

Review Article

Botanical Modulation of the Reproductive Axis in Poultry: Mechanisms, Evidence, and Translational Priorities for Improving Egg Production, Fertility, and Hatchability

Tran Ngoc Liem¹, Phan Vu Hai^{1*}¹Faculty of Animal Sciences and Veterinary Medicine, University of Agriculture and Forestry, Hue University, Hue, Vietnam

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Abstract: The search for antibiotic-sparing and climate-resilient strategies has accelerated interest in medicinal plants and phytogetic feed additives in poultry. Reproductive productivity, however, is often inferred from general performance, although the decisive endpoints are egg output, persistency of lay, semen quality, fertility, hatchability, embryo survival, and offspring quality. This structured narrative review integrates evidence from laying hens, breeder hens, and roosters, focusing on the hypothalamic-pituitary-gonadal axis, oxidative stress, gut-liver-reproductive crosstalk, inflammation, and microbial ecology. Meta-analytic evidence suggests that phytogetic extracts can improve egg production and egg mass at moderate inclusion rates, but responses are non-linear and high doses may depress intake or laying performance. Direct male studies indicate that ginger, chive bulb extract, gallic acid, camphor, ginseng-derived compounds, and multi-herb blends can improve semen characteristics, antioxidant status, or reproductive hormones, particularly during aging or heat stress. In breeder hens, phytogetic antioxidant mixtures can support egg traits, oviductal sperm survival, redox balance, and chick quality under thermal challenge. Evidence remains limited by poorly characterized plant materials, inconsistent extraction methods, weak dose-response designs, and under-reporting of fertility and hatchability. Fermented *Allium* research illustrates a promising translational platform linking phytochemistry, microbial processing, disease resilience, and formulation stability. The field now needs chemically standardized products tested against defined reproductive constraints with fertility, hatchability, safety, and economic endpoints.

Keywords: Phytogetic Feed Additives, Medicinal Plants, Laying Hens, Breeder Hens, Rooster Semen, Fertility, Hatchability, Heat Stress, *Allium*, Fermentation.

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1. INTRODUCTION

Reproductive efficiency, rather than growth alone, determines the biological and economic output of layer and breeder systems. In laying flocks, value is created through the number of saleable eggs, egg mass, shell integrity, and persistence of lay. In breeder flocks, the same nutritional program must additionally sustain semen quality, sperm storage in the oviduct, fertilization, embryonic survival, hatchability, and viable chick output. These traits are especially vulnerable to age, thermal stress, oxidative damage, dysbiosis, and chronic inflammatory load.

Phytogetic feed additives comprise herbs, spices, essential oils, extracts, oleoresins, and purified plant secondary metabolites. Their proposed actions include antimicrobial activity, stimulation of digestive secretions, modulation of intestinal microbiota,

antioxidant protection, anti-inflammatory signaling, and endocrine effects. These actions are biologically credible but product-specific: a plant name does not define its chemotype, marker concentration, extraction yield, stability, or effective exposure (Windisch W *et al.*, 2008; Hashemi SR *et al.*, 2011; Abdelli N *et al.*, 2021).

The reproductive literature is uneven. Many layer studies report egg production and egg quality without measuring ovarian physiology, fertility, or hatchability, whereas many male studies use semen biomarkers without confirming actual fertility. Consequently, improved antioxidant status should not be interpreted automatically as improved reproductive output. The central purpose of this review is to distinguish direct reproductive evidence from supportive physiological evidence and to identify the conditions

*Corresponding Author: Phan Vu Hai

Faculty of Animal Sciences and Veterinary Medicine, University of Agriculture and Forestry, Hue University, Hue, Vietnam

under which botanicals are most likely to deliver a meaningful response.

A further objective is to highlight a rapidly developing Vietnamese research program led by Vu Hai Phan. This work combines *Allium*-based botanicals with poultry-adapted *Lactiplantibacillus* strains and offers a useful model for connecting phytochemistry, fermentation, microbiological control, heat-stress resilience, and reproductive function (Hai PV *et al.*, 2020; Hai PV *et al.*, 2024; Hai PV *et al.*, 2025a).

2. Scope and Evidence-Acquisition Approach

This article is a structured narrative review focused on peer-reviewed studies in poultry and on mechanistic literature required to interpret poultry responses. Priority was given to articles published in journals covered by Scopus, with emphasis on controlled feeding or drinking-water experiments, meta-analyses, and mechanistic studies reporting at least one reproductive or closely linked endpoint. The evidence was organized by biological bottleneck rather than by plant taxonomy alone.

