LOW-DOSE MINERAL FLOW CONDITIONING IN VITAMIN-MINERAL PREMIXES FOR RUMINANT NUTRITION

Scientific rationale, evidence hierarchy, regulatory considerations and a validation framework for ACARISIN™

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Technical review and hypothesis-led validation framework

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Highlights

- Low-dose mineral surface conditioning has a credible anti-caking rationale in premixes.
- Silica-mediated flow improvement is matrix, moisture, and process-dependent.
- Physical premix stability must be distinguished from chemical vitamin stabilisation.
- Moisture, trace-mineral reactivity and choline are major vitamin-stability stressors.
- A controlled dose-response study can convert mechanistic plausibility into substantiated claims.

Graphical abstract concept

PREMIX STRESSORS	PHYSICAL FAILURE	ACARISIN™	PRIMARY OUTCOME	SECONDARY HYPOTHESIS
Humidity Fine particles Reactive minerals Choline	Cohesion Bridging Caking Segregation	Low-dose mineral surface conditioning	Lower cohesion Better flow Improved handling	More stable physical microenvironment Vitamin retention must be measured separately

Graphical abstract concept. The primary claim pathway is physical flow conditioning; vitamin retention remains a separate analytical endpoint.

Abstract

Vitamin-mineral premixes are technologically demanding particulate systems whose performance depends on far more than nominal nutrient composition. Flowability, resistance to caking, segregation behaviour, moisture distribution, dosing reproducibility and the chemical stability of labile micronutrients all determine whether a premix can deliver its formulated value during manufacture and storage. These challenges are especially relevant when vitamins coexist with hygroscopic ingredients and reactive trace-mineral salts. ACARISIN™ is a proprietary dry mineral preparation incorporating a silica-based surface-conditioning component within a processed mineral matrix under an specific mineral architecture known as SGFT* (Single Grain Fusion Technology). The quantitative formulation and manufacturing parameters and processes are proprietary and are not disclosed in this review. The application assessed here is low-dose incorporation, up to 3 g/kg of vitamin-mineral premix, before subsequent dilution into ruminant compound feed or dry-in application. This paper critically examines the scientific rationale for that technological use. Powder-science literature shows that appropriately dispersed silica materials can disrupt cohesive interparticle forces, alter contact geometry, improve flow and reduce caking tendency, with efficacy governed by host-particle properties, moisture, mixing conditions and concentration. In parallel, feed-premix research demonstrates that vitamin stability is strongly influenced by storage time, temperature, humidity, choline chloride and the source, particle size and reactivity of trace minerals. The evidence therefore supports a scientifically credible role for ACARISIN™ as a physical flow-conditioning and anti-caking system in dry vitamin-mineral premixes, but does not justify describing the product as a direct vitamin stabiliser without product-specific analytical data. Improved physical behaviour may create a more favourable microenvironment for vitamin retention; that secondary benefit remains a testable hypothesis. A tiered validation programme combining powder rheology, caking resistance, moisture and water-activity measurements, blend homogeneity, segregation testing and longitudinal vitamin assays is proposed. This evidence hierarchy provides a robust basis for technical positioning while preserving proprietary formulation confidentiality, what it´s mandatory under legal conditions and applicable law.

Keywords: *ACARISIN™; anti-caking; feed premix; powder flow; silica; vitamin stability; mineral premix; ruminant nutrition; powder rheology; technological conditioning.*

1. Introduction

Premixes are essential enabling systems in modern animal nutrition because they permit vitamins, trace elements and other microingredients to be distributed through much larger masses of compound feed with an acceptable degree of homogeneity. Their industrial function is therefore not merely compositional: they must also behave as reproducible particulate systems during weighing, mixing, transfer, bagging, transport, storage and final dosing.

Vitamin-mineral premixes are particularly demanding because they combine particles that differ substantially in density, size, morphology, hygroscopicity, electrostatic behaviour and surface chemistry. A formulation may be nutritionally correct on paper yet perform poorly if fine cohesive particles bridge in a hopper, if vibration drives density segregation, if moisture promotes caking, or if reactive mineral surfaces accelerate degradation of sensitive vitamins. The practical quality of a premix is consequently the product of nutritional design and powder engineering.

