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# Reframing Rabbit Nutrition Through Caecotrophy: Hindgut Resilience, Functional Feed Additives and Meat Biofortification

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### *Abstract*

Rabbit nutrition is moving beyond conventional nutrient-supply models toward functional feeding strategies that support hindgut resilience, reduce post-weaning digestive disorders and improve meat quality. Rabbits are unique hindgut fermenters because caecotrophy allows recycling of microbial protein, vitamins and potentially microbial lipid metabolites. Therefore, caecotrophy can serve as a central framework linking diet structure, caecal fermentation, microbiota, fusus coli function and functional meat production. Recent literature suggests that digestive disorders in rabbits may arise not only from pathogens but also from nutritional and physiological disturbances such as excessive fermentable starch or protein, inadequate structural fibre, altered digesta passage and caecal microbial instability (van der Sluis et al., 2024). Probiotics, prebiotics, macroalgae, phytogenic additives, antioxidant-rich feeds and lipid supplements are promising tools, but many studies still lack direct measurements of cecotroph production, cecotroph composition, fusus coli function and caecal microbiota dynamics (Al-Soufi et al., 2022; Adli et al., 2023; Siudak & Kowalska, 2024). This review integrates recent advances in rabbit nutrition and proposes a caecotrophy-centred approach for improving digestive health and meat biofortification.

**Keywords:** rabbit nutrition; caecotrophy; fusus coli; caecal fermentation; probiotics; macroalgae; functional meat; fatty acids

## 1. Introduction

Rabbit meat is nutritionally attractive because it is lean, digestible and rich in high-quality protein, essential amino acids and unsaturated fatty acids. It contains relatively low fat, cholesterol and sodium. Siudak and Kowalska (2024) reported that rabbit meat contains about 6.8% fat, 59 mg cholesterol/100 g meat and 37 mg sodium/100 g loin meat. They also noted that oleic and linoleic acids are dominant fatty acids and together represent nearly 60% of total fatty acids. Despite this nutritional value, rabbit production faces serious challenges. Post-weaning digestive disorders, epizootic rabbit enteropathy and reduced use of prophylactic antibiotics have increased the need for nutritional alternatives that stabilize gut function. Al-

Soufi et al. (2022) highlighted that rabbit production requires sustainable strategies capable of improving intestinal health and reducing antibiotic dependence. This article proposes that rabbit nutrition should be reframed through **caecotrophy-centred functional nutrition**. In this approach, diets are evaluated not only by growth or feed conversion but also by their effects on caecal fermentation, microbial balance, fusus coli-mediated digesta separation, soft faeces quality and functional meat enrichment.