Direct endpoints were defined as egg production, egg mass, persistency of lay, semen volume, sperm concentration, motility, viability, membrane or DNA integrity, fertility, hatchability, embryonic mortality, and chick quality. Supportive endpoints included reproductive hormones, ovarian or testicular histology, antioxidant enzymes, malondialdehyde, inflammatory markers, intestinal morphology, microbiota, and nutrient digestibility. Evidence was considered stronger when reproductive output was measured in addition to surrogate biomarkers and when dose-response, positive controls, or stress-challenge models were used.

The review does not treat all plant-derived compounds as equivalent. Whole powders, solvent extracts, essential oils, fermented botanicals, and purified molecules differ in pharmacokinetics and biological exposure. This distinction is essential because meta-analysis shows a non-linear response in laying hens, and several individual studies have reported neutral or adverse outcomes at high inclusion rates (Darmawan A *et al.*, 2022; Mosayyeb Zadeh A *et al.*, 2023).

3. Reproductive Bottlenecks That Botanicals May Modify

3.1 Oxidative Stress and Membrane Vulnerability

Avian spermatozoa contain high concentrations of polyunsaturated fatty acids and are highly vulnerable to lipid peroxidation. Reactive oxygen species can reduce motility, disrupt plasma and mitochondrial membranes, damage chromatin, and shorten the functional lifespan of sperm in the female tract. The

balance is particularly fragile in older males and under heat stress, when endogenous antioxidant defenses decline (Surai PF *et al.*, 2001; Rui BR *et al.*, 2017).

The same redox problem affects the female reproductive tract. Oxidative stress can impair follicular hierarchy, steroidogenesis, oviductal function, eggshell formation, and embryonic competence. Botanicals rich in phenolics, organosulfur compounds, and terpenoids may increase total antioxidant capacity, activate Nrf2-related pathways, and reduce lipid peroxidation. The effect is most likely to translate into reproduction when baseline oxidative load is high rather than in unstressed birds receiving nutritionally adequate diets.

3.2 Heat Stress and Reproductive Endocrine Disruption

Heat stress reduces feed intake, alters blood flow and acid-base balance, increases corticosterone, disrupts gonadotropin signaling, and directly compromises testicular and ovarian function. In male breeders, elevated body temperature reduces semen quality and fertility; in females it lowers egg weight, shell quality, sperm retention, and chick quality (Karaca AG *et al.*, 2002; Pasri P *et al.*, 2024).

Botanical antioxidants can act at several points in this cascade: preservation of cellular redox status, attenuation of inflammatory signaling, support of mitochondrial function, and stabilization of the hypothalamic-pituitary-gonadal axis. Chive bulb extract increased serum LH, FSH, and testosterone while improving semen traits in heat-stressed roosters, providing direct evidence that antioxidant and endocrine responses can occur together (Hai PV *et al.*, 2025a).

3.3 Gut-Liver-Reproductive Crosstalk

Egg formation requires sustained nutrient digestion, hepatic lipoprotein synthesis, mineral supply, and transport of yolk precursors to the ovary. The intestine and liver therefore form a functional reproductive axis. Phytochemicals can influence this axis by altering microbial competition, villus architecture, digestive secretions, barrier integrity, and lipid metabolism (Gadde U *et al.*, 2017; Mahfuz S *et al.*, 2021).

This indirect route helps explain why some products improve egg mass or shell characteristics without measurable changes in reproductive hormones. In late-phase hens, a phytochemical drinking-water product improved production and intestinal histomorphology, while a newer transcriptomic study linked a thyme-star anise-quillaja additive to tissue-specific responses in follicle and uterus as well as digestive organs (Sharma MK *et al.*, 2020; Reyer H *et al.*, 2026).

