

Fog-in-Place (FIP): Aerosol Engineering, Surface Decontamination, Industrial Evidence and Translational Opportunities for Livestock Arthropod Management

A critical review with reproducible synthetic transport modelling and a prospective industrial validation framework

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Abstract

Background: Fog-in-Place (FIP) is a convenient process-level term for automated airborne distribution of treatment media within industrial and animal-housing environments. It is not a standardized technology class, a formulation identity, or evidence of efficacy. **Objectives:** To critically integrate aerosol physics, peer-reviewed food-industry observations, microbial surface validation, arthropod ecology, European biocidal regulation and risk governance. **Methods:** A targeted, non-systematic critical review of identifiable primary studies, standards and legislation was combined with a transparent reduced-order deposition model. **Results:** Published experiments indicate pronounced dependence of treatment on droplet diameter and surface orientation; upward-facing surfaces may be more responsive than vertical or downward-facing targets. Standards for automated airborne room disinfection provide defined microbiological carrier tests, but no direct ovicidal or acaricidal validation. An illustrative model reveals how orientation, shielding and ventilation can create persistent underexposure despite plausible room-average aerosol concentration. **Conclusion:** FIP should be evaluated as a coupled equipment–medium–environment–target process. Claims of broad-spectrum efficacy, including eggs, larvae, nymphs and adults of arthropods, require separate organism - and stage-specific field evidence. No confidential operational identity, chemistry or formulation is disclosed.

Keywords: *Fog-in-Place; fogging; aerosol deposition; automated airborne room disinfection; food processing; livestock biosecurity; mites; ticks; ovicidal testing; EN 17272; transport modelling; biocidal regulation.*

Highlights

- FIP describes an engineered delivery approach, not a particular active substance or an established efficacy claim.
- The current EN 17272:2020+A1:2025 addresses automated antimicrobial decontamination of non-porous surfaces - not airborne disinfection or arthropod control.
- Historical food-industry experiments demonstrate a substantial orientation penalty that invalidates uniform-coverage assumptions.
- Two fully labelled computational illustrations separate physical deposition and arthropod-stage persistence from observed field outcomes.
- An auditable validation and regulatory pathway can protect sensitive industrial know-how without compromising reproducibility.

1. Introduction and problem formulation

Automated aerosols are increasingly discussed as a means of supplementing manual cleaning in industrial facilities with intricate surfaces, machinery and structural voids. The engineering rationale is compelling: an enclosure-wide airborne carrier may redistribute an agent without requiring a worker to access every surface physically. Yet dispersion is not deposition, deposition is not bioavailable dose, and dose is not biological kill. The distinction is particularly acute for hidden niches, organic soiling, biofilms, porous materials and arthropod eggs. This paper therefore resists the use of “whole-room treatment” as a surrogate for measured spatial efficacy [1–4].

The livestock use case extends beyond microbial hygiene. Poultry red mites can occupy narrow refuges within equipment and housing; cattle and swine systems have different ectoparasite species and exposure routes. Environmental application cannot replace appropriate on-animal veterinary treatment [10–12]. The present paper treats livestock arthropod control as a translational research question, not an already validated extension of antimicrobial fogging.

2. Review methodology and evidence classification

This is a structured narrative review and engineering perspective, not a PRISMA systematic review or meta-analysis. Sources were selected for direct relevance to automated disinfection standards, experimental aerosol deposition, food-factory applications, livestock pest ecology and binding European legal instruments. Publication details and the principal normative scope were checked against publisher/standards-body and EUR-Lex records available on 10 October 2026. Evidence is categorized as E1: standards and legislation (scope/requirements, not field outcomes); E2: peer-reviewed experimental observations; E3: peer-reviewed synthesis; E4: public industrial/vendor claims requiring independent examination; and S: fully synthetic calculations. Data from confidential customer operations were neither accessed nor presented as independently audited results.