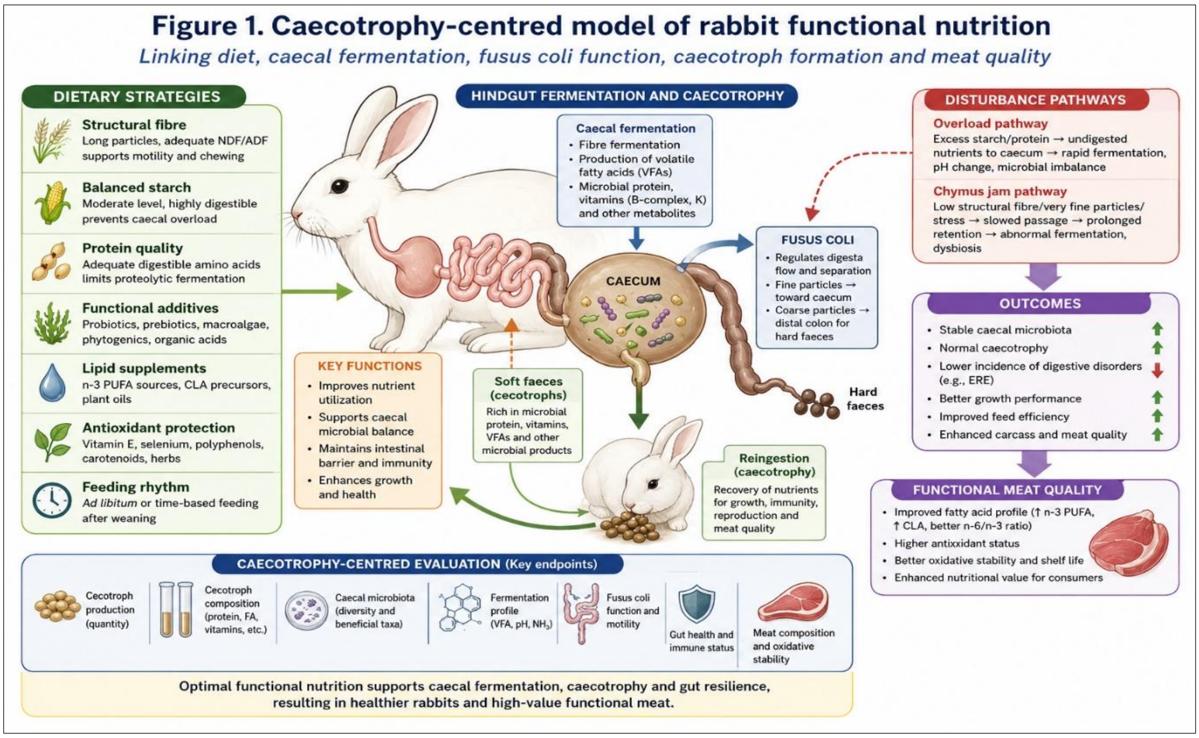

**Figure 1. Caecotrophy-centred model of rabbit functional nutrition**

*Linking diet, caecal fermentation, fusus coli function, caecotroph formation and meat quality*

Optimal functional nutrition supports caecal fermentation, caecotrophy and gut resilience, resulting in healthier rabbits and high-value functional meat.

**Figure 1:** Caecotrophy-centred model of rabbit functional nutrition linking dietary fibre, starch-protein balance, caecal fermentation, fusus coli function, soft faeces formation and gut resilience.

## 2. Caecotrophy and Hindgut Resilience

Rabbits are herbivorous hindgut fermenters with a large caecum that supports microbial fermentation. Caecotrophy—the reingestion of soft faeces or cecotrophs—allows rabbits to recover microbial protein, vitamins and other microbial products. Thus, caecotrophy is not only a behavioural feature but a central nutritional process (Al-Soufi et al., 2022). Caecotrophy begins to develop around three weeks of age, while digestive enzyme capacity becomes optimal at approximately 45–50 days. The caecal microbiota stabilizes around 30–40 days but remains strongly influenced by diet (Al-Soufi et al., 2022). This makes the early post-weaning period highly sensitive to dietary imbalance. The fusus coli is also critical. It regulates colonic motility, hard and soft faeces formation and separation of fermentable and indigestible fractions. van der Sluis et al. (2024) described it as a key regulator of digesta passage and caecotrophy-related function. Fine particles are redirected toward the caecum, whereas coarser particles pass distally for hard faeces formation. Therefore, caecotrophy depends on coordinated caecal fermentation, fibre structure, colonic motility and microbial activity.

**Table 1.** Caecotrophy-centred nutritional targets for improving rabbit hindgut resilience and functional meat quality

| Nutritional target | Main physiological link | Expected benefit |
|---|---|---|
| Adequate structural fibre | Supports gut motility, fusus coli activity and hard faeces formation | Lower risk of caecal retention and digestive instability |
| Fibre particle size | Influences separation of fine and coarse particles in the colon | Better regulation of caecal retention and soft faeces formation |
| Controlled starch supply | Reduces excess fermentable substrate entering the caecum | Lower risk of caecal hyperfermentation and microbial imbalance |
| Balanced protein level and quality | Limits excessive proteolytic fermentation and ammonia production | Better caecal microbial stability |
| Time-based feed restriction | May allow partial emptying of caecum/proximal colon | Reduced post-weaning digestive disorders |
| Probiotics and yeast | Modulate gut microbiota and intestinal barrier function | Improved body-weight gain and possible metabolic benefits |
| Prebiotics and macroalgae polysaccharides | Provide fermentable substrates for beneficial microbes | Potential improvement in caecal ecology and gut health |
| Antioxidant-rich phytogenic feeds | Improve oxidative stability and protect PUFA-rich tissues | Better meat shelf life and functional quality |
| n-3 PUFA-rich lipid supplements | Increase ALA, EPA, DHA and improve n-6/n-3 ratio | Functional meat biofortification |
| Caecotrophy-focused evaluation | Connects diet, caecal microbiota, microbial nutrients and meat traits | More accurate assessment of rabbit-specific nutritional responses |