Poor powder flow is a multi-factor phenomenon. Interparticle van der Waals forces, electrostatic attraction, capillary forces, friction and mechanical interlocking can all resist particle movement. As particle size decreases, surface forces become progressively more important relative to particle weight. Moisture can intensify cohesion through adsorbed water layers, capillary bridges or dissolution-recrystallisation processes. Reviews of powder flow and caking therefore emphasise that no single metric adequately predicts industrial behaviour and that testing should reproduce the stresses relevant to the intended unit operation (Shah et al., 2023; Chen et al., 2019).

The present review evaluates a specific technological hypothesis: whether ACARISIN™, used at low concentration within a dry vitamin-mineral premix for ruminant nutrition, has a scientifically credible role as a flow-conditioning and anti-caking system. A second, related question is whether improved physical behaviour could favour vitamin retention during storage. The distinction between these questions is central. Physical stabilisation of a particulate matrix and chemical stabilisation of vitamins are mechanistically related in some circumstances, but they are not equivalent claims.

2. ACARISIN™: application definition and confidentiality boundary

ACARISIN™ is a proprietary dry mineral preparation developed for food and feed applications. For the technological use discussed here, the relevant formulation attributes are qualitative: it is a dry processed mineral system incorporating a silica-based surface-conditioning component and designed for homogeneous dispersion in dry matrices. Exact quantitative composition, particle-engineering parameters and proprietary processing conditions are deliberately outside the scope of this paper.

The application under evaluation is incorporation at up to 3 g/kg of vitamin-mineral premix. This is a premix-level technological use; the preparation is subsequently diluted when the premix is added to compound feed. Accordingly, the primary performance endpoints are properties of the premix itself: flowability, cohesion, caking tendency, discharge behaviour, segregation resistance and maintenance of homogeneous distribution.

This use should be kept conceptually separate from any other intended function in finished feed. If a product is employed for a distinct purpose at the complete-feed level, that purpose requires its own effective concentration, efficacy endpoints, risk assessment and regulatory analysis. A low-dose premix-conditioning application should not be used as indirect evidence for a different final-feed claim.

3. Powder-science basis for mineral flow conditioning

3.1 Interparticle forces and cohesive failure

Powder flow reflects the balance between body forces that promote movement and interparticle forces that resist movement. In coarse, dense particles, gravity may dominate; in fine powders, surface forces become comparatively important. Van der Waals attraction, electrostatic charge, surface roughness and particle interlocking can create cohesive networks. Under humid conditions, adsorbed moisture adds capillary and, in some crystalline systems, solid-bridge mechanisms that can transform a free-flowing powder into a caked mass (Aguilera et al., 1995; Chen et al., 2019).

For this reason, the industrial behaviour of a premix cannot be inferred reliably from visual appearance alone. A material may pour freely immediately after manufacture yet consolidate during storage and then develop arching, ratholing or poor discharge. Conversely, a powder that appears somewhat cohesive under an angle-of-repose test may perform acceptably in a well-designed feeder. Shah et al. (2023) therefore support multi-method characterisation, typically combining simple indices with shear-based or dynamic measurements.

3.2 Mechanism of silica-mediated flow improvement

Silica-based flow conditioners have been studied extensively as glidants and anti-caking agents. Mechanistic work by Tran et al. (2019) showed that colloidal silica can improve powder flow by attaching to host-particle surfaces and disrupting the direct contacts responsible for cohesive interparticle forces. The magnitude and kinetics of this effect depended on host-particle size, surface texture, silica loading and mixing time. The central mechanism is therefore interfacial rather than simply volumetric.

The practical consequence is important: small quantities of a properly dispersed surface-active particulate conditioner can alter bulk behaviour disproportionately to their mass contribution. The effect is not universally linear with dose. Too little material may provide incomplete surface modification, whereas excessive or poorly dispersed fine material can fail to produce further benefit and, in some matrices, can worsen cohesion. Dose-response testing is therefore more scientifically appropriate than assuming that the highest inclusion level is necessarily optimal (Blanco et al., 2021; Ruzaidi et al., 2017).

Recent multi-scale work in crystalline salt systems provides additional mechanistic evidence that silica-based anti-caking approaches can alter water distribution and suppress the liquid- and solid-bridge processes associated with caking. Although an edible-salt matrix cannot be transferred quantitatively to feed premixes, the study by Du et al. (2026) reinforces two concepts relevant here: anti-caking efficacy is matrix-specific, and control of moisture mobility can be as important as simple bulk water content.

3.3 Moisture as a moderator of efficacy

Moisture changes both particle mechanics and surface chemistry. At low levels, water may adsorb onto particle surfaces and alter friction. At higher local water activity, capillary forces can increase cohesion; in soluble crystalline materials, dissolution followed by recrystallisation can generate much stronger solid bridges. Humidity cycling can therefore be more damaging than a constant moderate environment because repeated sorption and desorption promotes structural change (Chen et al., 2019).