Evidence class	Permitted inference	Impermissible inference
E1 Standards	Specified test method and scope	Automatic commercial authorization or universal efficacy
E2 Experimental	Performance for tested agent, substrate and conditions	Transfer to all media, surfaces or organisms
E3 Reviews	State of literature and recurring limitations	New primary industrial measurements
E4 Operator case reports	Operational plausibility and reported observations	Independently proven mechanism or causality
S Simulation	Consequences of declared assumptions	Measured product performance

3. Terminology: fog, mist, aerosol, vapour and FIP

An aerosol comprises suspended liquid or solid particles in a carrier gas. Vapour denotes the molecular gas phase; these are not synonymous. Cold atomization can use pneumatic, hydraulic, centrifugal or ultrasonic generators, while thermal fogging adds temperature-dependent evaporation and recondensation. Thermal energy may change a treatment medium before deposition. An aerosol generator may deliver a product reproducibly yet fail to distribute it evenly in a cluttered enclosure. FIP is used here only as a generic umbrella term; it should not be represented as a trademark-neutral equivalent of CIP, sterilization or the requirements of EN 17272 [1–3].

4. Transport, evaporation and surface delivery

4.1 Particle-size distributions and gravitational settling

For a sufficiently small spherical particle in the Stokes regime, a useful first-order approximation is $v_s = (\rho_p - \rho_{air})g d^2 C_c / (18 \mu)$, where v_s is terminal settling velocity, d particle diameter, C_c the slip correction (close to unity for many

micrometre-sized droplets), μ dynamic viscosity, and ρ the densities. This expression neglects evaporation, air motion, hygroscopic growth, electrostatic forces and near-wall turbulence. Its d^2 scaling clarifies why median particle diameter alone cannot define coverage. Number-median and volume-median diameters may diverge; a full distribution is needed [1].

Smaller droplets may follow circulating air longer while depositing little mass on individual surfaces. Larger droplets can accumulate rapidly on horizontal upward-facing surfaces but may offer poor penetration around obstacles. The historic food-factory work by Holah and colleagues identifies approximately 10–20 μm median droplets as a favourable range for the specific configurations investigated; this is a study-specific engineering result, not a universal setpoint [1].

4.2 Mass-balance representation

Let $C(t)$ be a well-mixed airborne mass concentration and V the effective room volume. A basic material balance is $dC/dt = Q(t)/V - (\lambda_v + \lambda_d + \lambda_l)C$, where Q is airborne source mass per unit time, λ_v ventilation removal, λ_d area-weighted deposition, and λ_l other losses. At a location i , a simplified surface load is $D_i = \eta_i k_i \int C(t)dt$, with $\eta_i \in [0,1]$ describing occlusion/orientation and k_i effective deposition velocity. Neither C nor D_i equals an active biocidal dose without information about composition, wetting, contact time and reaction kinetics. In real facilities, multizone transport or validated CFD may be required.

4.3 Mechanistic limits

Fine aerosol is not synonymous with penetration into cracks, animal bedding, dust deposits or the chorion of arthropod eggs. Internal air movement may bypass shielded cavities. Droplet evaporation can change the ionic strength, pH and morphology of residual deposits. Surface roughness and organic load modify both access and chemical demand. Conductivity alone does not imply an imposed electric field, and electroporation cannot be inferred from the description “ionized” in the absence of direct membrane-permeabilization measurements.

5. Industrial evidence: what is actually documented

A primary food-industry review and associated experimental programme by Holah and colleagues [1] documented efficacy against organisms on upward-facing surfaces but generally not on vertical and downward-facing ones; its modelling and experiments motivated a droplet-size window around 10–20 μm under investigated conditions. This is material, application and experiment specific. The published abstract does not support uniform coverage, universal pathogen reduction or all-factory generalization.

A more recent controlled research note compared fogging with immersion using specified sanitizer systems against *Staphylococcus aureus*, *Salmonella Typhimurium* and *Escherichia coli* on stainless steel [5]. It supports the relevance of fogging to food-contact surfaces under its tested conditions; it does not document a generalizable operational success rate for whole plants, nor evaluate arthropods. A 2026 review comprising 38 peer-reviewed food-sector articles selected from 2014–2024 describes encouraging pathogen reductions for tested chemistries but highlights inconsistent distribution, residues, worker safety and a shortage of industrially validated CFD [3].