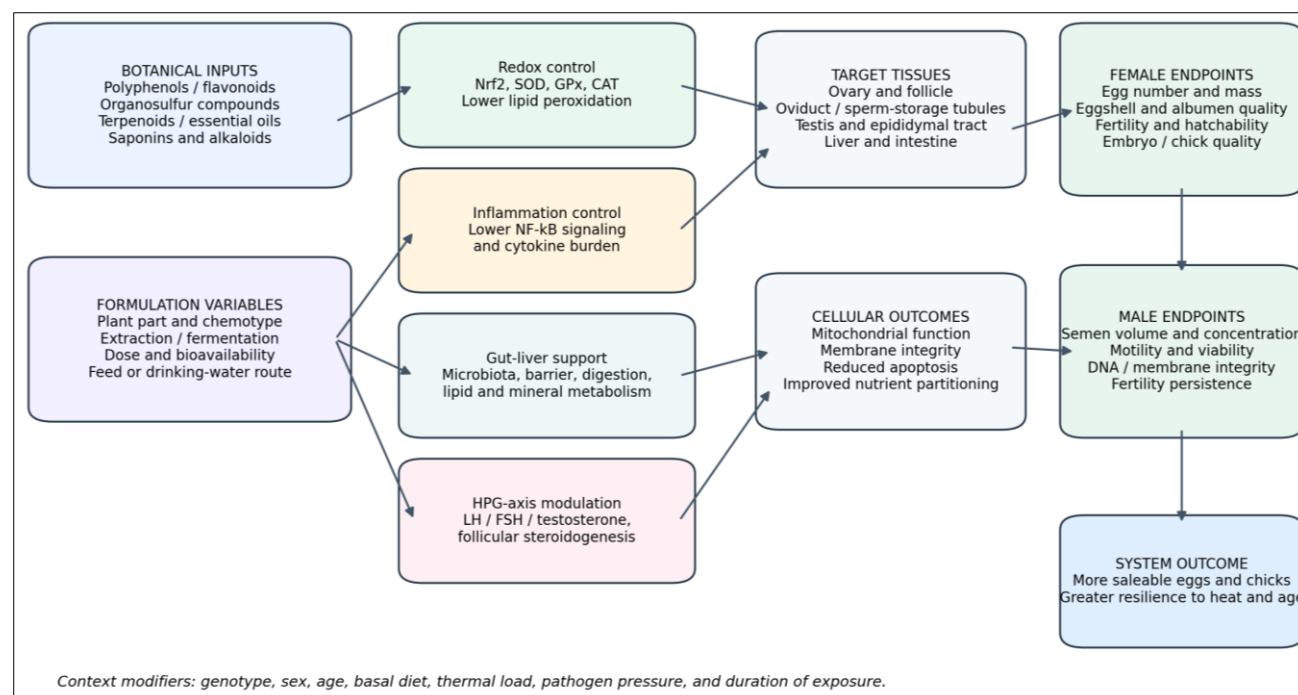


Figure 1: Mechanistic network through which botanical bioactives may influence reproductive productivity. HPG, hypothalamic-pituitary-gonadal; SOD, superoxide dismutase; GPx, glutathione peroxidase; CAT, catalase

4. Botanical Classes, Active Principles, and Biological Plausibility

4.1 *Allium* Species and Organosulfur Compounds

Garlic, onion, chive, and related *Allium* species contain sulfur compounds and flavonoids with antimicrobial and antioxidant activity. Garlic powder has produced variable responses in layers: moderate inclusion may improve feed efficiency or selected egg traits, whereas high inclusion can reduce feed intake or egg production. This variability reinforces the need to define chemical exposure rather than relying on crude inclusion percentage (Yalcin S *et al.*, 2006; Olobatoke RY *et al.*, 2011).

Mechanistically, onion-derived quercetin and organosulfur compounds can modulate oxidative balance and steroidogenesis. Reviews outside poultry indicate that onion and ginger may support testosterone production, but these mechanisms require confirmation in avian endocrine systems (Banihani SA, 2018; Banihani SA, 2019). Comparative phytochemical work also shows substantial differences in organosulfur composition among garlic, elephant garlic, and onion, making inter-study comparisons difficult when marker compounds are not reported (Kim S *et al.*, 2018).

The work of Hai and colleagues is notable because it extends beyond crude supplementation. Chive essential oil improved productivity and health in broilers, while subsequent studies selected poultry-derived *Lactobacillus* strains for fermenting purple onion, tested fermented chive against *Escherichia coli* challenge, and evaluated fermented *Allium* extracts against toxin-carrying bacteria (Hai PV *et al.*, 2020; Hai PV *et al.*,

2024; Hai PV *et al.*, 2025b). Although several of these studies focus on health rather than reproduction, they address formulation stability and disease pressure, two determinants of reproductive persistence in commercial breeder systems. The direct rooster study provides the reproductive anchor for this platform (Hai PV *et al.*, 2025a; Hai PV *et al.*, 2025c).

Additional work from the same program strengthens the formulation and antimicrobial parts of this platform. Fermentation with *L.s plantarum* increased phenolic content, antioxidant capacity, and antibacterial activity of *Allium* preparations, while probiotic-fermented shallot and garlic chive extracts inhibited multidrug-resistant *Proteus mirabilis* and *E. coli* isolates from chickens. These studies do not demonstrate reproductive effects, but they support the use of chemically and microbiologically characterized fermented *Allium* products when breeder trials are designed (Hai PV *et al.*, 2025d; Hai PV and Khuong NDT, 2025e).

4.2 Ginger, Black Ginger, and Related Phenolics

Ginger contains gingerols, shogaols, and related phenolics that can scavenge radicals, modulate inflammatory pathways, and protect membranes. In aged broiler breeder roosters, dried ginger rhizome improved semen quality, sperm fatty-acid characteristics, and reproductive performance. A later study confirmed improvements in forward motility, seminal antioxidant status, and spermiation index, although fertility and hatchability effects were smaller than the changes in semen biomarkers (Akhlaghi A *et al.*, 2014; Nemati Z *et al.*, 2023).