*ERE: epizootic rabbit enteropathy; VFA: volatile fatty acids; PUFA: polyunsaturated fatty acids; ALA: α-linolenic acid; EPA: eicosapentaenoic acid; DHA: docosahexaenoic acid. Evidence summarized from Al-Soufi et al. (2022), Adli et al. (2023), Delis-Hechavarria et al. (2021), Siudak and Kowalska (2024), and van der Sluis et al. (2024).*

## 3. Post-Weaning Digestive Vulnerability

The post-weaning period is a critical stage in rabbit production because rabbits shift from milk to solid feed while gastric acidity, digestive enzymes, caecal fermentation and immunity are still developing. Gastric pH may fall from above 5 to nearly 1.6 around weaning (Al-Soufi et al., 2022). During this stage, rabbits are highly susceptible to epizootic rabbit enteropathy and other non-specific enteropathies, especially at 6–8 weeks of age. ERE may cause morbidity up to 90% and mortality of 30–80%, with signs such as reduced intake, abdominal distension, mild diarrhoea and caecal impaction (Al-Soufi et al., 2022). Therefore, post-weaning diets should prioritize caecal stability and microbial balance rather than only nutrient density.

## 4. Overload and Chymus Jam Pathways

van der Sluis et al. (2024) proposed two conceptual mechanisms for digestive derailment: the **overload pathway** and the **chymus jam pathway**. In the overload pathway, excess starch or protein escapes small-intestinal digestion and enters the caecum, causing rapid fermentation, pH disturbance, ammonia accumulation and microbial imbalance. In the chymus jam pathway, low structural fibre, fine particles or stress reduce digesta passage, prolong caecal retention and promote abnormal fermentation. These pathways may overlap because low-fibre diets are often starch-rich. Thus, rabbit diets should balance fibre structure, starch, protein quality and feeding rhythm.

## 5. Fibre Structure and Feeding Rhythm

Fibre is essential for rabbit gut health, but its physical form is as important as its chemical fraction. Diets with similar NDF or ADF may differ biologically if particle size differs. Fine particles below about 0.3 mm tend to return toward the caecum, while larger particles move toward the distal colon (van der Sluis et al., 2024). Excessive grinding may increase caecal retention, whereas adequate coarse fibre supports motility, fusus coli function and normal hard/soft faeces rhythm. Time-based feed restriction after weaning may also reduce digestive problems, but its mechanism still needs validation.

## 6. Probiotics, Prebiotics and Macroalgae

Probiotics are promising alternatives to antibiotic growth promoters. A meta-analysis of 35 in vivo rabbit studies with 964 treatment units showed that lactic acid bacteria and yeast improved final body weight and body-weight gain, but effects on FCR, intake, mortality and digestibility were inconsistent (Adli et al., 2023). Therefore, probiotics should be considered gut-modulatory additives, not guaranteed enteropathy preventives.

Macroalgae are also promising because they provide polysaccharides, minerals, vitamins, polyphenols, PUFA and fermentable fibres. Brown algae contain laminarin, fucoidan and alginate; green algae provide ulvan; and red algae contain agar and carrageenan-related compounds (Al-Soufi et al., 2022). However, rabbit-specific evidence remains limited, so future studies should assess caecal VFA, microbiota, cecotroph composition and post-weaning morbidity.

## 7. Functional Feeds and Antioxidant Protection

Functional feeds provide benefits beyond basic nutrition. In rabbits, these include probiotics, prebiotics, algae, vitamins, minerals, carotenoids, anthocyanins, herbs, oils, fodder plants and plant by-products (Delis-Hechavarria et al., 2021). Phytogenic additives such as oregano, thyme, rosemary, moringa and olive leaves may improve meat quality and oxidative stability. Antioxidants are especially important when meat is enriched with PUFA because unsaturated fatty acids improve nutritional value but increase oxidation risk. Vitamin E, selenium, phenolic-rich plants and herbal extracts may help protect meat during storage. Controlled elicitation of plants to increase phenolics and flavonoids is a promising future strategy but needs validation in rabbits.