Hospital literature supplies another domain-specific analogue: Boyce [4] reviewed no-touch room decontamination systems and emphasized the role of environmental cleaning and the variability of methods. Hospital outcomes cannot be assumed to reproduce in animal housing or food factories. Food-industry air contamination reviews [6] likewise motivate environmental surveillance without establishing that microbiological gains translate into elimination of pests or biofilms.

Source / system	Documented observations	Important boundary
Holah et al., 1999 [1]	Experimental surface-orientation dependence; favourable droplets under studied conditions	Not proof of uniform coverage in a different plant
Lemos Jr et al., 2025 [5]	Controlled fogging-versus-immersion sanitizer comparison on inoculated steel	Not a validated fleet-wide or pest endpoint
Food Biophysics review, 2026 [3]	Critical synthesis of 38 food-relevant articles	Secondary synthesis; agent and substrate heterogeneity
Boyce, 2016 [4]	Review of hospital no-touch systems	Clinical context and chemistries differ
Confidential industrial implementation	Potential existence and feasibility of automated deployment	No public attributable numeric performance supplied or inferred

6. Microbial targets, validation and the standard of proof

Separate vegetative bacteria, mycobacteria, bacterial spores, yeasts, mould spores and viruses. Susceptibility is organism-, matrix-, chemistry- and method-dependent; vegetative cell reductions do not warrant sporicidal claims. A contaminated surface must be precleaned as specified in the intended programme because protective soil and mature biofilm can change accessibility and chemistry. Quantitative carrier experiments require appropriate neutralization, recovery controls, positive/negative controls, replication and recovery-limit reporting.

EN 17272:2020+A1:2025 specifically addresses automated distribution of chemicals by air diffusion for the disinfection of non-porous surfaces in medical, veterinary, food and institutional settings. It is not a method for establishing airborne disinfection, acaricidal activity, effectiveness within porous substrates, or legal approval of a product [2]. Microbial claims require testing under the applicable standard conditions, including defined organisms and distribution tests; additional use-condition tests are advisable for the intended plant geometry.

7. Translational livestock arthropod hypothesis

The poultry red mite *Dermanyssus gallinae* is a particularly useful model because adult, nymphal and immature stages occupy off-host refuges and reinfest surfaces when host access resumes [10–12]. Ticks exhibit species-specific life cycles and habitat choices; extrapolating poultry red-mite results to hard ticks would be scientifically unsound. Physical or mineral-based surface approaches reported in acarology have humidity- and particle-dependent effects [13], which cannot be credited to an undisclosed material by analogy alone. Eggs, larvae, nymphs and adults require separately identified endpoints, including hatching delay, viability, locomotion, mortality and subsequent emergence.

A sequential architecture can be hypothesized without describing any commercial formula: (A) enclosure-appropriate liquid environmental conditioning with measured surface deposition; (B) after safety and compatibility checks, a distinct dry-surface management intervention. The two stages should be factorially compared with untreated control, A alone, B alone and A→B. There is no basis for claiming synergy before demonstrating a positive interaction against a predeclared endpoint. Simultaneous mixing must not be assumed chemically or operationally compatible.

8. Reproducible computational illustrations - strictly synthetic

All values in this section are AI-driven created model inputs to expose engineering sensitivity. They have not been derived from pilot measurements, customer reports, treatment formulations or livestock studies. The code-equivalent equations and input values are stated to support reproduction.

8.1 Aerosol attenuation and surface exposure

Consider a notional enclosure with a normalized airborne mass concentration $C(0)=1$ following source shutoff. Let $\lambda_d = 0.020 \text{ min}^{-1}$, $\lambda_l = 0.010 \text{ min}^{-1}$ and three hypothetical ventilation removal rates $\lambda_v = 0.005, 0.030$ and 0.080 min^{-1} . Then $C(t)=\exp(-\lambda t)$, $\lambda=\lambda_d+\lambda_l+\lambda_v$, and $I(T)=\int_0^T C(t)dt=(1-\exp(-\lambda T))/\lambda$ for $T=45 \text{ min}$. Illustrative orientation factors η are 1.0 for exposed upward-facing, 0.35 for vertical, 0.12 for downward-facing and 0.04 for recessed surfaces; normalized deposition equals $\eta \times I(45)$. The orientation factors are illustrative, not measured coefficients from [1].