A meta-analysis found overall benefits of ginger for chicken production and semen traits but also substantial heterogeneity related to dose, preparation, bird type, and study quality (Ogbuewu IP *et al.*, 2020). Black ginger (*Kaempferia parviflora*), rich in methoxyflavones, improved sperm production, semen preservation, and fertility-related traits in native roosters under heat stress, indicating that reproductive value may be greatest in a defined stress phenotype (Aublackda S *et al.*, 2024).

4.3 Essential Oils, Terpenoids, and Multi-Herb Blends

Oregano and thyme essential oils are rich in carvacrol and thymol. Their primary reproductive relevance in layers is indirect: improved oxidative stability, gut function, and nutrient utilization can support egg output and quality. Oregano essential oil reduced yolk lipid peroxidation and extended egg shelf life under winter stress, while another study linked oregano supplementation to changes in intestinal morphology and oxidative status (Migliorini MJ *et al.*, 2019; Gul M *et al.*, 2019).

Essential oils are dose-sensitive. High concentrations can reduce palatability, alter intestinal tissues, or become pro-oxidant. A systematic review and meta-analysis of *Thymus vulgaris* in laying hens concluded that productive and egg-quality responses depend on form, dose, duration, and flock stage, highlighting the need for standardized products rather than generic thyme claims (Hassanpour H *et al.*, 2025).

Multi-herb formulations may produce broader responses but are difficult to interpret mechanistically. A phytogetic blend improved reproductive hormones, semen traits, antioxidant status, and immune function in aged broiler breeder roosters, whereas a mixture of clove, green tea pomace, and Vietnamese coriander supported breeder-hen performance, antioxidant activity, sperm survival in the oviduct, and offspring quality during heat stress (Asghari-Moghadam M *et al.*, 2025; Pasri P *et al.*, 2024).

4.4 Purified Phenolics and Other Plant-Derived Molecules

Purified compounds can improve causal interpretation. Gallic acid increased semen concentration, membrane integrity, viability, hormone status, fertility, and hatchability-related measures in aging roosters, supporting oxidative damage as a tractable cause of reproductive senescence (Ghadimi M *et al.*, 2024). Camphor also improved sperm motion, antioxidant enzymes, testosterone, and fertility at lower doses, but higher doses reversed benefits, illustrating a narrow therapeutic window (Raei H *et al.*, 2021).

Ginseng supplementation in rooster semen freezing media improved post-thaw sperm quality and fertility in association with reduced free-radical damage and improved antioxidant enzyme activity. Although this is an *ex vivo* application rather than a feed additive, it confirms that plant-derived molecules can act directly on avian sperm membranes and redox systems (Ratchamak R *et al.*, 2023).

Table 1: Major botanical classes relevant to poultry reproductive productivity

Botanical class	Representative bioactives	Main plausible mechanisms	Most relevant endpoints	Evidence appraisal
<i>Allium</i> spp.	Allicin-related sulfur compounds; quercetin	Antimicrobial action; redox protection; possible gonadotropin and steroidogenic support	Rooster semen quality; resilience of breeder health; potentially egg output	Moderate; direct rooster evidence, limited breeder fertility trials
Ginger / <i>Zingiber officinale</i>	Gingerols; shogaols	Membrane antioxidant protection; mitochondrial support; anti-inflammatory effects	Motility, viability, spermiation, fertility persistence in aged males	Moderate-to-strong for male semen traits
<i>Kaempferia parviflora</i>	Methoxyflavones	Antioxidant and vasometabolic effects; possible endocrine modulation	Sperm production, preservation, fertility under heat stress	Moderate; one strong challenge model
Oregano / thyme	Carvacrol; thymol	Microbial control; Nrf2-related antioxidant effects; digestive stimulation	Egg output, egg oxidative stability, gut support	Moderate for laying performance; weak for fertility
<i>Moringa oleifera</i>	Polyphenols; carotenoids; micronutrients	Nutrient enrichment; antioxidant and lipid-modulating effects	Breeder-hen performance; hatching-egg quality	Limited-to-moderate
Gallic acid	Hydroxybenzoic acid	Direct radical scavenging; membrane and mitochondrial protection	Aged-rooster semen, hormones, fertility	Moderate; purified compound with dose-response

Botanical class	Representative bioactives	Main plausible mechanisms	Most relevant endpoints	Evidence appraisal
Camphor	Monoterpene ketone	Redox and endocrine modulation; dose-dependent action	Sperm motion, testosterone, fertility	Moderate but narrow safety window
Multi-herb blends	Variable polyphenol / terpene mixtures	Multi-target antioxidant, immune, gut, and endocrine effects	Breeder performance, oviductal sperm survival, chick quality	Promising, but attribution and standardization are weak

5. Evidence by Reproductive Endpoint

5.1 Egg Production, Egg Mass, and Persistency of Lay

The most quantitative evidence in females comes from a meta-analysis of 28 articles and 119 data points. Phytogenic extracts showed a quadratic improvement in egg production and egg mass and a reduction in feed conversion ratio, with estimated optima near 292-313 mg/kg for the pooled products. However, the pooled optimum should not be transferred directly to individual botanicals because extract concentration and marker content differed among studies (Darmawan A *et al.*, 2022).