## 8. Lipid Nutrition and Functional Meat Biofortification

Dietary lipid manipulation is a rapid way to improve rabbit meat composition. Supplements such as linseed, chia, perilla, moringa, fish oil, soybean oil, silkworm oil, black soldier fly larvae fat and synthetic CLA can modify the fatty acid profile (Siudak & Kowalska, 2024). Linseed, chia and perilla are especially effective for increasing n-3 PUFA. Chia increased ALA in longissimus dorsi from 5.0% to 20.9–25.2%, while perilla reduced the n-6/n-3 ratio from 6.53 to 1.35–1.00. Moringa at 1.5% increased n-3 PUFA by about 33.71% (Siudak & Kowalska, 2024). CLA detected in cecotrophs suggests a possible link between caecal microbial lipid metabolism and meat lipid deposition, but this pathway remains unclear. PUFA enrichment should always be combined with antioxidant protection to prevent lipid oxidation and shelf-life loss.

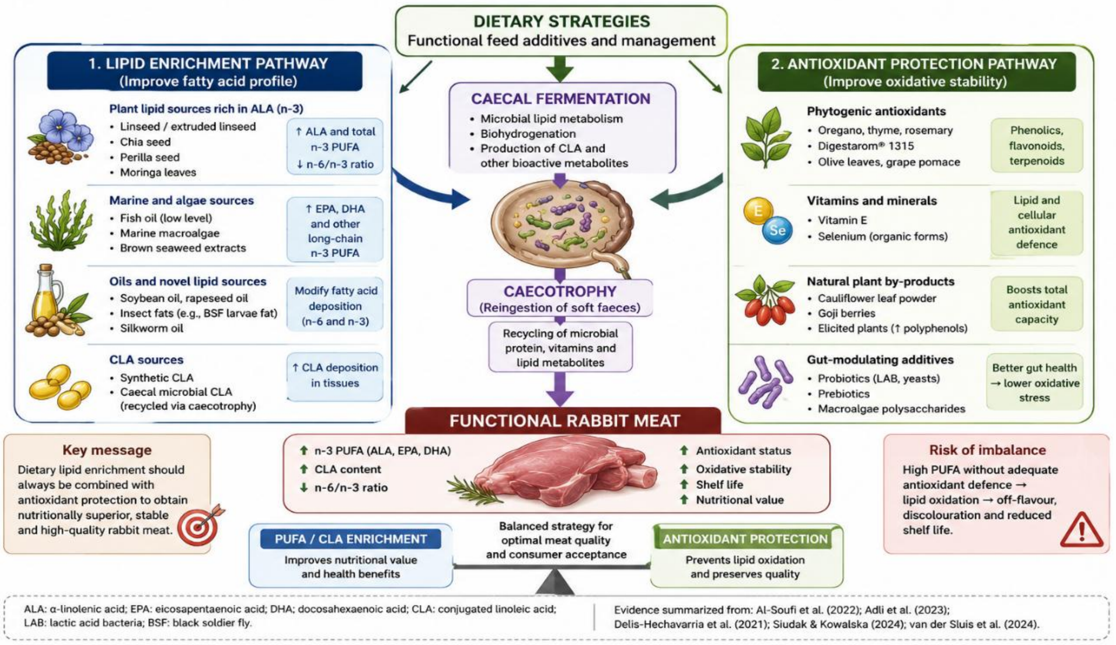

Figure 2. Dietary pathways for functional rabbit meat enrichment: balancing PUFA/CLA deposition with antioxidant protection

**Key message**

Dietary lipid enrichment should always be combined with antioxidant protection to obtain nutritionally superior, stable and high-quality rabbit meat.

**Risk of imbalance**

High PUFA without adequate antioxidant defence → lipid oxidation → off-flavour, discolouration and reduced shelf life.

ALA: α-linolenic acid; EPA: eicosapentaenoic acid; DHA; docosahexaenoic acid; CLA: conjugated linoleic acid; LAB: lactic acid bacteria; BSF: black soldier fly.

Evidence summarized from: Al-Soufi et al. (2022); Adli et al. (2023); Delis-Hechavarria et al. (2021); Siudak & Kowalska (2024); van der Sluis et al. (2024).

