isolation — every seed from this line carries the same fixed edits, so the only variable left in the field is how you grow it.

Seed anatomy, and why it governs the first month. A pepper seed is a flattened disc, roughly 3–4 mm across: a coiled embryo wrapped in a thin endosperm and a lignified seed coat, the testa. Its stored energy is largely oil, which is slow to mobilize and sensitive to rancidity — the reason viability falls faster in warmth and humidity than in a cool, dry drawer. There is an old agronomic rule of thumb, Harrington's, that for each 1% drop in seed moisture, or each roughly 5 °C drop in storage temperature, seed life doubles across the usable range. Stored properly — cool, dry, dark, the embryo near 5–8% moisture — a chinense seed holds strong germination for

years, not months. Stored warm and damp, it can be half-dead in a single humid summer. The genome is permanent; the seed around it is perishable. Treat the packet as the carrier of a design worth protecting.

What the seed does *not* carry is patience on your behalf. These are living embryos, and they keep the habits of their species. The flagship superhots are all *Capsicum chinense* — the habanero's hot-tempered cousin — and chinense germinates slowly and unevenly, the way it always has: two weeks is common, four is not a failure. The seed coat is a genuine barrier, the embryo small and oily, the dormancy shallow but real. None of that was edited; none of it needed to be. The trait lives in the placenta of a fruit that is a hundred days away. Everything between here and there is ordinary, demanding horticulture.

SEED PARAMETER	CHINENSE FLAGSHIPS	NOTE
Size	3–4 mm disc	small, oil-rich
Edits	Pun1: S39L · L345G	fixed, heritable
Storage moisture	~5–8%	the lower (within reason), the longer the life
Storage conditions	cool · dry · dark	viability measured in years
Pre-sow	soak 8–12 h, clean warm water	hydrates the testa, leaches inhibitors
Expect	slow, uneven break	normal for chinense; not a failure

Know the lot, and test it. Commercial seed arrives as a *lot* — a defined batch with a germination percentage and a purity, established by a germination test on a sample. A home grower can run the same test on a paper towel: count how many of twenty seeds break over a fortnight at the right warmth, and you know your real germination rate before you commit a tray. The number matters practically — if a lot germinates at 80%, you sow proportionally more to stand your target plant count — and it matters as a check: a lot that suddenly tests low has usually been stored wrong, and the failure is in the drawer, not the field. For a designed line there is a second check, **roguing.** Because G is fixed, true off-types should be vanishingly rare; if you see a plant that is genuinely not the line — not merely grown differently, but structurally other — you pull it before it flowers, because the one thing that can quietly corrupt a saved line over years is letting a stray in to shed pollen.

Read the packet, then, as a specification. It tells you the species and therefore the temperament; it tells you the line and therefore the ceiling; it tells you, in its germination percentage, how much to sow; and it tells you, implicitly, that the first act of growing a designed flavor is to do almost nothing — warmly, patiently — while the embryo decides to open. We spend a great deal of this guide on levers you will pull hard later. The seed asks the opposite virtue. Put it somewhere warm, give it moisture, and leave it alone.

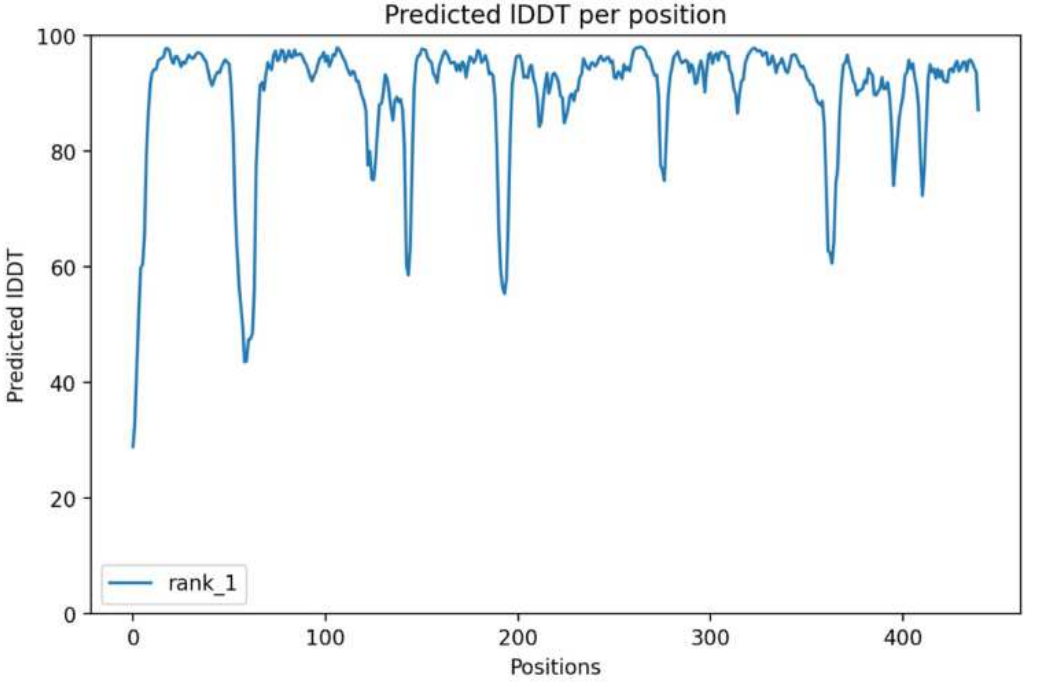
Chapter 2 · Reading the Design — *ceiling and realization.*

Here is the single idea that separates growing a designed crop from growing an ordinary one, and it is worth the whole chapter. **The design sets a ceiling. The field sets the realization.** The number on the card — IFI-H 4,200, IFI-U 2,600 — is not what every fruit will read. It is what a fruit *can* read when grown to the genotype's full expression. Your craft is the fraction between zero and that ceiling, and understanding where the fraction comes from is the difference between a grower who hits the card and one who wonders why they cannot.

Start with what the number means. The Iyengar Flavor Index is anchored to a receptor, not to a quantity of compound:

$$IFI(c) = 1000 \cdot EC_{50}(ref) \,/\, EC_{50}(c)$$

EC_{50} is the concentration at which a stimulus drives its receptor to half of full response. The *molecule's* EC_{50} is a physical constant — capsaicin's affinity for TRPV1 does not change because you watered differently. So at first glance the grower seems locked out of the number entirely: the loudness of the molecule is fixed. But a cultivar's axis score is not the loudness of one molecule in a buffer. It is the loudness the *fruit delivers* — the effective agonist concentration reaching the receptor when you eat it. And that concentration is exactly what the field controls.



The AlphaFold model of Pun1/AT3 that set Phoenix's heat ceiling — coloured by confidence, the active-site cleft resolved. The design is this structure's catalytic efficiency; the field is how much substrate it ever sees.

Put it formally. Let **A** be the concentration of the axis's agonist the ripe fruit actually delivers — capsaicinoids for heat, free glutamate for umami, menthol for cool. The receptor's response follows the Hill function

$$response = A^{n} \,/\, (EC_{50}{}^{n} + A^{n})$$

and the realized axis score tracks that response against the reference. The design fixes EC_{50} (the molecule) and fixes **A_max**, the ceiling concentration the genome is built to reach. The grower moves **A** between near-zero and A_max. Define the **realization fraction**

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φ = A / A_max
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and you have named the grower's entire job in one Greek letter. φ = 1 is the card. φ = 0.6 is a cold, hurried, over-fed, early-picked version of the same genome — the same seed, two-thirds of the flavor, and a formulator's rejected batch.

Two features of the Hill curve matter in the field, and a worked number makes them concrete. Take a Hill slope near n = 1.5. When the fruit delivers exactly A = EC_{50}, the response is 0.50 — half-maximal, the anchor point of the whole Index. Lift the delivered concentration by a fifth, to A = 1.2·EC_{50}, and the response rises to about 0.57; drop it by a fifth, to 0.8·EC_{50}, and it falls to about 0.42. The response is at its most *sensitive to concentration* right around the half-maximal point — exactly where much fruit lands — so a modest shift in what the fruit delivers moves the score more here than anywhere else on the curve. Layer onto that the fact that human sensation itself is roughly logarithmic (the Weber–Fechner relation), and a 20% change in delivered concentration is not a 20% change you can taste; it reads as more. This is why the grower's levers feel disproportionately powerful. They are. Near A_max, by contrast, the curve flattens: the last increments of concentration buy less and less perceived score, which is why forcing a plant past its comfort rarely pays and often costs. The sweet spot is to grow the plant *to* its ceiling, not to beat it against the ceiling.

TERM	MEANING	WHO SETS IT
EC_{50}(c)	molecule's receptor affinity	the design (fixed)
A_max	genotype's ceiling concentration	the design (fixed)
A	concentration the fruit delivers	**the grower**
φ = A / A_max	realization fraction	**the grower**
n (Hill slope)	steepness near threshold	the receptor

Each axis has its own agonist and its own delivery tissue, and knowing the pair tells a grower where to aim:

AXIS	RECEPTOR	AGONIST THE FRUIT DELIVERS	BUILT IN
Heat (H)	TRPV1	capsaicinoids	placenta glands
Sweetness (S)	TAS1R2 / R3	sugars, sweet proteins	fruit flesh, late
Umami (U)	mGluR1	free glutamate	ripening flesh
Zero-Bitter (B)	TAS2R38	(attenuation of bitters)	whole tissue
Kokumi (K)	CaSR	γ-glutamyl peptides	tissue, sulfur metabolism
Cool-Burn (C)	TRPM8	menthol	leaf trichomes
Pungency (P)	TRPA1	allicin, isothiocyanates	cut tissue
Astringency (A)	salivary PRPs	tannins / polyphenols	skin, seed coat

There is one more layer, and it is where flux-balance thinking earns its place in a grower's guide. A genome-scale flux model of the capsaicinoid pathway told us, early, that flux control sits upstream in the phenylpropanoid pathway — at 4CL and HCT — not at the terminal Pun1/CS step. Pun1 is the final capsaicin synthase; it labels the product, it does not govern the rate. That is a design fact: it is why the upstream gates matter as much as the terminal enzyme. It carries a field consequence. Think of carbon as a budget the plant partitions between primary growth and secondary chemistry. Flood the plant with nitrogen and the budget pours into growth — leaf, stem, more plant — and the secondary branch sees little; apply measured stress and the gate on the branch opens, and carbon that would have built leaf builds flavor instead. Because the upstream steps govern the rate, what helps most is (a) keeping those gates open — light on PAL, measured stress on the branch, warmth on the kinetics — so that carbon reaches the placenta, and (b) giving the final step *time* and *substrate at the right place* — on-plant ripening, which lets the glands fill as far as the upstream supply allows. The grower cannot change kcat. The grower can change how long the reaction runs and how much substrate reaches it. φ is built out of exactly those choices, and the rest of this guide is a catalogue of them.

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



PART II OF VII

Seed to Seedling

germination · the seedling · the clone

Chapter 3 · Germination — *the long, warm wait.*

Heat is the one thing a chinense seed will not forgive you for withholding. The embryo reads substrate temperature as permission, and below the low twenties Celsius it simply waits — sometimes long enough that an impatient grower throws out a perfectly good flat a week before it would have risen. Hold the medium at **28 to 30 °C** — bottom heat, not air heat — keep it evenly damp and never wet, and the radicle comes when the seed is ready and not before. We have learned, over many seasons, to trust the heat mat and distrust the calendar.

There is real biology under the folk wisdom. Germination is a race between two clocks: the mobilization of stored reserves, driven by the hormone gibberellin and gated by temperature, and the depletion of oxygen and the onset of rot in tissue that sits too wet too long. Warmth speeds the first clock; good drainage and air slow the second. The grower's whole task at this stage is to keep the first clock ahead of the second.



A propagation tray under controlled conditions — even moisture, bottom heat, and air movement keep the germination clock ahead of the rot clock.