Blanco et al. (2021) specifically demonstrated that moisture altered the response of powders to colloidal silica. This interaction is highly relevant to vitamin-mineral premixes because several common components are hygroscopic and because moisture also accelerates chemical deterioration of labile micronutrients. A successful premix conditioner should therefore be evaluated not only at baseline but after controlled exposure to realistic and accelerated humidity conditions.

4. Why vitamin-mineral premixes are a particularly demanding application

Ruminant vitamin-mineral premixes may contain macro-mineral carriers, trace-mineral salts, vitamin beadlets or adsorbates, choline preparations and other functional microingredients. These materials can differ by an order of magnitude or more in density and particle size. Such differences create a persistent risk of segregation during conveying, vibration, discharge and transport.

Hygroscopic components can further destabilise the powder system. Choline chloride is particularly relevant because its water-attracting behaviour can increase local moisture and has repeatedly been associated with reduced vitamin retention in premixes. Reactive trace-mineral salts add a second dimension: the same mineral required nutritionally can act as a catalyst or direct reactant in degradation pathways when highly concentrated within a premix.

Technological conditioning therefore has value beyond cosmetic improvement. Better flow and lower cohesion can support more consistent microdosing, reduce bridging and rework, and potentially help preserve spatial homogeneity. However, a flow conditioner cannot be assumed to neutralise chemical incompatibilities. The physical and chemical layers of premix stability must be measured separately.

5. Vitamin stability in vitamin-mineral premixes

5.1 Storage time, temperature and relative humidity

Saensukjaroenphon et al. (2020) demonstrated that fat-soluble vitamin stability is strongly influenced by premix type and storage environment. Vitamin and vitamin-trace-mineral premixes subjected to high-temperature/high-humidity conditions showed progressive losses that were greater than under room conditions. The study is especially useful because it examines premix systems rather than isolated vitamins.

The same research programme subsequently evaluated water-soluble vitamins and again found that stability depended on the specific vitamin, premix composition and storage condition (Saensukjaroenphon et al., 2022). Riboflavin, pantothenic acid and cobalamin did not behave identically, illustrating why a generic statement such as "vitamin stability" can obscure important differences among analytes.

These findings justify two practical principles for ACARISIN™ validation. First, real-time storage should remain the primary basis for shelf-life conclusions. Second, accelerated temperature/humidity exposure is valuable as a discriminatory stress test but should not be used to extrapolate commercial shelf life mechanically unless a validated kinetic relationship exists.

5.2 Choline chloride and reactive trace minerals

Yang et al. (2021) evaluated vitamin and vitamin-trace-mineral premixes over extended storage and found that choline chloride and high concentrations of copper and zinc increased losses of several vitamins. Storage time itself was a major negative factor. The study supports the view that premix design should minimise avoidable chemical contact stresses rather than rely solely on vitamin overages.

More recent work has added particle-scale detail. De Araujo et al. (2024) showed that moisture and copper source strongly influenced vitamin A degradation, and that a finer, more reactive copper sulfate fraction produced substantially greater deterioration than a less reactive hydroxy-copper source. This finding is directly relevant to the present hypothesis because it demonstrates that vitamin loss can be driven by local surface contacts and particle characteristics, not merely by bulk composition.

Together, these studies show that vitamin stability is controlled by a network of factors: moisture, temperature, time, trace-mineral form, particle size, choline, oxygen exposure and vitamin protection technology. A mineral flow conditioner may influence some physical contributors to this network, but it does not eliminate the underlying chemical reactivity of incompatible ingredients.

6. Can physical conditioning improve vitamin retention?

There is a rational but unproven product-specific pathway by which improved powder conditioning could favour vitamin retention. Caking, compaction and poor dispersion can increase local contact between vitamin particles and reactive mineral surfaces. Heterogeneous moisture distribution can create microenvironments with water activity substantially different from the bulk average. Segregation can also generate local zones enriched in catalysts or hygroscopic components.

If a conditioner reduces cohesion, improves dispersion and limits the development of strong moisture-mediated bridges, it may reduce some of these local physical stresses. This would be an indirect protective mechanism. It should be described as a hypothesis concerning the physical microenvironment, not as antioxidant activity and not as direct chemical stabilisation.

