From Bench to Batch

Scaling a chilled ready-meal sauce from a 1 kg recipe to a 10,000-portion kettle run: worked mathematics, failure library, hazard analysis, shelf life, costing and a five-gate procedure



Anthony Vondoom

Independent researcher | Chef de Cuisine

Intended use and limits	
What this is	A mathematical and conceptual handbook. It shows how to reason about scaling a recipe, finding the cause of a failure, setting hygiene limits and costing a production run, using one worked example: a 1 kg sauce taken to a 112.5 kg batch in a 150 L steam-jacketed tilting kettle.
What it is not	It is not a validated HACCP plan, a regulatory or process-authority approval, or legal, medical or professional food-safety advice. It does not replace a qualified food technologist, a HACCP practitioner or the competent authority.
Example values	Every quantity, price, temperature, time, limit and log marked assumed, example or (A) illustrates the method. None is a recommendation for any product or plant, and none should be copied into a plan.
Adapt and validate	Replace the examples with measurements from your own kettle, line, ingredients and product, and apply your own experience. Anything that affects safety (lethality, cooling, shelf life, allergens, hygiene) must be validated on your own process before it is relied on.
Jurisdiction	Rules and guidance differ between countries and change over time. The sources cited are guidance or retail and foodservice rules from several jurisdictions, graded in the text. Check the requirements where you produce and sell.
Responsibility	Use is at the reader's own risk. The handbook is provided for information, without warranty of accuracy, completeness or fitness for a particular purpose, and the author accepts no liability for loss or harm arising from its use. Each producer remains responsible for the safety and legality of its own products.

Disclosure of AI assistance and authorship

This work was produced jointly by the author and an AI assistant (Claude, Anthropic), each contributing to the other's part. The concept, the project brief, the equipment specification, the five-gate outline and the production questions were supplied by the author, who directed the work throughout. The AI assistant searched for sources to verify those inputs, carried out the calculations and stress tests, chose coherent example values where the author instructed that coherent figures be used (all listed in Section 10), and drafted the text under the author's direction, with the author's input and corrections shaping the result.

The author is responsible for the content. Calculations were checked by recomputation and sources by retrieval. **review by a qualified food technologist and a HACCP practitioner is advised before operational use.** This disclosure is made in accordance with the author's standard practice of transparent AI use across all published work.

How to read this handbook	
Structure	**Part A** (Sections 1-9, Appendix A) is the scale-up guide: mathematics, failure library, diagnosis, hygiene and costing. **Part B** (Sections B1-B11) applies five commercialisation gates, a hazard analysis and a shelf-life study plan to a 10,000-portion run on the same numbers.
Evidence grades	**Confirmed**: a source was retrieved and read. **Assumed**: an example value stated as such, to be replaced by measured or quoted data. **Unknown**: no source was found; nothing is claimed.
Formula cards	Cards 1-20 give, in the same order, the question, formula, symbols, why it works, steps with numbers, a template and common errors.
One batch	All sections use one batch of 112.5 kg (150 L kettle, 75% fill, 1.00 kg/L). The numbers are worked for this reference kettle; other kettle sizes are handled in Section 1.4.
Target	The production target is read as **10,000 portions** of 80 g sauce; a 10,000 kg target is also worked in Section B3. The reading is an assumption.

Abstract

Moving a recipe from a 1 kg bench batch to a 112.5 kg kettle batch changes the physics more than the arithmetic, and moving that batch into a factory adds gates that must be passed in order. This handbook carries one demonstration recipe (a creamy garlic-herb chicken sauce, a potato mash and a blanched green bean) through both steps on one set of numbers. Part A derives the scale factor, heating surface, evaporation, blanching temperature, cooling time and cost per portion step by step, stress-tests each against alternative assumptions, and sets out a failure library, diagnostic methods and hygiene limits. Part B applies five gates (metric profiling, industrial sourcing, pilot trials, line trials and SOP hardening) to a production target of 10,000 portions, which needs 8 kettle batches of the reference size once an assumed 2% heel loss is counted. Part B also sets out a hazard analysis and HACCP plan, with equivalent-lethality, cooling-validity and fill-time calculations, and the shelf-life rules that decide which heat process a sauce needs (Sections B9 and B10). The numbers are worked for a 150 L steam-jacketed tilting kettle, a type built by many manufacturers, and are recomputed for other sizes with the templates provided (Section 1.4). Heat-process and shelf-life rules come from UK and Australian guidance, cooling limits from the US Food Code, and no primary EU manufacturer rule was located. Where a figure could not be sourced, a coherent example value is used and flagged in the assumption register (Section 10). The handbook is a mathematical and conceptual framework and not a validated plan; readers adapt every example to their own process (see the notice on page 2).

Keywords: scale-up; cook-chill; steam-jacketed kettle; starch retrogradation; syneresis; Newton cooling; HACCP; pilot plant; recipe costing; SOP.

Part A. Scale-up: the worked guide

1. Scope, reference equipment and evidence status

1.1 Brief

The commissioning brief specifies three equipment types as the reference line: a steam-jacket tilting kettle (MKN Optima 850 class), a mixing combi-kettle (Metos Proveno 4G class) and a pump-and-chill line (JBT/Frigoscandia class). The manufacturer data for these machines was checked where it could be found. Machine energy consumption is excluded by instruction.

1.2 Equipment verification

Item	Verified (grade)	Not verified
MKN Optima 850 150 L kettle	Used-equipment listings (2014 and 2015 units): 150 L usable fill; inner kettle 665 mm diameter, 500 mm deep; double-jacketed with a separate integrated steam generator named VAPRO [S1]. Confirmed (dealer data, re-read 15 October 2026).	Energy type of the 150 L listing (the same dealer site lists gas variants of the Optima 850 range); power; heat-up time. The term 'Vapo-Control' was not found; VAPRO is the term used.
Metos Proveno 4G Combi 150E	150 L electric kettle with mixer; stepless mixing 15-140 rpm with auto-reverse; electric tilting; tilting while mixing; food and jacket temperature controlled separately; Delta-T cooking; wash programs [S2]. Confirmed (distributor listing, re-read 15 October 2026).	A manufacturer page for a Proveno 150E in another market lists a bottom-mounted two-direction mixing tool at 10-160 rpm [S3], so the speed range depends on the model generation. Whether the standard agitator scrapes bottom and sides is not stated in any source found. Power rating.
Pump-and-chill line	No JBT/Frigoscandia pump-fed tumble chiller page was found. In the DC Norris cook-chill system, a pump-fill station fills hot liquid into bags and the bags are cooled in chilled water in a tumble chiller [S4]. Belt tumble chiller: 85 °C to below 4 °C in 30-60 min, 300-1000 kg; rotary tumble chiller: below 4 °C in about 45 min (thin) to 90 min (thick), 300-1000 L; a 2021 release gives 35-45 min for the belt model [S4]. Confirmed (vendor claims).	That JBT supplies such a unit; any JBT chiller specification. Vendor times are claims for the vendor's own test products, not measurements for these sauces.

1.3 Limits of the evidence

- The stress cycle used throughout is cook, chill, hold for at least 7 days, reheat. It is an assumed cycle for a chilled ready meal; no product-specific shelf-life source is used.
- Dealer listings and vendor brochures are treated as claims, not measurements.

1.4 Applicability to other kettles

Steam-jacketed tilting kettles of this type are standard equipment in food processing plants and large kitchens. A buying guide gives capacities from 20 to over 200 US gallons [S5], and 100-gallon tilting kettles with a two-thirds steam jacket are listed by other makers, one electric [S6] and one with direct steam [S7]; the Optima 850 and Proveno of Section 1.2 are further examples. The method in this handbook therefore applies to any kettle of this type, and nothing in it depends on one customer or plant.

The numbers do not transfer unchanged. They are worked for one reference unit: 150 L net volume, 665 mm inner diameter and 500 mm depth (Section 1.2), 75% working fill and 1.00 kg/L. They hold for a kettle with the same net volume and shape. For any other kettle, the net volume, inner diameter and fill are replaced in Cards 1, 2 and 13, and every dependent figure (scale factor, heating surface, evaporation time, batch count, cost) is recomputed with the templates; Table 13 shows the effect of kettle size on the batch count. The jacket type (two-thirds or full) and the agitator also change heat-up and scraping behaviour, which the geometry-based cards do not capture.

2. Method and verification

All numbers come from one calculation module. Figures are read from that module; the few numbers typed into captions were re-checked against it. Verification used four checks:

- **Exact arithmetic.** The recipe columns were summed with exact fractions: lab 1,000 g and production 112,500 g.
- **Independent numerical check.** The analytic cooling equation was compared with a numerical differential-equation solution; the largest difference was 5.3e-10 °C.
- **Stress tests.** Fill and density, pan diameter, evaporation target, blanching load and start temperatures, cooling rate, coolant temperature, and every cost input were varied (Sections 3-8).
- **Monte Carlo.** 20,000 cost runs with a fixed random seed (20261014).

3. Demonstration recipe and the scale factor

Formula card 1: scale factor	
Question	How many times larger is the production batch than the bench batch, so that every ingredient can be multiplied by one number?
Formula	$M_{prod} = V_{net} \times f \times \rho$ $\quad SF = M_{prod} \div M_{lab}$
Symbols	V_{net} net kettle volume in litres (150, dealer listing). f working fill fraction (0.75, **assumed**). ρ batch density in kg per litre (1.00, **assumed**). M_{lab} bench batch mass in kg (1). SF scale factor, a pure number.
Why it works	A recipe is a set of ratios. Multiplying every ingredient by the same number keeps the ratios, so the product is the same. The kettle is not filled to the brim because room is needed for agitation, foaming and tilting. Mass (not volume) is used because ingredients are weighed.
Steps	1. Working volume = 150 × 0.75 = 112.5 L. 2. Mass = 112.5 × 1.00 = 112.5 kg. 3. SF = 112.5 ÷ 1 = **112.5**. 4. Multiply each lab gram by 112.5. Example: cream 400 g × 112.5 = 45,000 g = 45.000 kg. 5. Check: the production column must sum to 112,500 g.
Template	V_{net} = ___ L; f = ___; ρ = ___ kg/L; $M_{prod} = V_{net} \times f \times \rho$ = ___ kg; $SF = M_{prod} \div M_{lab}$ = ___. Weigh 1 L of the real bench sauce to obtain ρ.
Common errors	Using 150 L as if it were 150 kg. Assuming ρ = 1.00 for a fat-rich sauce without weighing it. Scaling salt and strong spices by the factor alone; these need a trial batch.

Table 1. Demonstration sauce recipe (creamy garlic-herb chicken sauce), lab and production quantities. Recipe proportions are an example formulation (assumed).

Ingredient	Lab g	Production kg (× 112.5)
Cream 35% fat	400	45.000
Chicken stock	426	47.925
Butter	60	6.75
Modified waxy starch	25	2.8125
Garlic puree	30	3.375
Dijon mustard	20	2.25
Lemon juice	15	1.6875
Parsley	15	1.6875
Salt	8	0.9
White pepper	1	0.1125
Total	**1,000**	**112.500**

Fat check. Cream 400 g × 0.35 = 140.0 g; butter 60 g × 0.82 = 49.2 g; total 189.2 g, which is 18.9% of the 1,000 g batch. The fat percentages (35% and 82%) are typical label values that were not sourced; supplier specifications replace them.

Mash and beans. Mash is dense, so its fill is assumed at 60% with 1.05 kg/L: 150 × 0.60 × 1.05 = 94.5 kg, SF_{mash} = 94.5. Potato 820 g × 94.5 = 77.49 kg. The mash columns sum to 94.5 kg. Beans are blanched in water at a fixed ratio (Section 4.3), so no factor is needed for them.

Table 2. Stress test: production batch mass (= scale factor against a 1 kg lab batch) across fill and density. Depth and free height use a cylinder of 665 mm diameter and 500 mm depth.

Fill f	ρ = 0.95	ρ = 1.00	ρ = 1.03	ρ = 1.10	Liquid depth / free height (mm)
65% (97.5 L)	92.6 kg	97.5 kg	100.4 kg	107.2 kg	281 / 219
70% (105.0 L)	99.8 kg	105.0 kg	108.2 kg	115.5 kg	302 / 198
75% (112.5 L)	106.9 kg	112.5 kg	115.9 kg	123.8 kg	324 / 176
80% (120.0 L)	114.0 kg	120.0 kg	123.6 kg	132.0 kg	346 / 154
85% (127.5 L)	121.1 kg	127.5 kg	131.3 kg	140.2 kg	367 / 133

Result. The scale factor ranges from 92.6 to 140.3 across plausible fill and density. A density change of 3% moves every ingredient by 3%, which is why the real density is measured first. **Dimensional caveat:** a 665 × 500 mm cylinder holds 173.7 L, but the listing states 150 L usable (86% of the cylinder). The real bowl shape is therefore not a plain cylinder, and depth and wall area are approximations.

3.1 Ingredient specification cards

Each card lists sourced behaviour and the fields to request from the supplier, so that a later sauce failure can be traced to a material property. Sourced values were not found for the garlic purée, stock, salt, parsley, potato, milk or beans; these are not given.

Ingredient	Sourced behaviour (grade)	Supplier fields to request
Modified waxy starch (thickener)	Waxy starches have very little amylose, are the least prone to retrogradation and are more freeze/thaw stable; hydroxypropylation is a common modification for freeze/thaw stability; low-pH sauces need modified starches or acid-tolerant native starches; batch-to-batch variation changes sauce stability [S8]. In white sauces, two modified waxy corn starches were unaffected by a freeze/thaw cycle, while normal native corn starch gave syneresis and native waxy starch was in between [S9]. Confirmed. Most of this evidence is for freeze/thaw; chill-hold equivalence is not demonstrated (Section 5.2).	Starch type and modification; pasting temperature; peak and final viscosity; acid and shear tolerance; chill-hold and freeze/thaw syneresis data; lot certificate. The gelatinisation temperature is taken from the supplier, not from a general figure.
Cream 35% fat	In frozen sauces, a high fat content or a good stabiliser system lowers the chance of a broken or grainy sauce after freeze/thaw [S8]. Confirmed (frozen sauces only). Other behaviour: Unknown (no source retrieved).	Fat %; protein %; stabiliser; pH; pasteurisation type; homogenisation.
Butter	No source retrieved. Unknown.	Fat %; moisture %; salt %.
Dijon mustard and lemon juice	Low-pH sauces need starches that tolerate acid [S8]. The roles of mustard (emulsifier) and lemon (acid): Unknown (no source retrieved).	pH or titratable acidity; salt %; solids.

4. Scale-up physics: what does not scale linearly

4.1 Heating surface per litre

Formula card 2: heated wall area per litre	
Question	How much heated wall does each litre of sauce touch, and how does that change from a lab pan to a kettle?
Formula	$A_{floor} = \pi\, d^2 \div 4$ $h = V \div A_{floor}$ $A_{side} = \pi\, d\, h$ $A_{tot} = A_{floor} + A_{side}$ $a = A_{tot} \div V$
Symbols	d inner diameter (m); V liquid volume (m³; 1 L = 0.001 m³); h liquid depth (m); A areas (m²); a area per litre. Pan: d = 0.16 m, V = 1 L (assumed). Kettle: d = 0.665 m (dealer listing), V = 0.1125 m³.
Why it works	Heat enters through the wall; volume grows with the cube of size while wall area grows with the square. Larger vessels therefore have less wall per litre, so heat-up is slower and the wall runs hotter than the bulk, which is where scorching starts.
Steps (kettle)	1. $A_{floor} = 0.7854 \times 0.665^2 = 0.3473$ m². 2. h = 0.1125 ÷ 0.3473 = 0.3239 m (324 mm). 3. $A_{side} = \pi \times 0.665 \times 0.3239 = 0.6767$ m². 4. $A_{tot} = 1.0240$ m². 5. a = 1.0240 ÷ 112.5 L = 91.0 cm² per litre.
Steps (pan)	$A_{floor} = 0.0201$; h = 0.0497 m; $A_{side} = 0.0250$; $A_{tot} = 0.0451$ m²; a = 451.1 cm² per litre. Ratio = 4.96.
Template	d = ___ m; V = ___ L; A_{floor} = ___; h = ___; A_{side} = ___; a = $A_{tot} \div V$ = ___ cm²/L. Compare pan and kettle.