The seed counts thermal time, not days. What the embryo is actually tracking is accumulated warmth above a base threshold — degree-days, the sum of (mean temperature − base) over time, with the base near 15 °C for chinense. Say a lot needs roughly 200 degree-days above base to emerge. Hold it steadily at 29 °C and it banks (29 − 15) = 14 degree-days each day, so it rises in about fourteen days. Let it drift to a 24 °C average and it banks only 9 a day — now it needs about twenty-two. Let it swing warm by day and cold by night to the same *average* and it does worse still, because the cold nights barely accumulate and the warm days cannot make

up the shortfall. The lesson is steadiness: a flat held *constantly* warm beats a flat that averages warm. This is the whole case for the heat mat and the covered dome, and it is why bottom heat — warming the medium directly — beats warming the air, which the evaporating surface fights.

PARAMETER	TARGET	WHY
Substrate temperature	28–30 °C (bottom heat)	peak germination rate; below ~20 °C it stalls
Base threshold	~15 °C	below this, thermal time barely accumulates
Days to emerge	14–28 (sometimes more)	chinense is slow and uneven by nature
Sowing depth	~6 mm	shallow; light not required to germinate
Moisture	evenly damp, never saturated	keeps the rot clock behind the growth clock
Air movement	gentle, continuous	suppresses damping-off

The pre-sow soak, and priming. The soak earns its keep two ways: it hydrates the lignified testa so the embryo can imbibe evenly, and it leaches a little of the germination-inhibiting chemistry the seed coat carries. Eight to twelve hours in clean, warm water is plenty; longer risks drowning the embryo. Growers who want more uniformity can go a step further and *prime* — hold the seed in controlled partial hydration (in plain water, hydropriming, or in an osmotic solution, osmopriming) so that the early metabolic machinery of germination starts but the radicle does not yet emerge, then dry the seed back. A primed lot, sown warm, comes up faster and far more evenly, which matters more than it sounds: an even stand is the first brick in a low-CV crop, because plants that emerge together stay in step all season. Sow shallow — about 6 mm, a seed's own length of cover — into a light, sterile starting medium that drains freely, firm gently so the seed meets moisture on all sides, and then give it warmth, patience, and restraint.

The enemy is damping-off — *Pythium*, *Rhizoctonia*, the fungal collapse that fells a seedling at the soil line overnight. It is a disease of stagnant wet and poor air, which is why we grow seedlings on the dry side of damp and keep a little air always moving across the flat. Sterile medium, clean tools, bottom watering rather than a hard overhead soak, and restraint with the can prevent more losses here than any treatment cures. A simple troubleshooting read:

SYMPTOM	LIKELY CAUSE	FIX
No emergence after 3–4 weeks	medium too cold	raise substrate to 28–30 °C
Seedlings keel at the soil line	damping-off (too wet, stagnant)	dry out, move air, sterile media
Patchy, drawn-out emergence	temperature swings, old seed	steady the heat; test the lot
Seed coat stuck on cotyledons	sown too dry / too shallow	mist to soften; sow at full depth

Nothing to feed yet, little to see — and that is the lesson of the chapter. The first act of growing a designed flavor is to do almost nothing, warmly, for a long time. The pathway we engineered is dormant in there with everything else, and it will wake in order: roots,

then the first true leaves, then — much later — the machinery that actually builds the capsaicin. Rush the front of that sequence and you pay for it at the back.

Chapter 4 · The Seedling & the Transplant — *building the frame.*

The cotyledons are not the plant; they are the lunchbox. The first true leaves are the plant announcing itself, and from that moment the grower's job shifts from *keeping the seed alive* to *building a frame strong enough to carry a full profile.* Everything a superhot will do in its hundredth day — the canopy it feeds the fruit with, the root that finds the water, the sheer architecture that holds a heavy, finishing crop — is scaffolded now, in the quiet weeks when nothing seems to be happening fast.

Light changes character here. In germination light was optional; now it is everything, and the commonest seedling failure we see is not too little warmth but too little light for the warmth given. The physiology has a name — **etiolation** — and a mechanism. A plant senses light quality through pigments called phytochromes, which read the ratio of red to far-red light; a seedling that perceives shade (low light, a low red-to-far-red ratio) runs a stretch program, pouring its early carbon into long, pale internodes and a weak hypocotyl, reaching for a sun that is not bright enough. That reach is not cosmetic. It is substance spent on length, and a stretched seedling rarely recovers the sturdiness it traded away. Give seedlings a real daily light integral — **10 to 14 mol·m^{-2}·day^{-1}** is plenty, more than most windowsills deliver and less than a fruiting canopy wants — with real intensity and a touch of blue in the spectrum, and they build short, thick, branching frames that will carry the season.



Seedlings potted on under full light — short internodes, thick stems, a root run given room to reach before the fruit ever asks it to.

Potting on is a root decision disguised as a leaf decision. A seedling that fills its cell with root wants a larger volume before it circles and stalls; a seedling potted into too much cold wet medium at once sits sulking while the roots fail to colonize it, the surplus medium staying wet and inviting rot. Step the volume up in stages — plug to small pot to final container or bed — so the root is always slightly chasing new ground. That chase is not incidental to flavor. A root system built in stages, forced to explore, develops the reach and the fine

architecture that later finds the water and the minerals the plant will spend on secondary chemistry. We grow for roots first and fruit second, every time, and the habit begins in the pot-up schedule.

STAGE	TRIGGER	GROWER'S MOVE
Cotyledon	emergence	hold warm, bright, lightly damp
First true leaves	2–3 weeks on	begin gentle feed (EC ~0.8–1.2)
Root-bound plug	roots to cell wall	pot on one size; never jump huge
Hardening off	7–10 days pre-transplant	stepped sun, wind, slight deficit
Transplant	nights hold above ~15 °C	into warm ground, undisturbed root ball

Hardening off is where tender greenhouse tissue earns the right to the field. A plant moved straight from a warm, still, humid propagation house into open sun and wind scorches, wilts, and checks — a setback that costs weeks. The fix is gradual exposure over seven to ten days: lengthening spells outdoors, a little real wind, a measured dip in water and warmth, so the plant thickens its leaf cuticle, lays down protective pigments against the raw sun, stiffens its stem against the wind, and tightens the behavior of its stomata before the move. A hardened transplant barely notices the shift. A soft one spends a fortnight recovering, and a fortnight of a hundred-and-twenty-day crop is real profile left on the table.

Transplant into warmth. Chinense checks hard in cold ground, and a transplant set out a fortnight too early — into soil still cold at night — can sit motionless until the warmth it was waiting for finally arrives, by which point a plant set out later into warm ground has caught and passed it. The calendar lies; the soil thermometer and the night low tell the truth. When the nights hold reliably above the mid-teens Celsius, settle the plant in with its root ball intact — disturb the roots as little as you can, because a torn root is a week of repair the plant pays for out of its season — water it gently home, and let the frame-building continue in its permanent place. Where a crop's ground carries a history of soilborne disease, this is also the moment a *grafted* transplant earns its keep, the designed top on a tougher root; we take that up in the next chapter.

Chapter 5 · Clones, Cuttings & Culture — *propagating what won't come from seed.*

Not everything in the library comes true from seed, and some of the most important crops do not come from seed at all. Peppermint is the clearest case and the most instructive. It is a **sterile triploid clone** — a plant that essentially cannot breed its way to better, because it sets little viable seed, so the only way to multiply a line is to copy it vegetatively, root for root and leaf for leaf. That is not a limitation to work around; it is a gift to a grower who wants consistency, because a vegetative clone is genetically identical to its parent by definition. There is no segregation, no drift, no cloud of genotypes — just the same plant, again, as many times as you can root a cutting.



Engineered peppermint — a rhizomatous, sterile clone grown for leaf, not fruit; every plant a vegetative copy of the line, the five-gene menthol pathway carried forward intact.

Cuttings and runners. Mint multiplies with almost comic ease: a node laid on damp medium throws roots in days, and the plant's own stolons and rhizomes do the work for you, colonizing a bed until you must physically bound it to keep it in line. For crops that root less eagerly, the craft is the old one — a clean cut just below a node, the lower leaves stripped, a dip of rooting hormone (an auxin, which is simply the plant's own rooting signal supplied from outside), and a humid, warm, bright-but-not-scorching propagation environment under mist or a dome until roots form. But the real discipline here is

less about coaxing roots and more about *sanitation and selection*, because a clone copies disease as faithfully as it copies the trait. A virus latent in a mother plant rides into every daughter, silent and multiplying. We take propagation material only from clean, vigorous, true-to-line stock — never from the tired field — precisely so a season's pest cannot quietly become a line's permanent passenger.

Grafting. For some fruiting crops — peppers and tomatoes among them — grafting a designed scion onto a vigorous, disease-resistant rootstock buys the best of both: the engineered profile up top, a tougher root below that resists soil pathogens and often lifts vigor and yield. The scion's fruit carries the design unchanged — the genome up top is what sets the flavor, and the rootstock is just the legs. The technique is exacting (a clean matched cut, a clip, and a warm, humid healing chamber while the vascular tissues knit) but it changes nothing about the flavor the scion was built to make, and in ground with a soilborne disease history, or under intensive repeated cropping, it can be the difference between a clean crop and a lost one.

Tissue culture and clean stock. At the foundation of the whole vegetative side sits micropropagation — growing plants from small pieces of tissue on sterile nutrient medium, under a controlled balance of hormones (auxin and cytokinin) that directs the tissue to multiply shoots, then to root. It runs in stages: establishing a sterile culture, multiplying it, rooting the plantlets, and acclimatizing them back to the greenhouse. Two things make it indispensable. First, speed — a single clean mother can become thousands of identical plants in a season. Second, and more important for a designed line, *cleaning*: meristem-tip culture, taking the tiny growing point that viruses have not yet invaded, can free a clone of infections that riddle the rest of the plant, resetting a tired, virused line to clean health. The one risk to respect is somaclonal variation — the rare genetic change tissue culture can introduce — which is why culture-derived stock of a designed line is checked back against the line before it is bulked.

For a licensee, the biology distills to a simple operating rule: **start from certified clean stock, keep a protected mother block, propagate only from plants you have watched stay healthy, and index everything.** Seed lines and clone lines ask different virtues of a grower. A seed line asks you to manage a population toward uniform expression. A clone line hands you uniformity for free and asks you, in exchange, to be its immune system — to keep the line clean, because nothing in a clone's biology will clean it for you. Know which kind of crop you have before you multiply it, and the propagation half of growing takes care of itself.



PART III OF VII

The Levers

light · water · root · nutrition · air · stress

Chapter 6 · Light — *the pathway's first switch.*

Now the science earns its place in the greenhouse. Light is not only the engine of the sugar a plant lives on; it is a direct signal to the phenylpropanoid branch, the sequence that feeds our whole design. **PAL** — the first enzyme of that branch, the gate through which the carbon for heat and for a dozen other axes must pass — is among the most light-responsive enzymes a plant owns. Its transcription rises with light; its product feeds the exact route we engineered. Give the crop generous, steady light and you are not just growing a bigger plant. You are up-regulating the first step of the pathway we wrote.

The number a grower actually sets is the **daily light integral** — DLI, the total photosynthetic photons delivered to a square metre across a day, in moles. It is the honest currency of light, because it folds intensity and duration into one figure the plant can bank. The arithmetic is simple and worth carrying in your head: DLI equals the instantaneous flux (PPFD, in $\mu mol \cdot m^{-2} \cdot s^{-1}$) times the seconds of light in the day, divided by a million. Run 400 µmol for a 14-hour day and you deliver 400 × 14 × 3600 ÷ 1,000,000 ≈ **20 $mol \cdot m^{-2} \cdot day^{-1}$.** Want 25 instead, in the same 14 hours? You need about 496 µmol. We grow fruiting peppers toward a DLI of **22 to 30** — enough that the plant can afford both a full canopy and the expensive secondary chemistry that makes the flavor. Skimp here and the plant spends its light on survival and leaves the profile half-built: the heat comes in low, the colors come in pale, the card and the fruit disagree.