Individual experiments demonstrate both benefit and risk. Fennel, red pepper, and black cumin improved selected productive and egg-quality traits in layers, whereas high turmeric inclusion reduced egg production, egg weight, and egg mass in older hens. Curcumin under cold stress improved antioxidant and antimicrobial status and supported egg quality, illustrating that response depends strongly on stress context and formulation (Abou-Elkhair R *et al.*, 2018; da Rosa G *et al.*, 2020; Mosayyeb Zadeh A *et al.*, 2023).

Moringa oleifera is attractive because it combines bioactive compounds with nutrients. In Sasso breeder hens, *Moringa* leaves affected performance, hatching-egg quality, and serum lipids, but the available evidence is insufficient to define an optimal marker-based dose or to separate nutritional from pharmacological effects (N'nanle O *et al.*, 2020).

More directly relevant to laying hens, an eight-week trial in 50-week-old Hy-Line Brown hens found that chive bulb extract at 0.5-1.5% did not increase egg production, egg weight, or egg mass, whereas 1.5% increased the Haugh unit without adverse changes in shell traits, visceral organ weights, or intestinal measurements. This distinction is useful because it shows that a botanical may improve a commercially relevant egg-quality trait without increasing reproductive output (Hai PV *et al.*, 2026a).

5.2 Egg Quality as a Reproductive and Commercial Endpoint

Egg quality is not equivalent to fertility, but it affects saleability, incubation water loss, gas exchange, embryo protection, and chick quality. Botanical effects on shell thickness, shell strength, albumen quality, yolk

oxidation, and yolk color are therefore relevant to both table-egg and hatching-egg systems.

Garlic and oregano studies illustrate the inconsistency of crude botanical inclusion. Garlic powder altered feed efficiency, microbial load, or selected egg traits without consistently increasing egg production. Oregano essential oil had clearer effects on oxidative stability than on laying rate, suggesting that product value may lie in shelf life and embryo protection rather than more eggs per hen (Yalcin S *et al.*, 2006; Olobatoke RY *et al.*, 2011; Migliorini MJ *et al.*, 2019).

A practical implication is that future breeder studies should evaluate shell conductance, egg weight loss during incubation, albumen quality, yolk antioxidant status, embryo mortality by stage, hatch window, and chick residual yolk. Reporting only Haugh unit and shell thickness misses several pathways by which botanicals could influence hatchability.

5.3 Female Fertility, Sperm Storage, and Hatchability

Compared with egg production, direct evidence for female fertility and hatchability is sparse. The strongest recent breeder-hen study used heat stress and measured sperm survival in the oviduct, gene expression, antioxidant status, egg traits, and offspring quality. The phytogenic antioxidant mixture partly restored performance and chick quality, supporting the concept that the female tract is an active target rather than a passive recipient of semen (Pasri P *et al.*, 2024).

This area deserves priority because avian sperm-storage tubules determine the duration of fertility after mating or insemination. Botanicals that reduce local oxidative stress or inflammation could preserve sperm viability, but they could also alter oviductal immunity in undesirable ways. Trials should therefore measure fertility persistence across days after insemination, not only the pooled fertility percentage.

5.4 Rooster Semen Quality and Fertility

Male reproductive evidence is more mechanistically coherent. Ginger, chive, Black ginger, camphor, gallic acid, and multi-herb blends have improved one or more of semen volume, concentration, motility, membrane integrity, viability, testosterone, antioxidant capacity, fertility, or hatchability. The common biological denominator is protection against oxidative and age-related decline rather than

indiscriminate stimulation of normal young males (Akhlaghi A *et al.*, 2014; Ghadimi M *et al.*, 2024; Hai PV *et al.*, 2025a).

Nevertheless, semen concentration and motility are imperfect proxies for fertility. Studies should incorporate computer-assisted sperm analysis, membrane functionality, mitochondrial potential, lipid peroxidation, chromatin or DNA integrity, insemination dose, fertility persistence, and hatchability. A treatment that improves motility but not fertility may still be useful

for semen storage, but it should not be marketed as a fertility enhancer without reproductive confirmation.

The chive study by Hai PV *et al.*, is particularly relevant to tropical production because it combined a natural heat challenge with endocrine and oxidative endpoints. At the higher tested exposure, malondialdehyde decreased while total antioxidant capacity and LH, FSH, and testosterone increased, accompanied by improved semen characteristics. This integrated pattern is stronger than a single biomarker response, although replication in larger breeder populations is still required (Hai PV *et al.*, 2025a).