Common errors	Mixing litres and m³. Using the full kettle depth instead of liquid depth. Assuming the jacket covers the full side wall; the jacket coverage of the Optima 850 was not verified.

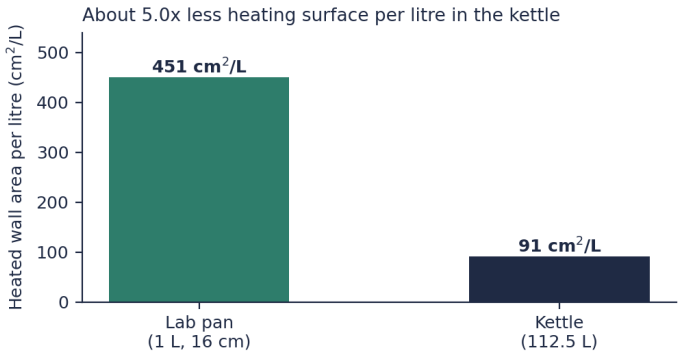


Figure 1. *Heated wall area per litre, pan versus kettle (cylinder approximation; assumed pan 16 cm).*

Table 3. Stress test of heating surface. Kettle area per litre is insensitive to fill (87-96 cm²/L); the ratio to the lab pan stays between 4.8 and 6.8 across pan sizes.

Variable	Value	Result
Kettle fill	65%	95.8 cm²/L
Kettle fill	70%	93.2 cm²/L
Kettle fill	75%	91.0 cm²/L
Kettle fill	80%	89.1 cm²/L
Kettle fill	85%	87.4 cm²/L
Lab pan diameter	14 cm	439.7 cm²/L (ratio 4.83)
Lab pan diameter	16 cm	451.1 cm²/L (ratio 4.96)
Lab pan diameter	20 cm	514.2 cm²/L (ratio 5.65)
Lab pan diameter	24 cm	619.1 cm²/L (ratio 6.8)

4.2 Evaporation and the finish-by-solids rule

Formula card 3: evaporation flux and time to target loss	
Question	A bench simmer of 10 minutes removed a known weight of water. How long does the kettle need to remove the same *percentage*?
Formula	$J = m_{lab} \div (A_{top,lab} \times t_{lab})$ $t_{kettle} = m_{target} \div (J \times A_{top,k})$
Symbols	J evaporation flux in g per m² per minute; m mass lost (g); A_{top} open liquid surface (m², equal to the floor area for a cylinder); t time (min).
Why it works	Water leaves through the open surface, so loss in grams scales with surface area, not with mass. A kettle holds 112.5 times the mass but only 17 times the open surface of the pan, so the same time removes a much smaller percentage.
Steps	Assumed bench result: 8% of 1 kg = 80 g lost in 10 min. 1. J = 80 ÷ (0.0201 × 10) = **398 g/m²/min**. 2. Same 10 min in the kettle: 398 × 0.3473 × 10 = 1,382 g = 1.23% of 112.5 kg. 3. Target 8% = 9,000 g. 4. t = 9,000 ÷ (398 × 0.3473) = **65.1 min**.
Template	m_{lab} = ___ g; $A_{top,lab}$ = ___ m²; t_{lab} = ___ min; J = ___; $A_{top,k}$ = ___ m²; m_{target} = ___ g; t = ___ min.
Common errors	Assuming the same time gives the same result. Ignoring that a lid, agitation and temperature change J: the model assumes a constant J, which is a simplification.

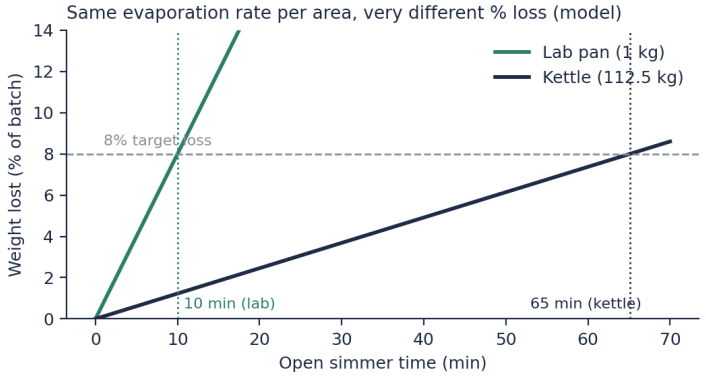


Figure 2. Modelled weight loss over time, lab pan versus kettle, from one assumed bench observation.

Table 4. Stress test: evaporation. The time for an equal percentage loss is 65.1 minutes at every bench loss, because $t = t_{lab} \times (M_k \div M_{lab}) \times (A_{lab} \div A_k)$ depends only on the mass-to-surface ratio. A 65-minute open simmer would itself change flavour and colour, so the practical fix is finishing by solids, below.

Bench loss	J (g/m²/min)	Kettle loss in same time	Time for same % in kettle
4%	198.9	0.69 kg (0.61%)	65.1 min
8%	397.9	1.38 kg (1.23%)	65.1 min
12%	596.8	2.07 kg (1.84%)	65.1 min

Formula card 4: finish by solids (mass balance)	
Question	At what finished weight, or what Brix reading, is a reduction done?
Formula	$M_f = M_0 \times s_0 \div s_1 \quad m_{evap} = M_0 - M_f \quad s_1 = s_0 \div (1 - \text{loss})$
Symbols	M_0 starting mass (kg); s_0 starting solids fraction (0.20, **assumed**); s_1 target solids fraction; M_f finished mass.
Why it works	Water evaporates but solids stay. Solids mass before ($M_0 \times s_0$) equals solids mass after ($M_f \times s_1$); rearranging gives M_f.
Steps	1. Solids = 112.5 × 0.20 = 22.5 kg. 2. For 8% loss, s_1 = 0.20 ÷ 0.92 = **21.74%**. 3. M_f = 22.5 ÷ 0.2174 = **103.50 kg**. 4. m_{evap} = 112.5 − 103.5 = 9.00 kg. A refractometer reading of Brix (a close proxy for soluble solids) of about 21.7 then marks the endpoint; the Brix-to-solids relationship for a cream sauce must be calibrated.
Template	M_0 = ___ kg; s_0 = ___; s_1 (target) = ___; $M_f = M_0 \times s_0 \div s_1$ = ___ kg; water to remove = ___ kg.
Common errors	Adding ingredients (such as lemon juice or parsley) after the weighing; the mass balance then needs the added solids. Using time as the endpoint.

Table 5. Stress test of the endpoint. The finished mass at 8% loss is 103.5 kg whatever the starting solids, but the Brix target moves with them. A 1.3-point error in the endpoint changes the finished mass by about 6 kg, about 6% of the batch, which feeds directly into cost (Section 8).

Start solids s_0	Target s_1 for 8% loss	Finished mass
18%	19.57%	103.5 kg
20%	21.74%	103.5 kg
22%	23.91%	103.5 kg

Chosen endpoint s_1	Finished mass	Water removed
20.50%	109.76 kg	2.74 kg
21.74%	103.5 kg	9.0 kg
23.00%	97.83 kg	14.67 kg

4.3 Blanching: why overloading makes beans mushy

Formula card 5: temperature after loading cold food into hot water (energy balance)	
Question	How far does the water temperature fall when a batch of cold beans is added, and what is the largest load that keeps the water above a chosen temperature?

Formula	$T_{mix} = (m_w\, c_w\, T_w + m_b\, c_b\, T_b) \div (m_w\, c_w + m_b\, c_b)$ $\quad m_{b,max} = m_w\, c_w\, (T_w - T_{min}) \div [c_b\, (T_{min} - T_b)]$
Symbols	m mass (kg); c specific heat (kJ/kg·K; water 4.18, beans 3.9 **assumed**); T temperature (C); subscripts w water, b beans. Water 100 kg at 95 °C; beans at 15 °C (assumed).
Why it works	Heat lost by the water equals heat gained by the beans. The mixed temperature is the weighted average of the two starting temperatures, with weights m × c (the heat capacity of each). Instant mixing and no heat input during mixing are assumed, so the result is the lowest point, before the kettle recovers.
Steps (10 kg)	1. Water term: 100 × 4.18 × 95 = 39,710. 2. Bean term: 10 × 3.9 × 15 = 585. 3. Top = 40,295. 4. Bottom: 418 + 39 = 457. 5. T_{mix} = 40,295 ÷ 457 = **88.2 °C**.
Steps (max load)	For T_{min} = 85 °C: $m_{b,max}$ = 100 × 4.18 × (95 − 85) ÷ [3.9 × (85 − 15)] = 4,180 ÷ 273 = **15.3 kg**, a ratio of about 1 : 6.5 beans to water.
Template	m_w = ___; T_w = ___; m_b = ___; T_b = ___; T_{mix} = ___. Set T_{min} = ___ and solve $m_{b,max}$ = ___.
Common errors	Forgetting the weights are m × c, not m. Treating the result as steady: it is the dip. Ignoring that the textural effect also depends on time and temperature. Retrieved studies show that low-temperature blanching (about 60-70 °C), with calcium in some, improved firmness retention in onion, soybean sprout, carrot, sweetpotato, tomato and potato [S10, S11, S12, S13]. Green beans were not among the vegetables tested, so the effect on beans is an extrapolation.

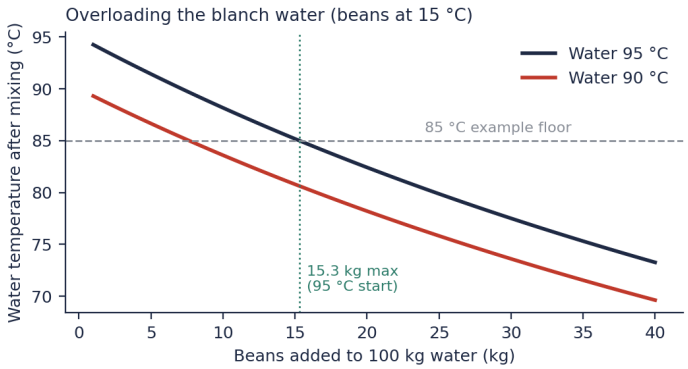


Figure 3. *Water temperature after loading beans into 100 kg of water (bean specific heat assumed 3.9 kJ/kg·K).*

Table 6. Stress test of blanch water temperature (beans 3.9 kJ/kg·K). Changing the bean specific heat between 3.5 and 4.1 moves the 10 kg result by only 0.97 °C (88.82 to 87.85 °C), so the model is far more sensitive to start temperatures and load than to c_b.

Water start	Bean start	10 kg	20 kg	30 kg	Max load for 85 °C
90 °C	5 °C	82.7 °C	76.6 °C	71.4 °C	6.7 kg
90 °C	15 °C	83.6 °C	78.2 °C	73.6 °C	7.7 kg
90 °C	20 °C	84.0 °C	79.0 °C	74.7 °C	8.2 kg
95 °C	5 °C	87.3 °C	80.8 °C	75.3 °C	13.4 kg
95 °C	15 °C	88.2 °C	82.4 °C	77.5 °C	15.3 kg
95 °C	20 °C	88.6 °C	83.2 °C	78.6 °C	16.5 kg

4.4 Agitation

Agitator speed is set in rpm (15-140 rpm on the Proveno 4G Combi 150E [S2]; 10-160 rpm on another page [S3]). No verified method was found to convert a bench stirring action into a kettle rpm, and no value is proposed. The speed is found by trial batches judged by the sauce measurements in Section 6 (Bostwick, syneresis, visual scorching), changing one setting at a time. **Grade: Unknown.**

5. Failure library

The failure library connects the dish types of a chilled ready-meal range to what is known to go wrong. Section 5.1 sets out the dish families; Section 5.2 gives the failure, mechanism, test and fix per family with the evidence grade; Section 5.3 works one problem end to end.

5.1 Dish families

Twelve families cover the usual dish types in a chilled ready-meal range: F1 cream, cheese and butter sauces; F2 gravies, jus and braised meat; F3 pasta, gnocchi and lasagna; F4 rice, risotto, grits and quinoa; F5 mash, potato and hash; F6 whole lean protein (chicken, steak, chop, tenderloin, fish, shrimp); F7 soups, chili, stew and curry; F8 dough items; F9 egg dishes; F10 cold bowls and

salads; F11 burgers with toppings; F12 named vegetable components. A single dish usually belongs to several families (a sauced chicken with pasta and vegetables, for example), and these combined dishes carry the highest risk, because sauce, starch and vegetable must all survive the same chill-hold-reheat cycle.

5.2 Failures by family

Family	Failure	Mechanism and source	Test	Corrective action and grade
F1 Cream, cheese, butter sauces	Watery liquid, lumps or slimy texture after chill and reheat; set-back.	Starch sauces can set to a gel or lumps under chill or ambient storage even without freezing, and the gel does not melt on reheating; after freezing, reheating can give a slimy texture and liquid separation; native starch systems are not stable on reheating [S14]. Modified waxy starch sauces were unaffected by freeze/thaw; normal native corn starch gave syneresis [S9].	Syneresis %; Bostwick.	Modified waxy starch; high fat or stabiliser (frozen sauces) [S8]; supplier chill-hold data. **Confirmed** (patent, journal). Chill-hold ranking of starches not demonstrated.
F2 Gravies, jus, braises	Same starch failures; stale or cardboard flavour in cooked meat on reheating.	Starch effects as F1. Oxidised flavours can be present in cooked, refrigerated meat in less than 48 h; turkey and chicken are more susceptible than pork and beef, and dark meat more than white [S15, S16].	Syneresis %; sensory panel.	Starch choice as F1; antioxidants; lower cooking heat; tight temperature control; flash-freezing has its own trade-offs [S15]. **Confirmed**.
F3 Pasta, gnocchi, lasagna	Soft, gummy pasta after reheat (reported in practice).	No source verified in this fact-check.	Texture analyser hardness; sensory.	None claimed. **Unknown**.
F4 Rice, risotto, grits, quinoa	Firm, grainy starch after chilling (reported in practice).	No source verified in this fact-check.	Texture; sensory.	None claimed. **Unknown**.
F5 Mash, potato, hash	Gluey, grainy or weeping mash.	No source retrieved.	Viscosity; syneresis (Section 6).	None claimed. **Unknown**.
F6 Whole lean protein	Dry or rubbery; flavour loss after reheat.	Lipid oxidation after cooking and chilling, as in F2 [S15, S16]; in one study cooked beef was more stable than chicken white meat, and white more than dark [S17]. Moisture loss: no source retrieved.	Sensory; weight loss on reheat.	Antioxidants; lower cooking heat [S15]. **Confirmed** (oxidation); dryness **Unknown**.
F7 Soups, chili, stew, curry	Thinning, separation; split coconut-milk emulsions.	Starch effects as F1. Coconut-milk emulsion behaviour: no source retrieved.	Bostwick; syneresis.	As F1 for starch. **Likely** (starch); emulsion **Unknown**.
F8 Dough items	Soggy crust, dry filling (reported in practice).	No source verified in this fact-check.	Crust moisture; crispness.	None claimed. **Unknown**.
F9 Egg dishes	Weeping, rubbery eggs.	No source retrieved.	Weight loss on reheat; texture.	None claimed. **Unknown**.
F10 Cold bowls and salads	Texture and cold-chain issues.	Texture: no source retrieved. The Food Code danger zone starts at 41 °F (5 °C) [S18].	Temperature log; sensory.	Cold-chain control. Texture **Unknown**.
F11 Burgers with toppings	Topping quality (for example guacamole colour).	No source retrieved.	Colour, sensory.	None claimed. **Unknown**.
F12 Vegetable components	Soft, mushy vegetables after reheat.	Low-temperature blanching (about 60-70 °C), with calcium in some studies, improved firmness retention in onion, soybean sprout and carrot through cook/chill storage and reheating [S10], and in sweetpotato [S11], tomato [S13] and potato [S12]. In potato, the calcium-pectin-PME route was judged secondary to other mechanisms [S12]. Green beans were not tested.	Texture analyser force; sensory.	Low-temperature blanch, with calcium where the product allows; fixed bean-to-water ratio (Section 4.3). **Confirmed** for the vegetables named; green beans **extrapolated**.

