SCIENTIFIC PERSPECTIVE & TRANSLATIONAL REVIEW

Designing Pesticide-Minimised Infant Diets from the Raw-Material Stage

A source-control framework for early-life food safety and the potential role of bicarbonate-based mineral pest-management technologies ACARISIN™ and ECO-EFF™

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Central thesis. The scientifically defensible value of ACARISIN™/ECO-EFF™ is the possibility of making defined conventional pesticide interventions unnecessary. Because the formulations retain a bicarbonate-based mineral architecture and use proprietary processing to enhance performance rather than to create a new pesticidal molecule, the established EU regulatory and toxicological precedent for sodium hydrogen carbonate is directly relevant to their assessment, subject to product specification, intended use and applicable authorisation requirements.

Abstract

Infants and young children are subject to unusually stringent pesticide-residue protection because early life combines high food intake relative to body weight, restricted dietary diversity and continuing physiological development. This precautionary architecture should not be misrepresented as evidence that modern infant foods are generally unsafe: European Union (EU) monitoring for 2024 found no quantified residues in 83.4% of 1,546 samples of foods for infants and young children and classified 0.9% as non-compliant after measurement uncertainty, while a 2023–2025 U.S. Food and Drug Administration market-basket survey detected no pesticide in 99% of 312 infant-formula samples tested for 318 pesticides. The opportunity for improvement therefore lies not in alarmism but in prevention of avoidable chemical inputs. This article develops a source-control model for cereals and other durable raw materials used directly or indirectly in infant diets. Stored-product insects and mites remain important causes of quantitative and qualitative loss, and their control frequently relies on fumigants or residual insecticides. Mineral and inert technologies provide an established alternative or complementary mode of action within integrated pest management

(IPM), although performance is formulation-, commodity-, pest- and environment-specific. ACARISIN™ and ECO-EFF™ are considered as proprietary bicarbonate-based mineral systems in which the underlying mineral structure is retained while processing is intended to reinforce functional performance. This distinction is materially relevant in the EU because sodium hydrogen carbonate (CAS 144-55-8) is approved both as a basic substance and as a low-risk active substance under Regulation (EC) No 1107/2009 and is expressly permitted for plant protection in organic production under the current implementing rules. The article proposes three translational constructs—Infant-Safe Raw Material Design (ISRMD), a Pesticide Exposure Budget (PEB), and an Avoided Pesticide Treatment Index (APTI)—and a multicentre non-inferiority/pesticide-displacement validation programme. The central hypothesis is falsifiable: where a bicarbonate-based mineral system provides non-inferior pest control and replaces a conventional pesticide intervention, the treatment-derived pesticide input and associated residue potential are prevented by design. This proposition requires product-specific analytical, efficacy, occupational-safety, technological and regulatory validation but offers a rigorous pathway from residue compliance to exposure prevention.

Keywords: *infant nutrition; pesticide residues; sodium hydrogen carbonate; bicarbonate; ACARISIN; ECO-EFF; integrated pest management; stored-product insects; raw-material safety; low-risk active substance; organic production; pesticide displacement; exposure prevention*.

Highlights

- EU 2024 monitoring shows high compliance in foods for infants and young children; the rationale for further pesticide reduction is continuous improvement, not a claim of generalised danger.
- Sodium hydrogen carbonate has an unusually strong EU regulatory precedent: food character/basic-substance recognition (2015), low-risk active-substance approval (2020), and express inclusion for organic plant protection (2023).
- As ACARISIN™/ECO-EFF™ preserve the bicarbonate-based mineral identity while proprietary processing enhances performance, that regulatory and toxicological precedent is directly relevant; product/use authorisation remains a separate legal question.
- The strongest product claim is “pesticide intervention avoided”:source control should be measured against a conventional storage programme.
- The paper proposes ISRMD, PEB and APTI as testable tools for infant-food procurement, formulation and post-harvest pest-management design.

1. Introduction: From Residue Compliance to Exposure Prevention

Pesticides are biologically active tools that protect crops and stored foods against organisms capable of causing substantial loss, quality deterioration and food-safety problems. The relevant scientific discussion is therefore not whether all pesticide use is intrinsically undesirable, but whether each intervention provides a net benefit and whether a lower-hazard or non-conventional alternative can deliver equivalent protection. The World Health Organization (WHO, 2022) explicitly recognises both sides of this balance: pesticides have an important role in food production, yet their intrinsic biological activity requires strict regulation, control and residue monitoring.

This distinction is particularly important in infant nutrition. Maximum residue levels (MRLs) are enforcement limits established after toxicological and dietary-exposure assessment and good agricultural practice; detection below an MRL is not synonymous with toxicity. Conversely, regulatory compliance does not preclude technological optimisation. Where a chemical treatment can be safely and reliably avoided, the absence of that intervention eliminates one potential source of residue, occupational exposure, resistance selection and environmental burden.

The present paper therefore reframes the question. Instead of asking only whether the final infant food complies with a residue limit, it asks whether the raw-material chain can be designed so that avoidable pesticide interventions never occur. This is a prospective, engineering-oriented approach to chemical food safety: prevention is moved upstream to agricultural procurement, post-harvest storage and ingredient handling, while finished-product analysis remains the verification step rather than the sole control mechanism.

2. Scope, Terminology and Evidentiary Discipline

This article is a narrative scientific review, regulatory analysis and translational framework rather than a systematic review or meta-analysis. It integrates primary and authoritative sources from EFSA, the European Commission, EPA, FDA, Codex Alimentarius and WHO with peer-reviewed literature on early-life pesticide exposure, organic-diet biomonitoring, stored-product pest management, phosphine resistance and inert/mineral control technologies.

Four evidence levels are deliberately separated. First, there are established regulatory facts concerning sodium hydrogen carbonate. Second, there is class-level evidence for mineral and inert pest-management systems. Third, there are product-specific facts concerning the bicarbonate-based architecture and proprietary processing of ACARISIN™/ECO-EFF™. Fourth, there are product-specific outcome claims—such as displacement of a conventional insecticide programme—that must be demonstrated experimentally. Conflating these levels would weaken the paper; separating them creates a falsifiable and regulatorily defensible argument.

Throughout the manuscript, “pesticide minimisation” means reduction of avoidable pesticide interventions and/or treatment-derived residues without compromising pest control, microbiological safety, nutritional quality, technological performance, affordability or food security. It does not mean indiscriminate elimination of all pesticides, nor does it imply that trace compliant residues are unsafe.