Golden-hour under glass — fruiting peppers banking a high daily light integral, which the plant spends on both canopy and the costly secondary chemistry that carries the profile.

There is a floor and a ceiling to this, drawn by the photosynthesis light-response curve. Below the **light compensation point**, a leaf respires more than it fixes and runs at a loss; above it, fixation climbs with light until it **saturates**, where more photons no longer buy more sugar and can begin to damage. A fruiting pepper has a high saturation point, which is why it rewards high DLI; a shade-adapted herb saturates low and will bleach under a crop lamp meant for tomatoes. Matching the light to the crop's curve is the first act of lighting.

CROP	DLI TARGET (MOL·M⁻²·D⁻¹)	PHOTOPERIOD	NOTE
Fruiting peppers	22–30	12–14 h	high light for secondary chemistry
Tomato	20–30	14–16 h	generous; supports late-ripening glutamate
Peppermint (leaf)	16–22	long day	vegetative; drives oil and biomass
Leafy / herb seedlings	10–14	—	gentle; builds a short, sturdy frame
Stevia	18–24	long day	steviol glycosides track light

Spectrum is the second dial, and the plant eats the whole band. Red and blue do the heavy lifting of photosynthesis — the photosynthetic action spectrum peaks in those bands — but the plant reads the ratios as information: the balance of red to far-red tells it whether it is shaded and how to shape itself (more far-red, more stretch); blue, sensed through cryptochromes, governs stomata and keeps a plant compact. For our purposes the most interesting edge of the spectrum is the one just past visible — **UV-B.** A measured dose of UV-B is a stressor the plant answers by inducing exactly the phenylpropanoid and flavonoid chemistry we care about, PAL among the first responders, because those compounds are in part the plant's own sunscreen. Pushed carefully, UV can lift the very axes that live on that branch — astringency, some of the heat, protective phenolics. Pushed carelessly, it damages tissue and the harvester's eyes. It is a lever for the experienced hand, applied in small, deliberate doses near the finish, never as a blunt instrument.

Photoperiod and canopy. How long the light runs matters as much as how bright it is — not only for DLI but as a signal, since some crops flower by day length. And the best DLI in the house is wasted on a crop so dense that interior leaves sit in shade, respiring more than they photosynthesize — lazy leaves, a net cost. Open the canopy. Prune and train so light reaches *into* the plant, not just across its top, so that the leaves nearest the ripening fruit are the ones working hardest. A well-opened pepper plant ripens more evenly, colors more fully, and finishes a higher φ than a jungle of the same genome under the same lamps. Light is the grower's first real lever, and it moves the number more than almost anything else you will touch — but only if it reaches the leaf that needs it.

Chapter 7 · Water — *the shape of the burn.*

Here is the grower's most beautiful lever, and the one that most rewards nerve. Capsaicin is, among other things, a stress response. A pepper under a measured water deficit — thirsty, not dying — concentrates its heat; a pepper kept lush and fully watered grows larger, heavier fruit that taste milder for it. This is old knowledge the chile fields have always carried, and it is real biochemistry: mild drought shifts carbon away from growth and toward the phenylpropanoid branch, toward the very enzymes we engineered, and the placenta answers by packing its glands fuller.



Dawn dew on a finishing crop — water is the dial that sets intensity. Full to establish, lean through ripening: thirsty, here, is the plant doing exactly what you want.

The mechanism is worth stating precisely, because it tells you how far to push. Water moves through the plant down a gradient of **water potential** (ψ), the sum of a solute term and a pressure term, ψ = ψ_s + ψ_p, measured in megapascals and almost always negative in a working plant — water flows from the wetter soil (less negative) through the plant to the drier air (far more negative), the whole soil–plant–atmosphere continuum a single tensioned thread. When the soil dries and ψ falls, the plant senses it and releases the stress hormone **abscisic acid (ABA)**, which closes stomata to conserve water and, downstream, reallocates carbon from primary growth toward secondary metabolism and up-regulates stress-responsive branches of the phenylpropanoid pathway. Capsaicinoid accumulation in the placenta rises accordingly. But the relationship is a hump, not a ramp: *mild* deficit concentrates heat and holds quality; *severe* deficit stalls the plant, aborts fruit, and ultimately lowers the total yield of the compound even as its concentration climbs, because there is simply less fruit and less functioning tissue to make it. The art is to live on the near side of the hump — to keep the plant working hard and slightly hungry, never shutting down.

So water becomes a dial on the finished profile, and the formal name for working it is **regulated deficit irrigation.** You water full while the plant establishes and sets fruit, then pull back deliberately as the fruit sizes and ripens — enough to live, never enough to be comfortable. In a controlled house you can instrument the deficit: a

tensiometer reads soil water tension in kilopascals, and you might irrigate to hold a comfortable −30 to −50 kPa through establishment, then let the crop run drier, toward −60 to −80 kPa, through ripening — pushing the plant without crashing it past the point of recovery. Substrate-weight sensors do the same job by mass; stem-diameter micro-variation, which contracts under deficit, reads the plant's water status before a leaf ever droops.

GROWTH STAGE	WATER STRATEGY	EFFECT ON PROFILE
Establishment	full, generous	builds frame and root; no stress yet
Vegetative	steady, ample	canopy for the finish
Flower & set	steady; avoid swings	protects fruit set
Fruit sizing	begin controlled deficit	trades some size for concentration
Ripening	lean, deliberate	pushes capsaicinoids toward the ceiling

Reading the plant is the skill that replaces the formula, because no two houses dry alike. Midday leaf wilt that recovers by evening is the plant telling you it is working at the edge, which is often exactly where you want it near the finish; wilt that does not recover by morning is a plant past the edge, and you give back. Watch the newest growth, the set of the leaves, the gloss of the fruit; put a thumb in the soil. The deficit asks you to hold your nerve against a plant that looks thirsty, because thirsty, here, is the plant doing exactly what you want — and it asks judgment, not a recipe, because the right deficit depends on your light, your medium, your air, your cultivar's place on the ladder. The shape of the burn is partly ours, written into Pun1. The intensity of it, at the end, is partly yours — written into the irrigation.

Chapter 8 · The Root & the Ground — *where the body begins.*

If there is an axis that lives underground, it is kokumi — the one you feel rather than taste, the richness and continuity the calcium-sensing receptor reads as *body.* The axis is this book's accent for a reason: a grower builds it the way a stock is built, slowly, from the ground up, out of a root system that has had room and time and a living medium to work in. We grow for roots first and fruit second, because a shallow, hurried root throws a shallow, hurried flavor, and no amount of late feeding buys back the depth a plant should have grown into from the start.

Be precise about what kokumi actually is, because the honest biochemistry is better than the metaphor. Kokumi compounds are **γ-glutamyl peptides** — glutathione (γ-glutamyl-cysteinyl-glycine) and its relatives, short peptides built on the plant's sulfur and nitrogen metabolism — and they are read not by a taste receptor in the usual sense but by **CaSR**, the calcium-sensing receptor, which registers them as fullness, continuity, and mouthfeel rather than a flavor you can name. The plant builds those peptides from its amino-acid and sulfur pools: sulfate taken up by the root is reduced, step by step, to cysteine, and cysteine is assembled with glutamate and glycine into glutathione. That whole chain runs well when the plant is growing steadily in a healthy root zone with balanced nutrition — not when it is flushed with nitrogen into fast soft growth, and not when it is starved of sulfur or stalled by a sick root. The body of the flavor really is grown, and it is grown here, below the line, out of the root's quiet sulfur chemistry.



A well-rooted transplant settling into open ground — peppers hate wet feet; the medium must drain freely and still hold a little, and the root must be given room to reach.

The medium wants to drain freely and still hold a little. Peppers hate wet feet and sulk in dense, airless ground, where roots suffocate and *Phytophthora* waits; they equally dislike a medium so sharp it dries to the point between every watering. What you are really managing is the balance of water-holding and air-filled porosity — a root needs both moisture and oxygen in the same handful of medium. In the field that means working toward tilth and organic

matter over seasons, building the crumb structure that breathes; in containers it means a coarse, well-structured mix. Soil's capacity to hold and hand back nutrients — its cation-exchange capacity, the negative sites on clay and organic matter that grip calcium, potassium, magnesium and ammonium and release them to the root — is part of what makes a good soil forgiving, buffering the plant against the swings a bare medium would pass straight through. The root volume matters as much as the root medium: give the plant room to build architecture, and it will spend that reach on the chemistry you are growing for.

The living root zone. A root is not a straw; it is an ecosystem's doorway. Mycorrhizal fungi — the arbuscular kind, which thread into the root and out into the soil — extend a plant's reach for phosphorus and water far beyond what the roots alone can touch, trading those minerals for a little of the plant's sugar; a healthy rhizosphere of bacteria and fungi cycles nutrients, suppresses pathogens, and buffers stress. We grow, wherever we can, for a soil that is alive — not as an article of faith but because a living root zone demonstrably steadies nutrient supply and stress tolerance, and a steadier plant finishes a more consistent profile. In a sterile hydroponic system you give up that biology and must supply its services yourself through precise fertigation and clean-root discipline; in soil you can let the community do much of the work, if you feed it and do not poison it.

The nitrogen trap, seen from below. The commonest mistake we see from eager growers is too much nitrogen early — it buys a gorgeous jungle of leaf and a plant too pleased with itself to bother setting much fruit, let alone finishing it. Seen from the root, the error is a carbon-allocation one: abundant nitrogen keeps the plant investing in fast primary growth and signals *no need* for the stress chemistry that makes our axes, tipping the root-to-shoot balance toward shoot and away from the exploring root that builds depth. Feed for balance, keep the plant a little hungry for richness through the back half, and let it reach. A plant that has to work for its minerals builds more of the chemistry we care about than a plant handed everything. The body of the flavor, like the body of the plant, is grown, not added — and it begins in the dark, in the root, long before the first flower.

Chapter 9 · Nutrition — *feeding the chemistry.*

Nutrition is where a grower most often confuses *more* with *better*, and where the designed crop punishes the confusion fastest. The goal is not maximum growth. The goal is a plant with exactly the resources it needs to build its frame and then pour its surplus into the secondary chemistry we score. That is a narrower target than "feed it well," and hitting it is a matter of balance, timing, and restraint — fed through the honest instruments of **EC** (the total salt concentration of the feed, read on a meter) and **pH** (which governs whether the minerals are even available to the root).

Seventeen elements are essential — the plant cannot complete its life without any one of them — and the oldest law in the field still governs: **Liebig's law of the minimum**, that growth is set by the scarcest resource, not the average. A plant perfectly supplied with everything but boron grows like a plant starved of boron. But the companion truth matters just as much for a designed crop: the elements interact, and an excess of one can lock out another — too much potassium suppressing magnesium and calcium uptake, too much phosphorus tying up zinc and iron. The target is not maximum of each; it is *balance.*



A finishing cluster — fed for balance, not bulk. The surplus a well-nourished, slightly hungry plant can't spend on leaf goes into the chemistry on the card.

The macronutrient arc. Nitrogen builds leaf and stem; phosphorus builds root and energy transfer; potassium builds fruit quality, sugar transport, and stress tolerance. The classic error is to run nitrogen high all season. Instead, ride an arc: moderate nitrogen to build a frame, then taper it as the plant moves into flower and fruit, while holding potassium honest right through the finish. A plant eased off nitrogen at fruit set stops throwing new leaf and turns its attention — and its carbon — to ripening the fruit and filling its chemistry. The form of the nitrogen matters too: nitrate (NO_3^-) tends to steady,

balanced growth, while too much ammonium (NH_4^+) pushes soft, lush tissue and can acidify the root zone. The arc, not the average, is what matters.