5.3 Worked problem: the sauce turns watery by day 5

Formula card 6: syneresis percentage, mean and sample standard deviation

Question	How much water separates from the sauce, and is a difference between two starches larger than batch-to-batch noise?
Formula	syn% = $m_{liquid} \div m_{sauce} \times 100$ (definition used in this handbook) $\bar{x} = \Sigma x \div n$ $s = \sqrt{[\Sigma(x - \bar{x})^2 \div (n - 1)]}$
Symbols	m_{liquid} mass of liquid that separates (g); m_{sauce} total sauce mass in the test (g); x one result; n number of batches; $\bar{x}$ mean; s sample standard deviation.
Why it works	The percentage allows different sample sizes to be compared. The mean shows the typical result; the standard deviation shows the scatter. If the gap between two means is much larger than the scatter, the difference is real and not batch noise.
Steps	Example: 12 g liquid from 250 g sauce: 12 ÷ 250 × 100 = **4.8%**. Assumed data for five batches of the control sauce: 4.8, 5.4, 4.1, 5.0, 4.6 %; mean = 4.78, s = 0.48. Modified waxy starch sauce: 0.8, 1.1, 0.7, 0.9, 1.0 %; mean = 0.90, s = 0.16. Gap = 3.88 points, about 8.1 times the larger s.
Template	Sauce ___; n = ___; results ___; $\bar{x}$ = ___; s = ___. Compare two sauces: gap = $\bar{x}_A - \bar{x}_B$ = ___; ratio to larger s = ___.
Common errors	Testing one batch only. Comparing samples held for different times or reheated differently. Treating the 1% limit used below as a standard: it is an example.

- **Symptom.** Liquid pools in the tray after 5 days chilled and reheating (the stress cycle of Section 1.3).
- **Why 1.** Syneresis, so the thickened phase is releasing water.
- **Why 2.** The starch has retrograded; the starch type and its modification influence how much [S8, S14, S9].
- **Why 3.** The starch chosen was not tested through a chill hold, only fresh.
- **Test.** Measure syneresis % at day 0, 3 and 5 on five batches per starch, against a control, using the same reheating method. Assumed data above give a gap of 3.9 points against a scatter of 0.5 points.
- **Fix and decision rule.** Adopt the modified waxy starch if its mean at day 5 is under the limit set by the operator (example limit 1%) and the gap to the control exceeds three times the larger standard deviation. Record the lot, the change and the new control limit, then re-scale (Section 3).

6. Diagnosis: root-cause method and measurements

6.1 Root-cause method

5 Whys repeats the question 'why' until a changeable cause is reached (worked in Section 5.3). A **fishbone** table sorts candidate causes before testing begins. Both are standard quality-management tools (grade: general practice, not sourced here).

Category	Candidate causes for a thin or separated sauce
Materials	Starch lot or type changed; cream fat or protein lot; water quality; ingredient temperature at addition.
Method	Heat profile; hold time at temperature; order of addition; cook-out time of starch; shear; hold before filling.
Machine	Fill level; agitator speed; jacket temperature; scraper wear; pump shear.
Measurement	Probe calibration; sampling point; temperature at which viscosity was read.
People and records	Weighing error; deviation from batch record; undocumented change.

6.2 Measurements

Formula card 7: Bostwick consistency	
Question	How thick is the sauce, in a form that can be compared between batches?
Formula	Reading = distance (cm) flowed along a graduated trough in a fixed time (30 s) after the gate is released [S19]. Higher viscosity gives a shorter distance.
Symbols	No calculation. Temperature must be fixed because it changes flow: 25 °C in one patent [S19], 20 °C in the USDA ketchup grading range of 3-7 cm in 30 s [S20]. Sample volume follows the instrument manual.
Why it works	A thick sauce resists flow, so it travels less in the same time under its own weight. It is an empirical measure and does not replace full rheology.
Steps	1. Level and clean the instrument. 2. Fill the reservoir with sauce at the fixed temperature. 3. Release the gate and start timing. 4. Read the distance at 30 s. 5. Repeat three times and average. Example: target 6.0 ± 0.5 cm (**assumed**; the 5-7 cm in one patent was for tomato sauce [S19] and does not transfer to a cream sauce). Reading 8.0 cm: gap = 8.0 − 6.0 = 2.0 cm too runny.
Template	Temp ___ C; readings ___, ___, ___; mean ___ cm; target ___ ± ___; gap ___ cm.
Common errors	Reading at different temperatures; not levelling; comparing sauces with different solids.

Measure	What it shows	How	Grade
Core temperature log	Cook-out, cooling time, hygiene limits	Probe in the slowest point; fixed interval; record with batch.	General practice
Bostwick (cm per 30 s)	Consistency	Card 7.	Confirmed [S19, S20]
Syneresis %	Water release on holding	Card 6, same method every time.	Definition used in this handbook
Brix	Soluble solids; reduction endpoint	Refractometer; calibrate against oven-dry solids for the sauce (Card 4).	General practice
pH	Acidity; starch and dairy stability	Calibrated meter at fixed temperature.	General practice
Texture (pasta, mash, vegetables)	Firmness after reheat	Texture analyser force or scored sensory panel.	General practice

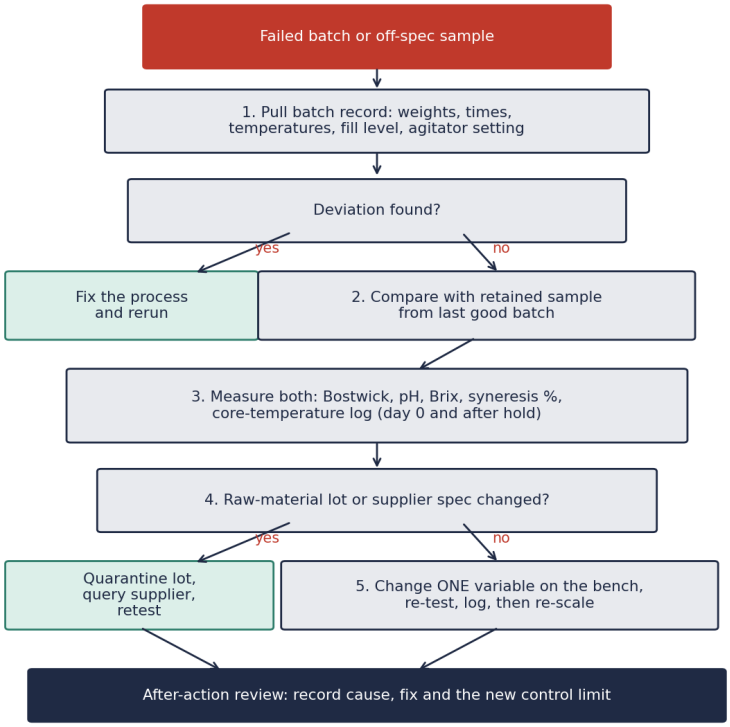


Figure 4. *Troubleshooting flow. Rules: one variable at a time, a retained sample from every batch, every change logged.*

7. Food hygiene: limits, cooling model and control points

Use note. The limits here are published guidance, often written for retail and foodservice, and the examples are illustrations. A producer sets and validates its own limits for its own product and process, under the rules that apply where it operates.

7.1 Limits that could be sourced

Rule	Content	Scope and grade
US Food Code, two-stage cooling	Danger zone 41-135 °F (5-57 °C). Cool from 135 °F to 70 °F within 2 h, then to 41 °F or below within the next 4 h, 6 h in total [S18, S21].	FDA employee sheet (primary) and Oregon Health Authority fact sheet. Confirmed. The Food Code is a model code aimed at retail and foodservice.
Same limits in C	57 °C to 21 °C within 2 h; 5 °C or below within 6 h total [S18, S21].	Confirmed.
UK guidance	Local-authority advice: cool food as quickly as possible, ideally within 90 min, then refrigerate; the legal requirement for chilled food is 8 °C or below, with 5 °C recommended [S22].	Council guidance documents. Confirmed as guidance.
EU manufacturer rule	No primary text found. A forum thread reports that the EC had no specific time and temperature guideline in about 2005, that Irish guidance says chilling should begin within 90 min of the end of cooking, and that company and council practices vary between 63 to 8 °C and 70 to 3 °C within 90 min [S23].	**Unknown.** Secondary source. Check Regulation (EC) 852/2004 and the plant's validated HACCP plan.

Rule	Content	Scope and grade
Cook-chill vendor claims	Belt tumble chiller 85 to below 4 °C in 30-60 min; rotary tumble chiller about 45 min (thin) to 90 min (thick) [S4].	Vendor claims. Confirmed as claims.
Cook-chill heat process (UK guidance and Australian limits)	Shelf life up to 10 days: 70 °C for 2 min or equivalent (6-log Listeria); over 10 days: 90 °C for 10 min or equivalent at the slowest heating point (6-log non-proteolytic C. botulinum) [S24, S25, S26]. Equivalent processes use z = 7 °C below 90 °C and z = 10 °C above it [S26]; for Listeria z = 7.5 °C is used with 70 °C for 2 min [S27].	Confirmed (UK and Australian guidance, ACMSF report).
Shelf-life rule for vacuum or bagged chilled food	Maximum 10 days at 8 °C or below, unless a controlling factor applies: 90 °C for 10 min or equivalent, pH 5 or less, 3.5% salt in the aqueous phase, aw 0.97 or less, or a validated combination [S28, S26]. Chill temperatures of 3-8 °C are to be maintained; below 3 °C, non-proteolytic C. botulinum does not grow [S26, S25].	Confirmed (UK guidance for vacuum and modified-atmosphere packed foods).
Lethality target for a given product	Set by the shelf-life category above and validated at the cold spot (Card 18, Sections B9 and B10).	**Validate on site.**

The Food Code is a foodservice model code. A manufacturing site works to its own validated HACCP plan. The limits above are therefore a floor to test against, not a licence.

Formula card 8: Fahrenheit to Celsius	
Question	How can US limits be read in Celsius?
Formula	°C = (°F − 32) × 5 ÷ 9
Steps	135 °F: (135 − 32) × 5 ÷ 9 = 103 × 0.5556 = **57.2 °C**. 70 °F: 38 × 0.5556 = **21.1 °C**. 41 °F: 9 × 0.5556 = **5.0 °C**.
Template	°F = ___; minus 32 = ___; × 5 = ___; ÷ 9 = ___ °C.
Common errors	Multiplying before subtracting 32.

7.2 Cooling model

Formula card 9: Newton's law of cooling	
Question	How long does the product take to cool from one temperature to another in chilled water, and does that meet a limit?
Formula	$T(t) = T_c + (T_0 - T_c) \times e^{-kt}$ $k = \ln[(T_1 - T_c) \div (T_2 - T_c)] \div (t_2 - t_1)$ $t = \ln[(T_a - T_c) \div (T_b - T_c)] \div k$
Symbols	T(t) product temperature at time t (C); T_c coolant temperature (1 °C, **assumed**); T_0 starting temperature (85 °C, assumed); k cooling constant per minute (a measure of how quickly the gap closes); ln natural logarithm; e ≈ 2.718; T_a and T_b the temperatures between which time is wanted.
Why it works	The heat flow out of the product is proportional to the temperature gap between product and coolant. A large gap cools fast; as the gap shrinks, cooling slows. This gives an exponential decay of the gap, e^{-kt}. Two consequences: (1) the product can only approach the coolant temperature, never pass it, so a target at or below T_c is unreachable; (2) each interval of ln 2 ÷ k halves the gap. Here ln 2 ÷ 0.0555 = 12.5 minutes.
Assumptions	The product has one uniform temperature, k is constant and the coolant stays at T_c. In thick sauces the centre lags the surface, so k must be measured from the **centre** probe. The base k below is derived from a vendor claim, not from a measurement. Card 19 (Section B9) tests whether a single constant is valid for a thick bag and explains why centre-probe data are required.
Steps: find k	Assumed anchor (vendor claim, upper end of the 30-60 min belt-chiller range [S4]): 85 °C to 4 °C in 60 min in 1 °C coolant. The 90-minute claim for thick products in the rotary chiller [S4] gives k = ln(84 ÷ 3) ÷ 90 = 0.0370. 1. Gap ratio = (4 − 1) ÷ (85 − 1) = 3 ÷ 84 = 0.0357. 2. ln(0.0357) = −3.33. 3. k = 3.33 ÷ 60 = **0.0555 per minute**. From logger data instead: 85 °C at 0 min and 17 °C at 30 min gives k = ln(84 ÷ 16) ÷ 30 = ln 5.25 ÷ 30 = 0.0553.
Steps: times	57 °C to 21 °C: ln[(57 − 1) ÷ (21 − 1)] ÷ k = ln(2.8) ÷ 0.0555 = 1.03 ÷ 0.0555 = **18.5 min**. 21 °C to 5 °C: ln(20 ÷ 4) ÷ k = 1.61 ÷ 0.0555 = **29.0 min**. Total 57 °C to 5 °C = 47.5 min against the 6 h limit; stage one against the 2 h limit.
Template	T_c = ___; T_1 = ___ at t_1 = ___; T_2 = ___ at t_2 = ___; k = ln[($T_1 - T_c$) ÷ ($T_2 - T_c$)] ÷ ($t_2 - t_1$) = ___. Time from T_a to T_b = ln[($T_a - T_c$) ÷ ($T_b - T_c$)] ÷ k = ___ min.
Common errors	Using the coolant as the target; reading k from the bag surface instead of the centre; starting the clock at the fill instead of when the product passes the upper limit (57 °C for the Food Code); using log base 10 instead of the natural log.

Table 7. Modelled core temperature in 1 °C coolant from 85 °C (assumed k = 0.0555 per minute).

Minutes	0	5	10	15	20	30	45	60
Core °C (base k)	85.0	64.6	49.2	37.5	28.7	16.9	7.9	4.0

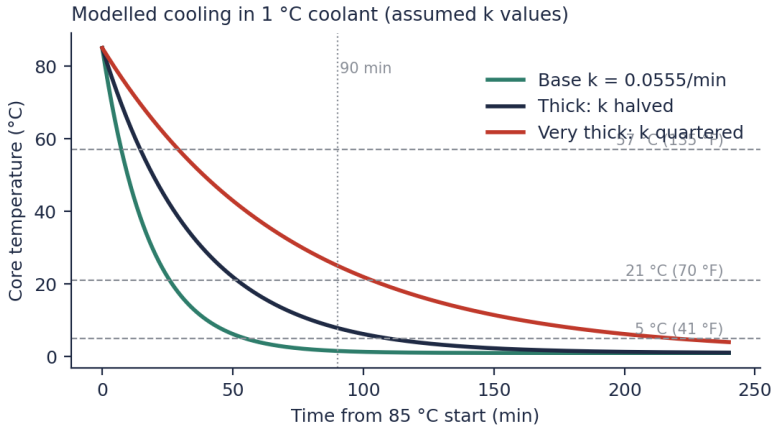


Figure 5. *Modelled cooling for three assumed values of k. Dashed lines mark 57, 21 and 5 °C.*

Table 8. Stress test of the cooling model. Every scenario meets the Food Code windows. The UK guideline of 90 minutes fails when k falls to a quarter of the base value or when a 4 °C coolant is combined with halved k; the vendor thick-product claim (90 min) passes both. A target at or below the coolant temperature is never reached (for example 3 °C in a 4 °C coolant). A product with low k therefore needs a colder coolant, a smaller bag or a thinner fill, and the coolant must sit below the target with margin.