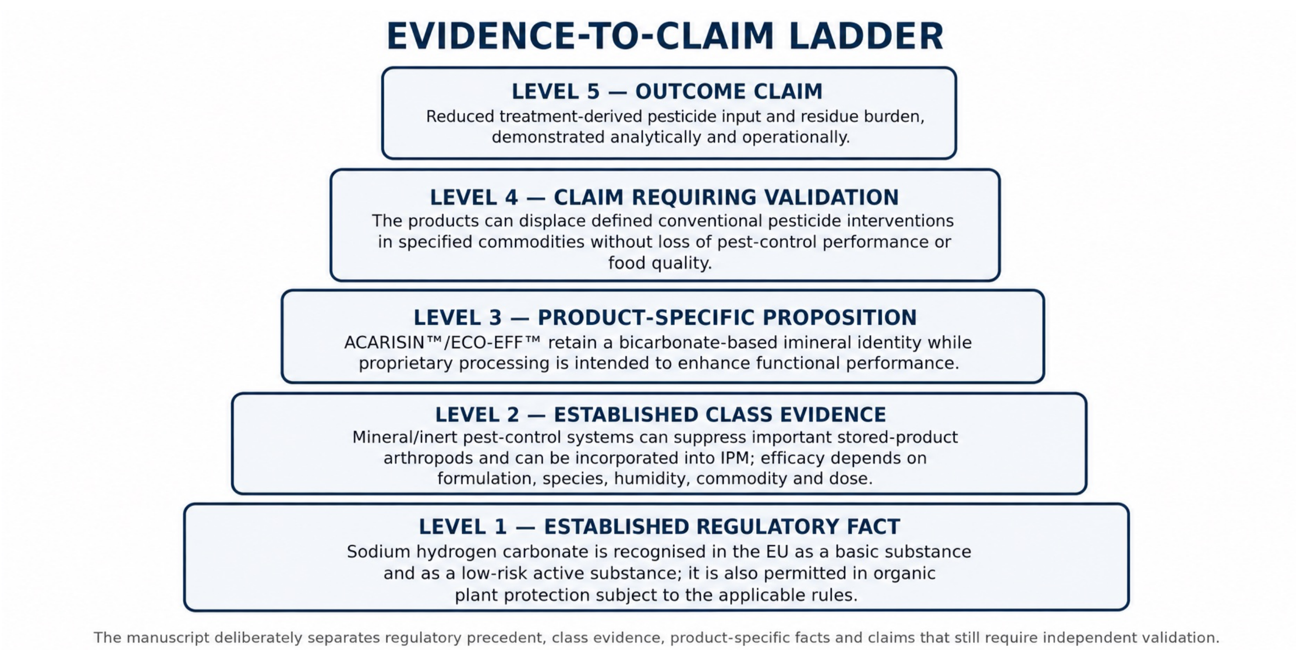

Figure 1. Evidence-to-claim ladder used in this article. Regulatory precedent and class evidence support plausibility; product-specific displacement and residue outcomes require dedicated validation.

3. Why Early-Life Dietary Exposure Deserves Special Attention

3.1 Developmental physiology and exposure patterns

Infants are not simply small adults. Gastrointestinal function, renal clearance, hepatic enzyme systems, body composition, immune regulation and neurological development change rapidly during the first months and years of life. Sensitivity is pesticide-specific rather than universal; nevertheless, the combination of developmental windows and distinctive exposure patterns justifies dedicated assessment. EFSA's scientific opinion on pesticides in foods for infants and young children concluded that the conventional toxicological approach requires particular care for infants below 16 weeks and evaluated the adequacy of health-based guidance values for this age group (EFSA Panel on Plant Protection Products and their Residues [PPR Panel], 2018).

Food intake per kilogram body weight is also high in early life. EFSA used high infant-formula consumption around 260 g/kg body weight/day in its assessment. A concentration of 0.01 mg/kg in a food consumed at 0.260 kg/kg body weight/day corresponds arithmetically to 0.0026 mg/kg body weight/day. This simple calculation illustrates why residue limits that appear extremely low on a food-concentration basis still warrant careful toxicological interpretation when the consumer is very small and intake per kilogram is high.

Restricted dietary diversity is another relevant feature. During complementary feeding, cereals, milk-based products, fruits and vegetables can account for a substantial proportion of total intake. Repeated exposure from a narrow ingredient set may therefore matter more than in a diverse adult diet, even though risk must still be assessed substance by substance and against appropriate health-based guidance values.

3.2 Developmental toxicology without alarmism

Epidemiological literature has reported associations between some prenatal or childhood pesticide exposures and neurodevelopmental outcomes. A systematic review of organophosphate exposure identified consistent signals across several neurobehavioural domains but also substantial heterogeneity in exposure measurement and outcome assessment (Muñoz-Quezada et al., 2013). A newer systematic review of postnatal exposure to current-use pesticides similarly found heterogeneous associations and emphasised the need for longitudinal, mixture-aware studies with stronger exposure characterisation (Viglietti et al., 2026).

These studies do not demonstrate that trace residues below legal limits in compliant infant foods cause neurodevelopmental disease. The correct inference is narrower: developmental windows can be toxicologically important, and avoidable exposure reduction is a legitimate risk-optimisation objective. The manuscript therefore rejects both complacency and chemophobia.

4. What Contemporary Surveillance Actually Shows

4.1 European Union: 2024 infant and young-child food data

The latest comprehensive EFSA report is reassuring. In 2024, reporting countries analysed 1,546 samples of foods for infants and young children. Of these, 1,290 samples (83.4%) contained no quantified residue, 227 (14.7%) contained residues at or above the analytical LOQ but at or below the applicable MRL, 29 (1.9%) exceeded an MRL, and 14 samples (0.9%) were ultimately classified as non-compliant after measurement uncertainty was considered (EFSA et al., 2026).

2024 EU infant/young-child food result	Samples	Share
No quantified residues	1,290	83.4%
Quantified ≥ LOQ but ≤ MRL	227	14.7%
MRL exceedance	29	1.9%
Non-compliant after measurement uncertainty	14	0.9%

Table 1. EFSA 2024 results for 1,546 samples of foods for infants and young children (EFSA et al., 2026).

The 14.7% quantification rate should not be interpreted as 14.7% conventional pesticide contamination. EFSA reported that the increase was largely driven by copper; fosetyl/phosphonate-related residues and chlorate were also prominent. Copper has nutritional and agricultural uses, while chlorate can arise from sanitation processes. Glyphosate was analysed in 429 infant/young-child food samples and all results were below the LOQ (EFSA et al., 2026).

Across the broader EU monitoring programme, EFSA concluded that estimated acute and chronic dietary risk remained low for most assessed substances and population groups. A pesticide-minimisation strategy is therefore a quality-improvement proposition layered on top of an already protective regulatory system, not evidence that the system has failed.