STAGE	EC (MS·CM⁻¹)	PH	N	P	K	INTENT
Seedling	0.8–1.2	5.8–6.2	low–mod	mod	low	gentle start
Vegetative	1.8–2.4	5.8–6.2	higher	mod	mod	build the frame
Flower & set	2.0–2.6	5.8–6.2	taper	up	up	protect set
Fruit & ripen	2.4–3.0	5.8–6.2	low	mod	high	finish the chemistry

Starting guidance for intensive pepper culture; tune to crop, medium, and water chemistry.

pH is the gatekeeper. A perfectly balanced feed is useless if the root cannot take it up, and uptake is governed by root-zone pH. In the mildly acidic band — roughly **5.8 to 6.2** in soilless systems, a touch higher in soil — the full suite of nutrients stays available. Drift high and iron, manganese, and phosphorus lock away, and the plant shows deficiency in the midst of plenty; drift low and other problems appear. Check it, correct it, and most "mystery" nutritional faults never arise. EC tells you *how much* salt the plant is drinking; pH tells you *whether it can reach* what is dissolved. Growers who master those two numbers rarely need the rest of the troubleshooting chapter — and the two readings, logged daily, are the backbone of the consistency this book builds toward.

Reading a deficiency. The plant signs its own shortages, and the first thing to notice is *which leaves* show it, because that tells you whether the element is mobile. A mobile nutrient (nitrogen, phosphorus, potassium, magnesium) is pulled from old tissue to feed new growth, so its deficiency shows in the *old* leaves first; an immobile one (calcium, iron, boron, manganese) cannot be moved, so its deficiency strikes the *new* growth.

DEFICIENCY	WHERE IT SHOWS	CLASSIC SIGN
Nitrogen	old leaves	uniform pale/yellow, stunted
Potassium	old leaves	scorched, curling margins
Magnesium	old leaves	yellowing between the veins
Calcium	new growth / fruit	blossom-end rot, deformed tips
Iron	new leaves	interveinal yellowing, veins stay green
Boron	growing points	brittle, deformed new growth, poor set

Calcium, and the body axis. Calcium deserves its own line, both because its deficiency causes the blossom-end rot that ruins peppers and tomatoes and because of its quiet link to our accent axis. Calcium moves only in the transpiration stream and cannot be remobilized, so a plant whose water is erratic — swinging wet to dry — cannot deliver calcium reliably to the fast-growing fruit tip, and the tissue there collapses. Steady water is steady calcium; the fix for blossom-end rot is almost always in the irrigation, not the feed. And while CaSR, the kokumi receptor, responds to γ-glutamyl peptides rather than to dietary calcium directly, a plant with sound calcium nutrition and steady, unstressed growth is a plant building clean cell walls and healthy tissue — the substrate on which the sulfur-and-nitrogen chemistry of kokumi is laid down. Feed calcium steadily, water evenly, supply a complete micronutrient package at the right

pH, and do not chase phantoms. The plant asks for very little in the traces, and gives back disproportionately when the little is right. Feed for balance, keep the plant honestly hungry through the back half, and let its surplus become the number on the card.

Chapter 10 · Heat, Cold & Air — *temperature, CO_2, and the atmosphere.*

Capsicum is a creature of warmth from root to fruit, and the plant builds the most chemistry where it feels the most. But "warm" is not one number, and the grower who understands *which* warmth, *when*, holds a lever as strong as water. Temperature sets the speed of every enzyme in the pathway. The rule of thumb is the Q_{10} — the factor by which a reaction's rate changes for each ten-degree rise — and for most enzymatic steps within the working range it sits near 2, a rough doubling per 10 °C. So the pathway we engineered literally runs about twice as fast at 30 °C as at 20 °C, up to the point where heat begins to denature and damage, past the low-to-mid thirties for these crops, where the rate collapses. Every crop has its **cardinal temperatures** — a base below which almost nothing happens, an optimum where it runs fastest, and a ceiling above which it fails — and good growing is largely the art of keeping the plant between the first and the last and near the middle.



A controlled chamber holding day and night temperature, humidity, and air on set points — where the atmosphere becomes an instrument instead of a weather report.

Day and night are different tools. Warm days drive photosynthesis and the kinetics of the pathway. Night temperature governs respiration — how much of the day's hard-won sugar the plant burns back in the dark — and influences the plant's shape through the day-minus-night difference known as **DIF**: a positive DIF (warmer day than night) tends to stretch a plant, a smaller or negative DIF keeps it compact, a lever greenhouse growers use to shape a crop without chemicals. Nights that crash too cold stall chinense and can stall the pathway with it, so the fruit that sets through a cold week

carries the memory of it in a lower number; nights too warm waste sugar to respiration that should have gone into fruit and chemistry. What the plant ultimately banks is the *integral* of temperature over the day, which is why controlled houses manage toward a target 24-hour average and let the day and night float around it. The flagships want warm days and warm — but not hot — nights that hold above the mid-teens Celsius, across a long unbroken season. Protect against the cold snap at the wrong moment: it does not merely slow the plant; it stalls the secondary chemistry, and that is φ lost that the season will not give back.

CO_2, the invisible fertilizer. In a sealed or semi-sealed house, carbon dioxide is often the hidden limit on growth. Ambient air runs near 420 ppm; enrich a well-lit, actively photosynthesizing crop toward **800–1000 ppm** and photosynthesis climbs, giving the plant more carbon to spend on both frame and chemistry. The caveat is strict and follows straight from Liebig: CO_2 only helps when light is not the limit — enrichment in a dim house is wasted, because the plant cannot use the extra carbon it cannot power. Pair high light with enrichment and the two compound; pair enrichment with gloom and you have spent money on nothing. In the open field, of course, you take the atmosphere you are given.

ATMOSPHERIC LEVER	WORKING RANGE	WHAT IT GOVERNS
Day temperature	24–30 °C	photosynthesis + pathway kinetics ($Q_{10} \approx 2$)
Night temperature	16–20 °C	respiration, partitioning, fruit set
24-h average	~22–25 °C	what the plant actually banks
CO_2 (enriched)	800–1000 ppm	carbon supply — only when light is ample
Relative humidity	60–75%	transpiration, calcium delivery, disease
VPD	~0.8–1.2 kPa	the true driver of water loss

VPD is the number behind humidity. Vapor pressure deficit — the drying power of the air, the gap between how much moisture the air is holding and how much it *could* hold at that temperature — is what actually drives a plant's transpiration, and therefore its water use, its calcium delivery, and its stress. You can compute it: the saturation vapor pressure rises steeply with temperature (near 3.2 kPa at 25 °C), and VPD is that figure times the fraction of dryness, (1 − RH/100). At 25 °C and 70% humidity, VPD ≈ 3.2 × 0.30 ≈ **0.95 kPa** — a comfortable middle. Too low a VPD (humid, still air) and the plant barely transpires, calcium stalls at the fruit tip, and fungal disease flourishes; too high (hot, dry air) and the plant loses water faster than the root can supply, closing its stomata and shutting down photosynthesis in the middle of the day. Hold VPD in the comfortable band — roughly 0.8 to 1.2 kPa through most of the crop — and the plant transpires steadily, feeds evenly, and stays healthy. Managing

the air is managing the water by another route, and in a controlled house it is one of the levers that separates a grower who hits 7% CV from one who merely hopes to.

Chapter 11 · Stress, On Purpose — *the grower's art.*

Everything in the last five chapters converges here, in the single idea that most distinguishes an artful grower of designed crops from a careful one. **The flavor we score is, in large part, stress chemistry** — capsaicin, the phenylpropanoids, the flavonoids and tannins are compounds plants make to defend themselves, to screen the sun, to answer drought and wounding and cold. A plant living in perfect comfort has little reason to make them. A plant pushed, precisely, to the edge of its tolerance makes them in abundance. The grower's highest craft is to apply the right stress, in the right amount, at the right moment — to practice *eustress*, the good stress that strengthens, and to stop short of *distress*, the bad stress that damages.



Finishing fruit under deliberate, measured pressure — the near side of the hormesis curve, where the plant builds defensive chemistry without tipping into damage.

The governing shape is the **hormesis curve** — a hump, like the deficit curve in Chapter 7, and in fact the same logic generalized. A little stress lifts the chemistry; too much collapses it. Plot the realized score against the applied stress and it rises to a peak and then falls, and the entire art is to locate and live on the near side of that peak. There is a mechanism under the curve worth knowing, because it tells you why *moderation* and *memory* both matter. Most stresses — drought, high light, UV, salinity, heat — raise the plant's level of reactive oxygen species, and the plant answers with an antioxidant and defensive response that *includes* the phenolic chemistry we

score. A mild, survivable dose trains that response; the plant even remembers it, so a crop gently hardened earlier meets a later stress better primed. An overwhelming dose outruns the defenses, oxidative damage wins, tissue and fruit are lost, and the chemistry goes down with the plant. Push toward the peak; do not go over.

Every lever in the toolbox is, at its edge, a stressor you can meter:

- **Water deficit** — the strongest and best-understood lever for heat; mild drought concentrates capsaicinoids through the ABA pathway.
- **UV-B** — a measured dose near the finish induces phenylpropanoid and flavonoid chemistry; the plant answers with its own sunscreen.
- **High light** — generous DLI is itself a mild oxidative pressure the plant meets with protective compounds.
- **Controlled salinity** — a modest lift in root-zone EC applies osmotic stress that can concentrate flavor, used with care and never to the point of scorch.
- **Temperature edge** — working the warm end of the range speeds the pathway; cold is the one stress that only ever costs.
- **Mild mechanical or wounding cues** — within reason, can prime defensive metabolism, and some growers use elicitor sprays (methyl jasmonate, salicylic acid — the plant's own defense signals, applied from outside) to call up the response without the damage.

STRESS LEVER	AXIS IT LIFTS	THE NEAR-SIDE LIMIT
Water deficit	Heat (H), secondary chem	recoverable midday wilt only
UV-B dose	Astringency (A), H, flavonoids	brief, late, no tissue burn
High DLI	H, C, secondary chem	no photobleaching of leaves
Root-zone salinity	concentration of several	modest EC lift; never scorch
Warm temperature	H (kinetics)	below the mid-thirties
Elicitor spray	defensive phenolics	low dose; the signal, not the wound

The discipline that makes this safe rather than reckless is **one change at a time, watched closely, written down.** Stress interacts; pile three pressures on a plant at once and you cannot tell which helped, which hurt, or where the edge was, and you will cross it blind. Apply one lever, read the plant daily — the newest growth, the midday set of the leaves, the color and gloss of the fruit — and record what you did and what happened. Over a season or two the plant teaches you its particular edges, and your hand learns to find them before your head does. This is also where the clean-growing ethos and the commercial number turn out to be the same thing: a plant stressed with care, never poisoned and never broken, finishes a fuller profile *and* a sounder food. We do not force these plants. We ask them, firmly, for everything they were built to give — and then we stop, one step short of asking too much.



PART IV OF VII

The Season

flower · placenta · ripening · harvest

Chapter 12 · Flower & Set — *the quiet middle.*

The flowers are easy to walk past. Small, white or faintly green, nothing like the fruit to come — and yet this is the hinge of the season, because the capsaicin you are growing will be built in a tissue that does not exist until the flower is pollinated and the fruit begins to form. Everything before this chapter built the plant that makes the flower. Everything after it depends on the flower becoming fruit. Miss the quiet middle and there is nothing to finish.



A pepper in flower — perfect, self-fertile, and easy to overlook; every flower helped to set is a placenta you will later fill with the number on the card.