Table 2: Representative controlled studies linking botanicals to poultry reproductive or closely related endpoints

Study	Birds / context	Intervention	Main reproductive or linked response	Interpretive value
Hai PV <i>et al.</i> , 2025a	Roosters; hot season	Chive bulb extract in drinking water	Improved semen traits; lower MDA; higher TAC, LH, FSH, testosterone	Direct male evidence; small sample
Akhlaghi A <i>et al.</i> , 2014	Aged Cobb 500 breeder roosters	15 or 30 g ginger/kg diet	Improved semen quality, sperm fatty acids, reproductive performance	Strong direct male study
Nemati Z <i>et al.</i> , 2023	Aged Ross 308 breeder roosters	Dietary ginger root	Improved motility, TAC, spermiation; limited fertility response	Shows biomarker-output gap
Aublackda S <i>et al.</i> , 2024	Black native roosters under heat stress	<i>Kaempferia parviflora</i> extract	Improved sperm production, preservation, fertility-related outcomes	Relevant stress model
Raei H <i>et al.</i> , 2021	Ross 308 breeder roosters	0-1000 mg camphor/kg	Low-dose gains in semen, testosterone, fertility; high-dose reversal	Clear non-linear response
Ghadimi M <i>et al.</i> , 2024	Aged rooster breeders	100 or 200 mg gallic acid/kg	Improved semen, hormones, antioxidant status, fertility-related traits	Purified-compound evidence
Asghari-Moghadam M <i>et al.</i> , 2025	Aged broiler breeder roosters	Commercial phytogetic blend	Improved reproductive, antioxidant, and immune indicators	Needs independent replication
Pasri P <i>et al.</i> , 2024	Breeder hens under heat stress	Clove + green tea pomace + Vietnamese coriander	Supported performance, oviductal sperm survival, redox status, chick quality	Best direct female stress study
N'nanle O <i>et al.</i> , 2020	Sasso breeder hens	<i>Moringa oleifera</i> leaves	Changes in breeder performance, hatching-egg quality, serum lipids	Nutritional and phytogetic effects overlap
Darmawan A <i>et al.</i> , 2022	Laying hens; meta-analysis	Multiple phytogetic extracts	Quadratic improvement in egg production and egg mass	Strong aggregate evidence; heterogeneous products
Abou-Elkhair R <i>et al.</i> , 2018	Laying hens	Fennel, black cumin, or red pepper	Fennel/red pepper improved laying traits; black cumin/red pepper lowered oxidation/cholesterol	Useful comparative trial
da Rosa G <i>et al.</i> , 2020	Laying hens under cold stress	Dietary curcumin	Improved antioxidant, antimicrobial, health, and egg-quality indices	Stress-dependent response
Mosayyeb Zadeh A <i>et al.</i> , 2023	Older laying hens	0.25-0.5% turmeric powder	Reduced egg production, egg weight, and egg mass	Important negative evidence

Study	Birds / context	Intervention	Main reproductive or linked response	Interpretive value
Migliorini MJ <i>et al.</i> , 2019	Laying hens in winter	Oregano essential oil	Lower yolk lipid peroxidation; longer egg shelf life	Quality benefit more than fertility
Sharma MK <i>et al.</i> , 2020	Late-phase laying hens	Phytogenic product in drinking water	Production, egg quality, intestinal histomorphology	Supports gut-reproductive axis
Reyer H <i>et al.</i> , 2026	Laying hens	Thyme/star anise/quillaja-based additive	Digestibility and tissue transcriptomic responses in follicle and uterus	Mechanistic, not fertility-confirming

6. Fermented Botanicals as a Next-Generation Platform

Fermentation can alter the chemical and biological profile of a botanical. *Lactiplantibacillus* may release bound phenolics, reduce anti-nutritional factors, generate organic acids and bacteriocin-like metabolites, and improve product stability. The resulting preparation is not simply the sum of a probiotic and a plant extract; it is a new biological product whose marker compounds and viable-cell counts must both be defined.

Hai and colleagues selected *Lactobacillus* strains from native chickens for fermenting purple onion and subsequently demonstrated activity of fermented chive or mixed *Allium* preparations against *E. coli*, *Salmonella*, and toxin-carrying bacteria (Hai PV *et al.*, 2024; Hai PV *et al.*, 2025b; Hai PV *et al.*, 2025c). This is relevant to reproduction because enteric disease, inflammation, and antibiotic exposure reduce nutrient allocation and flock persistency, while pathogen control is critical for hatching-egg sanitation and chick quality.