4.2 United States: recent infant-formula testing

FDA's 2023–2025 market-basket survey tested 312 infant-formula samples across 16 brands and multiple lots for 318 pesticides. No pesticide was detected in 309 samples (99%); glyphosate and glufosinate were not detected in any sample. Only three samples had detectable pesticide-related substances, each at very low concentrations (U.S. Food and Drug Administration [FDA], 2026).

This U.S. dataset further reinforces the central premise: the scientific case for ACARISIN™/ECO-EFF™ should not depend on portraying infant formula as a major pesticide-residue problem. The opportunity lies upstream, particularly in raw materials for complementary foods and in the progressive family diet where conventional commodities increasingly dominate exposure.

5. Regulatory Architecture: EU, United States and Codex

System	Regulatory architecture	Infant/child principle	Source-control implication
European Union	Infant-food-specific residue rules plus general MRL law	Default 0.01 mg/kg per active substance for infant formula/follow-on formula and processed cereal-based baby foods, with stricter provisions for selected substances	Raw-material qualification and treatment history are central because finished foods must meet exceptionally low residue specifications.
United States	EPA pesticide/crop tolerances under FFDCA as amended by FQPA	"Reasonable certainty of no harm"; aggregate exposure and special risks to infants/children are explicitly considered; additional 10× factor unless data justify another factor	No single universal baby-food MRL; prevention complements pesticide-specific tolerance and risk assessment.
Codex Alimentarius	International standard supported by JMPR risk assessment	Infant formula should be prepared so pesticide residues required during production, storage or processing do not remain or are reduced to the maximum extent technically possible	Direct conceptual support for minimising storage-derived pesticide inputs where technically feasible.

Table 2. Comparison of the principal regulatory logics relevant to pesticide residues in infant foods.

5.1 European Union infant-food MRLs

Commission Delegated Regulation (EU) 2016/127 establishes that infant formula and follow-on formula shall not contain residues of individual pesticides exceeding 0.01 mg/kg, subject to specific exceptions and more restrictive provisions for selected active substances. Directive 2006/125/EC applies the same general 0.01 mg/kg approach to processed cereal-based foods and baby foods. The legislation is explicitly designed around very low residues and makes raw-material selection an essential control point (European Commission, 2006, 2016).

These limits are not equivalent to generic MRLs for many adult foods and should not be interpreted as an assertion that 0.011 mg/kg is intrinsically toxic while 0.009 mg/kg is safe. They are deliberately conservative product-specific regulatory limits for a vulnerable population.

5.2 United States: FQPA and the "reasonable certainty of no harm" standard

Under section 408 of the Federal Food, Drug, and Cosmetic Act, EPA sets tolerances for pesticide residues and must determine that aggregate exposure provides a "reasonable certainty of no harm." The assessment expressly considers toxicity, dietary and other exposure pathways and special risks to infants and children (U.S. Environmental Protection Agency [EPA], 2026a).

FQPA also introduced an additional tenfold safety factor for infants and children unless reliable evidence supports a different factor (EPA, 2026b). This framework is pesticide-specific rather than based on a universal infant-food MRL, but its underlying principle is analogous: early-life exposure deserves explicit, conservative consideration.

5.3 Codex: the importance of storage and processing

Codex CXS 72-1981 is especially pertinent to the present thesis because it extends the pesticide-residue principle beyond field production. The standard requires infant formula to be prepared with special care under good manufacturing practices so that residues of pesticides required in the production, storage or processing of raw materials or finished ingredients do not remain, or, where technically unavoidable, are reduced to the maximum extent possible (Codex Alimentarius Commission, 1981/2024). In conceptual terms, this is already a source-control mandate.

6. Dietary Pesticide Exposure Is Modifiable

Controlled dietary-intervention studies provide useful mechanistic evidence that food choices can materially alter internal pesticide exposure. Lu et al. (2006) replaced most conventional foods in 23 children with organic alternatives for five days and observed rapid reductions in urinary metabolites associated with malathion and chlorpyrifos, with concentrations returning after conventional foods were reintroduced. Bradman et al. (2015) likewise reported reductions in several pesticide biomarkers during an organic-diet phase in young children. Hyland et al. (2019) extended these observations to several pesticide classes in children and adults, reporting significant reductions in multiple urinary pesticide metabolites or parent compounds after an organic dietary intervention.

These studies do not prove that organic diets improve clinical outcomes, nor do they demonstrate that every conventional pesticide exposure is harmful. Their relevance here is narrower and robust: dietary pesticide exposure is modifiable. A source-control strategy simply moves that modification further upstream—from consumer purchasing to agricultural and post-harvest process design.

7. Stored Raw Materials as a Critical Control Point

Cereals, pulses, seeds, flours, cocoa-derived materials, nuts, dried fruits and other durable ingredients can remain in storage for months. Stored-product insects and mites can cause direct mass loss, kernel damage, contamination with fragments and excreta, heating, moisture redistribution, loss of technological quality and facilitation of fungal deterioration. Relevant pests include Sitophilus spp., Rhyzopertha dominica, Tribolium spp., Oryzaephilus spp., Cryptolestes spp., Trogoderma spp., Plodia interpunctella and storage mites such as Tyrophagus putrescentiae.

The legitimate objective is therefore not “no pest control”. It is equivalent or superior protection with the lowest overall toxicological, occupational, environmental and resistance burden. This is the classic domain of integrated pest management (IPM): sanitation, exclusion, monitoring, temperature and moisture management, physical control, mineral/inert technologies, controlled atmospheres, biological tools and—where necessary—authorised conventional pesticides or fumigants.

8. Why Alternatives to Conventional Stored-Product Insecticides Matter

Phosphine remains one of the world’s most important stored-product fumigants because of its low cost, broad efficacy, penetration and compatibility with many storage systems. It should not be dismissed as obsolete. However, resistance has become a major global constraint. Nayak et al. (2020) reviewed the increasing prevalence and severity of phosphine resistance, while a later global meta-analysis confirmed extensive resistance across major stored-product pest species (Machuca-Mesa et al., 2024).

Diversification of control mechanisms is therefore a resistance-management objective as well as a residue-minimisation objective. Physical and physicochemical technologies exert different selection pressures from conventional target-site insecticides and can reduce dependence on a narrow set of chemical modes of action.