The flower's design. Peppers carry *perfect* flowers — each with both stamens and a central pistil — and are largely self-pollinating, which is part of why a designed line stays true: there is little outcrossing to dilute it. Pollination here is mostly a matter of the plant's own pollen reaching its own stigma, and that transfer wants a little help the wind would give outdoors. In a still greenhouse the pollen can sit undisturbed in the anther and the flower can drop unfertilized, and a grower watching flowers fall without fruit is often watching a pollination failure, not a nutritional one. The fix is air and vibration: a soft daily shake of the plant, a fan, a pass of breeze, or — in a sealed house — managed pollinators such as bumblebees, whose buzz shakes the pollen loose far better than still air ever will. Every flower you help set is a placenta you will later fill.

Why flowers drop. Flower and fruit abscission is the plant's way of shedding what it cannot support, and it reads as a signal to the grower. The common triggers are temperature extremes (set falls when nights drop below the mid-teens or days climb past the low-thirties Celsius, outside the pollen's comfortable window), water or heat stress at the wrong moment, excessive nitrogen driving leaf at the expense of fruit, and poor pollination. Notice the overlap with earlier chapters: the same nitrogen trap that bought a leafy, fruitless plant shows up here as dropped flowers, and the same deficit that *concentrates* heat later will *abort set* if applied now. Timing is everything. The deliberate deficit you will lean on through ripening is held *off* through flowering and set, because the plant at this moment needs steadiness, not pressure.

SET PROBLEM	LIKELY CAUSE	GROWER'S RESPONSE
Flowers drop, no fruit	poor pollination (still air)	add air movement or pollinators
Widespread flower drop	night cold / day heat	protect temperature; wait for the window
Lush plant, few flowers	excess nitrogen	taper N; shift to fruiting feed
Set then abort	water / heat stress spike	steady the water through set

Load and balance. Once fruit sets, a second judgment opens. A plant is a budget of carbon shared among all its fruit — a source-and-sink economy — and a plant that sets more fruit than it can finish will ripen all of them a little short, each one a lower φ. For the top of the heat ladder especially, where there is the most chemistry to build per fruit, some growers deliberately thin: removing the earliest flowers to let the plant build frame first, or trimming an overheavy set so the remaining fruit finish full. It feels like a loss and is usually a gain — fewer fruit, each one carrying the whole number, beats a crowd of half-finished ones. Hold the plant steady through the quiet middle — even water, balanced feed easing toward fruiting, temperature in the window, air moving, the load balanced to what the plant can carry — and set is generous, even, and finishable. An even set is a gift that pays out at harvest: fruit that formed together ripens together, which is the foundation of a clean, uniform, low-CV crop. The dramatic levers come back soon enough. For now, the craft is steadiness, and the patience to let a plant full of inconspicuous white flowers turn, over a couple of weeks, into a plant full of the fruit you have been growing toward all season.

Chapter 13 · The Placenta — *where the number is built.*

Now we arrive at the tissue the whole guide has been circling, and it is one most people cut out and throw away. The heat is not in the seeds — that is the durable kitchen myth, and it is wrong. The capsaicin lives in the **placenta**, the pale membrane that holds the seeds, and specifically in tiny glands on the **interlocular septum**, the ridge of placental tissue running down the fruit's interior. This is where the enzymes we engineered do their final work, and where φ is ultimately won or lost. A grower who understands this tissue grows differently — and better — than one who pictures the heat spread evenly through the flesh.



A ripe superhot in cross-section — the pale placental tissue and the septum, where blister cells on the interlocular ridge fill with capsaicinoids as the fruit matures.

The gland, up close. On the epidermis of the placenta sit specialized blister-like cells — the capsaicinoid factories. Two arms of chemistry meet inside them. The **phenylpropanoid arm** begins when PAL deaminates phenylalanine to cinnamic acid; C4H hydroxylates it to p-coumaric acid; 4CL activates that to its CoA thioester; and through HCT, C3H and the O-methyltransferases the pathway works toward feruloyl-CoA and on to vanillin, which **pAMT** then transaminates to **vanillylamine**. The **branched-chain fatty-acid arm** starts from valine and leucine, which **BCAT** converts to branched-chain keto acids that a fatty-acid synthase including **KAS** elongates into **8-methyl-6-nonenoyl-CoA.** Then the terminal step, the one the whole design turns on: **Pun1/CS**, the capsaicin synthase — the AT3 acyltransferase whose structure we redesigned — condenses the vanillylamine and the branched-chain acyl-CoA into **capsaicin.** (Give it the saturated acyl chain instead and you get dihydrocapsaicin; the balance of the two sets the shape of the burn.) The capsaicinoids are secreted into vesicles that accumulate against the cuticle, sometimes visibly, as the droplets a cut superhot beads under a bright light.

PATHWAY STEP	ENZYME	INTERMEDIATE	WHAT THE GROWER CONTROLS
phenylpropanoid entry	PAL	phenylalanine → cinnamic acid	light, UV, measured stress — open the gate
hydroxylation / activation	C4H · 4CL	→ p-coumaroyl-CoA	— (feed the precursor pool)
toward the amine	HCT · COMT · pAMT	→ vanillin → vanillylamine	ripening time, healthy tissue
branched-chain acyl arm	BCAT · KAS	valine/leucine → 8-methyl-nonenoyl-CoA	balanced amino-acid pool
final condensation	**Pun1/CS**	**→ capsaicin**	substrate + time; on-plant ripening
gland filling / secretion	—	vesicles at the cuticle	warmth + days on the plant

Mutations that made the ceiling. It is worth the grower knowing, concretely, what was changed, because it explains why the ceiling is where it is and why consistency is possible at all. Two substitutions in the shipped construct — found by an ESM2 650-million-parameter protein language model scoring every possible single-residue change for catalytic efficiency times fold stability, then confirmed by a genome-scale flux-balance model and written in with CRISPR:

EDIT	EFFECT	ΔΔG (KCAL·MOL⁻¹)
S39L	binding affinity ↑ (N-terminal)	−2.1
L345G	steric relief at the active-site cleft	−1.8
C175S *(structural annotation — not in shipped construct)*	disulfide-misfold prevention	−0.9

Together, our model predicts peak output at approximately 2.94 million SHU, at a batch-to-batch coefficient of variation design target of **≤7%**, against **42%** in the wild type. Read that pair of numbers as a grower: the design did not only raise the ceiling; it tightened the *variance*, which is what makes a seven-percent promise keepable in the first place. A wild chile swings forty percent batch to batch no matter how carefully it is grown, because the genome itself is loose — and, historically, pungency itself hangs on a functional Pun1 locus, since the sweet peppers are simply the ones that lost it. Ours did not lose it; ours was rebuilt to hold.

What the grower does for this tissue. From roughly ten to twenty days after the flower opens, the glands begin to fill, and they go on filling through development, the capsaicinoids climbing toward a peak around full ripeness and sometimes easing slightly in the most overripe fruit. Nothing visible marks the filling — the most important chemistry of the whole plant is happening quietly, inside a green fruit, in a tissue you cannot see. The grower serves it by keeping the upstream regulatory gates open (light on PAL, measured deficit through this window), by keeping the plant warm enough that the

kinetics run, and above all by *giving it time on the plant.* The single most powerful thing you can do for the number now is not to add anything — it is to wait, and let the reaction run to its end, the glands filling as far as the upstream supply allows. Which is the subject of the next chapter.

Chapter 14 · Ripening — *when the number arrives.*

A green fruit is an unfinished sentence. Through ripening, the capsaicin glands fill toward their peak, the color turns as the pigments build, the sugars and acids settle into balance, and — crucially — a pepper does almost all of this *on the plant.* This single fact governs the end of the whole season, and it divides the library into two kinds of crop that must be grown, at the finish, by opposite rules.



Fruit coloring up on the plant — the pigments building as the glands fill. A pepper finishes its number where it hangs; pulled early, it never reaches the card.

Non-climacteric: the pepper finishes where it hangs. Peppers are non-climacteric — they lack the ethylene-driven ripening burst that lets some fruit continue to mature after picking. A pepper pulled green will turn a bit of color and soften, but it will not meaningfully gain heat, develop its full pigment, or complete its chemistry off the plant. **The number you harvest is very near the number you keep.** This is why we preach patience to pepper growers right up to the last warm week: a fruit pulled early to beat the weather is a fruit that never reached its card, and no cellar or process will add back the φ the plant did not finish. The whole season's work is cashed, or forfeited, in the decision of when to pick.

Climacteric: the tomato forgives, but fuller is still on the vine. The tomato is the opposite case — climacteric, carrying on ripening after it leaves the vine, driven by its own ethylene. The gas is made from the amino acid methionine, through SAM to ACC (by ACC synthase) and on to ethylene (by ACC oxidase), in an autocatalytic burst the fruit can run on the counter — which is why a tomato has always forgiven a slightly early pick, and why the global supply chain picks it green and gasses it later. But forgiveness is not fullness. The umami we grew back into the tomato — IFI-U climbing from a pale supermarket **300** toward a restored **2,600** — is laid down through on-vine ripening, as the plant's own **GAD** and **GDH1** pathways convert the fruit's nitrogen into the free glutamate the mGluR1 receptor reads as savory depth. The sweetness settles and the color builds at the same time, as chlorophyll breaks down and the carotenoid pathway runs — GGPP to phytoene to lycopene, the red of a ripe tomato, and on toward the β-carotene and, in peppers, the

capsanthin that paints a ripe pod. A tomato *can* finish on the counter; it finishes *fuller* on the vine. So even with a crop that forgives, we still say: leave it as long as the vine and the season allow.

	NON-CLIMACTERIC (PEPPERS)	CLIMACTERIC (TOMATO)
Ripening driver	gradual, on-plant	ethylene burst, continues off-plant
Pick early?	no — number is forfeit	tolerable, but fuller on the vine
What finishes late	capsaicinoids, pigment	free glutamate (umami), sugars
Grower's rule	wait for full color on the plant	ripen on the vine as long as season allows

The ripening curve, and sampling it. The practical grower does not guess at where the chemistry peaks — they *sample.* Pick one fruit at color break, one at full color, one a few days past, and read where the heat and the depth actually top out for *your* cultivar in *your* conditions. A commercial operation can put numbers on it: capsaicinoid content by assay, sugars as degrees Brix on a refractometer, color as a measured value rather than an eye's guess, each tracked across the ripening window until it plateaus. The curve shifts with climate and culture, and the only way to know your own peak is to have measured your way to it at least once, then to trust what you learned. Ripeness is not a date on a calendar. It is the moment the chemistry the design specified has actually been built — and the plant will tell you, if you have learned to read it, exactly when that is.

Chapter 15 · The Harvest — *read the plant, not the calendar.*

Harvest is the exam the whole season has been studying for, and the grader is the plant, not the page. Full color, full size, the fruit yielding its particular way to a gentle press, the glands behind that membrane as full as this plant in this ground was ever going to fill them — you learn the signs crop by crop, and after a season or two your hand knows before your head does. There is no substitute for this learned judgment and no formula that replaces it, because the plant finishing in front of you is the only authority on whether it is finished.