Scenario (assumed)	k	57 → 21 °C (min)	57 → 5 °C (min)	63 → 8 °C (min)	Food Code (≤120, ≤360)	UK guide (63 → 8 °C ≤ 90)
Base: vendor belt-chiller upper claim (85 to 4 °C in 60 min), coolant 1 °C	0.0555	18.5	47.5	39.3	pass	pass
Vendor thick-product claim (85 to 4 °C in 90 min), coolant 1 °C	0.037	27.8	71.3	58.9	pass	pass
Thicker than vendor claim (k halved)	0.0278	37.1	95.0	78.6	pass	pass
Very thick (k quartered)	0.0139	74.2	190.1	157.1	pass	FAIL
Warm coolant 4 °C, base k	0.0555	20.5	71.5	48.5	pass	pass
Warm coolant 4 °C, k halved	0.0278	40.9	143.0	96.9	pass	FAIL
Hot start 95 °C, k halved	0.0278	37.1	95.0	78.6	pass	pass

7.3 Critical control points (general HACCP framework)

Step	Hazard controlled	What to monitor	Limit
Cook	Survival of pathogens	Cold-spot temperature and time (Card 18)	Lethality of 70 °C for 2 min equivalent (shelf life up to 10 days) or 90 °C for 10 min equivalent (longer) at the slowest heating point [S26, S24, S25]; validated per product
Hot-fill and pump	Growth and recontamination during delay	Time from end of cook to sealed bag (Card 20)	Set from the fill duration and site validation; reference: the Food Code danger zone ends at 57 °C (135 °F) [S18]
Chill	Growth in the danger zone	Core temperature versus time (Card 9 model, then logger)	Food Code floor: 57 → 21 °C in 2 h, 57 → 5 °C in 6 h [S18, S21]; UK guidance: ideally within 90 min [S22]; manufacturer rule **Unknown**
Cold storage and portioning	Growth	Air and product temperature	41 °F (5 °C) or below under the Food Code [S18]; UK legal maximum 8 °C, 5 °C recommended [S22]
Reheating (consumer)	Survival after storage	Label instructions validated for the pack	**Unknown**: pack-specific validated instruction

Cleaning and allergens. The Proveno has programmable wash programs (distributor listing, [S2]). No cleaning-validation or allergen-changeover source was retrieved. Ready-meal ranges commonly include fish, shellfish, dairy, egg, nut and gluten-containing dishes (general knowledge, not sourced here), so changeover cleaning and allergen control must be defined in the site's HACCP plan; Section B9.3 gives the allergen matrix for the demonstration recipe. A full hazard analysis and shelf-life section follow in Part B (Sections B9 and B10). Grade: **Unknown** (no figure claimed).

8. Costing

All prices, labour rates, packaging, overhead and yields in this section are assumed example values. Replace them with quotations and weighed trials. Machine energy is excluded by instruction. Currency: euro.

Formula card 10: yield and ingredient cost	
Question	What does 1 kg of usable ingredient really cost when trimming is lost?
Formula	Yield = EP ÷ AP Cost per kg EP = price per kg AP ÷ Yield Line cost = kg AP × price per kg AP, where kg AP = kg EP ÷ Yield
Symbols	AP as purchased; EP edible portion (usable after trimming); price in EUR per kg.
Why it works	The purchase is made on AP weight, but the recipe uses EP weight. The difference is paid for and discarded.
Steps	Parsley: assumed yield 60%, price EUR 6.00 per kg AP. 1. Recipe needs 1.6875 kg EP. 2. AP = 1.6875 ÷ 0.60 = 2.8125 kg. 3. Cost = 2.8125 × 6.00 = **EUR 16.88** (EUR 10.00 per kg EP). Yield from a trial: trim 1 kg, weigh usable portion, divide.
Template	Price AP = ___; trial AP = ___ kg; EP = ___ kg; yield = ___; kg EP needed = ___; kg AP = ___; cost = ___.
Common errors	Costing on EP weight at an AP price.

Table 9. Ingredient cost for the 112.5 kg batch (assumed prices).

Ingredient	kg EP	kg AP	EUR/kg AP (assumed)	Cost EUR
Cream 35% fat	45	45	4.50	202.50
Chicken stock	47.925	47.925	0.80	38.34
Butter	6.75	6.75	8.00	54.00
Modified waxy starch	2.8125	2.8125	3.50	9.84
Garlic puree	3.375	3.375	4.00	13.50
Dijon mustard	2.25	2.25	3.50	7.88
Lemon juice	1.6875	1.6875	2.50	4.22
Parsley	1.6875	2.8125	6.00	16.88
Salt	0.9	0.9	0.40	0.36
White pepper	0.1125	0.1125	18.00	2.02
Total				**349.54**

Formula card 11: cost per portion and price from a margin	
Question	What does one portion cost and what price gives a chosen margin?
Formula	$M_{fin} = M_0 \times (1 - \text{loss})$ portions = $\lfloor M_{fin} \div \text{portion mass} \rfloor$ cost per portion = (ingredients + labour + packaging + overhead) ÷ portions price = cost ÷ (1 − margin)
Symbols	loss process weight loss (0.08, assumed); ⌊ ⌋ round down to whole portions; overhead as a fraction of the other three lines (0.15, assumed); margin as a fraction of the selling price.
Why it works	The product that is sold is the finished weight, not the raw weight. Margin is measured on price, so price = cost ÷ (1 − margin); a markup is measured on cost and gives a smaller margin.
Steps	1. M_{fin} = 112.5 × 0.92 = 103.5 kg. 2. Portions at 80 g (assumed) = 103.5 ÷ 0.080 = 1,293.75, rounded down to **1,293**. 3. Ingredients EUR 349.54. 4. Labour: 2 people × 3 h × EUR 20 = EUR 120.00. 5. Packaging: 1,293 × 0.05 = EUR 64.65. 6. Subtotal EUR 534.19; overhead 15% = EUR 80.13. 7. Total EUR 614.32; per portion = 614.32 ÷ 1,293 = **EUR 0.4751**. 8. Price at 30% margin = 0.4751 ÷ 0.70 = **EUR 0.6787**; check (price − cost) ÷ price = 30.0%. A 30% *markup* gives 0.6176, a margin of only 23.1%.
Template	M_0 = ___; loss = ___; M_{fin} = ___; portion = ___ kg; portions = ___; ingredients ___ + labour ___ + packaging ___ = ___; overhead % ___; total ___; cost/portion ___; margin ___; price ___.
Common errors	Dividing by raw weight (understates the ingredient cost per portion by about 8% here: 0.2486 against 0.2703). Mixing margin and markup. Rounding portions up.

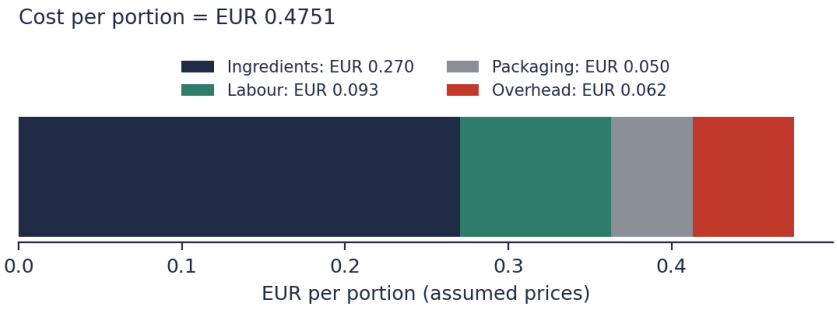


Figure 6. Cost per portion by component (assumed inputs). Ingredients 56.9%, labour 19.5%, overhead 13.0%, packaging 10.5%; cream and butter make up 73% of ingredient cost.

8.1 Stress tests

One at a time. Figure 7 shows portion mass is the most influential input (EUR 0.423 to 0.527), then cream price, labour hours, overhead and packaging. **Monte Carlo.** With assumed ranges on loss (6-12%), labour (2.5-3.5 h), portion (75-85 g), packaging, overhead, parsley yield and four ingredient prices, 20,000 runs gave a median of EUR 0.485 per portion, a 5th to 95th percentile of EUR 0.433 to 0.541, and a mean of 0.486 (s = 0.033). The median exceeds the deterministic EUR 0.475 because the assumed loss range averages 9%, above the 8% base. At a 30% margin the price range is EUR 0.619 to 0.774.

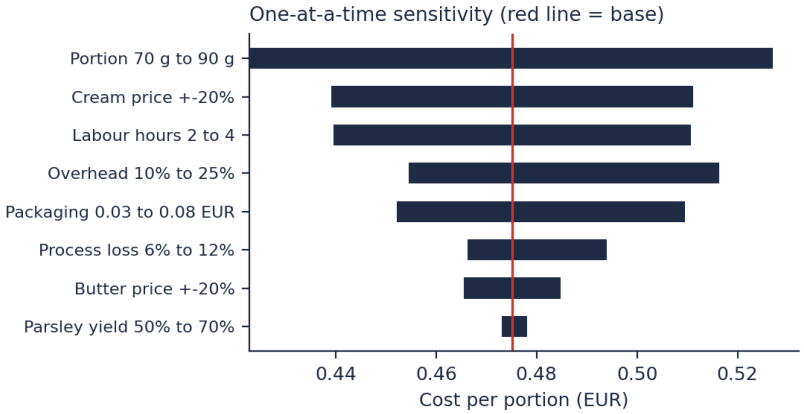


Figure 7. One-at-a-time sensitivity of cost per portion.

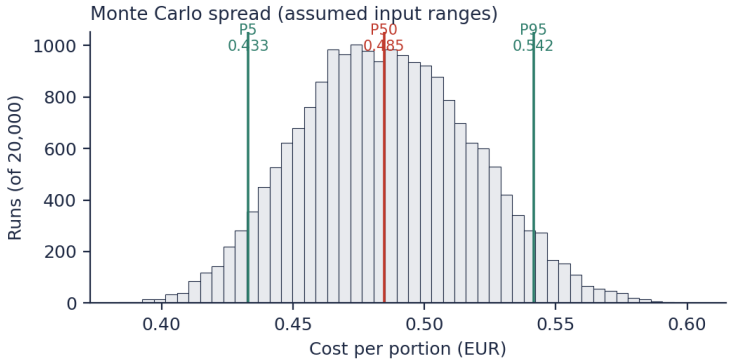


Figure 8. Distribution of cost per portion over 20,000 Monte Carlo runs (assumed ranges).

8.2 What scale-up does to cost

A 1 kg bench batch yields 0.92 kg and 11 portions at 80 g. If one person works 1.5 h at EUR 20, labour is EUR 30.00 ÷ 11 = EUR 2.73 per portion, against EUR 0.0928 at production scale, a fall of about 29 times. Ingredient cost per portion stays near EUR 0.27. Scale-up therefore saves labour, not ingredients, and the biggest ingredient risks are the cream price and the finish-weight error (Table 5).

9. Quick deployment checklist

- Weigh 1 L of the real bench sauce to fix ρ; record f from a measured fill line (Card 1).
- Run one bench simmer and record the weight lost and time; compute J and the kettle time (Card 3); set the endpoint by Brix or finished weight (Card 4).

- Fit the blanch load to the bean-to-water limit (Card 5).
- Instrument the chiller with centre probes; compute k from the log (Card 9) and compare with the limits in Section 7.1 and the manufacturer's own rule.
- Measure syneresis (Card 6) and Bostwick (Card 7) at day 0, 3 and 5 on five batches per formulation.
- Set the shelf-life category and the lethality target before the first pilot batch (Sections B9 and B10).
- Replace every assumed price and yield (Section 10) with quotations and trial data, then recompute Section 8.

Part B. Commercialisation: the five-gate procedure

Part B continues from Part A on the same recipe, the same 112.5 kg kettle batch and the same cost model. Cards 12-20 continue the numbering of Part A. Section numbers in Part B carry the prefix B. Every limit, temperature, time, quantity and price in Part B is an example of the method, to be replaced by the reader's own validated or measured values.

B1. Scope and two practical questions

Two questions come up in the first weeks at a new production facility: what to commercialise first, and whether the line runs in batches or continuously. They are answered here from the reference equipment and Part A.

Question	Answer used in this document	Grade
Which food category first?	Chilled ready meals (cook-chill, never frozen). This is the product class assumed for this document.	Assumed.
Continuous line or batch kettles?	Batch kettles, matching the reference equipment of Section 1.2: a 150 L steam-jacket kettle and a 150 L mixing kettle, followed by a pump-and-chill line. What a particular plant actually runs must be confirmed on site.	Reference configuration.

Chilled, not frozen. Some commercialisation procedures assume freeze-thaw, retort or blast-freezing. The product class assumed here is chilled and never frozen, so the stability tests are chill-hold tests (3, 5 and 7 days) and no retort step is used. Formulas continue from Part A: Cards 1-11 are in Part A, Cards 12-20 are in Part B.

B2. The gate ladder and the scale ladder

Table 10. The five gates, what each must prove, and the Part A material it reuses.

Gate	Must prove	Reuses (Part A)
1. Commercial deconstruction and metric profiling	The recipe is a weighed, percentage-based formula with measured baselines.	Card 1, Table 1; Cards 4, 6, 7
2. Industrial sourcing and functionality mapping	Each ingredient can survive pumping, chilling and a 7-day hold at target cost.	Section 3.1 cards; Cards 10-11
3. Pilot trials and engineering validation	Physical behaviour holds at 10x and 50x before the full kettle.	Cards 2, 3, 5, 9
4. Line trials and packaging integration	The product pumps, fills, seals, chills and holds in its final pack.	Section 7; Table 8
5. SOP hardening	An operator can repeat the result without the developer present.	Cards 1, 4, 11

Formula card 12: scale ladder and relative heating surface	
Question	How many steps, and of what size, lead from the bench batch to the full kettle, and what happens to heating surface per litre on the way?
Formula	Step ratio = $SF_{next} \div SF_{previous}$ $a_{rel} = SF^{-1/3}$ (geometrically similar vessels, constant density)
Symbols	SF scale factor against the 1 kg bench batch (Card 1); a_{rel} heated wall area per litre relative to the bench; −1/3 is the exponent that follows because area grows with length squared and volume with length cubed.
Why it works	If a vessel is enlarged without changing its shape, every length is multiplied by the same number L. Area scales as L^2 and volume as L^3, so area per litre scales as $L^2/L^3 = 1/L$, and $L = SF^{1/3}$. Heating surface per litre therefore falls as $SF^{-1/3}$. Practitioners report that scale-up usually needs experiments at two scales, not necessarily the target scale [S29], and that surface-to-volume ratio normally changes on scale-up and burn-on is a common result [S30].
Steps	1. Ladder: 1, 10, 50, 112.5 kg. 2. Step ratios: 10 ÷ 1 = 10; 50 ÷ 10 = 5; 112.5 ÷ 50 = 2.25. 3. a_{rel} at 10: $10^{-1/3} = 0.464$; at 50: 0.271; at 112.5: 0.207. 4. Check against Part A's measured geometry: kettle 91.0 cm²/L ÷ pan 451.1 cm²/L = 0.202, against 0.207 predicted (the pan and kettle are not exactly similar in shape).
Template	SF_1 = ___; SF_2 = ___; SF_3 = ___; step ratios = ___; $a_{rel} = SF^{-1/3}$ = ___.

Common errors	Using a ladder with one large jump (for example 1 to 112.5). Assuming the real pilot vessel is similar in shape to the line kettle; measure its diameter and liquid depth and use Card 2 of Part A instead.