9. Mineral and Inert Pest-Control Technologies: Scientific Basis

The scientific basis for mineral and inert materials in stored-product protection is well established as a technological class. Diatomaceous earths and related mineral materials can act through adsorption of epicuticular lipids, cuticular disruption, abrasion and enhanced transcuticular water loss, leading to desiccation and population suppression. Their activity is predominantly physical/physicochemical rather than classical neurotoxicity (Guru et al., 2022; Athanassiou et al., 2025).

Semi-field trials have demonstrated prolonged suppression of several major stored-product insect species. Rigopoulou et al. (2023) showed that diatomaceous earth applied to hard wheat suppressed both artificially introduced and naturally occurring stored-product insects for four months under fluctuating environmental conditions, although grain bulk density was affected. Mortazavi et al. (2025) reported strong long-term suppression of Sitophilus granarius, Rhyzopertha dominica and Tribolium confusum in wheat treated with a commercial diatomaceous-earth product for up to one year under the tested conditions.

This class evidence is relevant but cannot be used as direct proof for ACARISIN™/ECO-EFF™. Mineral formulations differ in chemistry, surface characteristics, particle-size distribution, dose, carrier system and environmental behaviour. Humidity, temperature, commodity and pest species can materially influence performance (Athanassiou et al., 2025).

10. ACARISIN™ and ECO-EFF™: From "New Pesticide" to Technologically Reinforced Mineral System

Public technical documentation describes ACARISIN™ as a technologically processed formulation based on authorised food-grade mineral ingredients, with proprietary ***Single Grain Fusion Technology*** as a central manufacturing feature (ND Pharma & Biotech, 2025a). Historical technical documentation identifies a sodium hydrogen carbonate-based composition together with mineral components and an anti-caking fraction, and describes purification, crystallisation and proprietary processing steps (ND Pharma & Biotech, 2014). ECO-EFF™ is presented as a related, reinforced formulation intended to provide enhanced persistence and functional performance under more demanding environmental conditions (ND Pharma & Biotech, 2025b).

The key scientific clarification supplied for this paper is that the proprietary process does not seek to create a novel pesticidal molecule: the underlying bicarbonate-based mineral structure is maintained while the process reinforces functional performance. This distinction matters because the regulatory question becomes one of continuity of active-substance identity/specification and product/use authorisation rather than automatic classification as a chemically unrelated active substance.

Accordingly, this article uses the term "bicarbonate-based mineral system" rather than implying a new synthetic pesticide chemistry. The strongest mechanistic proposition is that proprietary processing modifies the performance of a recognised mineral platform—potentially through particle, surface, matrix, dispersion, persistence or interaction characteristics—while preserving the underlying mineral identity. Any more specific mechanistic claim can be supported by analytical and physicochemical data, and specific features of formulated product are well described in public information released by the producer.

11. The EU Regulatory Position of Sodium Hydrogen Carbonate and Why It Is Directly Relevant

11.1 Basic substance recognition

Commission Implementing Regulation (EU) 2015/2069 approved sodium hydrogen carbonate (CAS 144-55-8) as a basic substance under Regulation (EC) No 1107/2009. The Commission expressly noted that the substance fulfils the criteria of a foodstuff under Regulation (EC) No 178/2002, is not predominantly used for plant-protection purposes, and is nevertheless useful in plant protection (European Commission, 2015). This is a particularly important precedent because it formally reconciles food character with plant-protection functionality.

11.2 Low-risk active-substance approval

Commission Implementing Regulation (EU) 2020/1263 subsequently approved sodium hydrogen carbonate as a low-risk active substance. The Commission stated that it is not a substance of concern and fulfils the low-risk criteria in Annex II to Regulation (EC) No 1107/2009 (European Commission, 2020). This provides a second and distinct regulatory pathway in which the substance is recognised not merely as a basic substance but as an approved low-risk active substance in plant protection.

11.3 Organic production

The relevance extends to organic production. Commission Implementing Regulation (EU) 2023/2229 recorded that sodium hydrogen carbonate was already listed as a basic substance usable in organic production and added that, because it is also a low-risk substance under Regulation (EC) No 1107/2009, it should likewise be authorised as a low-risk substance for plant protection in organic production (European

Commission, 2023). The consolidated Annex to Implementing Regulation (EU) 2021/1165 lists sodium hydrogen carbonate (CAS 144-55-8) among low-risk active substances permitted for organic plant protection subject to the applicable conditions.

11.4 Continuity of identity after a proprietary manufacturing process

The existence of proprietary processing does not, by itself, mean that the active substance becomes a new chemical entity. Article 29(1)(b) of Regulation (EC) No 1107/2009 expressly contemplates an active substance produced by a different source or by the same source with a change in manufacturing process and/or manufacturing location. The relevant questions include whether the resulting specification deviates significantly from the approved specification and whether impurities generated by the changed process create additional harmful effects (European Parliament & Council, 2009).

This provision is highly relevant to ACARISIN™/ECO-EFF™ as analytical characterisation confirms that the proprietary process preserves the sodium hydrogen carbonate identity and relevant purity/specification while enhancing functional properties. Under that factual premise, the regulatory and toxicological history of sodium hydrogen carbonate is not merely analogous; it becomes directly pertinent to the assessment of the active mineral basis.

A separate legal question remains, mean that approval of an active substance is not identical to authorisation of every formulated plant-protection product, claim, target organism, application pattern or jurisdictional use. The paper therefore distinguishes (a) continuity of active-substance identity and the transferability of the existing low-risk/basic-substance scientific precedent from (b) the specific legal route required for the proprietary product and intended use. This is not a retreat from the regulatory argument; it is the distinction that makes the argument legally durable.

Regulatory fact	Legal significance for bicarbonate-based ACARISIN™/ECO-EFF™ assessment	What requires verification
2015: sodium hydrogen carbonate approved as an EU basic substance	Formal recognition that a foodstuff can perform a plant-protection function.	Whether a proposed use falls within the basic-substance route and its conditions.
2020: approved as a low-risk active substance	Strong toxicological/regulatory precedent for the active mineral itself.	Product specification, impurities, formulation and product authorisation where applicable.
2023: expressly authorised as a low-risk substance for organic plant protection	Supports compatibility of the active mineral with organic-production rules under specified legal conditions.	Certification/authorisation of the particular product and use; compliance with organic rules and national implementation.
Reg. 1107/2009 Art. 29 recognises changed manufacturing processes	A proprietary process need not imply a new active substance if specification continuity and impurity safety are demonstrated.	Analytical proof that the modified process preserves the relevant identity/specification and introduces no additional harmful impurity profile.

Table 3. Regulatory continuity argument for a sodium-hydrogen-carbonate-based proprietary mineral system.