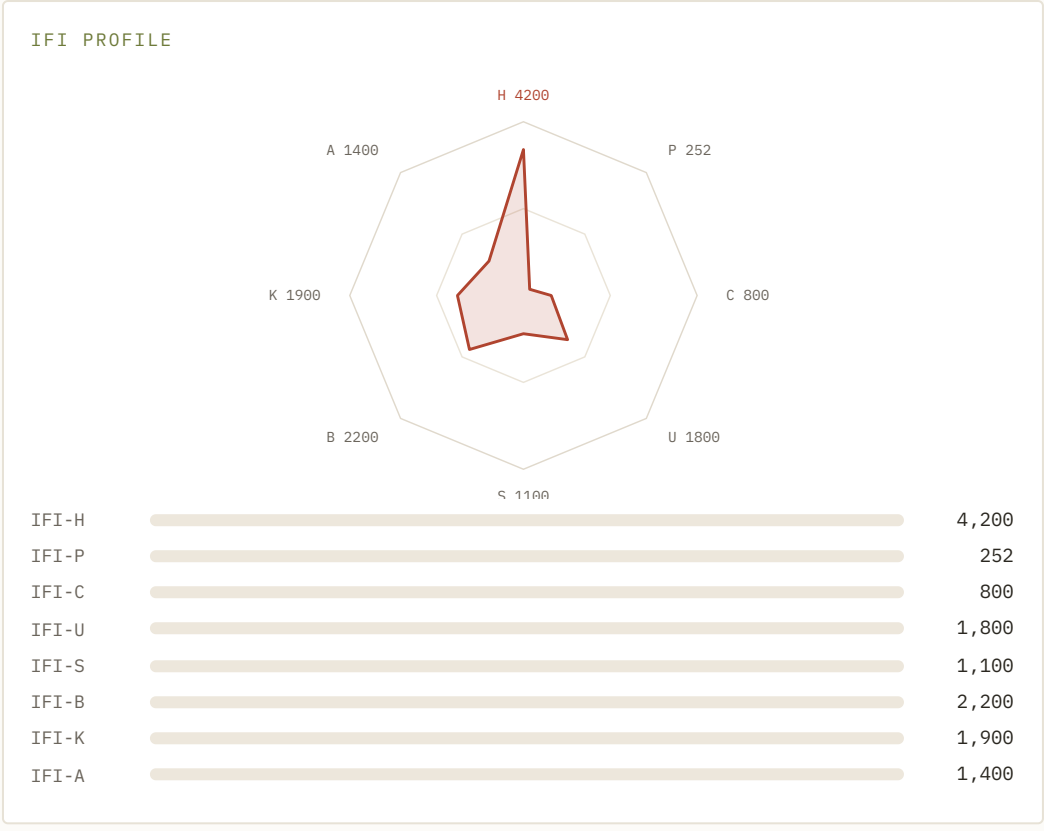
The harvested fruit passed, gloved, from field to the first cool — handled like the carrier of a number that it is. Everything after this is the preservation of what the field already built.

Maturity indices, and the single pick. Commercially, "ready" is pinned to a *maturity index* — a measurable sign you can train a crew on, so the judgment is repeatable across many hands: full cultivar color, a firmness that gives just so, a size in range, the days-after-set a crop typically takes in your conditions. Peppers do not ripen in unison — a plant carries fruit at every stage at once — so most are harvested in repeated passes, picking only what is ready each time and coming back, which protects φ by never pulling a fruit early to catch its neighbors. For the superhots, where the number is everything, we pick ripe and pick often, and we sort at harvest so a crate holds one stage of ripeness and therefore one φ.

The timing of the day. Pick into the cool of the morning, before the day's heat raises the fruit's temperature and its respiration with it. A fruit harvested hot is a fruit already beginning to spend the sugars and soften the tissue you worked all season to build; a fruit picked cool and moved quickly into shade and then into proper storage holds its profile and its shelf life far longer. The first hours after harvest are a continuation of the grow, not a separate chapter — we will give post-harvest its own full treatment shortly — but the habit begins at the moment of the cut: morning, cool, gentle hands, out of the sun, fast. Cut rather than tear, leaving a short stem, so you do not wound the fruit or the plant you mean to come back to.

Handling the superhots. At the top of the ladder, the fruit you are harvesting carries capsaicinoid concentrations that demand respect for the harvester, not just the crop. Gloves, covered skin, care around the eyes and face — a cut Phoenix will remind anyone who forgets, and the oils linger on hands and tools long after. This is a matter of ordinary safety, handled with ordinary sense, and it is worth stating plainly in a grower's guide because the people doing the picking deserve the warning. Grown right, these fruits are extraordinary. Handled carelessly, they are genuinely unpleasant to be careless with.

When it is done right, the harvested fruit reads to its design. This is the card the whole guide has been growing toward — the full-spectrum flagship, the only cultivar we have ever built to register on all eight axes at once, grown to the profile it was engineered to carry:



Phoenix · SS-0096 · grown to spec. IFI-H 4,200 corresponds to our model's prediction of approximately 2.94 million Scoville heat units — the highest heat design target we have specified, and the first fruit in history designed to carry company on every other axis. The design, remember, sets that ceiling; the number above is what a season of right growing hands back. Start cold, feed heavy, water lush, pick early, and the same genome reads lower on every line — φ below one, the card unmet. The seed was built to reach this. The grower is why it does.

The harvest is where the abstraction of φ becomes a crate of fruit a formulator will either accept or reject. Every chapter before this was an argument for the number in that `ifi` block; the harvest is the verdict. Read the plant honestly, pick it at its peak, sort it by stage, handle it like the carrier of a number that it is — and then turn to the quieter craft of keeping what the field built.



PART V OF VII

Systems & Defense

field · glass · hydroponics · the living defense

Chapter 16 · Under Glass, Under Sky — *field and controlled environment.*

There are two honest ways to grow these crops, and the point of this chapter is that both arrive at the same card. The open field gives the plant real sun, real wind to toughen it, and a root run no pot can match — and it gives you weather, which does not consult the schedule. The controlled environment gives you the dials: light set to a number, night held steady, water metered to the hundred-millilitre, every stress applied on purpose instead of suffered by chance. One is a conversation with a season. The other is an instrument. We grow both, and we do not think one is more honest than the other.



A field plot under open sky — real sun, real wind, a root run no container matches, and a season that does not consult the schedule.

Why they land in the same place. A field-grown Phoenix and a glass-grown Phoenix should read the same on the eight axes, because the genome is the same and the design set the ceiling; the grower's craft is simply the route to it. φ does not care whether the light came from the sun or a lamp, whether the deficit came from a dry spell or a dialed-down dripper. It cares only about the dose the fruit delivered. The field and the greenhouse are two paths up the same mountain to the same summit — and the choice between them is not about quality but about *control.*

	OPEN FIELD	PROTECTED / GREENHOUSE	CONTROLLED ENVIRONMENT (CEA)
Light	free, variable	enhanced, partly managed	set to a DLI number
Water / stress	weather-dependent	buffered	metered precisely
Season length	climate-bound	extended	year-round
Repeatability	lowest	moderate	highest
Cost / input	lowest	moderate	highest
Best for	flavor depth, scale, economy	shoulder-season reliability	formulator-grade consistency

What control buys. The decisive thing the controlled environment buys — and it buys it decisively — is **repeatability**: the ability to hand a formulator the same fruit in February that they had in August. When the light is a set number, the night is held, the water is metered and the stress is applied on a schedule rather than suffered by accident, the crop converges, every fruit finishing in the same place because every fruit was grown the same way. That convergence is the whole subject of the consistency chapter to come, and it is why the most demanding commercial supply — the batches held to ≤7% CV — tends to come from glass and chambers rather than open ground. Controlled-environment agriculture, including the vertical, stacked-canopy systems that multiply growing area under lights, is the industrial expression of the whole philosophy of this book: every variable named, metered, and held. Its honest cost is energy and capital — sunlight replaced by electricity is never free — and the grower who goes this way does so because the premium on sameness, for a formulator building to a target, pays for the lamps.

What the field buys. What the field buys back is the particular depth of a plant that grew up outdoors — the sun's full spectrum, including the UV a glass roof filters away; the toughening wind; the vast living root run; the economics of sunlight that costs nothing. For many crops and many purposes the field is not a compromise; it is the better instrument, and a skilled field grower reading the weather and the plant can finish a profile as full as any chamber's. The field's discipline is different — you cannot dial the weather, so you *place* the crop against it: the right region, the right planting date, protection for the shoulders of the season, a variety matched to the length of your summer. Choose by what you are growing for: formulator-grade month-to-month sameness leans toward glass; depth, scale, and economy lean toward the field; most operations use both, the greenhouse for the shoulders of the season and the field for its heart. Neither road changes what the seed was built to become. They only change how reliably, and at what cost, you get there.

Chapter 17 · Water Systems & Hydroponics — *growing without soil.*

When a grower moves into the controlled environment, soil often comes out of the equation and a water system takes its place — and the designed crop, with its demand for metered stress and repeatable nutrition, is unusually well suited to it. Hydroponics is not a shortcut; it is a transfer of responsibility. In soil, a living root zone buffers the plant and supplies much of what it needs through biology you cannot see. In hydroponics you take on those duties yourself — every nutrient, every pH point, every milliliter of water — in exchange for a precision soil can rarely match. For hitting a number to within seven percent, that trade is often worth making.



A controlled growing system where every input is metered — the root zone's biology traded for the precision that a formulator-grade number demands.

The systems, in brief. The family of soilless methods runs from the nearly-soil to the nearly-bare-root:

SYSTEM	HOW IT WORKS	FITS
Drip into substrate (coir, rockwool, perlite)	metered feed to a root in inert media	fruiting peppers, tomato — the workhorse
Dutch bucket / bato	recirculating drip into media-filled buckets	vining fruit crops, long season
NFT (nutrient film)	thin film of solution over bare roots	fast leafy crops, herbs, mint
Deep water culture	roots suspended in aerated solution	leafy crops, propagation
Ebb and flood	periodic flooding and draining of a tray	trays, propagation, herbs

For the fruiting crops that carry most of this library, **drip-fed inert substrate** — coir or rockwool or a blend — is the workhorse: it keeps something of the buffering a medium provides while handing you full control of the feed. For the leafy and the herbaceous, including mint grown for leaf, the barer-root systems move faster. The choice follows the crop's root habit and the length of its season.

The nutrient solution is a recipe. Without soil to supply and buffer minerals, you provide them all, dissolved to a formula — a complete solution in the spirit of the classic Hoagland recipe, carrying the macronutrients and the full set of traces, chelated so iron and the metals stay available at the working pH. Two decisions shape the

whole system. **Drain-to-waste** feeds fresh solution and lets the excess run off — simple, forgiving, but hungry on water and fertilizer. **Recirculating** reuses the solution — efficient, but it concentrates whatever the plant does not take up and shares one pool among every plant, so it demands constant monitoring and correction and a way to keep the water clean. Water quality underneath it all matters more than growers expect: a source high in alkalinity fights your pH, and one high in sodium slowly poisons a recirculating system, so you test the water before you ever mix the feed.

Root-zone control is the whole game. Because the root responds instantly to what you supply — the system's great strength and its great danger — **EC** and **pH** must be measured and corrected continuously, not weekly; a drift that soil would have absorbed, water will not. Dissolved oxygen at the root matters as much: roots respire, and a warm, under-aerated solution starves them and invites *Pythium*, so the water is aerated and the root-zone temperature held down, since there is no soil mass to steady it. And because a recirculating system shares one solution among every plant, sterility is not optional — clean water, often UV- or ozone-treated, and vigilance against the one root disease that could ride the pipes to the whole crop.

Precision, in service of the number. The reason to take all this on is that a water system lets you apply the levers of the earlier chapters with a precision the field cannot. The controlled deficit of Chapter 7 becomes a dialed reduction in feed volume, read off substrate-weight sensors to the gram. The nutritional arc of Chapter 9 becomes a recipe changed on a schedule, the same every cycle. The salinity stress of Chapter 11 becomes a measured lift in solution EC, applied for a set window and withdrawn. Every imprecise thing the field does by weather, the system does by number — which is exactly what a crop grown to a card, and held to a coefficient of variation, most wants. Hydroponics is the grower's instrument tuned to its finest resolution. It asks constant attention in return, and it punishes neglect faster than soil ever would. For the right crop and the right purpose, it is how you grow a number you can promise.

Chapter 18 · The Living Defense — *IPM, and growing clean.*

A designed crop is still a crop, and the same pests that have always loved peppers and tomatoes and mint love these no less. How a grower meets them is, for us, not only an agronomic question but an expression of the whole ethos of the company — because the food we are growing is food we mean for people to take into their bodies with intention, and the way it is defended is part of what it becomes. We grow, wherever we can, by **integrated pest management** — a living defense that reaches for biology and prevention first and for intervention last, and that keeps the finished fruit clean in every sense.