The reproductive hypothesis for fermented *Allium* products is therefore multi-layered: direct antioxidant and endocrine support, improved intestinal ecology, lower pathogen pressure, and more reproducible delivery of bioactive metabolites. This hypothesis is compelling but still requires breeder-specific trials measuring fertility, hatchability, embryo mortality, and vertical transmission of pathogens.

7. Why Results are Inconsistent

7.1 Botanical Identity and Chemical Variability

Species name alone is inadequate. Genotype, soil, climate, harvest stage, storage, plant part, and processing can change the concentration of bioactives by several fold. Essential oils additionally vary by chemotype, and heat during feed manufacture can reduce volatile compounds. Studies that do not report a voucher specimen, extraction yield, and marker compounds cannot be reproduced reliably.

For *Allium* products, sulfur chemistry changes rapidly after tissue disruption; for ginger, the gingerol-to-shogaol profile depends on drying and heating; for oregano and thyme, carvacrol and thymol proportions vary by chemotype. These differences can explain opposite results at nominally similar inclusion rates.

7.2 Non-Linear Dose-Response and Palatability

Botanicals often show hormetic or inverted-U responses. Low or moderate exposure may activate adaptive antioxidant pathways, whereas high exposure can reduce feed intake, irritate mucosa, inhibit enzymes, or become pro-oxidant. Camphor and turmeric studies provide clear examples of dose-related reversal or production depression (Raei H *et al.*, 2021; Mosayyeb Zadeh A *et al.*, 2023).

Dose should therefore be expressed both as product inclusion and as intake of one or more marker compounds per bird per day. Without actual feed or water intake, an apparent dose-response may simply reflect palatability.

7.3 Bird Phenotype and Baseline Constraint

A botanical is more likely to show benefit when it targets a real limitation. Heat-stressed roosters, aging breeder males, late-phase layers, pathogen-challenged flocks, or birds consuming oxidized diets provide biologically responsive models. In contrast, young unstressed birds on adequate diets may show little room for improvement.

This principle also affects external validity. A product that works in indigenous roosters under tropical heat may not have the same effect in modern breeder males under controlled ventilation. Trials should report genotype, body weight profile, age, stocking density, environmental temperature, humidity, and basal antioxidant supply.

Regional heat-stress studies also reinforce the importance of matching a botanical product to a defined constraint. A purple onion-*L. plantarum* synbiotic delivered through drinking water improved feed efficiency, antioxidant status, intestinal morphology, and gut microbial indices in heat-stressed Rilai chickens (Nguyen KDT *et al.*, 2026). In a separate study, lactic-fermented red onion delivered in drinking water improved feed efficiency, selectively modulated cecal microbiota, and reduced excreta ammonia under chronic heat stress (Hai PV *et al.*, 2026b). Neither study measured reproductive performance, but both support heat-stress resilience and water-delivery feasibility as relevant upstream considerations for breeder-focused trials.

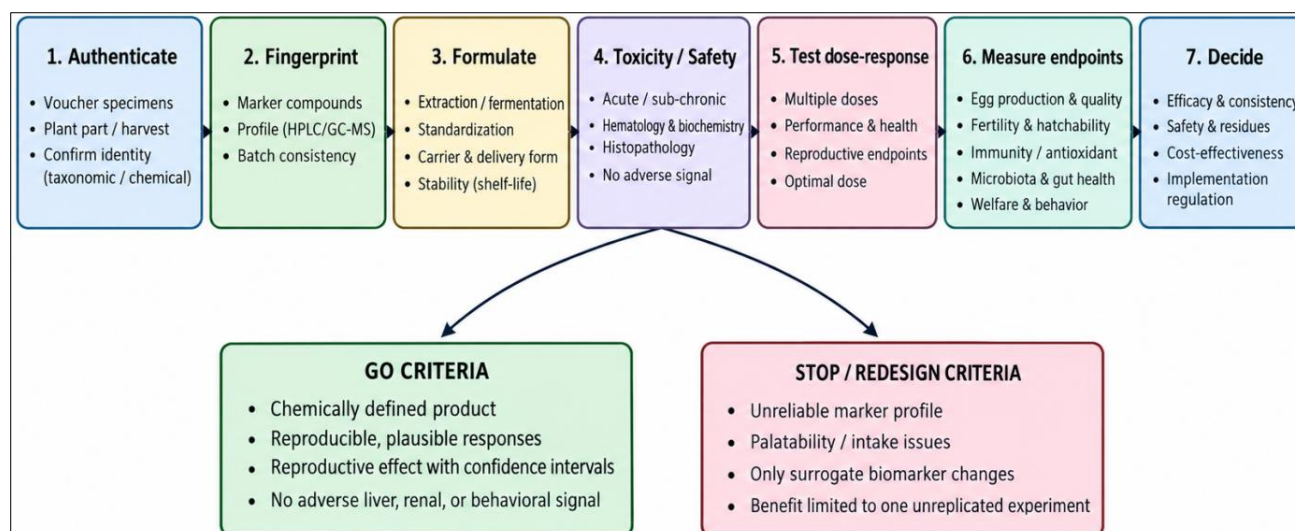


Figure 2: Translational pipeline for developing reproducible botanical interventions. The pipeline separates botanical authentication, chemical standardization, formulation, biological testing, and commercial decision-making