The distinction matters experimentally. A premix could show markedly better flow and caking resistance while vitamin retention remains statistically unchanged. That result would still support a valuable technological function. Conversely, if vitamin retention improves significantly, the additional benefit would require replication and mechanistic interpretation before being presented as a general stabilisation claim.

A scientifically mature claim hierarchy therefore places anti-caking and flow conditioning first, physical premix stability second, and chemical vitamin stabilisation only after direct analytical demonstration.

7. Evidence hierarchy for the proposed application

Table 1 separates the external scientific evidence from the product-specific evidence that is still required. This hierarchy is intentionally conservative and is designed to prevent mechanistic plausibility from being presented as demonstrated ACARISIN™ efficacy.

Proposition	External evidence	ACARISIN™-specific status	Defensible statement today
Silica-based surface conditioning can reduce powder cohesion	Strong mechanistic and experimental support across particulate systems	Mechanistically applicable; matrix-specific magnitude untested	Scientifically plausible basis for flow-conditioning evaluation
Low-dose conditioning can improve flow	Supported; response depends on dose, dispersion and host-particle properties	Dose-response not yet quantified in representative ruminant premix	Evaluate 1-3 g/kg against untreated control
Anti-caking / storage physical stability	Supported by caking science and silica anti-caking literature	Product-specific storage data required	Potential anti-caking function subject to matrix validation
No adverse effect on vitamin retention	Not guaranteed by flow improvement; must be measured	Not yet established in the target premix	Require vitamin non-inferiority as a safety/performance endpoint
Direct vitamin stabilisation	General literature identifies physical contributors but no automatic equivalence	Not established	Do not claim until superior retention is demonstrated analytically
Finished-feed hygiene or other final-feed function	Separate efficacy and regulatory question	Outside this premix-conditioning evidence pathway	Assess independently at the effective final-feed concentration

Table 1. Evidence hierarchy and claim discipline for low-dose ACARISIN™ use in vitamin-mineral premixes.

8. European Union regulatory considerations

Regulation (EC) No 1831/2003 establishes the Union framework for feed additives and lists anti-caking agents and stabilisers among technological additive functions. Anti-caking agents are defined by reference to reducing the tendency of individual feed particles to adhere to one another. This functional definition aligns closely with the primary technological hypothesis discussed in this paper.

The same Regulation establishes a product-specific authorisation system. Consequently, the fact that a mechanism is scientifically associated with a recognised technological function does not by itself establish that a proprietary preparation may be marketed under that additive function. The exact regulatory identity of each constituent, the authorised specifications and conditions of use, the nature of the preparation, and the current EU Register of Feed Additives must be verified before commercial positioning.

Sodium bicarbonate is listed in the EU Catalogue of Feed Materials under entry 11.4.2 (Commission Regulation (EU) No 68/2013, as amended). In organic animal production, the current consolidated implementing rules also recognise selected silica materials under binders and anti-caking agents. These provisions demonstrate the established regulatory relevance of mineral and silica-based materials in feed technology, but they should not be used to bypass the product-specific classification analysis required for a proprietary preparation.

Where claims are made in the labelling or presentation of feed materials or compound feed, Article 13 of Regulation (EC) No 767/2009 requires claims to be objective, verifiable and scientifically substantiated. For additives and premixtures, the authorising act and the labelling provisions of Regulation (EC) No 1831/2003 remain central. The practical implication is straightforward: technical language should follow the strength of the evidence actually available.

For ACARISIN™, initial scientific position is therefore a hypothesis-led technological use centred on powder flow, cohesion and caking aside of all other technological functions well-known and recognised. A direct vitamin-stabilisation claim should be reserved for a later stage if comparative analytical studies demonstrate superior retention. This review is a scientific framework and not a substitute for a formal legal classification opinion on the final commercial specification.

9. Proposed product-specific validation framework

The appropriate next step is a controlled comparative programme using a representative commercial ruminant vitamin-mineral premix. The central design principle is to hold the premix composition, raw-material lots, mixing process, packaging and storage conditions constant while varying only ACARISIN™ inclusion.

A four-level dose-response design (0, 1, 2 and 3 g/kg premix) provides a practical first screen. At least three independently manufactured batches per treatment are preferable so that conclusions do not depend on a single blending event. The untreated formulation is essential; comparisons against historical experience alone are insufficient because powder behaviour is highly sensitive to raw-material and environmental variation.