A healthy cluster under a living defense — prevention, sanitation, and beneficial insects first; the crop kept clean in every sense of the word.

Know the usual suspects. The pests worth watching, and the reason each matters:

PEST	HARM	FIRST RESPONSE
Thrips	rasping damage + vectors tomato spotted wilt virus	blue sticky traps, predatory mites, sanitation
Aphids	sap loss, honeydew, virus spread	ladybeetles, lacewings, parasitic wasps
Spider mites	stippling, webbing in hot dry air	predatory mites, raise humidity
Whitefly	sap loss, sooty mold, virus	*Encarsia* wasps, yellow traps
Fungus gnats	larvae damage roots in wet media	dry the surface, *Bacillus*, beneficial nematodes
Damping-off (fungal)	seedling collapse at the soil line	sterile media, air movement, restraint with water

The two most important columns are the last two, because the disease a pest *carries* is often worse than the pest — thrips spreading tomato spotted wilt virus can cost a crop far beyond the feeding damage — and because the **first response** is almost never a spray.

The order of operations. A living defense is a ladder you climb only as far as you must. **Prevention** comes first: clean stock, sterile media, sanitation, insect screening on the vents, quarantine of incoming plants, and the environmental control that denies pests

their preferred conditions — spider mites thrive in hot dry air, so managing VPD is pest management; fungus gnats breed in stagnant wet, so watering discipline is pest management. **Monitoring** comes second: sticky traps counted on a schedule, a hand lens, and a regular walk through the crop catch an outbreak while it is still a few plants — and here the idea of an *economic threshold* earns its place, the pest level at which action is worth taking, below which a few insects are simply food for the beneficials and not a problem to solve. **Biological control** comes third and carries most of the load: predatory mites for thrips and spider mites, parasitic wasps for whitefly and aphids, beneficial nematodes for soil larvae, sometimes kept resident on banker plants so a standing guard is always present — the natural enemies that keep a pest in check without ever touching the fruit. Only at the top of the ladder, and only when the lower rungs have failed, does **targeted intervention** enter: chosen to be as specific and as gentle as the problem allows — often a biopesticide, a living or biological agent rather than a broad chemical — timed to spare the beneficials, rotated so nothing builds resistance, and never as a routine.

Why clean-grown is the same as well-grown. There is no tension between the ethos and the economics here; they point the same way. A crop defended by biology and prevention is a crop whose fruit carries nothing it should not — which is exactly the fruit a formulator wants and exactly the food we mean to grow. The healthy plant is also the resistant plant: a vigorous, well-rooted, properly-fed crop under managed air shrugs off pressures that flatten a stressed one, so every good practice in the earlier chapters is also a line of defense. We do not grow clean as a marketing posture. We grow clean because a plant grown with that much attention is, at the end, both the more flavorful food and the better one — and because the person who eats it deserves nothing less than a crop we were proud of the whole way down.



PART VI OF VII

The Whole Library

42 organisms, each its own agronomy

Chapter 19 · Beyond the Pepper — *organism agronomy across the library.*

The platform reaches well past Capsicum — **42 host organisms** live today, each with its own agronomy, and sixty-four more on the roadmap — and a grower moving from peppers to the rest of the library has to learn new tells. The principles do not change: design sets the ceiling, the field sets φ, and the same levers of light, water, nutrition, warmth, and stress apply. What changes is *which* lever matters most, *which* tissue holds the number, and *when* in the plant's life the chemistry is built. This chapter is a working tour — not every crop, but enough of the range that you can read a new one when it arrives. Ask of any crop three questions — *where is the number built, when, and which lever moves it* — and the forty-two become one practice wearing many faces.



The umami-restored tomato — the crop that taught us why cultivation matters at all. A century of shipping-first breeding bred the depth out; on-vine ripening grows it back in.

The tomato is the crop that taught us why cultivation matters at all, because a century of shipping-first breeding bred the umami out of it and we grew it back in — 2,040 constructs restoring the savory depth. Here the whole season bends toward **on-vine ripening**: the restored IFI-U, climbing toward 2,600 against a supermarket 300, is laid down late, in the last days on the plant, as the fruit's own GAD and GDH1 route builds free glutamate. The grower's discipline is to

resist the early pick that logistics always wants. A tomato is climacteric and will finish on the counter — but it finishes *fuller* on the vine, and the difference is most of the number.

AXIS	CALDERA (UMAMI-RESTORED TOMATO), GROWN ON-VINE
IFI-U · Umami	2,600 — savory depth, built late and on the plant
IFI-S · Sweet	the ripe-afternoon sweetness, settled at full ripeness
IFI-K · Kokumi	roundness grown in, not boiled in
IFI-H · Heat	none — this crop is about depth, not fire

Primary axes for tomato are S / U / F / M; the locked figure is the restored umami at 2,600, roughly three times a shipping tomato.



Peppermint — grown not for fruit but for leaf, its cool built in peltate glandular trichomes on the leaf surface, and its menthol peaking in a narrow window at first flowering.

Peppermint is a different animal entirely — a spreading, rhizomatous perennial that will colonize a bed if you let it, grown not for fruit but for leaf. The cool it carries comes from a **five-gene menthol pathway** we reconstituted, and the menthol is built in **peltate glandular trichomes** on the leaf surface — the tiny oil glands you can smell when you brush the plant. The agronomy turns on a single fact: menthol content climbs toward **early flowering** and then begins to decline as the plant diverts toward menthofuran and other side products. The harvest window is therefore narrow and the timing is everything — cut at the first flush of bloom, in the morning, for the fullest, cleanest cool. With 2,360 constructs behind it, engineered peppermint reaches an IFI-C a wild plant never touches, but only if the grower catches that window. Miss it by a week and the oil has already begun to turn.



The alliums — garlic and onion, the savory floor of nearly every cuisine; grown long and slow for kokumi and a low pungent hum, then cured hard so the body sets.

The alliums — garlic and onion — are the savory floor, grown long and slow for kokumi and a low pungent hum. They ask less drama than a superhot and more patience than almost anything: a crop you plant in one season and harvest in the next, where the flavor is quite literally a function of time in the ground. The pungency chemistry — the allicin that forms when the tissue is cut, as an enzyme meets its substrate across broken cells — and the kokumi body both depend on the plant's sulfur metabolism, so sulfur nutrition and a long, unhurried bulking matter more here than any stress lever. And the allium's defining move comes *after* lifting: a hard **cure**, weeks of dry airflow, during which the body sets, the skins tighten, and the flavor concentrates and stabilizes. An allium rushed off the field undried is an allium that never finished.

The tannin crops — grape and tea foremost — hold their number in skin, seed, and young leaf rather than in flesh. Grape builds its astringency as proanthocyanidins (condensed tannins) through the flavonoid pathway, the route the index names through **ANR**; those tannins ripen on a clock of their own after *veraison*, the moment the fruit softens and colors, and sun exposure on the cluster and a measured water deficit both push the structure fuller — which is why a winegrower manages the canopy leaf by leaf around the fruit. Tea holds catechins (astringency and the attenuable bitter) in its youngest flush, and builds the L-theanine that reads as umami in its roots, which is why the prized teas are picked as the tenderest two-leaves-and-a-bud and why shading the bush before harvest lifts the savory side. Both reward a grower who knows that here the lever is light and ripeness on a specific tissue, not the whole plant.

ORGANISM	CONSTRUCTS	PRIMARY AXES	DIFFICULTY	THE GROWER'S KEY LEVER
Pepper	1,060	all	Native	light + controlled deficit
Tomato	2,040	S / U / F / M	Easy	on-vine ripening
Habanero	3,190	F / M	Hard	long warm season, lean finish
Black Mustard	2,790	P / M	Hard	glucosinolate intact to harvest
Peppermint	2,360	C / M	Hard	cut at first flowering
Grape	1,610	B / A / M	Hard	sun exposure + tannin ripeness
Stevia	910	S / F / M	Moderate	long days, pre-bloom harvest
Garlic	560	K / P	Moderate	long season + hard cure
Broccoli	380	B / M	Moderate	cool season, tight heads
Soybean	360	U / K	Frontier	even moisture through pod fill
Tea	280	U / B / A	Hard	shade + young-flush picking
Yeast / Koji	240 / 80	U / K	Hard	fermentation control, not field
Blueberry	120	A	Moderate	acid soil, full ripeness
Ginger	120	P	Moderate	warm, long, rich root zone
Vanilla	40	K	Hard	hand pollination + long cure

The table is a map of attention. A superhot asks for nerve on the water; a tomato asks for patience on the vine; a mint asks for timing on the knife; an allium asks for months and a good cure; a grape asks for sun on the cluster; a vanilla asks for a hand at every flower and a cure measured in weeks — the orchid sets no pod without hand pollination outside its native range, and the green pod carries no vanilla flavor until months of killing, sweating, and drying let an enzyme free the vanillin from its bound form. Sixty-four more concept organisms wait on the roadmap, from a volcanic tomato to a sweet-heat strawberry, and every one of them will arrive as the same three questions in new clothing. Learn to ask them, and the whole library opens.



PART VII OF VII

The Promise

consistency · post-harvest · stewardship

Chapter 20 · Consistency — *the same fruit, every time.*

A formulator does not want a brilliant fruit. A formulator wants *this* fruit, again, in six months, indistinguishable from the last. Reproducibility is the quiet promise under the whole commercial program, and the number that holds us to it is a **batch coefficient of variation at or under 7%** — meaning any two harvests of the same cultivar read within a hair of each other on every axis. The genome makes that possible; only the grower makes it real.



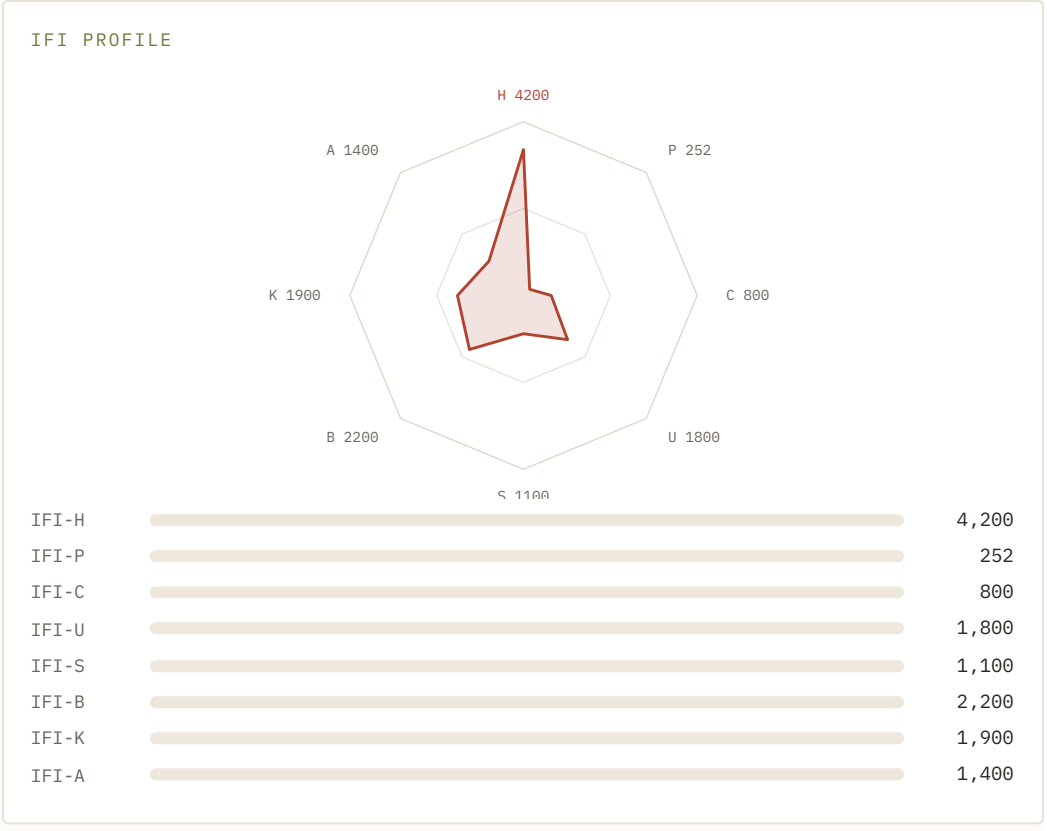
A fruit on the microscope stage, assayed against its card — the promise under the whole program is not a single brilliant harvest but the same harvest, again, to within seven percent.