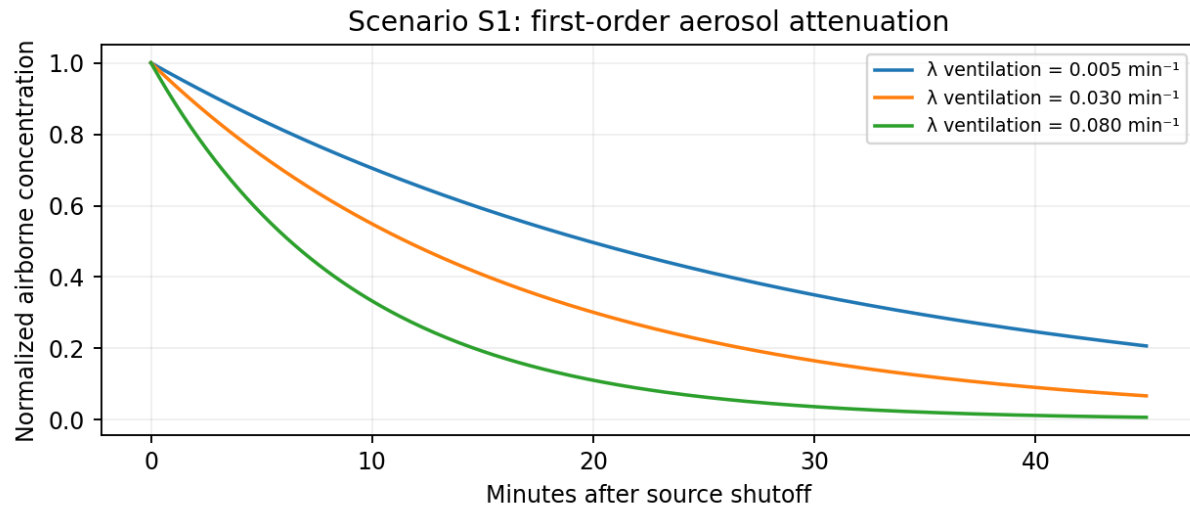


Figure 1. Purely synthetic aerosol-concentration curves using declared first-order removal coefficients; not CFD or field measurements.

Ventilation loss min ⁻¹	Upward index	Vertical index	Downward index	Recessed index
0.005	22.66	7.93	2.72	0.91
0.030	15.55	5.44	1.87	0.62
0.080	9.03	3.16	1.08	0.36

The model demonstrates that raising ventilation loss decreases integrated airborne exposure in this specific source-off model and that highly shielded surfaces can receive only a small fraction of the exposure received by an exposed upward-facing reference. Real-world operation may involve active generation, recirculation, turbulent eddies and treatment-specific reaction losses, so numerical results must not be used as engineering design recommendations.

8.2 Stage-resolved hypothetical arthropod persistence

A second independent synthetic scenario allocates an arbitrary 1,000 initial units to eggs 350, larvae 250, nymphs 220 and adults 180. Hypothetical stage-specific fractional effects of phase A are 0.18, 0.46, 0.52 and 0.56; those of phase B are 0.26, 0.48, 0.57 and 0.60. Under conditional independence, zero recruitment and full accessibility, $N_{\text{after}} = N_{\text{initial}}(1-r_A)(1-r_B)$. These assumptions are neither validated nor biologically universal. The scenario intentionally omits mechanistic synergy and stochastic uncertainty.