12. Food-Grade Status, Oral Safety and the Limits of Extrapolation

Food-grade status is scientifically valuable but should not be overextended. Oral safety of an ingredient does not automatically determine occupational inhalation safety, environmental behaviour or legal classification when the same material is intentionally used for pest control. Particle-size distribution, dustiness, impurities, application method and exposure route all matter.

Where silicon dioxide (E551) or other food-grade mineral components are present, the relevant specifications should be considered individually. EFSA's 2024 re-evaluation of silicon dioxide concluded that authorised food-additive uses did not raise a safety concern at reported use levels, including the assessed infant context, while also recommending tighter control of certain impurities and addressing remaining uncertainties regarding nanoscale fractions (EFSA Panel on Food Additives and Flavourings [FAF Panel], 2024). The lesson is methodological: “food grade” supports safety assessment, but exact specification and exposure remain essential.

For a publication focused on infant-food raw materials, the product dossier should therefore include at minimum active-mineral assay, identity, particle-size distribution, crystalline-silica characterisation where relevant, arsenic, lead, cadmium, mercury and other appropriate impurities, microbiological criteria, dustiness and evidence that proprietary processing does not generate new toxicologically significant reaction products.

13. What ACARISIN™/ECO-EFF™ Can Legitimately Be Claimed to Do

Claim category	Scientifically defensible formulation	Status
Composition/technology	Bicarbonate-based mineral systems whose underlying mineral structure is maintained while proprietary processing is intended to enhance functional performance.	Product-specific fact to document analytically.
Regulatory relevance	EU basic-substance and low-risk active-substance precedent for sodium hydrogen carbonate is directly relevant where identity/specification continuity is demonstrated.	Strong regulatory-scientific argument.
Pesticide reduction	May reduce or replace selected conventional pesticide interventions where equivalent pest control is demonstrated.	Testable product-specific claim.
Residue prevention	A displaced conventional pesticide treatment cannot generate its treatment-derived residue.	Logical consequence.
Pesticide removal	Removes pesticide residues already present in the commodity.	Not supported unless specific degradation/adsorption studies demonstrate it.
“Pesticide-free” finished food	Guarantees absence of all pesticide residues, in certain conditions of production and control.	Only supportable if pesticides are absent all along the production process as far as residues may originate upstream, from drift, transport or cross-contamination.
Universal organic status	Automatically authorised for all organic uses worldwide.	Not supportable; product/use and jurisdiction-specific rules remain relevant.

Table 4. Claim discipline for scientific publication and B2B communication.

14. The Core Mechanistic Proposition: Pesticide Avoidance, Not Pesticide Removal

The decisive conceptual advantage of a mineral substitution strategy is causal simplicity. If a conventional insecticide or fumigant application does not occur because an alternative programme provides adequate control, residues attributable to that treatment are not introduced. This does not require claiming that the alternative product detoxifies or removes residues from previous agricultural treatments.

This distinction also protects the article from an unnecessary burden of proof. Demonstrating removal of hundreds of possible pesticide molecules would be chemically and analytically complex. Demonstrating displacement of a defined storage treatment is operationally tractable: compare treatment records, active substance used per tonne, pest-control outcomes and terminal residue fingerprints between reference and mineral/IPM programmes.

15. Proposed Framework I: Infant-Safe Raw Material Design (ISRMD)

Infant-Safe Raw Material Design (ISRMD) is proposed as a six-layer supply-chain architecture in which contaminant prevention is built into raw-material design rather than left solely to finished-product testing. The framework does not replace HACCP, supplier assurance or statutory residue monitoring; it connects those systems around an explicit exposure-prevention objective.

Layer 1 — Agricultural design: prioritise agronomic practices and suppliers that minimise unnecessary pesticide use while preserving crop safety and yield.

Layer 2 — Treatment-history qualification: obtain documented active-substance, fumigation and storage-treatment histories.

Layer 3 — Incoming analytical qualification: apply infant-food-appropriate multiresidue specifications and targeted analyses.

Layer 4 — Post-harvest exposure prevention: deploy sanitation, environmental control, monitoring and validated mineral/physical technologies before chemical rescue treatment.

Layer 5 — Segregated logistics: prevent cross-contamination from treated commodities, transport, mills and warehouses.

Layer 6 — Finished-product verification: confirm that source-control measures translate into the intended residue and contaminant profile.

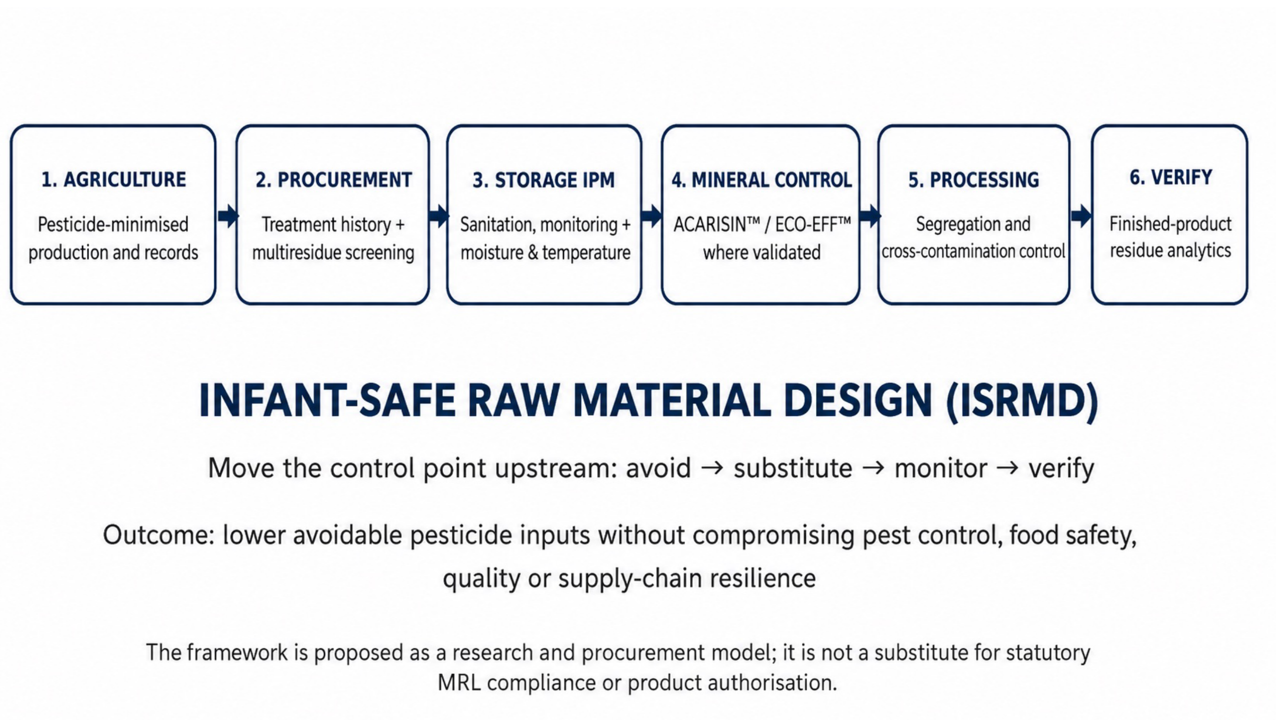

Figure 2. Infant-Safe Raw Material Design (ISRMD): a proposed source-control architecture for pesticide-minimised infant-food supply chains.