Domain	Recommended measurement	Primary purpose	Interpretation
Baseline physical state	Particle-size distribution; bulk and tapped density; moisture; water activity	Characterise starting matrix	Required to interpret between-lot variability
Simple flow screening	Angle of repose; Carr Index; Hausner Ratio; flow-through-orifice/discharge time	Rapid comparative screen	Use as supportive, not stand-alone, evidence
Mechanistic flow behaviour	Shear-cell flow function; cohesion; internal friction; dynamic flow energy where available	Quantify stress-dependent flow	Most useful for hopper/handling relevance
Caking	Consolidated storage; controlled compression; caking strength or break-force; humidity cycling	Measure time-dependent physical failure	Distinguishes initial flow from storage stability
Homogeneity	Representative tracer or micronutrient CV before and after handling challenge	Confirm uniform distribution	Assess whether better flow preserves blend uniformity
Segregation	Vibration/transfer challenge with top-middle-bottom sampling	Quantify density/size segregation	Important for transport and feeder accuracy
Vitamin chemistry	Validated assays for A, D3, E plus selected B vitamins appropriate to the formulation	Test non-inferiority or superiority	Chemical endpoint must remain separate from flow metrics
Packaging interaction	Standard commercial pack versus high-barrier reference where relevant	Separate formulation effect from packaging effect	Prevents confounding by moisture ingress

Table 2. Recommended analytical domains for ACARISIN™ validation in a representative vitamin-mineral premix.

9.1 Storage design

A real-time arm should reproduce the intended commercial environment as closely as possible and extend through the claimed premix shelf life. Sampling at manufacture and at predefined intervals should quantify both physical and chemical change. Temperature and relative humidity should be continuously recorded because nominal room conditions can conceal substantial seasonal variability.

An accelerated arm can be used for early discrimination. Feed-premix studies have successfully used conditions around 40 °C and 75% relative humidity as a high-temperature/high-humidity stress (Saensukjaroenphon et al., 2022). Such conditions are useful for ranking treatments and exposing weak formulations, but the accelerated result should not be converted directly into a commercial shelf-life claim without validated kinetics.

If the target customer formulation contains highly hygroscopic choline preparations or reactive copper/iron salts, a second-phase stress matrix is advisable. This allows the conditioner to be tested where the physical and chemical challenges are greatest rather than only in a relatively benign premix.

9.2 Statistical hierarchy and decision rules

Primary endpoints should relate to the proposed primary function: flow and caking. Treatment, time and their interaction should be analysed using an appropriate mixed model with independent batch as a random effect where possible. Dose-response patterns are more informative than isolated pairwise significance because they can identify an optimum rather than simply a difference.

For vitamins, the first product-development question should be non-inferiority: does ACARISIN™ preserve vitamin activity at least as well as the untreated control within a pre-specified analytical and commercial margin? Only after non-inferiority is established should superiority be evaluated. The margin must be justified in advance from analytical precision, product specification and normal premix variability rather than selected retrospectively.

This hierarchy protects against a common evidentiary error: using a positive physical result to imply a chemical benefit that was never measured. It also creates commercially useful outcomes even if vitamin superiority is absent. A conditioner that significantly improves handling without damaging vitamin retention remains technically valuable.

10. Interpretation of possible experimental outcomes

Observed result	Scientific conclusion	Permissible technical positioning
Flow improves; caking decreases; vitamins unchanged	Validated physical conditioner; no chemical effect detected	Flow-conditioning / anti-caking benefit with vitamin compatibility
Flow improves; vitamins also retain significantly better	Physical benefit plus secondary chemical-retention signal	Investigate and replicate before vitamin-stability claim
Flow improves; one or more vitamins decline faster	Physical benefit accompanied by formulation interaction	Reformulate or restrict use; no vitamin-compatibility claim
No meaningful physical improvement	Matrix/dose/process not responsive	Do not generalise efficacy; reassess dose, dispersion or target matrix
Effect differs by dose	Non-linear surface-conditioning response	Define optimum inclusion rather than defaulting to maximum dose

Table 3. Decision framework for interpreting the first product-specific validation study.

11. Industrial implications for premix manufacturing

If validated, a low-dose mineral conditioner could deliver benefits that extend beyond visual free-flowing appearance. Reduced cohesion can improve hopper discharge, feeder reproducibility, packaging speed and operator handling. Lower caking can decrease manual break-up, reprocessing and material loss. Improved distribution stability may also support more consistent microingredient delivery after transport.