Stage	Initial synthetic units	Hypothetical A	Hypothetical B	Modelled remainder
Eggs	350	18%	26%	212.4
Larvae	250	46%	48%	70.2
Nymphs	220	52%	57%	45.4
Adults	180	56%	60%	31.7

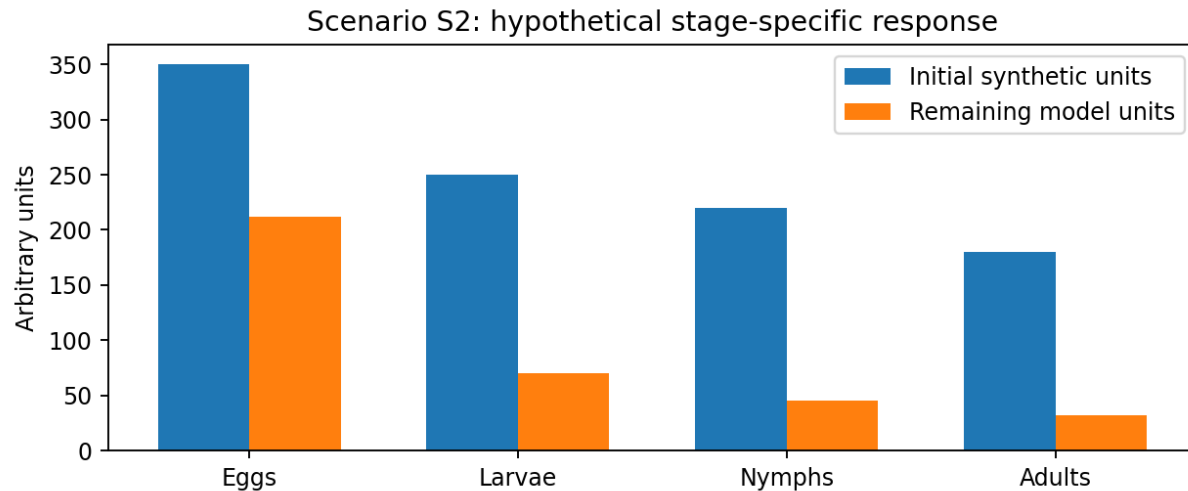


Figure 2. Hypothetical counts produced by multiplication of stated assumed effects. No empirical ovicidal, larvicidal or acaricidal inference is permitted.

The assumed aggregate model outcome is 359.7 residual units out of 1,000, equivalent to an arithmetic 64.0% modeled reduction. This percentage is not experimental evidence and must never be used in product literature as an efficacy claim. Correlation between the phases, re-emergence from refuges and nonuniform deposition would invalidate the simple independence calculation.

8.3 Sensitivity, model falsifiability and future CFD

A validated programme should vary droplet-size distribution, volumetric air exchange, relative humidity, ambient and surface temperature, loading density, generator placement and occlusion. CFD, if undertaken, should document turbulence model, mesh sensitivity, wall boundary conditions, droplet evaporation and deposition submodels, and residual errors against traceable spatial tracer measurements. Performance must be evaluated across the worst-accessible sites, rather than only room mean values. An experiment that rejects a uniformity or biological-effect hypothesis is informative and must remain reportable.

9. Industrial experimental programme

9.1 Phase 0: process definition and hazardous-area review

Define facilities as bounded zones with site plans, equipment, exposed substrates, food-contact surfaces, water systems, air handling and livestock movement. Categorize ordinary, intensive, extensive and organic operations separately. In open-sided or extensive facilities, enclosing and treating a bounded substructure is more plausible than claiming a stable airborne treatment for pasture, soil or open air. Conduct chemical, thermal, electrical, aerosol, corrosion, feed contamination and worker/animal exposure reviews before any pilot. Proprietary composition can be maintained in a protected regulatory dossier while public descriptions use independent analytical fingerprints and neutral product codes.

9.2 Phase 1: engineering qualification

Measure generator repeatability and droplet size at the outlet and representative room positions; use nonhazardous deposition tracers, surface coupons at multiple heights and orientations, mass balance and replicated runs. Report deposition distributions, sample recovery, background, spatial coefficient of variation and predefined worst-case sites. Retain all deviations. If treatment medium chemistry changes on aerosolization, independently profile outlet and deposited material without disclosing manufacturing know-how.