What CV actually measures. The coefficient of variation is the standard deviation divided by the mean — σ/μ, expressed as a percent — a pure measure of *scatter relative to size.* A worked example makes the promise concrete. Say four harvests of Phoenix assay at IFI-H 4,160, 4,240, 4,180 and 4,220. The mean is 4,200; the standard deviation is about 35; the CV is 35 / 4,200 ≈ **0.8%** — comfortably inside the band. Now recall the design numbers. The wild chile swings at **42%** CV, loose in its very genome — on a mean of 4,200 that would be a standard deviation near 1,760, harvests scattering from under 2,500 to over 5,000, a different fruit every crate. The engineered line was built to **≤7%**, the variance tightened along with the ceiling raised. But that 7% is a genetic *potential* for tightness, not a guarantee. Two plants of identical seed, grown under different light and water and warmth, will miss each other by far more, and the card stops meaning anything. The genome supplies the *possibility* of consistency. The field either collects on it or squanders it.

Where variance comes from, and how to kill it. Trace the scatter and it almost always resolves into environment, not genetics:

SOURCE OF VARIANCE	HOW IT SHOWS UP	HOW THE GROWER KILLS IT
Uneven light	some fruit under-finished	open canopy; set a DLI; even the lamps
Erratic water	φ scattered fruit to fruit	meter irrigation; sensor-driven feed
Temperature swings	pathway runs fast then stalls	hold day/night set points
Uneven ripeness at pick	mixed φ in one crate	harvest by color, not by date; sort
Mixed-age plantings	different stages, same batch	stagger cleanly; keep records

Every row points the same way: **the controlled environment and the written record are the mechanisms of the promise.** The thinking is borrowed, deliberately, from manufacturing — statistical process control, where you track a number over time on a chart and act not when a single reading looks off but when the *pattern* drifts, so you correct a trend before it becomes a bad batch. When the light is a set number, the night is held, the water is metered, the stress is applied on a schedule, and every input is written down, the crop converges — every fruit finishing in the same place because every fruit was grown the same way — and a batch that *does* drift can be traced to the day and the cause rather than guessed at. The grow-sheet is not bureaucracy; it is the instrument of reproducibility, and it is also, not incidentally, the record a license and a buyer will want to see.



Phoenix · SS-0096 — the target card. Consistency means this profile, delivered again and again, each axis landing within ~7% of the one before. Holding a thousand live cultivars to that band, across every grower who licenses them, is in the end less a feat of genetics than of discipline in the field. The design built a line that can hold. The grower is the reason it does — every season, every batch, the same fruit the formulator was promised.

A designed flavor is only as trustworthy as the hands that can grow it the same way twice. That is the whole commercial case for everything in this book: not that you can grow a remarkable fruit once, but that you can grow the remarkable fruit *reliably* — and reliability, it turns out, is just attention made systematic.

Chapter 21 · Keeping What You Grew — *post-harvest and the preservation of a number.*

The field builds the number; the hours and weeks after harvest decide how much of it survives to the formulator or the plate. Post-harvest is not a separate trade from growing — it is the last act of the grow, the preservation of a profile that is now fixed and can only be held or lost, never improved. A pepper, remember, is non-climacteric: it will not gain anything after the cut. Everything from here is defense of what the plant already built.



The finished fruit handed on from the field — the number is now fixed and can only be held or lost. Cool it fast, handle it gently, process it with intention.

The first hours: respiration is the enemy. A harvested fruit is still alive and still respiring — burning its own sugars, losing water, warming itself from within. Respiration follows the same Q_{10} as any metabolism: roughly double the rate for every 10 °C warmer. So a fruit held at 30 °C spends itself about twice as fast as one at 20 °C and four times as fast as one at 10 °C. The single most important post-harvest act is therefore to **remove field heat quickly** — move the crop out of the sun at once, and cool it as soon as practical — because every degree you take off slows the clock that is quietly eroding quality and shelf life. A fruit picked cool in the morning and cooled further within the hour can hold its profile for days or weeks; the same fruit left to sit hot in a bin begins to degrade before it ever reaches storage. Cool, gentle, fast: the discipline of the harvest morning, continued.

FATE	METHOD	WHAT IT PRESERVES — AND CHANGES
Fresh	rapid cooling, cold chain, high humidity	holds full profile; shortest window
Dried	low, slow airflow (or gentle dehydration)	concentrates; some volatiles lost; capsaicin stable
Cured (alliums)	weeks of dry airflow	sets body, tightens skin, stabilizes flavor
Frozen	fast freeze	holds chemistry; softens texture
Processed (sauce, powder, extract)	milled, cooked, or extracted	concentrates heat; cooking alters volatiles

Drying, and what heat costs. Many of these crops reach the market dried or powdered, and drying is a lever with a trade-off. Capsaicinoids are remarkably heat-stable — the heat survives drying and even cooking largely intact — but the **volatile aromatics** that carry the top notes of a fruit's character are not: push the drying temperature high to go fast, and you boil off the very volatiles that distinguish one superhot from another, leaving heat without nuance. Low and slow preserves more of the whole profile. What you are really managing as you dry is **water activity** — not the total water but the *available* water that microbes and spoilage reactions can use; bring it low enough and the product is shelf-stable, which is the whole point of drying, but get there gently so the fragile chemistry survives the trip. The same logic runs through all processing: the robust, non-volatile chemistry (heat, much of the bitterness and astringency) survives; the delicate, volatile chemistry (aroma, the fine aromatic top of the flavor) is the part you can lose to careless heat. A grower who understands which axes are fragile processes to protect them.

Storage and the cold chain. For fresh fruit, the triad is cold, humid, and still-breathing: low temperature to slow respiration, high humidity to prevent the water loss that shrivels a pod, and enough air exchange to clear the carbon dioxide and any ethylene that accumulates — the latter mattering most for the climacteric crops like tomato, where stray ethylene from one ripe fruit accelerates ripening in its neighbors whether you want it or not. The most demanding operations go further, into *controlled* or *modified atmospheres* that hold the oxygen and carbon dioxide around the fruit at levels which slow its metabolism further still. But there is a floor: the peppers, like many warm-climate crops, are chilling-sensitive, damaged by cold *above* freezing if you hold them too cold too long, so the cold chain is a *band*, not a race to the coldest number. Know your crop's band and hold it.

The through-line is simple and worth saying plainly: **you cannot add φ after the harvest, only subtract it.** The whole craft of post-harvest is subtraction minimized — the careful holding of a number the field already won. Handle the crop as the carrier of that number from the cut to the cooler to the process, and the fruit that reaches the end of the line still reads to the card the plant was grown to make.

Chapter 22 · The Steward — *the seed you save.*

Because the edits are fixed and heritable, these lines come true from saved seed — which places something in the grower's hands that most of modern agriculture gave up a long time ago. You can keep the seed of the plant that grew best for you, in your ground, under your light, and sow it again, and it will carry the same designed profile forward. A licensee is not renting a trait for a season. They are tending a line — and a line tended well in one place for several seasons becomes, in the small ways that matter, *theirs*: selected not for the trait, which is locked, but for how beautifully it grows where they grow it.



A seed specimen set aside from the best of the crop — the oldest act in agriculture, keeping the seed of the one that moved you, now carrying a design written to come true again.

Saving seed, done right. The mechanics are the old ones, and they reward care. Take seed only from fully ripe fruit off your healthiest, truest plants — the ones that expressed the profile best and carried no disease — because a saved line concentrates whatever you select for, including problems. Clean the seed of its pulp, because residues invite rot and some carry germination inhibitors; dry it thoroughly but gently, to the low moisture that long storage wants; and keep it cool, dry, and dark, where the oil-rich embryo holds for years. For peppers, which largely self-pollinate, the line stays true with little effort; where a crop outcrosses more freely, an **isolation distance** — space, timing, or a physical barrier between your seed plants and any other pollen — keeps it clean. And index everything you save: cultivar, source plant, season, how it grew. A saved line is only as good as your knowledge of what it is; the genome is permanent, but your records are how you keep it legible, and how you prove, years on, that the line in your cooler is the line you were licensed.

Stewardship is also obligation. Growing a genetically engineered, licensed line carries responsibilities beyond the agronomic, and a grower's guide would be incomplete to leave them unsaid. We write the posture here, not the law, because the specifics live in your license and in the rules of your jurisdiction — and those rules differ markedly from country to country and change over time, so the paperwork, not this page, is your authority on what is permitted

where you grow. The posture is containment and good faith: grow within the terms you agreed to; keep the records the program and the regulators ask for; handle pollen and seed so a line stays where it belongs and does not cross into a neighbor's crop or escape to the wild; label and trace your stock so any fruit can be followed back to its field; and do not propagate, sell, or distribute seed or plants outside what your license permits. None of this is onerous for a careful grower — most of it is the record-keeping you already do for consistency, pointed now at compliance — and we handle the regulatory frame alongside you, as the license sets out. Your part is to grow it straight and keep it clean.

We think of that as the truest form of the partnership, and the oldest. Long before anyone could edit a pathway, growing was already an act of stewardship — keeping the seed of the one that moved you, handing it on, trusting the next pair of hands to carry it well. We have changed what is written in the seed. We have not changed what it asks of the person who grows it: attention, patience, a willingness to read the plant and answer it honestly, and the care to keep a good thing good. Steward the line, save the seed of your best, keep it clean and within the terms, and the design travels forward in good hands — which is the only way any of this was ever meant to last.



CODA

The Ninth Axis

what good growing serves, beyond the card

A closing note · the grower's ninth axis

There is a measurement this guide has not asked you to take, and it is the one we think about most. A plant grown all the way to its fullest flavor is, almost without exception, a plant grown toward its fullest nourishment. The same patient on-vine ripening that fills a tomato with umami fills it with its lycopene and its vitamin C; the same lean, attentive growing that builds the chemistry we score builds a food that gives the body more of what it came for; the same healthy root and living soil and clean defense that make the fruit read to its card make it a fruit worth eating in the first place. We measure eight axes of taste. There is a ninth thing, beyond the scope of this book and beyond any number on any card, for what a body actually draws from the meal — and good growing serves it in the very same motions that serve the flavor.

That is not a claim, and we are careful never to let it become one. It is an observation about how growing works: that attention is indivisible, that you cannot grow a food to its fullest taste while starving it of everything else, that the practices which bring φ to one are, over and over, the practices that bring it to the other. Reverence for the plant is not sentiment. It is, in the end, just the most accurate way to grow.

So the grower's real work turns out to be larger than any axis on any scorecard. You are not only bringing a designed flavor to its ceiling. You are growing food the way it was always supposed to be grown — on purpose, with care, toward the most it can carry — and handing it on to the people who will eat it. The seed arrives with the design already written in: the pathway, the receptors, the ceiling, the two substitutions in Pun1 that no breeder ever found. What you add is everything that cannot be written — the warm wait over the slow flat, the held nerve against a thirsty plant, the morning you knew, before you could have said how, that the fruit was ready. Grow it right, and the plant becomes exactly what it was built to be. That was always the whole point of measuring anything.

We wrote the pathway. You turn it on. Between the two of us, with a little warmth and a great deal of patience, the seed becomes the fruit it was always meant to be — and the fruit becomes a meal, given to a body, on purpose. Welcome to the growing. There is no better work we know.