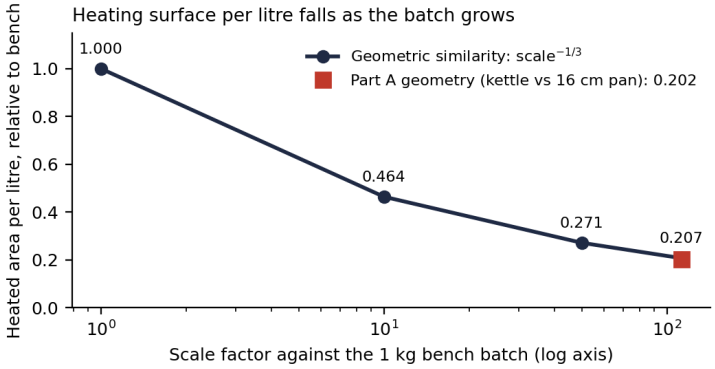


Figure 9. *Relative heating surface per litre along the ladder; the measured Part A geometry (red) agrees with the similarity law to within 3%.*

Table 11. Pilot ladder. Batch size assumes 1.00 kg/L (assumed, as in Part A).

Stage	Batch (kg)	Scale factor	Step ratio	Relative area per litre	Purpose
Bench	1	1	-	1.000	Gold standard and baselines (Gate 1)
Pilot A	10	10	10.0	0.464	First check of heating, hold and chilling behaviour
Pilot B	50	50	5.0	0.271	Agitation, evaporation and heel-loss trials
Line	112.5	112.5	2.25	0.207	Full kettle batch; line trials (Gate 4)

B3. The 10,000-portion plan

Formula card 13: batches, heel loss and portions	
Question	How many kettle batches deliver 10,000 portions once product left in pumps and filler heads is counted?
Formula	$M_{fin} = M_0 \times (1 - \text{loss})$ $M_{pack} = M_{fin} \times (1 - \text{heel})$ portions per batch = $\lfloor M_{pack} \div \text{portion mass} \rfloor$ batches = $\lceil N \div \text{portions per batch} \rceil$
Symbols	M_0 raw batch (112.5 kg); loss process loss (8%, assumed in Part A); heel product left in pipes, pump and filler as a fraction of finished mass (2%, **assumed**); $\lfloor\ \rfloor$ round down; $\lceil\ \rceil$ round up; N target portions.
Why it works	Only the product that reaches the pack can be sold. Rounding portions down and batches up keeps the plan on the safe side: a partial portion cannot be sold, and a partial batch still has to be cooked in full.
Steps	1. $M_{fin} = 112.5 \times 0.92 = 103.50$ kg. 2. $M_{pack} = 103.50 \times 0.98 = 101.43$ kg. 3. Portions per batch = $\lfloor 101.43 \div 0.080 \rfloor = \lfloor 1267.87 \rfloor =$ **1,267** (without heel loss: $\lfloor 1293.75 \rfloor = 1{,}293$). 4. Batches = $\lceil 10{,}000 \div 1{,}267 \rceil = \lceil 7.89 \rceil =$ **8** (without heel loss: $\lceil 7.73 \rceil = 8$). 5. Portions made = 8 × 1,267 = 10,136; surplus = 136 (1.36% of target).
Template	M_0 = ___; loss = ___; heel = ___; portion = ___ kg; portions per batch = ___; N = ___; batches = ___.
Common errors	Forgetting heel loss; rounding batches down; planning on raw weight (112.5 kg) instead of packed weight.

If the target is 10,000 kg. Finished packed product per batch is 101.43 kg, so batches = $\lceil 10{,}000 \div 101.43 \rceil = \lceil 98.59 \rceil =$ **99**. If 10,000 kg means raw batch mass, batches = $\lceil 10{,}000 \div 112.5 \rceil = \lceil 88.89 \rceil = 89$.

Table 12. Time to run 8 batches. The 3 h cycle per batch is Part A's labour assumption, not a measurement; chilling capacity is assumed not to limit (a vendor tumble chiller takes 300-1000 kg per load [S4], and a kettle batch is 112.5 kg, so several batches fit one load, but the real constraint depends on the bagging rate and was not verified).

Kettles in parallel	Rounds = ⌈batches ÷ kettles⌉	Hours = rounds × 3 h
1	8	24
2	4	12
3	3	9
4	2	6

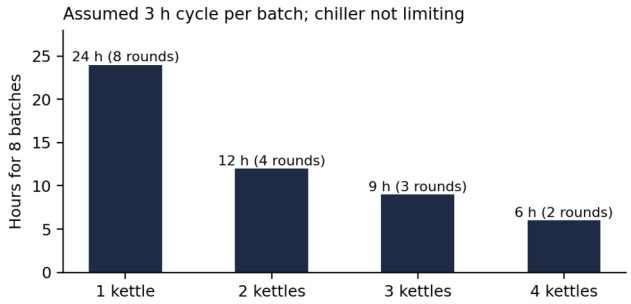


Figure 10. *Hours for the run by number of kettles (assumed 3 h cycle).*

Allergen changeover. Table 12 counts cooking time only. Cleaning and validated allergen changeover between products with different allergen profiles (Section B9.3) add time that is not in the 3 h cycle. With an assumed 1.5 h changeover after the run, the totals become 25.5 h, 13.5 h, 10.5 h and 7.5 h for 1, 2, 3 and 4 kettles; with a product change after every run, cleaning is likely to set the daily capacity.

Cost of the run. Heel loss lowers packed portions per batch from 1,293 to 1,267, which raises cost per portion. Using Part A's cost model with the combined loss of 9.84% (1 − 0.92 × 0.98), cost per portion is EUR 0.4837, against EUR 0.4751 without heel loss. Cooking 8 full batches costs 8 × EUR 612.82 = EUR 4,902.57; spread over the 10,000 portions delivered this is EUR 0.4903 per portion, because the 136 surplus portions are paid for. With Part A's Monte Carlo range (EUR 0.433 to 0.541 per portion, no heel loss), 10,000 portions cost EUR 4,330 to 5,415. All prices are Part A's assumed example prices.

Table 13. The same recipe in kettles of other net volume (Section B3 method: 75% fill, 1.00 kg/L, 8% process loss, 2% heel loss, 80 g portions, all assumed). The last column uses the similarity law of Card 12 and holds only if the kettle has the same shape as the reference unit; real values need the kettle's inner diameter (Card 2). Large kettles leave large surplus when the target is not a multiple of the batch output: a part batch would have to run below the validated fill.

Net volume (L)	Batch mass at 75% fill (kg)	Scale factor	Packed portions per batch	Batches for 10,000	Made / surplus portions	Heating area per litre vs 150 L (similar shape)
100	75.00	75.00	845	12	10,140 / 140	1.145
150	112.50	112.50	1,267	8	10,136 / 136	1.000
200	150.00	150.00	1,690	6	10,140 / 140	0.909
300	225.00	225.00	2,535	4	10,140 / 140	0.794
375	281.25	281.25	3,169	4	12,676 / 2,676	0.737

B4. Gate 1: commercial deconstruction and metric profiling

Unit conversion. Volumetric measures (cups, spoons, pinches) are replaced by weighed grams or kilograms; fluid measures are converted through the weighed density of the actual ingredient, not a table value, in line with Part A's rule to weigh 1 L of the real sauce (Card 1). Recipes that start from weights convert directly to percentages that apply to any batch size [S31].

Formula card 14: formula percentage and batch quantity	
Question	What is each ingredient as a percentage of the batch, so that any batch size can be written from one table?
Formula	% = ingredient mass ÷ total batch mass × 100 quantity = % ÷ 100 × batch mass
Symbols	Masses in grams or kilograms; total batch mass is the sum of all ingredients (1,000 g for the bench sauce; 112,500 g for the kettle batch).
Why it works	A percentage removes the size from the recipe. Applying the same percentages to a different batch mass is mathematically the same as multiplying every ingredient by the scale factor (Card 1). The baker's percentage (relative to flour) has no equivalent in a sauce without a dominant dry ingredient, so total-mass percentage is used.
Steps	1. Cream: 400 ÷ 1,000 × 100 = 40.0%. 2. Production quantity at 112.5 kg: 40.0 ÷ 100 × 112.5 = 45.000 kg (the Table 1 value of Part A). 3. Check: the percentages add to 100.0%.
Template	Ingredient ___ g; total ___ g; % = ___; batch ___ kg; quantity = ___ kg.
Common errors	Rounding percentages to whole numbers before scaling (a 0.1 pt error on 112.5 kg is 112 g); mixing a total-mass percentage with a baker's percentage in one table.

Table 14. The demonstration sauce as a percentage formula (same recipe as Part A, Table 1).

Ingredient	Bench g	% of batch	Kettle kg (112.5)
Cream 35% fat	400	40.0	45

Ingredient	Bench g	% of batch	Kettle kg (112.5)
Chicken stock	426	42.6	47.925
Butter	60	6.0	6.75
Modified waxy starch	25	2.5	2.8125
Garlic puree	30	3.0	3.375
Dijon mustard	20	2.0	2.25
Lemon juice	15	1.5	1.6875
Parsley	15	1.5	1.6875
Salt	8	0.8	0.9
White pepper	1	0.1	0.1125
Total	**1,000**	**100.0**	**112.500**

Analytical baselines for the bench prototype

Baselines are measured on the chef-made prototype before anything is changed, so that every later change has a reference. Water activity (a_w) describes the available water, not the total moisture [S32]. pH and a_w together decide whether a heat-treated, packaged food needs time and temperature control: in the FDA job aid, tables of pH and a_w mark combinations as non-TCS, as product-assessment (PA) cases or as TCS foods, and heat-treated animal or plant foods are TCS unless the values place them in a non-TCS box [S33]. For a creamy sauce with chicken, assumed values of pH 6.2 and a_w 0.98 (both **assumed**, to be replaced by measurements) lie in the PA region of Table A (pH above 5.6, a_w above 0.95), so the sauce is treated as needing time and temperature control. Brix and Bostwick consistency (Cards 4 and 7) complete the profile.

Baseline	Instrument	Why	Target	Grade
pH	Calibrated meter, fixed temperature	Microbial control; protein and starch behaviour	Measure on bench; example 6.2 (assumed)	Method confirmed [S33]
Water activity	Water-activity meter	Available water for growth [S32]	Measure on bench; example 0.98 (assumed)	Method confirmed [S33, S32]
Brix	Refractometer	Reduction endpoint (Card 4)	21.7 from Part A's assumed 20% start	Assumed
Bostwick consistency	Bostwick consistometer	Pumpability and texture (Card 7)	6.0 ± 0.5 cm in 30 s (assumed)	Method confirmed in Part A
Syneresis %	Card 6	Chill-hold stability	Example limit 1% at day 5 (assumed)	Definition used in this handbook

B5. Gate 2: industrial sourcing and functionality mapping

Retail and kitchen ingredients are matched to commercial equivalents only where the replacement is tested against the Gate 1 baselines. Each swap changes flavour, pH, a_w or viscosity, so each swap is one controlled change followed by re-measurement (Section 6). Common swaps and additions, graded:

Swap or addition	Evidence retrieved	Grade and treatment
Modified starch in place of native starch	Native starch sauces can set to a gel or lumps on chilled storage, and the gel does not melt on reheating [S14]. Waxy starches are the least prone to retrogradation, and hydroxypropylation improves freeze/thaw stability [S8]. Modified waxy corn starches were unaffected by freeze/thaw in a white sauce, while normal native corn starch gave syneresis [S9].	**Confirmed.** Mostly freeze/thaw data; test chill-hold at 3, 5 and 7 days.
Xanthan gum or carrageenan against syneresis	No source retrieved for these two hydrocolloids in a chilled cream sauce.	**Unknown.** Not recommended until sourced and trialled.
Standardised low-microbial garlic powder in place of fresh garlic	No source retrieved.	**Unknown.** Needs sensory and baseline re-test.
Heat-stable homogenised dairy emulsion in place of fresh cream	In frozen sauces, high fat or a good stabiliser system lowers the chance of a broken sauce after freeze/thaw [S8]. Nothing retrieved for chilled hold.	**Confirmed** for frozen sauces only; chilled hold **Unknown**.

Cost constraint. Ingredient choices are checked against the raw-material cost target of the product brief. The brief's target was not supplied, so the check uses Part A's costing: ingredient cost per portion EUR 0.2703 (Card 11), with cream and butter making up 73% of ingredient cost. A swap is accepted only if its effect on cost per portion is computed with Card 10 and Card 11 and falls within the brief's target.

B6. Gate 3: pilot plant trials and engineering validation

The pilot ladder of Table 11 tests physical transformations at an intermediate scale. Three measurements are carried through every stage.

B6.1 Thermal dynamics

Heat-up and cool-down ramps are logged at each stage (core-temperature probe, fixed interval). Part A's cooling model (Card 9) gives the expected shape and is refitted to each stage: k is recomputed from the log, and the 57 to 21 °C and 57 to 5 °C times are compared with the Food Code windows of 2 h and 6 h [S18, S21]. Heating surface per litre falls along the ladder (Card 12), so burn-on risk rises with scale [S30]; Delta-T cooking limits the jacket-to-food temperature gap on the mixing kettle (Section 1.2).

B6.2 Shear and agitation

Formula card 15: agitator tip speed (bookkeeping)	
Question	How fast does the agitator tip move at a chosen rpm, so that settings can be compared between vessels of different size?
Formula	$v = \pi \times d \times N \div 60$
Symbols	v tip speed (m/s); d agitator sweep diameter (m); N rotational speed (rpm). Dividing by 60 converts minutes to seconds.
Why it works	In one revolution the tip travels one circumference (π d). N revolutions per minute therefore give π d N metres per minute, and dividing by 60 gives metres per second.
Steps	Assumed sweep d = 0.60 m (the real value is in the equipment manual and was not found). 1. At 15 rpm: $\pi \times 0.60 \times 15 \div 60 = 0.471$ m/s. 2. At 25 rpm (the example SOP): 0.785 m/s. 3. At 60 rpm: 1.885 m/s. 4. At 140 rpm: 4.398 m/s. The range 15-140 rpm is that of the Proveno 4G Combi 150E (Section 1.2).
Template	d = ___ m; N = ___ rpm; $v = \pi \times d \times N \div 60$ = ___ m/s.
Common errors	Using the vessel diameter instead of the agitator sweep. Treating equal tip speed as the correct scale-up rule: that choice is not sourced here. Scale-up criteria depend on the process physics, and mechanical energy input often correlates well with product properties [S29]; the speed that works is found by trial.

Trial design. At Pilot B, three agitator speeds (for example low, middle and high within 15-140 rpm) are run on otherwise identical batches. For each, Bostwick, syneresis at day 0 and day 5, and a visual scorch and emulsion check are recorded. The setting with the best results and the widest tolerance is carried to the line. Mixing duration is varied the same way. Vegetables are checked for breakdown by texture measurement.

B6.3 Yield and heel loss

Formula card 16: heel loss	
Question	How much product is lost to pipes, pumps and filler heads, and how does it change the batch size needed?
Formula	heel % = $(M_{in} - M_{out}) \div M_{in} \times 100$ $M_{0,needed} = M_{pack,target} \div [(1 - loss)(1 - heel)]$
Symbols	M_{in} finished mass leaving the kettle; M_{out} mass weighed into packs; loss process loss; heel loss as a fraction. The heel definition is this handbook's own mass balance; no source was retrieved for the term.
Why it works	Mass is conserved: what does not reach the pack remains in the equipment or is discarded. Measuring both ends of the line gives the heel directly.
Steps	Assumed measurement: 103.50 kg leaves the kettle and 101.43 kg is packed. 1. Lost = 103.50 − 101.43 = 2.07 kg. 2. heel % = 2.07 ÷ 103.50 × 100 = **2.0%**. 3. To pack 100 kg: $M_{0,needed} = 100 \div (0.92 \times 0.98) = 110.91$ kg raw batch.
Template	M_{in} = ___ kg; M_{out} = ___ kg; heel % = ___; target pack mass = ___ kg; raw batch needed = ___ kg.
Common errors	Weighing only the kettle, not the packs; ignoring product returned from rework; assuming heel is a fixed mass (it scales with line length and viscosity).