These outcomes have direct nutritional relevance because nutrient specifications are meaningful only when the manufacturing system can deliver the formulated microingredients consistently. Precision nutrition increases, rather than decreases, the importance of particulate engineering because lower safety margins require tighter control of dosing and homogeneity.

The commercial value proposition should therefore be framed primarily around process robustness and physical premix quality. Any subsequent vitamin-retention benefit should be presented as an additional validated property, not as the starting assumption.

12. Research agenda beyond the initial validation

Once a first ruminant premix study establishes a reproducible physical effect, subsequent work should determine the boundaries of the technology. Priority variables include premix mineral architecture, choline source, vitamin protection technology, particle-size distribution, mixing energy, storage humidity and packaging barrier.

A factorial programme could compare highly soluble sulfate minerals with less reactive mineral sources, coated versus uncoated vitamin preparations, and low versus high hygroscopicity matrices. Such work would clarify whether ACARISIN™ mainly acts as a general flow conditioner or whether its effect is particularly valuable in specific high-risk premix architectures.

Advanced characterisation could also examine surface coverage by electron microscopy, dynamic vapour sorption, low-field NMR for water mobility, and powder rheometry under consolidation. These techniques are not required for routine quality control, but they can help connect macroscopic performance with mechanism and create a stronger scientific platform for future publication.

13. Limitations

The principal limitation of this review is deliberate: it does not present ACARISIN™-specific comparative efficacy data because such data must be generated prospectively. The paper therefore establishes plausibility, evidence boundaries and a validation pathway rather than claiming completed proof.

Much of the mechanistic literature on colloidal silica and powder flow originates in pharmaceutical or general particulate systems rather than feed premixes. Transfer of the underlying physics is reasonable because interparticle forces, capillary bridging and surface modification are general phenomena, but quantitative effect sizes cannot be transferred directly between matrices.

The vitamin-stability literature is more directly relevant to feed premixes, yet it also demonstrates strong matrix dependence. The behaviour of a specific ruminant premix will depend on its actual vitamin forms, mineral sources, particle sizes, carriers, choline content, moisture and storage environment. Product-specific testing remains indispensable.

Finally, this paper is not a regulatory authorisation dossier. The scientific rationale must be integrated with a separate legal assessment of the exact commercial specification, current feed-additive authorisations, labelling and intended claims in each target market.

14. Conclusions

Vitamin-mineral premixes are complex powder systems in which physical handling and chemical micronutrient stability interact but remain analytically distinct. Established powder science shows that silica-based surface conditioning can reduce cohesive interparticle forces and improve powder flow, while caking science identifies moisture distribution and interparticle bridge formation as key determinants of storage failure.

Feed-premix research independently demonstrates that vitamin stability is strongly affected by time, temperature, humidity, choline chloride and the chemical form and particle characteristics of reactive trace minerals. These findings provide a coherent scientific basis for investigating ACARISIN™ as a low-dose physical conditioner in vitamin-mineral premixes for ruminant nutrition.

The current evidence supports a credible anti-caking and flow-conditioning hypothesis. It does not yet justify a direct claim that ACARISIN™ chemically stabilises vitamins. The appropriate scientific sequence is therefore to demonstrate improved physical behaviour, confirm non-inferior vitamin retention, and only then evaluate whether a reproducible secondary vitamin-retention benefit exists.

A controlled dose-response study using representative commercial premixes can convert this rationale into product-specific evidence without disclosure of the proprietary quantitative formulation. Such an evidence-led approach provides the strongest basis for technically robust, commercially useful and regulatorily defensible positioning.

Declarations

Author contributions

José M. López: Conceptualization; technical framing; methodology; literature synthesis; regulatory interpretation; writing - original draft; writing - review and editing; supervision.

Conflict of interest

The author is Technical Director and R&D Director of INTABIOTECH S.L., a company that commercializes ACARISIN™. This commercial interest constitutes a potential conflict of interest and is declared transparently. The manuscript deliberately distinguishes external scientific evidence from product-specific hypotheses and does not claim efficacy data that have not been generated.

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Data availability

No new experimental dataset was generated for this review. The scientific analysis is based on the cited public literature and on non-quantitative technical characteristics of the proprietary preparation. Product-specific performance data will require prospective validation.

Proprietary formulation statement

The quantitative composition and proprietary manufacturing parameters of ACARISIN™ are confidential industrial information and are intentionally not disclosed. The scientific conclusions of this review do not depend on publication of those confidential details.

Ethics statement

Not applicable. This review did not involve human participants, animals or new biological experimentation.

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