9.3 Phase 2: microbiological efficacy

Use relevant EN 17272 testing where applicable, plus plant-specific nonporous carriers inoculated with selected challenge organisms or surrogates justified by risk analysis. Apply neutralizer validation and calculate log10 reduction as $\log_{10}(\text{control recovered CFU}) - \log_{10}(\text{treated recovered CFU})$, with censoring where the detection limit is reached. Include routine

swabs/ATP only as operational supplements, not replacements for pathogen-specific challenge tests. Repeat after defined cleaning and soiling conditions, and audit environmental monitoring trends.

9.4 Phase 3: acarology and ovidal proof

For each identified arthropod species, use field-derived and laboratory-confirmed populations when feasible. Randomize structures or compartments to control, A, B and A→B, with blinding of counting and independent specification of sample size. Stage-specific outcomes: egg hatch proportion over a complete observed incubation period; larval/nymphal/adult survival; viable emergence; shelter recolonization; and infestation pressure at prespecified follow-up intervals. Analyze as binomial, negative-binomial or survival endpoints according to distributions and hierarchical clustering; do not confuse the animal with the facility as the randomization unit. Measure humidity and refugial exposure because these can explain heterogeneity [10–13].

9.5 Phase 4: cross-site validation and quality assurance

Run independent seasonal sites with prospective protocols and preserved raw datasets. Predefine primary estimands, multiplicity management, material compatibility, maintenance requirements and re-entry criteria. Document operator safety and residue transfer to food/feed-contact surfaces. Independent audits must inspect deviations and adverse events as closely as favourable results. Publish anonymized datasets and methods sufficient to assess causality while withholding identities, formulation and plant-specific security configurations.

Gate	Minimum evidence	Decision rule
G0 Safety/legality	Exposure assessment, permitted intended use, site controls	No trial absent acceptable documented safety and legal position
G1 Delivery	Spatial tracer data and source characterization	Advance only if predefined critical surfaces are reached
G2 Microbiology	Controlled carrier test with neutralization	Target-specific result; never extrapolate to pests
G3 Arthropods	Stage-specific factorial controlled trial	Each claimed taxon and stage validated independently
G4 Industrial transfer	Replicated sites, seasons, operators	Publish uncertainty and failures as well as successes

10. Governance, safety and European law

Regulation (EU) No 528/2012 (BPR) determines the conditions for placing biocidal products on the European market and their uses, including product-type 2 for specified surface and environmental disinfection, product-type 3 for veterinary hygiene including animal housing, and product-type 4 for food/feed areas. A product with intended pest-control action may implicate other BPR product types, including PT18 for insecticides, acaricides and products to control other arthropods. Classification follows intended function, substances and claims that are familiar to certain conventional and proposed alternative names do not automatically remove a pest-control use from regulation [7].

Food-processing facilities must also address hygiene systems under applicable food-law requirements, and occupational chemical agents duties. Organic animal production entails additional use restrictions under Regulation (EU) 2018/848 and its applicable implementing measures, including Regulation (EU) 2021/1165 and subsequent amendments [8,9]. These rules require use-specific assessment rather than assuming mineral origin establishes organic compliance. Any intended physical or chemical action against livestock arthropods must be assessed for classification and approval independently of its performance in microbiological cleaning.

Neither a food-grade constituent nor an environmental treatment medium is automatically safe for inhalation as droplets. Equipment compatibility, respirable aerosol, deposition on feed and drinkers, corrosivity, runoff, residual wetness, animal re-entry, bystander exposure and environmental releases are operationally critical. No dosage, contact interval, ventilation plan or re-entry time is recommended here because such values depend on the exact validated process and authorization conditions.

11. Discussion

The strongest evidence currently lies in the physical feasibility of distributing aerosolized liquids and in particular controlled antimicrobial surface outcomes. The weakest is any inferred cross-kingdom extension from tested bacteria to arthropod eggs or ticks. The geometry of the facility is an effect modifier, not a nuisance covariate; showing a fog entering a room is not sufficient to prove it enters a refuge. Facility-level pest suppression further depends on reintroduction, host movements and sanitation practices. A claims ladder should therefore differentiate aerosol generation, deposition, microorganism-specific inactivation, organism-specific ovicidal efficacy, operational durability and regulatory authorization. These are distinct propositions.