16. Proposed Framework II: Pesticide Exposure Budget (PEB)

For internal formulation and procurement optimisation, a Pesticide Exposure Budget (PEB) can complement—but never replace—statutory MRL and dietary-risk assessment. For pesticide j across n ingredients:

$$\mathbf{PEB_j = \Sigma_i \, (C_{ij} \times IR_i) \; / \; BW}$$

where C_{ij} is the concentration of pesticide j in ingredient i, IR_i is expected daily intake of ingredient i, and BW is body weight. Where an appropriate health-based guidance value (HBGV) exists, the estimated exposure can be normalised as a percentage of that HBGV. The value of the construct is practical: it allows procurement teams to distinguish two legally compliant ingredient lots that contribute very differently to a formulation's overall residue/exposure profile.

The PEB should be conservative, transparent and substance-specific. It should not imply toxicological additivity across unrelated pesticides unless a validated cumulative assessment group or common mechanism justifies such aggregation.

17. Proposed Framework III: Avoided Pesticide Treatment Index (APTI)

Finished-product analysis does not capture treatments that were successfully avoided. The Avoided Pesticide Treatment Index (APTI) is proposed to quantify chemical-intervention displacement against a defined conventional reference programme:

$$\mathbf{APTI = [(Tref - Talt) \; / \; Tref] \times 100}$$

where Tref is the number of conventional pesticide treatment events in the validated reference programme and Talt is the number required after implementation of the alternative programme. A weighted version can incorporate grams of active substance per tonne and, after methodological validation, hazard or risk weighting. Until such weighting is validated, the most transparent primary endpoints are treatment events avoided and grams of conventional active substance avoided per tonne successfully protected.

18. Proposed Industrial Validation Programme

18.1 Study objective and hypothesis

The decisive study should be a pesticide-displacement trial, not merely an insect-mortality assay. The primary hypothesis is that a storage programme incorporating ACARISIN™/ECO-EFF™ can achieve non-inferior control of predefined stored-product pests while significantly reducing conventional pesticide intervention. The null hypothesis should be that the alternative programme either fails non-inferiority for pest control or does not materially reduce conventional pesticide use.

18.2 Design

Prospective, controlled, replicated and preferably multicentre industrial or semi-industrial study.

Priority commodities: wheat, oats, rice and maize because of their relevance to complementary infant feeding and dry-storage pest risk.

Randomisation at bin, silo, pallet, lot or storage-unit level where operationally feasible.

Predefined non-inferiority margin based on commercial pest-damage thresholds, not post-hoc statistical convenience.

Sufficient follow-up to cover realistic storage duration and at least one complete pest-generation cycle under expected environmental conditions.

18.3 Experimental arms

Arm	Programme	Purpose
A	Untreated/monitoring control where ethically and operationally acceptable	Defines natural infestation dynamics and background quality change.
B	Validated conventional facility programme	Reference for pest control, active-substance input and cost.
C	ACARISIN™/ECO-EFF™ + standard sanitation/monitoring	Estimates product contribution under routine management.
D	Enhanced IPM: mineral technology + intensified monitoring + environmental control + threshold-triggered rescue treatment	Tests the full pesticide-minimisation system rather than product-only performance.

Table 5. Proposed experimental arms for a pesticide-displacement validation trial.

18.4 Target organisms and environmental covariates

A core panel should include representative primary and secondary pests such as Sitophilus oryzae/S. granarius, Rhyzopertha dominica, Tribolium castaneum, Oryzaephilus surinamensis and Cryptolestes spp.; Tyrophagus putrescentiae should be included where mites are commercially relevant. Commodity temperature, grain moisture, water activity, relative humidity, storage duration, initial infestation, aeration and treatment history should be continuously or periodically recorded and incorporated into statistical models.

18.5 Primary and secondary endpoints

Domain	Primary endpoints	Why it matters
Pest control	Live insects/kg; F1 progeny; trap captures; damaged kernels; time to control failure	Demonstrates non-inferior protection rather than short-term mortality only.
Chemical displacement	Conventional treatment events; fumigations; g active substance/t; APTI	Directly tests the central pesticide-minimisation claim.
Residues	GC-MS/MS + LC-MS/MS multiresidue profile at T0–T5	Verifies whether operational displacement translates into residue prevention.

Domain	Primary endpoints	Why it matters
Food technology	Bulk density; flowability; milling yield; colour; hydration; viscosity; sensory/reconstitution endpoints	Prevents a pest-control gain from becoming a food-quality loss.
Contaminants	Heavy metals, relevant mineral impurities, crystalline silica where applicable, microbiology and mycotoxins	Ensures that one risk is not exchanged for another.
Occupational safety	Dustiness, respirable fraction, operator exposure, PPE/engineering controls	Separates oral food safety from inhalation exposure.
Economics	Total cost/t successfully protected; cost per conventional treatment avoided	Determines commercial scalability.

Table 6. Minimum endpoint set for a credible industrial validation programme.

18.6 Residue sampling architecture

T0 — incoming raw material before storage treatment.

T1 — immediately after application of the assigned storage strategy.

T2 — intermediate storage.

T3 — end of storage.

T4 — after milling/processing.

T5 — finished infant-food prototype or representative final matrix.

This longitudinal design is important because a terminal result alone cannot distinguish residues carried into storage from residues introduced during storage. Treatment-history data and time-resolved analysis create causal attribution.

18.7 Statistical plan

Pest-control efficacy should be analysed as a non-inferiority problem. Mixed-effects models can incorporate treatment, commodity, time, temperature, humidity and initial infestation as fixed effects with facility/storage unit as random effects. Time to pest-control failure can be analysed using survival methods. Count data may require negative-binomial or zero-inflated models.