B7. Gate 4: line trials and packaging integration

Line trials run the full kettle batch through the actual pump, filler, sealer and chiller. The checks follow the HACCP principles as standardised by the Codex Alimentarius Commission: hazard analysis, critical control points, critical limits, monitoring, corrective actions, verification, and record keeping [S34]. The full plan is in Section B9.

Check	What is done	Limit or target	Grade
Pumpability and filling	Run the batch through the filler; record dripping, clogging, splashing on seal edges; Bostwick before and after pumping	Bostwick change within the example ±0.5 cm; no seal contamination	Test design; limits assumed

Check	What is done	Limit or target	Grade
Cook step (CCP 1)	Cold-spot temperature log per batch; lethality F (Card 18)	Cold-spot lethality of at least 70 °C for 2 min equivalent (shelf life up to 10 days) or 90 °C for 10 min equivalent (longer), validated (Section B10) [S26, S24, S25]	Confirmed (guidance); product validation needed
Chill step (CCP 3)	Core temperature versus time; refit k (Card 9)	Food Code: 57 to 21 °C within 2 h, 5 °C or below within 6 h [S18, S21]; vendor claim 85 to below 4 °C in 30-60 min (belt chiller) [S4]; manufacturer rule **Unknown**	Confirmed (floor and claims)
Post-kill hygiene	Environmental monitoring for Listeria spp.; cleaning validation; seal and leak checks	Zone-based programme with corrective actions [S35]; limits set by the plant	Confirmed (guidance)
Shelf-life study	Storage trial and challenge testing at day 0 to 10 (Section B10)	Acceptance set by the HACCP team	Test design
Metal detection and X-ray	Calibrate with test pieces per the site's procedure	Common check; no source retrieved here	Unknown
Packaging interaction	Weigh purge or free liquid in the sealed tray at day 0, 3, 5, 7; compute syneresis % (Card 6); inspect the seal	Example limit 1% (assumed); no source retrieved for vacuum or MAP-specific limits	Test design; limits assumed

B8. Gate 5: SOP hardening

B8.1 Bill of materials (one 112.5 kg batch)

Table 15. Bill of materials from Part A (Tables 1 and 9). Vendor codes are assigned by procurement when suppliers are chosen; they are not part of this document. Prices are Part A's assumed example prices.

Ingredient	kg EP	kg AP	EUR/kg (assumed)	EUR	Spec fields
Cream 35% fat	45	45	4.50	202.50	Part A, Section 3.1
Chicken stock	47.925	47.925	0.80	38.34	Part A, Section 3.1
Butter	6.75	6.75	8.00	54.00	Part A, Section 3.1
Modified waxy starch	2.8125	2.8125	3.50	9.84	Part A, Section 3.1
Garlic puree	3.375	3.375	4.00	13.50	Part A, Section 3.1
Dijon mustard	2.25	2.25	3.50	7.88	Part A, Section 3.1
Lemon juice	1.6875	1.6875	2.50	4.22	Part A, Section 3.1
Parsley	1.6875	2.8125	6.00	16.88	Part A, Section 3.1
Salt	0.9	0.9	0.40	0.36	Part A, Section 3.1
White pepper	0.1125	0.1125	18.00	2.02	Part A, Section 3.1
Total	**112.500**			**349.54**	

B8.2 Process SOP (example values)

Table 16. Example SOP for the demonstration sauce. Values marked (A) are assumed and must be replaced by validated or measured values; the structure is the point. Order of addition is an example, but every ingredient enters before the lethality step.

Step	Action	Parameter	Record
1	Weigh Phase A (cream 45.000 kg, stock 47.925 kg, butter 6.750 kg) into the kettle	Mass within the tolerance set by QA (A)	Scale ID, lot numbers
2	Add Phase B (starch 2.8125 kg, salt 0.900 kg, white pepper 0.1125 kg) with the agitator running	Agitator 25 rpm (A); range 15-140 rpm (Section 1.2)	rpm, time
3	Add Phase C (garlic purée 3.375 kg, Dijon 2.250 kg, lemon juice 1.6875 kg, parsley 1.6875 kg); heat with Delta-T cooking	All ingredients enter before the lethality step; fresh herbs have no kill step of their own [S36]	Lot numbers, core temperature log
4	Reduce to the finish weight or Brix	Finish weight 103.5 kg or Brix 21.7 (A, Card 4)	Weight, Brix
5	Lethality step: bring the slowest-heating point to the set point and hold	Shelf life up to 10 days: cold-spot lethality of at least 70 °C for 2 min equivalent; example set point 80 °C (A), confirmed by the log (Card 18). Longer life: 90 °C for 10 min equivalent [S26, S24, S25]	Cold-spot log, F value

Step	Action	Parameter	Record
6	Pump to the bag filler within the hold limit; seal	Hold limit from Card 20 (A); packed mass recorded for heel (Card 16); seal check	Packed kg, time stamps
7	Tumble chill	Core to 4 °C or below (A); planning time 60 min from the vendor upper claim [S4]; Food Code floor [S37]; measured time from the log	Time-temperature log
8	Store	5 °C (41 °F) or below [S18]; 3 °C or below if shelf life exceeds 10 days [S26, S25]	Store temperature

Where the reduction itself holds the slowest-heating point at a high temperature, its minutes add to the lethality of Card 18, and the lethality step is then confirmed from the log rather than assumed. Quality limits (scorching, cream stability) usually cap how long that can run.

B8.3 Quality assurance control plan

Formula card 17: colour difference (CIE76 ΔE*)	
Question	How different in colour is a line batch from the bench gold standard?
Formula	$\Delta E^* = \sqrt{[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]}$
Symbols	L* lightness, a* green-red, b* blue-yellow, as read by a colorimeter; Δ is the line value minus the bench value. This is general practice and was not sourced in this document.
Why it works	The three colour coordinates form a space. ΔE* is the straight-line distance between two colours in that space, so one number summarises the difference.
Steps	Assumed readings. Bench: L* 78.2, a* −1.1, b* 19.4. Line: L* 77.1, a* −0.8, b* 20.6. 1. ΔL* = −1.1; Δa* = 0.3; Δb* = 1.2. 2. Squares: 1.21 + 0.09 + 1.44 = 2.74. 3. ΔE* = √2.74 = **1.66**. Against an example limit of 2.0 (A), the batch passes.
Template	Bench L* ___ a* ___ b* ___; line L* ___ a* ___ b* ___; ΔE* = ___; limit ___.
Common errors	Reading different spots on the sample; comparing samples at different temperatures; using one reading, not the mean of several.

Parameter	Method	Sign-off target	Frequency
Taste and texture	Trained sensory panel against the bench standard	Panel scale and threshold set from the bench panel (**Unknown** until run)	Every batch at first, then by plan
Colour	Colorimeter, Card 17	ΔE* ≤ 2.0 (A)	Each batch
Viscosity	Bostwick, 30 s, fixed temperature	6.0 ± 0.5 cm (A)	Each batch, after chill
Stability	Syneresis %, day 0, 3, 5, 7	≤ 1% at day 5 (A)	First five batches, then sampling plan
pH and a_w	Meter	Within the range measured at Gate 1	Each batch
Chill record	Core-temperature log	Per Section B7	Each batch

B9. Hazard analysis and HACCP plan

Use note. This section shows the structure of a hazard analysis and the way limits are derived. It is not a plan to adopt. Each producer builds and validates its own plan, with qualified people, for its own product, equipment and jurisdiction.

Part A and Gates B4-B8 define what is made and how. This section sets out the safety plan around it. The structure follows the seven Codex principles as stated by Manitoba Agriculture: hazard analysis, critical control points, critical limits, monitoring, corrective actions, verification and record keeping [S34]. In a cook-chill process there are generally four critical control points: cooking, bagging, cooling and chilling [S38]. A cook step does not destroy bacterial spores, which is why the chill step and the shelf-life rules matter [S38]. The limits below are examples tied to sourced guidance; the plant's own HACCP team sets and validates the final plan.

B9.1 Product description and flow

Product (demonstration): a chilled, heat-treated, bagged cream sauce containing chicken-derived stock, intended for reheating by the consumer, with a working shelf life of 7 days at the storage temperature (assumed; see Section B10). **Flow:** receiving and storage, weighing, kettle (cook with the lethality step last), hold, pump and fill, seal, tumble chill, cold store, dispatch, consumer reheating.

B9.2 Hazard analysis (example)

Table 17. Hazard analysis for the demonstration product (example). Classes: PRP (prerequisite programme), CCP (critical control point) or communication.

Step	Hazard	Control	Class
Receiving and storage	Pathogens and spores in cream, stock and garlic; allergens; foreign bodies	Approved suppliers, specifications, receiving checks	PRP
Fresh herbs (parsley)	Salmonella, STEC, Cyclospora. Fresh herbs are typically eaten without a kill step; FDA surveillance found Salmonella in 2 of 261 parsley samples [S36]	Add before the lethality step (Table 16); supplier control	Covered by CCP 1 if added before the kill step
Weighing and charging	Wrong quantity; allergen cross-contact	Batch record, scale checks, allergen matrix (B9.3)	PRP
Cook (lethality)	Survival of Listeria and Salmonella; spores of non-proteolytic C. botulinum	Cold-spot lethality set by shelf-life category (Card 18, Section B10) [S26, S24, S25]; agitation to avoid cold spots	CCP 1
Hold before filling	Growth and recontamination during the wait	Maximum hold time and temperature (Card 20); the Food Code danger zone ends at 135 °F (57 °C) [S18]	CCP 2 (or PRP, per the hazard analysis)
Pump, fill and seal	Recontamination with Listeria from pump, filler and seal area; defective seals	Hygienic zoning, validated cleaning, environmental monitoring for Listeria spp. with zones and corrective actions [S35]; seal inspection	PRPs
Tumble chill	Growth in the danger zone; chill-water ingress through leaking bags	Core temperature against time (Card 9, Table 8); chill water sanitised [S39]; pinholes of a few to tens of micrometres can admit bacteria in flexible pouches, so seals and leak testing matter [S40]	CCP 3; water and bag integrity as PRPs
Cold storage and dispatch	Growth of Listeria and non-proteolytic C. botulinum	5 °C (41 °F) or below; 3 °C or below where shelf life exceeds 10 days [S26, S25, S41]	CCP 4
Allergen changeover	Cross-contact between products	Validated changeover cleaning; allergen matrix; label control	PRP
Metal detection or X-ray	Metal and hard foreign bodies	Calibrated detection with test pieces (common check; no source retrieved)	PRP or CCP per site analysis
Consumer reheating	Survival or growth after mishandling	Label instructions validated for the pack	Communication; pack-specific value **Unknown**

Formula card 18: equivalent heat process and cold-spot lethality	
Question	Does the heat actually received at the slowest-heating point match the required process, including the come-up and cool-down, and what hold at another temperature gives the same lethality?
Formula	$t_T = t_{ref} \times 10^{(T_{ref} - T) \div z}$ lethal rate $L = 10^{(T - T_{ref}) \div z}$ $F = \Sigma\, L \times \Delta t$
Symbols	T_{ref} reference temperature (70 °C for Listeria; 90 °C for non-proteolytic C. botulinum); t_{ref} reference time (2 min; 10 min); z the temperature change that changes the kill time tenfold: 7.5 °C for the Listeria reference [S27], and 7 °C below 90 °C and 10 °C above 90 °C for the botulinum reference, as recommended by the UK advisory committee [S26]; F accumulated lethality in minutes at T_{ref}; Δt logging interval.
Why it works	A bacterial population falls by a fixed factor per unit time at a fixed temperature, and the time for a tenfold fall changes tenfold for every z degrees. Dividing by that scale turns any temperature into 'minutes at the reference temperature', so every minute of the log can be added up, including the minutes while the product is still warming and cooling. The guidance states the botulinum process as 90 °C for 10 min or equivalent lethality at the slowest heating point in the food [S26].
Steps	1. Equivalent hold at 80 °C for the Listeria route: $2 \times 10^{(70 - 80) \div 7.5} = 2 \times 10^{-1.333} = 0.093$ min (6 s). 2. For the botulinum route at 85 °C: $10 \times 10^{(90 - 85) \div 7} = 10 \times 10^{0.714} = 51.8$ min. 3. Cold-spot log (assumed, one reading per minute): 62, 66, 70, 74, 77, 79, 80, 80, 80, 79, 75, 70, 65 °C. 4. Sum the lethal rates against 70 °C (z = 7.5): $F_{70} = 115.6$ min, which is above the 2 min needed. 5. The same log against 90 °C (z = 7): $F_{90} = 0.20$ min, far below the 10 min needed. The same cook therefore passes the shorter-life route and fails the longer-life route.
Template	T_{ref} = ___; t_{ref} = ___; z = ___; logged cold-spot temperatures ___; $L = 10^{(T - T_{ref}) \div z}$ for each reading = ___; $F = \Sigma\, L \times \Delta t$ = ___ min; required = ___ min; pass if F is at least the required time.
Common errors	Logging the kettle wall or jacket instead of the slowest-heating point; ignoring that thick or starch-thickened product heats unevenly without agitation; using one z for temperatures on both sides of 90 °C; summing readings as whole minutes (rectangle rule) when they are further apart than about a minute, where the trapezoid rule or more frequent logging near the peak is safer; treating the example log as a validated process.

Table 18. Equivalent holds computed from Card 18. The botulinum route at 80 °C needs about 268 min, which shows why a sauce cooked to a Listeria-type process cannot carry a longer shelf life.

Temperature (°C)	Listeria route: hold with the same lethality as 70 °C for 2 min (z = 7.5 °C)	Botulinum route: hold with the same lethality as 90 °C for 10 min (z = 7 °C below 90 °C, 10 °C above)
65	9.3 min	37275.9 min
70	2.0 min	7196.9 min
72	1.1 min	3727.6 min
75	0.43 min (26 s)	1389.5 min
80	0.09 min (6 s)	268.3 min
85	0.02 min (1 s)	51.8 min
90	0.00 min (0 s)	10.0 min
95	0.00 min (0 s)	3.2 min

The two routes are those of the UK and Australian guidance: a heat process of 70 °C for 2 min or equivalent for refrigerated food with a short shelf life, and 90 °C for 10 min or equivalent for an extended shelf life over 10 days [S24, S25]. The 6-log target for each route is stated in the same sources [S24, S25].

B9.3 Allergen matrix for the demonstration recipe

Table 19. Allergen status of each ingredient (demonstration recipe).

Ingredient	Allergen status	Note
Cream and butter	Milk: EU list and US nine	Present in the sauce.
Dijon mustard	Mustard: EU list and Canada; not one of the US nine [S42]	Present in the sauce; labelling depends on the market.
Chicken stock	Celery may be present: EU list [S42]	Check the stock specification.
Modified waxy starch	Check the crop source; wheat-derived starch would bring cereals containing gluten (EU) or wheat (US) [S42]	Check the specification.
Garlic purée, lemon juice, parsley, salt, pepper	None expected	Check the supplier specification for carriers and additives.

The EU list has 14 allergens, including milk, celery and mustard [S42]. The US list has nine: milk, eggs, fish, crustacean shellfish, tree nuts, peanuts, wheat, soy and sesame [S42]. The demonstration recipe therefore contains at least milk, and mustard where the EU or Canadian rules apply. Changeover cleaning between products with different allergen profiles must be validated and verified, and the capacity plan must include its time (Section B3).

B9.4 Critical limits, monitoring and corrective action (example plan)

Table 20. Example plan for the four critical control points.