It would also be inaccurate to represent an industrial implementation known only through confidential operational communications as an independently documented case study. Public operator materials could corroborate that a system exists and that selected microbiological outcomes are reported, but without accessible protocols, comparator groups, species confirmation and raw datasets they cannot support quantified universal efficacy. This manuscript makes no customer-specific efficacy claims, does not identify a facility indirectly and does not disclose formulation, concentration, process settings or trade secrets.

12. Limitations

The literature assessment is targeted rather than systematic, so publication and selection bias are possible. Full paywalled datasets were not reconstructed. The synthetic transport model assumes spatial mixing and constant first-order removal, while the arthropod model assumes independent effects and no reproduction or migration; neither is calibrated. No original industrial field dataset or safety dossier is included, so the paper cannot claim experimentally established success for a confidential platform. These limits are precisely why the proposed validation hierarchy is essential.

13. Conclusions

FIP is best understood as a coupled aerosol engineering and environmental intervention architecture rather than a guarantee of sanitation. Reproducible facility-scale success requires characterization of aerosol and deposition physics, biologically valid end points, realistic worst-case surfaces, worker and animal safety, and use-specific regulatory assessment. Published food-factory evidence supports the viability of selected microbiological applications, but also documents a pronounced orientation limitation. Translating FIP to mite and tick populations—including eggs, larvae, nymphs and adults—remains a credible research programme, not a demonstrated generalized outcome. A publishable industry evidence base can be built without naming customers or disclosing protected manufacturing know-how.

Declarations

Article type: Critical narrative review and methodological perspective incorporating original synthetic modelling. No clinical, veterinary or industrial intervention study involving living subjects was undertaken for this manuscript. **Data availability:** all synthetic inputs and equations are explicitly stated in Section 8; no confidential datasets are reproduced. **Competing interests:** the author has professional affiliations with industrial biotechnology and ingredient-development activities; the present paper deliberately contains no brand or proprietary commercial claims. **Funding:** No independent external grant is claimed. **Ethical approval:** Not applicable to the synthetic calculations and literature review. **Statement of evidentiary integrity:** all simulated figures and values are made under AI -driven modelling parameters and engineered software, so those should be treated as merely hypothetical and are not observations.

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Appendix A. Transparent reproducibility specification

Synthetic aerosol curves: for t from 0 to 45 minutes, sampled at 250 uniformly spaced points, compute $C(t) = \exp[-(0.020 + 0.010\lambda_v)t]$, for $\lambda_v \in \{0.005, 0.030, 0.080\} \text{ min}^{-1}$. Deposition index by location: $I_i = \eta_i [1 - \exp(-(0.030 + \lambda_v)45)] / (0.030 + \lambda_v)$, with $\eta_i \in \{1, 0.35, 0.12, 0.04\}$. No random numbers or experimental parameters are used. Arthropod scenario: $N = (350, 250, 220, 180)$, $r_A = (.18, .46, .52, .56)$, $r_B = (.26, .48, .57, .60)$; compute $N \times (1 - r_A) \times (1 - r_B)$ componentwise. Inputs are illustrative and may be freely altered by readers for sensitivity analysis.

Appendix B. Proposed anonymized industrial data dictionary

Field	Type / reporting logic
Facility code	Nonidentifying arbitrary site ID; exclude site location
Surface stratum	Upward / vertical / downward / shielded / porous
Aerosol characterization	Distribution summary and validated analytical descriptors
Environmental context	Air exchange category; temperature and RH as approved bins
Microbiology	Organism, matrix, controlled baseline, log reduction, detection limit
Arthropod efficacy	Species, eggs/larvae/nymphs/adults, survival and follow-up
Controls	Positive, negative, untreated and procedure blanks
Safety	Incident classification, anonymized exposure findings
Compliance	Territory, intended use and evidence of applicable approval

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