Residue datasets will contain many values below LOQ and should therefore use appropriate censored-data methods rather than assigning arbitrary zeros or half-LOQ values without sensitivity analysis. Treatment-displacement endpoints should be analysed both as event counts and as active-substance mass per tonne. A priori statistical analysis plans and blinded analytical laboratories would materially strengthen publication credibility.

19. Product Characterisation Required Before Infant-Food Positioning

Confirmed identity and assay of sodium hydrogen carbonate and other declared mineral components.

Comparison of post-process specification with relevant approved/food-grade specifications.

Impurity profile, including arsenic, lead, cadmium, mercury and other relevant inorganic contaminants.

Particle-size distribution and nano-fraction characterisation where scientifically relevant.

Crystalline-silica characterisation where applicable.

Dustiness and occupational inhalation profile.

Microbiological specifications.

Stability and batch-to-batch reproducibility.

Physicochemical evidence that the proprietary process enhances performance while preserving underlying mineral identity.

Commodity-specific use level and technological compatibility.

This characterisation is not an unnecessary regulatory burden. It is the evidence that converts the user's key factual premise—"the mineral structure is maintained but reinforced by processing"—into a publishable scientific proposition.

20. The Organic-Production Opportunity

Sodium hydrogen carbonate's explicit position in the EU organic-production framework materially strengthens the strategic relevance of a bicarbonate-based mineral platform. It demonstrates that the EU legal system does not treat the substance merely as an ordinary food chemical; it recognises a plant-protection role compatible with organic production under the applicable conditions (European Commission, 2023).

For ACARISIN™/ECO-EFF™, however, the strongest statement is not "automatically organic everywhere." It is that the active mineral basis has an established pathway compatible with organic plant protection, and a proprietary formulation that preserves that identity can be assessed within that favourable regulatory context. Certification, product authorisation and the exact intended use must still be checked by jurisdiction.

However, the producer (ND Pharma-Intabiotech) has launched a secondary formula that prays in label as **ACARISIN™/ Eco-Eff™ Organic EU** since is fully adapted to existing regulations to consider all components within the scope of "Organic" regulations existing within the EU.

21. Occupational and Environmental Risk: Avoiding a One-Dimensional Safety Claim

A robust paper should resist the temptation to call a mineral powder simply "non-toxic." This can work as a colloquial way of gather attention, having account, as it should be that, toxicity depends on dose, route and physicochemical form. Operators who handle powders may experience inhalation exposures that are irrelevant to consumers ingesting the finished food. Dust suppression, closed dosing, local exhaust ventilation and appropriate PPE should therefore be included in product stewardship. So the expression of non-toxic should be constrained to the final customer, and not the intermediaries and/or operators that use it industrially and con be exposed eventually.

Environmental superiority should likewise be demonstrated at system level. Mineral extraction, processing, transport and application have environmental burdens. The appropriate comparison is life-cycle burden per tonne of usable food successfully protected, including food loss avoided, chemical treatment displaced, energy use, packaging, transport and waste. A pesticide-minimisation technology should win because the whole system is better, not because "mineral" is rhetorically equated with "harmless."

22. Mycotoxins and Microbiological Safety: Secondary Benefits Must Be Proven Separately

Stored-product insects can contribute indirectly to fungal deterioration by damaging kernels, redistributing spores and altering local moisture and temperature. Therefore, effective insect suppression may reduce some conditions that favour mould development. This does not mean that an insect-control technology automatically prevents aflatoxins, ochratoxin A, deoxynivalenol, fumonisins or other mycotoxins.

Any ACARISIN™/ECO-EFF™ claim concerning a specific mould or mycotoxin should be supported by controlled challenge studies that measure fungal growth and toxin concentration under predefined water activity, temperature, inoculum and storage conditions. Product-specific historical or external testing can be cited as hypothesis-generating evidence, but infant-food positioning warrants replicated, peer-reviewed data.

Certain studies performed by different institutions, including independent third parties have confirmed this claims, in different levels of success, so any query regarding should be referred to the appropriate study or comparison.

23. Resistance Management

One strategic advantage of a mineral/physical mode of action is reduced dependence on a single biochemical target. This can diversify selection pressure within IPM programmes and may help preserve the efficacy of phosphine and other conventional tools by reducing treatment frequency. This is particularly important in view of the global resistance problem documented for phosphine (Machuca-Mesa et al., 2024; Nayak et al., 2020).

The article should nevertheless avoid the absolute statement that pests “cannot develop resistance.” Biological systems can adapt behaviourally, physiologically or ecologically. The defensible position is that multi-factor physical/physicochemical control is less dependent on classical target-site susceptibility and can therefore contribute to resistance-management diversification.

24. Economics: Cost per Tonne Successfully Protected

A technology that reduces chemical input but increases food loss, downtime or cost beyond commercial viability will have limited public-health impact. The correct denominator is not €/kg of treatment product but total cost per tonne of commodity successfully protected to specification.

Conventional programme cost elements	Mineral/IPM programme cost elements
Pesticide/fumigant purchase	Mineral technology purchase
Application labour/equipment	Application labour/equipment
PPE, safety controls and downtime	Monitoring and environmental control
Ventilation/re-entry requirements where applicable	Dust-control measures where applicable
Retreatment and resistance-management costs	Threshold-triggered rescue treatment if needed
Residue analysis and rejected lots	Residue/contaminant verification
Commodity loss and quality deterioration	Commodity loss and quality deterioration

Table 7. Cost structure for whole-system economic comparison.

A particularly useful management metric is cost per conventional pesticide treatment avoided, accompanied by cost per tonne protected and residue-compliance outcomes. This makes sustainability legible to procurement and finance teams rather than leaving it as a qualitative marketing claim.

25. Claim Language for Scientific, Regulatory and Commercial Use

Preferred scientific wording: “bicarbonate-based mineral pest-management technology designed to reduce dependence on selected conventional pesticide interventions.”

Preferred validated B2B wording: “In the validated use scenario, the programme achieved non-inferior pest control while reducing X% of conventional pesticide-treatment events and Y g active substance per tonne.”

Preferred residue wording: “No additional residue attributable to the displaced storage treatment was introduced,” only where analytically and operationally demonstrated.

Avoid: “chemical-free,” because all mineral ingredients are chemicals.

Avoid: “pesticide-free,” unless an appropriately validated analytical definition, scope and jurisdictional basis exist.

Avoid: “totally non-toxic” or “resistance impossible,” because these are unnecessarily absolute and scientifically vulnerable.

26. Implications for Infant-Food Manufacturers

For infant-food manufacturers, the principal benefit is not a consumer-facing health claim but **a stronger raw-material assurance system.** A validated post-harvest substitution programme can increase the margin between observed residues and infant-food limits, reduce dependence on active substances that may later be restricted, support organic or low-input sourcing strategies, and provide auditable treatment-history evidence.