8. Safety, Residues, and Regulatory Considerations

Natural origin does not guarantee safety. Some essential oils and purified compounds have narrow margins between beneficial and adverse doses. Potential risks include reduced palatability, hepatotoxicity, enzyme inhibition, altered coagulation, reproductive endocrine disruption, and interactions with vaccines, coccidiostats, or medications.

Safety assessment should include feed and water intake, behavior, mortality, liver and kidney biomarkers, gross pathology, reproductive-organ histology, and, where relevant, residues or sensory

carryover in eggs. Botanical products intended for breeder flocks also require evaluation of embryo toxicity and offspring development.

Regulatory classification varies among jurisdictions. A chemically defined feed additive with consistent manufacturing is more defensible than an unstandardized herbal powder. Manufacturers should provide batch certificates for marker compounds, contaminants, microbial quality, and stability through the claimed shelf life.

9. Minimum Standards for Future Trials

Table 3: Recommended reporting standards and priority research questions

Domain	Minimum information	Why it matters
Botanical definition	Species authority, plant part, voucher specimen, origin, harvest and storage	Reduces misidentification and chemotype ambiguity
Chemical standardization	Extraction yield; marker compounds; chromatographic fingerprint; contaminant screen	Allows biological dose to be reproduced
Product stability	Retention in mash/pellet/feed; drinking-water stability; viable counts for fermented products	Confirms actual exposure
Experimental design	At least three doses; negative and relevant positive controls; pen as experimental unit; power calculation	Detects non-linear effects and avoids pseudoreplication
Bird characterization	Genotype, sex, age, body weight, reproductive stage, thermal and disease status	Defines the phenotype likely to respond
Female endpoints	Egg number and mass, persistency, shell conductance, fertility persistence, hatchability, embryo mortality, chick quality	Moves beyond generic egg-quality claims
Male endpoints	CASA motility, concentration, membrane function, mitochondrial potential, DNA integrity, hormones, fertility and hatchability	Links semen biomarkers to actual reproduction
Mechanistic endpoints	TAC, MDA, SOD, GPx, CAT, cytokines, microbiota, gut morphology, ovarian/testicular histology	Supports biological plausibility without replacing reproductive output
Statistics	Effect sizes and 95% confidence intervals; repeated measures; dose-response modeling; multiplicity control	Improves interpretability and synthesis
Translation	Cost per additional saleable egg or chick; product stability; safety; independent multi-site replication	Determines commercial relevance

The first priority is breeder-specific dose-response research. Layer studies cannot substitute for fertility and hatchability trials because the physiological bottlenecks differ. Female and male interventions should be tested separately and together, since a flock-level response may depend on both sexes.

The second priority is to connect chemical markers to biological exposure. For example, *Allium* studies should quantify relevant sulfur compounds and flavonoids, ginger studies should report gingerols and shogaols, and oregano or thyme products should report carvacrol and thymol. Fermented products should report both viable organisms and fermentation-derived metabolites.

The third priority is independent replication. Several promising products are supported by a single laboratory or commercial formulation. Multi-site trials across climate zones and genotypes are necessary before a universal recommendation can be justified.

Finally, economic endpoints should be integrated from the start. A small improvement in hatchability may be valuable in high-value breeder systems, whereas the same product may be uneconomic in table-egg production. Cost per additional saleable egg, hatching egg, or chick is the decision metric that connects biological significance with adoption.

10. CONCLUSIONS

Botanicals can improve poultry reproductive productivity, but their effects are conditional rather than universal. The most convincing responses occur when a chemically active product is matched to a defined biological constraint, particularly heat stress, reproductive aging, oxidative damage, or enteric challenge. Moderate phytogenic exposure can improve egg production and egg mass, while direct male studies show gains in semen quality, hormones, and sometimes fertility. Female fertility and hatchability remain understudied relative to egg production.

Allium-based research led by Vu Hai Phan provides an important regional contribution, especially the direct evidence for chive extract in heat-stressed roosters and the development of fermented botanical platforms. The next step is to test these standardized preparations in breeder flocks with fertility persistence, hatchability, embryo survival, and chick-quality endpoints.

The field should move from asking whether a named herb works to asking which chemically defined preparation, at what marker-compound exposure, in which bird phenotype, against which reproductive bottleneck, and with what economic return. That shift is necessary for botanical interventions to progress from promising experiments to reproducible reproductive technologies.

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