CCP	Critical limit (example)	Monitoring	Corrective action (example)
1 Cook	Cold-spot lethality of at least 70 °C for 2 min equivalent (shelf life up to 10 days) or 90 °C for 10 min equivalent (longer) [S26, S24, S25]; validated per product	Cold-spot probe log per batch; F calculation (Card 18)	Continue heating if time allows and the validated process still applies; otherwise hold and evaluate; no release without a documented decision
2 Hold and fill	Maximum hold time and temperature from the fill duration (Card 20); reference: the Food Code danger zone ends at 57 °C (135 °F) [S18]	Time stamps; kettle temperature	Evaluate the time-temperature history; discard product beyond the limit or of unknown history
3 Chill	Food Code floor: 57 to 21 °C within 2 h, 5 °C or below within 6 h in total [S37]; faster targets from the plant's validation	Centre probe log per chiller load; seal and leak checks	Retail guidance: reheat and re-cool by a faster method within the allowed window, or discard; discard beyond 6 h [S37]. The plant plan states who decides release.
4 Cold storage	5 °C or below; 3 °C or below if shelf life exceeds 10 days [S26, S25]	Store temperature record; product probe checks	Segregate; evaluate time above limit; discard if unknown

Validation and verification. Validation proves the plan works before use: the lethality study (Card 18), the worst-case cooling study (Card 19) and the shelf-life study (Section B10). Verification proves it keeps working: probe calibration, record review, environmental monitoring for Listeria spp. at product-contact and adjacent sites with trend analysis [S35], and periodic product testing. Records for every batch are part of the plan [S34].

Formula card 19: is the single-constant cooling model valid? (Biot number)	
Question	Card 9 treats the bag as one uniform temperature. When is that acceptable, and what is the alternative?
Formula	$Bi = h \times L_c \div k \quad L_c = V \div A_s$

Symbols	h surface heat-transfer coefficient (W/m²K); L_c characteristic length, volume divided by the surface area exposed to the coolant (m); k thermal conductivity of the product (W/m K).
Why it works	Bi compares the resistance to heat flow inside the product with the resistance at its surface. The lumped model of Card 9 (an exponential in time) is accepted when Bi is below about 0.1; above that, a temperature gradient builds up between skin and centre and the heat equation must be solved, with graphical charts available for Bi between 0.1 and 100 [S43].
Steps	Assumed inputs: a flat bag 40 mm thick cooled on both faces, so L_c = 0.02 m; k = 0.5 W/m K (assumed, close to water-rich food); h = 50, 300 or 1000 W/m²K (assumed). Bi = 2.0, 12.0 and 40.0. All exceed 0.1 by a wide margin. For Bi below 0.1 at h = 300, L_c would have to be below 0.1 × 0.5 ÷ 300 = 0.00017 m.
Result	The simple model does not describe the centre of a thick bag. The constant k of Card 9 is only an empirical value for one bag thickness, fill and load, fitted from a centre-probe log. Cooling is limited by conduction inside the product, and in general heat-transfer scaling the conduction-limited time grows roughly with the square of the thickness (grade: Likely, not sourced here), so bag thickness is the strongest lever on cooling time.
Template	h = ___; L_c = ___ m; k = ___; Bi = ___. If Bi ≥ 0.1, measure the centre temperature for the worst case (thickest bag, fullest chiller, warmest start) and use that log, not an average.
Common errors	Fitting k from a vendor claim or from the bag surface; validating with a half-loaded chiller; changing bag thickness without repeating the cooling study.

Formula card 20: fill duration and hold time of the last bag	
Question	How long does the last bag of a batch wait before sealing and chilling?
Formula	$t_{fill} = \lceil M_{pack} \div m_{bag} \rceil \div r$
Symbols	M_{pack} packed mass per batch (kg); m_{bag} mass per bag (kg); r bags filled per minute; ⌈ ⌉ round up.
Why it works	Bags are filled one after another from the same kettle, so the last bag has waited for all the others. Its hold time at temperature is at least t_{fill}, and the cooling clock for that bag starts later than for the first.
Steps	Assumed: M_{pack} = 101.43 kg (Card 13), m_{bag} = 5 kg, r = 2 bags/min. Bags = ⌈101.43 ÷ 5⌉ = 21. t_{fill} = 21 ÷ 2 = 10.5 min. The hold limit of CCP 2 must be longer than this plus the allowance for stoppages, and the chilling limit applies to the last bag from its own sealing time.
Template	M_{pack} = ___; m_{bag} = ___; r = ___; bags = ___; t_{fill} = ___ min; hold limit = ___ min.
Common errors	Timing the first bag only; forgetting that a stoppage lengthens the hold; letting the kettle temperature fall below the hold floor during a long fill.

B10. Shelf life: setting, validating and labelling

Use note. The rules quoted are published guidance from the UK and Australia and New Zealand, with US context. They do not apply identically everywhere. Shelf life for a real product is set by that product's own studies and the rules of the market where it is sold.

B10.1 The rules found

Table 21. Published rules on heat process and shelf life, by source.

Source and scope	Rule	Grade
UK guidance for vacuum and modified-atmosphere packed chilled food	Maximum shelf life 10 days at 8 °C or below unless a controlling factor is in place: 90 °C for 10 min or equivalent, pH 5 or less, 3.5% salt in the aqueous phase, aw 0.97 or less, or a combination shown to prevent growth and toxin formation [S28, S26, S24]. Chill temperatures of 3 to 8 °C are to be maintained [S26].	Confirmed (guidance; not law)
Australia and New Zealand limits for cook-chill	Heat process 70 °C for 2 min or 75 °C for short-life food (under 10 days), 90 °C for 10 min or equivalent for over 10 days; chilling to 3 °C or below stops growth of non-proteolytic C. botulinum; cooling 60 to 21 °C within 2 h, then to 5 °C within 4 h [S25].	Confirmed
Listeria monocytogenes	It can grow at refrigeration temperatures, down to about −2 °C according to EU shelf-life guidance quoted by the Chilled Food Association, so its growth must be considered when setting shelf life [S41]. Domestic fridges often run at 6 to 8 °C [S44].	Confirmed (secondary reports of guidance)
Other controlling factors	If safety relies on any factor other than pH, aw, aqueous salt or heat treatment, proof that the control works is needed, and the factors are identified in the HACCP documentation [S24].	Confirmed
US position	This handbook did not locate a single US manufacturer rule equivalent to the 10-day rule. Cook-chill with reduced-oxygen packaging in retail and foodservice is regulated through the Food Code and a HACCP plan [S38]; manufacturers follow their own regulations and guidance, including Listeria guidance [S35].	**Unknown** for manufacturers; check the authority

B10.2 Applying the rules to the demonstration sauce

Table 22. Controlling factors of the UK guidance against the assumed values of the demonstration sauce (pH 6.2 and aw 0.98 as in Section B4; recipe salt 0.8% of the batch is about 1% of the aqueous phase if the water fraction is assumed at 70%).

Factor	Required for more than 10 days	Demonstration sauce (assumed)	Met?
Heat treatment	90 °C for 10 min or equivalent at the slowest point	Depends on the process (Card 18, Table 18)	Only if validated
pH	5 or less throughout	6.2	No
Aqueous salt	3.5% or more	About 1%	No
Water activity	0.97 or less throughout	0.98	No

The UK guidance is written for vacuum and modified-atmosphere packs; a sealed bag of hot-filled sauce is treated as one here, which is the cautious assumption. Unless the process delivers 90 °C for 10 min or equivalent, none of the controlling factors is met, so the shelf life stays within 10 days at 8 °C or below. The working label of 7 days used in this handbook sits inside that limit. A 7-day claim with a Listeria-type heat process (70 °C for 2 min or equivalent) is therefore the planning case; a longer claim needs the botulinum route or a validated combination, and cooling to 3 °C or below should then be required. These values are assumed and are replaced by measurements.

B10.3 Shelf-life study plan (test design)

Table 23. Shelf-life study plan (test design).

Element	Design	Note
Storage temperatures	Intended storage temperature, plus a temperature-abuse condition representing a domestic fridge [S44]	Abuse value set by the HACCP team
Time points	Day 0, 3, 5, 7 and 10 (day 10 shows the margin)	As in the handbook's stability work
Safety	Listeria monocytogenes challenge or storage testing, and total counts, per the plant's validation protocol	Design and acceptance by the HACCP team and a laboratory; general practice, not sourced here
Quality	Syneresis % (Card 6), Bostwick (Card 7), pH, aw, colour (Card 17), sensory	Same methods as the gates
Worst case	Largest bag, thickest fill, fullest chiller load, warmest start, longest fill time	Links to Cards 19 and 20

B11. Evidence behind the five gates

Commercialisation is described in practical sources rather than by one exact standard: a product-development textbook describes a structured, staged process [S45], and an IFT article reports that scale-up usually needs experimentation at two scales [S29]. The five gates are therefore a working framework. The table lists statements commonly made about each gate, what the sources retrieved say, and how each is treated here.

Statement	Finding	Treatment
Start from weights and convert to percentages usable for any batch size	Stated by an OSU food scientist [S31]; OSU fact sheet notes that values must be converted to weights [S30].	Verified; Card 14
Baker's percentage	Not applicable to a sauce without a dominant dry ingredient.	Adapted to total-mass percentage
pH and water activity as baselines	FDA tables use pH and a_w together [S33]; a_w is available water [S32].	Verified
Brix or Bostwick for flow and pumpability	Consistent with Part A's Bostwick work; no new source needed.	Verified in Part A
Commercial ingredient swaps (garlic powder, stable dairy)	No source retrieved for chilled sauces.	Kept as test items; Unknown
Modified starches, xanthan gum, carrageenan prevent syneresis	Modified starch: confirmed [S8, S14, S9]. Xanthan and carrageenan: no source retrieved.	Starch kept; gums removed
Freeze-thaw, retort, blast-freezing	The product class assumed here is chilled, not frozen.	Adapted to chill-hold; retort not used
Pilot at 10x-50x then full scale	Scale-up usually needs experiments at two scales [S29].	Adopted; Table 11
Surface-to-volume ratio changes on scale-up; burn-on	Stated in the OSU fact sheet [S30].	Verified
Food stays hotter for longer in large kettles, overcooking proteins	No source retrieved; Part A shows less heating surface per litre, which slows heat-up.	Removed

Statement	Finding	Treatment
Heel loss accounting	Concept not sourced; defined here as a mass balance.	Kept as Card 16
HACCP principles and CCP validation	Seven Codex principles confirmed [S34]; kill-step routes now sourced (Section B10), product validation still needed.	Verified; product validation needed
Metal detection and X-ray; MAP moisture release	No source retrieved.	Kept as checks; Unknown limits
Example SOP: 25 rpm, 85 °C for 3 min, 4 °C within 45 min	Illustrative only. 85 °C for 3 min is not a validated lethality; 45 min is shorter than the base model time of 47.5 min for 57 to 5 °C.	Replaced by Table 16 and Section B10; the kill step now follows the published heat-process routes
Further reading	Earle, Earle and Anderson, Food Product Development: Maximising Success (Woodhead, 2001), whose free web edition covers the management of product development rather than techniques [S45]; Scott, Bowser and McGlynn, Scaling Up Your Food Process (OSU Extension FAPC-141, 2010), a qualitative fact sheet of scale-up issues [S30].	Recommended reading

10. Assumption register

Every example value that was not sourced or measured is listed here. Replace each by data before operational use.

Value	Used	Where	Replace with
Working fill f	0.75	Card 1	Measured safe fill line
Batch density ρ	1.00 kg/L (mash 1.05)	Cards 1, 3	Weighed 1 L
Mash fill	0.60	Section 3	Trial
Lab pan	16 cm, 1 L	Card 2	Actual vessel
Bench evaporation	8% in 10 min	Card 3	Measured simmer
Start solids	20%	Card 4	Brix / oven-dry solids
Specific heat of beans	3.9 kJ/kg·K	Card 5	Reference value or measurement
Water / bean temperatures	95 / 15 °C	Card 5	Logged values
Cooling anchor	85 → 4 °C in 60 min, 1 °C coolant	Card 9	Centre-probe log
Thick-product k	one half, one quarter	Table 8	Measured
Syneresis data and limit	Section 5.3 values; 1%	Card 6	Own trials and spec
Bostwick target	6.0 ± 0.5 cm	Card 7	Own spec
Prices	Table 9	Section 8	Supplier quotes
Parsley yield	60%	Card 10	Trim trial
Process loss	8%	Cards 3, 4, 11	Weighed batches
Portion mass	80 g	Card 11	Product spec
Labour, packaging, overhead	2 × 3 h × EUR 20; EUR 0.05; 15%	Card 11	Costing records
Margin	30%	Card 11	Commercial decision
Monte Carlo ranges	Section 8.1	Section 8	Observed variation
Fat contents	35% cream, 82% butter	Section 3	Supplier spec
Kettle net volume and inner dimensions	150 L; 665 x 500 mm (dealer listing)	Cards 1, 2; Section 1.4	Datasheet of the kettle actually used
Production target reading (Part B)	10,000 portions of 80 g	Section B3	The brief's actual target
Heel loss	2% of finished mass	Cards 13, 16	Weighed line trial
Cycle time per batch	3 h	Table 12	Timed pilot and line runs
Pilot ladder	1, 10, 50, 112.5 kg	Table 11	Available pilot vessels
Agitator sweep diameter	0.60 m	Card 15	Equipment manual
pH and water activity	6.2 and 0.98	Section B4	Bench measurements
Kill step	85 °C for 3 min	Table 16	Validated lethality study
Chill target time	60 min	Table 16	Logged centre-probe data
Colour readings and limit	Card 17 values; delta E* <= 2.0	Card 17	Colorimeter data and spec

Value	Used	Where	Replace with
Working shelf life	7 days at the storage temperature	Section B10	Validated shelf-life study
Cold-spot temperature log	13 readings, 62 to 80 °C	Card 18	Logged cold-spot data
Biot inputs	40 mm bag; k 0.5 W/m K; h 50-1000 W/m2K	Card 19	Measured bag, product and chiller values
Fill rate and bag size	5 kg bags; 2 bags/min	Card 20	Line data
Changeover time	1.5 h after the run	Section B3	Validated cleaning time

11. Sources

Sources were retrieved and re-checked between 14 and 24 October 2026. Several are patents, vendor pages or secondary sites and are graded accordingly in the text. A source is listed only if it was used above.