The approach also aligns naturally with supplier quality agreements. Instead of requiring only a certificate of analysis, manufacturers can request a Chemical Intervention History documenting crop treatments, fumigations, warehouse insecticides, dates, doses, alternative interventions and associated residue analytics. This converts source control into a procurement specification.

27. Proposed New Procurement Category: Pesticide-Minimised Raw Material

A useful B2B category is “pesticide-minimised raw material,” defined not by an unrealistic promise of absolute zero but by a documented management system: conventional pesticide intervention minimised through IPM; all treatments traceable; post-harvest pesticide applications avoided where validated alternatives exist; residues verified analytically; and corrective chemical treatment permitted when food protection genuinely requires it. This definition is rigorous enough to audit and flexible enough to protect food security.

28. Limitations and Research Gaps

The peer-reviewed literature supporting mineral/inert pest-control technologies as a class is substantially larger than the publicly available peer-reviewed literature specific to ACARISIN™/ECO-EFF™.

Class evidence cannot establish dose, efficacy, persistence or technological compatibility of a proprietary formulation in a specific commodity.

The regulatory relevance of sodium hydrogen carbonate is strong, but product/use authorisation remains dependent on the exact legal classification, claim, target organism, route and jurisdiction.

Reduced pesticide intervention is a process and exposure endpoint; it should not be converted into a clinical health-benefit claim without epidemiological or intervention evidence.

High humidity and commodity characteristics can reduce or modify performance of mineral/inert systems; environmental robustness must be quantified.

Occupational inhalation and dust handling require separate assessment from oral food safety.

ISRMD, PEB and APTI are proposed constructs and require prospective validation before they can be treated as established industry standards.

29. Discussion

The central scientific tension in this field is productive rather than contradictory. Modern infant foods in regulated markets show very high pesticide-residue compliance, yet regulators apply special precaution to early life. The appropriate response is neither complacency nor fear. It is continuous improvement: identify intervention points where avoidable pesticide input can be removed without weakening food protection.

Post-harvest storage is a particularly attractive intervention point because the operator has direct control over treatment choice and because the affected commodities—especially cereals—feed into multiple products. An alternative that works at storage level can therefore prevent a pesticide input before milling, blending and final infant-food manufacture multiply the value locked into the commodity.

The regulatory position of sodium hydrogen carbonate gives ACARISIN™/ECO-EFF™ an unusually favourable scientific starting point. The EU has already recognised the substance as a foodstuff useful in plant protection, approved it as a low-risk active substance and authorised it in organic plant protection under the relevant implementing rules. If the proprietary process preserves that mineral identity and approved-specification relevance while reinforcing performance, the scientific narrative is not “a new pesticide seeking a safer image.” It is “a recognised low-risk mineral active whose technological performance has been engineered to expand practical utility.”

That proposition should still be tested rather than merely asserted. The strongest future paper would report a multicentre industrial non-inferiority trial in which ACARISIN™/ECO-EFF™ reduces the number or mass of conventional pesticide interventions per tonne while maintaining pest control, grain quality and residue compliance. Such a study would produce a result that is simultaneously entomological, toxicological, regulatory, operational and economic.

The proposed ISRMD, PEB and APTI constructs turn this philosophy into management tools. ISRMD moves prevention upstream. PEB helps formulation and procurement teams compare legally compliant lots through an exposure-optimisation lens. APTI measures chemical interventions that never occurred. Together they create a language for moving from “low residue” to “low avoidable chemical input” without confusing the two concepts.

30. Conclusion

Pesticide safety in infant nutrition should be grounded in evidence rather than fear. The latest EU and U.S. monitoring data show that foods specifically designed for infants are generally characterised by very low pesticide-residue burdens and high regulatory compliance. That success does not eliminate the possibility of improvement; it defines the baseline from which improvement should proceed. The next technological frontier is not simply better detection after treatment, but prevention of treatments that can be made unnecessary. ACARISIN™ and ECO-EFF™ are particularly relevant to this objective because they are described as bicarbonate-based mineral systems whose underlying mineral identity is maintained while proprietary processing reinforces functional performance. Sodium hydrogen carbonate already possesses a distinctive EU regulatory history as a basic substance, a low-risk active substance and a permitted low-risk plant-protection substance in organic production. Where analytical characterisation confirms continuity of identity/specification, that regulatory and toxicological precedent is directly relevant to the active mineral basis of the proprietary technology. The decisive evidence, however, must remain product- and use-specific. The scientifically strongest claim is not that the products remove pesticides already present, but that they can—where validated—make defined conventional pesticide interventions unnecessary. If a multicentre displacement trial demonstrates non-inferior pest control, lower conventional active-substance input, equivalent or improved food quality, acceptable occupational safety and favourable economics, the resulting conclusion would be unusually robust: pesticide-residue prevention can be engineered into the raw-material chain rather than merely verified at its end. For infant foods, where both regulatory margins and societal expectations are exceptionally high, that transition from residue compliance to exposure prevention is a technically coherent, legally relevant and environmentally meaningful direction for innovation.

Declarations

Author contributions

Conceptualisation, regulatory interpretation, translational framework, manuscript development and proposed validation architecture is devoted to the work of the author, Mr. José M. López.

Conflict of interest

ACARISIN™ and ECO-EFF™ are proprietary technologies associated with ND Pharma & Biotech and it´s commercialized mainly throughout INTABIOTECH. This relationship constitutes a commercial and intellectual-property interest and must be disclosed transparently. Evidence concerning diatomaceous earth, inert dusts, sodium hydrogen carbonate and other mineral technologies is used to establish scientific and regulatory context.

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Data availability

No original experimental dataset is reported in this narrative review. Data cited from regulatory surveillance and peer-reviewed studies are available from the referenced public sources. Product-specific technical data should be archived and made available to reviewers or competent authorities subject to legitimate confidentiality and intellectual-property protections.

Ethics statement

Not applicable to the present narrative review. Any future human biomonitoring, occupational exposure or clinical component would require appropriate ethics review and informed consent.

Scientific claims statement

This manuscript does not claim that legally compliant pesticide residues in infant foods are inherently unsafe; that ACARISIN™/ECO-EFF™ remove pesticide residues already present in food; that food-grade composition automatically authorises every pest-control use; or that a mineral mode of action can replace every conventional pesticide under all conditions. The central hypothesis is narrower: where the bicarbonate-based mineral system provides validated equivalent pest protection and displaces a conventional pesticide intervention, it prevents the treatment-derived pesticide input that would otherwise have occurred.

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