Code	Source	URL
S1	Machineseeker, MKN Optima 850 150 L kettle listings (used units, dealer)	https://www.machineseeker.ie/mkn-optima+850/i-22459867 ; https://www.machineseeker.my/mkn-optima+850/i-21051132
S2	Moffat, Metos Proveno 4G Combi 150E (distributor listing)	https://moffat.com.au/node/43177
S3	Metos Estonia, Proveno 150E combi kettle page	https://metos.fi/et/web/assortment-estonia/p/-p_mg4224608
S4	DC Norris cook-chill: Belt Tumble Chiller; Tumble Chiller; TC30; tumble chiller web page; 50-years release (2021)	https://www.dcnorris.com/wp-content/uploads/2022/04/Belt-Chiller-1pg.pdf ; https://www.dcnorris.com/wp-content/uploads/2022/04/Tumble-Chiller.pdf ; https://www.dcnorris.com/systems/cook-chill-systems/tumble-chiller/ ; https://dcnorris.com/?p=1194
S5	Surplus Record, Industrial cooking kettles buying guide (capacity range, kettle types)	https://surplusrecord.com/buying-guides/industrial-cooking-kettles-buying-guide/
S6	Cleveland KEL100T 100-gallon (375 L) electric tilting kettle, two-thirds steam jacket (Zanduco listing)	https://www.zanduco.com/us/cleveland-kel100t-floor-type-tilting-2-3-steam-jacketed-electric-kettle-100-gallon-375-liters-208-240v.html
S7	Crown DLT-100 100-gallon tilting kettle, direct steam, two-thirds jacket (restaurantsupply.com listing)	https://restaurantsupply.com/crown-dlt-100-tilting-kettle-direct-steam-100-gallon-capacity
S8	Prepared Foods, Saucy Success (starch-based sauces)	https://preparedfoods.com/articles/103836-saucy-success
S9	Arocas, Sanz and Fiszman (2009), Influence of corn starch type on a white sauce after heating and freezing	https://www.sidalc.net/search/Record/dig-iata-es-10261-333641
S10	Effect of blanching on textural properties of refrigerated and reheated vegetables (KoreaScience)	https://koreascience.kr/article/JAKO200411922367965.do
S11	USDA ARS, Low-temperature blanching of sweetpotatoes to improve firmness retention	https://ars.usda.gov/ARSUserFiles/60701000/Sweetpotato Publications/S113.pdf
S12	Andersson et al. (1994), Effect of preheating on potato texture	https://repositorio.ucp.pt/entities/publication/cb15157b-82c0-44f3-a2f0-365a72a1e163
S13	Thuy and Ha (2021), low-temperature blanching in calcium chloride and firmness of cherry tomatoes (AGRIS)	https://agris.fao.org/search/es/records/65fc2580ce216acd4b80e492
S14	EP 0639056 B1 and US 5,538,751 (Unilever), starch-thickened foodstuff, storage and reheat stability (patents)	https://data.epo.org/publication-server/rest/v1.2/patents/EP0639056NWB1/document.pdf ; https://patents.google.com/patent/US5538751
S15	Meatingplace, Preventing lipid oxidation of precooked meat; Tips to avoid warmed-over flavor in precooked meat and poultry	https://meatingplace.com/preventing-lipid-oxidation-of-precooked-meat/ ; https://meatingplace.com/tips-to-avoid-warmed-over-flavor-in-precooked-meat-and-poultry/
S16	National Pork Board / AMSA fact sheet on warmed-over flavor (hosted by eXtension); MSU thesis on TBA values in cooked meats	https://swine.extension.org/?p=886 ; https://d.lib.msu.edu/etd/14944/FULL_TEXT/view
S17	Igene et al. (1979), Journal of Animal Science 49(3): 701-707	https://academic.oup.com/jas/article/49/3/701/4699258
S18	FDA, Cooling Cooked TCS Foods and the FDA Food Code: for Food Employees	https://fda.gov/media/181882/download
S19	US 6,004,591 and US 5,902,616, tomato sauce Bostwick viscosity method (patents)	https://image-ppubs.uspto.gov/dirsearch-public/print/downloadPdf/6004591
S20	UC ANR, Bostwick measurement and tomato ketchup (USDA 3-7 cm in 30 s at 20 °C)	https://ucanr.edu/datastoreFiles/608-852.pdf
S21	Oregon Health Authority, Food Code Fact Sheet 31: Cooling	https://www.oregon.gov:443/oha/PH/HEALTHYENVIRONMENTS/FOODSAFETY/Documents/FactSheet31Cooling.pdf
S22	Runnymede and West Norfolk councils, chilled storage and cooling advice (UK local-authority guidance)	https://www.runnymede.gov.uk/downloads/file/527/chilled-storage-and-cooling-improver ; https://www.west-norfolk.gov.uk/download/downloads/id/1120/chilled_storage_and_cooling_advice.pdf

Code	Source	URL
S23	IFSQN forum threads on cooling-time legislation and cooling validation of sauces (secondary)	https://www.ifsqn.com/forum/index.php/topic/33438-legislation-on-cooling-times ; https://ifsqn.com/forum/index.php/topic/41612-cooling-validation-of-sauces/?ampmode=1
S24	Campden BRI, Microbiological safety and quality of chilled pasteurised food products; New Food, Managing the risks of C. botulinum in chilled foods (10-day rule)	https://www.campdenbri.co.uk/white-papers/microbiology-safety-chilled-foods.php ; https://newfoodmagazine.com/?p=98466
S25	Food Standards Australia New Zealand, Safe Food Australia, Appendix 3: Limits for food processes	https://www.foodstandards.gov.au/sites/default/files/publications/SiteAssets/Pages/safefoodaustralia3rd16/Appendix 3 - Limits for food processes.pdf
S26	UK ACMSF, Report on Botulinum Neurotoxin-Producing Clostridia (recommendations: 90 °C for 10 min or equivalent at the slowest heating point; z = 7 and 10 °C)	https://acmsf.food.gov.uk/node/7201?print=1 ; https://acmsf.food.gov.uk/Recommendations
S27	Public Health Ontario, Case study: sous vide (70 °C for 2 min, z = 7.5 °C; chill to 3 °C or lower)	https://www.publichealthontario.ca/-/media/documents/case-study-sous-vide.pdf?la=en
S28	Torbay Council, Vacuum packing foods: guidance notes (UK controlling factors and 10-day rule)	https://www.torbay.gov.uk/media/2270/vacuum-packing-foods.pdf
S29	IFT Food Technology, Scaling-Up Food Processes (after K. J. Levine)	https://www.ift.org/food-technology-magazine/scaling-up-food-processes
S30	Scott, D. D., Bowser, T. J. and McGlynn, W. G. (2010), Scaling Up Your Food Process, OSU Extension FAPC-141	https://extension.okstate.edu/fact-sheets/scaling-up-your-food-process.html ; https://shareok.org/handle/11244/50196
S31	KOSU, OSU Research Matters: how to scale up a recipe (D. Scott)	https://www.kosu.org/podcast/osu-research-matters/2021-12-16/just-in-time-for-the-holidays-learn-how-to-properly-scale-up-a-recipe
S32	Purdue Extension, The role of water activity and pH (FS-15-W)	https://www.extension.purdue.edu/extmedia/fs/fs-15-w.pdf
S33	FDA, Job Aid: Time and Temperature Control for Safety Foods (Tables A and B)	https://fda.gov/media/101004/download
S34	Manitoba Agriculture, HACCP overview and the Codex seven principles	https://gov.mb.ca/agriculture/food-safety/education-resources/haccp.html
S35	FDA, Control of Listeria monocytogenes in Ready-To-Eat Foods (draft guidance); FSNS summary; 9 CFR 430.4 (USDA FSIS)	https://fda.gov/media/102633/download ; https://fsns.com/control-listeria-monocytogenes-ready-eat-foods/ ; https://www.govinfo.gov/content/pkg/CFR-2020-title9-vol2/pdf/CFR-2020-title9-vol2-sec430-4.pdf
S36	FDA, Microbiological Surveillance Sampling FY17-21: fresh herbs (cilantro, basil, parsley)	https://www.fda.gov/Food/ComplianceEnforcement/Sampling/ucm590449.htm
S37	Oregon Department of Agriculture, Food Code 3-501.14 cooling text; SC Department of Agriculture, Importance of proper cooling; AFDO, Immediate corrective actions for food service managers (Table 4)	https://www.oregon.gov/oda/agriculture/Documents/Rulemaking/Chap3_supplemental_docs.pdf ; https://agriculture.sc.gov/wp-content/uploads/2026/01/Importance-of-Proper-Cooling-final.pdf ; https://www.afdo.org/wp-content/uploads/2020/09/Table-4-Immediate-Corrective-Action-for-Food-Service-Managers_2019.05.pdf
S38	Food Safety Magazine, Cook-chill and reduced oxygen packaging in retail and foodservice operations	https://food-safety.com/articles/4494-cook-chill-reduced-oxygen-packaging-in-retail-and-foodservice-operations
S39	USDA FSIS thermal processing training, Module 19 Container handling (cooling water sanitation); FDA guide to inspections of low-acid canned food	https://www.fsis.usda.gov/sites/default/files/media_file/2022-02/19-Container-Handling.pdf ; https://www.fda.gov/inspections-compliance-enforcement-and-criminal-investigations/inspection-guides/guide-inspections-low-acid-canned-food-45
S40	USDA NAL, Post-process contamination of flexible pouches challenged by in situ immersion biotest	https://nal.usda.gov/research-tools/food-safety-research-projects/post-process-contamination-flexible-pouches-challenged
S41	Chilled Food Association, response to the ACMSF report (storage below 3 °C; Listeria growth to about -2 °C)	https://www.chilledfood.org/?p=5918
S42	Allergen lists: FARRP (University of Nebraska) EU Annex II; Faegre Drinker on the FASTER Act and the EU list; Keller and Heckman on the US nine	https://farrp.unl.edu/farrp-resources/regulatory/european-union ; https://www.fbm.com/post/102ks23/ ; https://webiis10.mondaq.com/unitedstates/food-and-drugs-law/1270304/sesame-listed-as-major-food-allergen
S43	Biot number: Wikipedia; Firgelli engineering calculator (lumped capacitance and charts for 0.1 < Bi < 100)	https://en.wikipedia.org/wiki/Biot_number ; https://www.firgelliauto.com/blogs/engineering-calculators/biot-numer-calculator
S44	Food Manufacture, Way of shelf-life (10-day rule; domestic fridge temperatures)	https://foodmanufacture.co.uk/Article/2010/05/01/Way-of-shelf-life
S45	Earle, M., Earle, R. and Anderson, A. (2001), Food Product Development: Maximising Success, Woodhead; free web edition by NZIFST	https://www.nzifst.org.nz/resources/foodproductdevelopment/index.htm ; https://shop.elsevier.com/books/food-product-development/earle/978-1-84569-722-8

Appendix A. Fact-check record

- **Scope.** Every sourced factual claim in Part A (equipment, hygiene limits, failure mechanisms, measurements) and every calculation.
- **Task.** Confirm each claim against its source, keep what holds, qualify what the source qualifies, and remove what could not be confirmed.
- **Action.** Each source was re-opened or re-searched between 14 and 24 October 2026 and the cited statement compared with the text; calculations were re-run from the single calculation file.
- **Result.** 38 claim groups checked: 25 verified or recomputed (several with caveats stated in the text), 10 removed because they could not be re-verified, 3 recorded as unknown or not stated. Part A now contains only claims backed by a retrieved source, values marked assumed, or items marked unknown.
- **Second pass (page by page).** Five further corrections: the cost understatement from dividing by raw weight is about 8%, not 8.7%; the order of cost sensitivities in Section 8.1 was corrected to cream price, labour hours, overhead, packaging; the empty maximum-load cells in Table 6 were computed; the statement that no figure is typed by hand was narrowed; and the 10-160 rpm Proveno variant was cross-referenced in Section 4.4.

Area	Claim	Source	Outcome
Equipment	Optima 850 150 L: 150 L usable, 665 × 500 mm inner kettle, double jacket, VAPRO steam generator	S1	Verified (used units, dealer data)
Equipment	Steam-jacketed tilting kettles are built by many makers; capacities 20 to over 200 gallons; 100-gallon two-thirds-jacket units listed	S5, S6, S7	Verified (buying guide, dealer listings)
Hygiene	UK and Australian heat-process routes (70 °C for 2 min; 90 °C for 10 min or equivalent); z = 7 and 10 °C; z = 7.5 °C for Listeria	S26, S24, S25, S27	Verified
Hygiene	Shelf-life rule: 10 days at 8 °C unless a controlling factor (heat, pH 5, 3.5% salt, aw 0.97); no growth of non-proteolytic C. botulinum at 3 °C or below	S28, S26, S25	Verified (guidance)
Hygiene	Listeria can grow down to about -2 °C; domestic fridges often 6 to 8 °C	S41, S44	Verified (secondary reports)
Hygiene	Cook-chill has four typical CCPs; cook step does not destroy spores	S38	Verified
Hygiene	Post-kill Listeria control: zones, environmental monitoring, corrective actions	S35	Verified
Hygiene	Cooling-water sanitation; pouch pinhole leaks admit bacteria	S39, S40	Verified (canning and retort-pouch context, applied by analogy)
Hygiene	Allergen lists: EU 14 including milk, celery, mustard; US nine; mustard not in the US nine	S42	Verified
Hygiene	Fresh herbs eaten without a kill step; Salmonella in 2 of 261 parsley samples	S36	Verified
Hygiene	Biot number below 0.1 for the lumped model; charts for 0.1 to 100	S43	Verified
Hygiene	Food Code 3-501.14 cooling text; retail corrective actions (reheat or discard)	S37	Verified (retail guidance)
Equipment	Energy type of the 150 L Optima listing	S1	Not stated; kept as Unknown
Equipment	Term 'Vapo-Control'	none	Not found; VAPRO used
Equipment	Proveno 150E: 150 L electric, 15-140 rpm, auto-reverse, electric tilt, Delta-T, wash programs	S2	Verified; another page lists 10-160 rpm (S3)
Equipment	Heavy-duty mixing tool option and wireless HACCP sensor	earlier page	Not re-verified; removed
Equipment	Standard Proveno agitator scrapes bottom and sides	none	No source; Unknown
Equipment	DC Norris belt chiller 85 to below 4 °C in 30-60 min; 300-1000 kg; rotary 45/90 min; pump-fill station	S4	Verified (vendor claims)
Equipment	Cooling water at about 0 °C (tumble-chiller patent)	earlier patent	Not re-verified; removed (1 °C coolant stays an assumption)
Hygiene	Food Code: 135 to 70 °F in 2 h; 41 °F or below, 6 h in total; danger zone 41-135 °F	S18, S21	Verified
Hygiene	Reheat to 165 °F for 15 s	earlier page	Not re-verified; removed

Area	Claim	Source	Outcome
Hygiene	UK guidance: ideally within 90 min; legal 8 °C; 5 °C recommended	S22	Verified as guidance; earlier '70 to 3 °C in 90 min' source replaced
Hygiene	EU rule vague; Irish guidance 'begin within 90 min'	S23	Verified as a forum report (secondary)
Starch	Waxy starch least prone to retrogradation; hydroxypropylation; low-pH needs; batch variation	S8	Verified
Starch	Modified waxy vs native corn starch white sauce, freeze/thaw, syneresis	S9	Verified (freeze/thaw only; native sauces largely recovered on heating)
Starch	Gel set-back under chill; slimy texture and liquid separation after reheating	S14	Verified (patents)
Starch	Gelatinisation near 60-75 °C; oxidised/acid-thinned starch lowers pasting temperature	earlier pages	Not re-verified; removed
Dairy	High fat or stabiliser reduces broken sauce after freeze/thaw	S8	Verified (frozen sauces only)
Dairy	Rapid heating curdles dairy sauces	earlier page	Not re-verified; removed
Measurement	Bostwick: distance in 30 s; 25 °C; tomato sauce 5-7 cm; USDA ketchup 3-7 cm at 20 °C	S19, S20	Verified
Measurement	Bostwick sample 75-100 ml; syneresis formula attributed to a paper	earlier pages	Not re-verified; removed or restated as Part A's own definition
Meat	Oxidised flavours in under 48 h; chicken and turkey more susceptible than pork and beef; dark more than white	S15, S16, S17	Verified
Meat	Microwave reheating gave the highest oxidation in chicken fillets	earlier page	Not re-verified; removed
Vegetables	Low-temperature blanching with calcium kept firmness: onion, soybean sprout, carrot (cook/chill, reheated), sweetpotato, tomato, potato	S10, S11, S12, S13	Verified; green beans not tested; extrapolated
Vegetables	Carrot texture kinetics: higher temperature, faster degradation	earlier page	Not re-verified; removed
Pasta, rice, dough	Pasta heats faster than sauce; moisture migration; rice oil coat; pastry moisture barriers	earlier pages	Not re-verified; removed; families F3, F4, F8 marked Unknown
Cooling	Retail-pot cooling study; public cook-chill centre 180 to 40 °F in 1 h	earlier pages	Not re-verified; removed
Calculation	All formulas, scale factor, geometry, evaporation, mixing, cooling, cost, Monte Carlo	calculation file	Recomputed; unchanged except Table 8 (new UK criterion and vendor scenario)