**Table 2**. Functional feed additives for improving rabbit meat bioactive value and oxidative stability

| **Feed additive/category** | **Reported level or inclusion** | **Main biofortification effect** | **Main limitation/caution** |
|---|---|---|---|
| Linseed / extruded linseed | ~3–8%; also 100–200 g/kg DM in reviewed studies | Increases ALA and total n-3 PUFA; lowers n-6/n-3 ratio | High inclusion may increase lipid oxidation and reduce shelf life |
| Chia seed | 10–15% | Markedly increases ALA in longissimus muscle | High inclusion needs evaluation for cost, intake and meat stability |
| Perilla seed | 5–10% | Strongly reduces n-6/n-3 ratio; 5% may be more practical | Higher inclusion may not always improve overall carcass/meat traits |
| Moringa leaves | 0.5–1.5% | Increases n-3 PUFA in a dose-dependent manner | Reproductive effects may be sex-dependent; needs dose validation |

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|---|---|---|---|
| Oregano extract | 2% | Reduces saturated fatty acids and increases PUFA in loin meat | Response may differ between loin and hind leg meat |
| Thyme | 3% | Increases n-3 PUFA and reduces lipid oxidation during storage | Requires broader validation under different diets |
| Digestarom® 1315 herbal blend | 300 mg/kg feed | Increases EPA and DHA; improves n-3 profile | Timing of supplementation influences response |
| Olive leaves / Se-enriched olive leaves | 10% olive leaves; selenium-enriched form in reviewed study | Does not impair meat quality; may improve ALA and oxidative status | More dose-response data needed |
| Avocado waste | 4.32–12.25% | Increases n-3 PUFA and lowers n-6/n-3 ratio | High inclusion may increase meat pH and reduce technological suitability |
| Grape pomace | 20% | Reduces some saturated fatty acids and increases PUFA, mainly linoleic acid | May reduce ALA and increase n-6/n-3 ratio |
| White lupin seed | 120 g/kg feed | Lowers SFA; increases ALA and EPA; improves lipid health indices | Needs performance and economic evaluation |
| Soybean oil | 1.5–3% | Improves unsaturated fatty acid deposition | Mainly supports n-6 enrichment; should be balanced with n-3 sources |

| | | | |
|---|---|---|---|
| Rapeseed oil + fish oil | 2% rapeseed oil + 1% fish oil | Increases EPA/DHA and reduces SFA | Fish oil should remain low to avoid sensory defects |
| Mulberry silkworm oil | 13 g/kg feed | Increases n-3 fatty acids and reduces n-6/n-3 ratio | Evidence is recent and limited |
| Black soldier fly larvae fat | 30–60 g/kg DM | Modifies lipid profile, especially long-chain n-6 fatty acids | Less effective than linseed for n-3 enrichment |
| Synthetic CLA | 0.5–1% or 5–10 g/kg feed | Increases tissue CLA and modifies lipid metabolism | Dose-response and duration effects are inconsistent |
| Brown seaweed + plant polyphenols | 0.3–0.6% | May improve antioxidant status and meat quality | Rabbit-specific evidence remains limited |
| Probiotics: LAB/yeast | Variable CFU/kg feed | Improves body-weight gain; may influence lipid-related blood metabolites | Effects on FCR, mortality and digestibility are inconsistent |

*ALA: α-linolenic acid; EPA: eicosapentaenoic acid; DHA: docosahexaenoic acid; CLA: conjugated linoleic acid; PUFA: polyunsaturated fatty acids; SFA: saturated fatty acids; LAB: lactic acid bacteria; DM: dry matter. Evidence summarized from Al-Soufi et al. (2022), Adli et al. (2023), Delis-Hechavarria et al. (2021), and Siudak and Kowalska (2024).*

## 9. Future Research Priorities

Current rabbit nutrition studies often focus on growth, blood metabolites or meat composition, while direct measurements of cecotroph production, cecotroph nutrient profile, caecal microbiota, fusus coli function and particle-size-dependent digesta flow are rarely included. Future research should combine cecotroph analysis, fibre particle-size evaluation, caecal VFA and microbiome profiling, and validation of overload and chymus jam pathways. Dose-response studies on macroalgae, phytogenic additives and PUFA–antioxidant combinations are also needed to improve gut resilience and meat quality without compromising shelf life.

## 10. Conclusion

Rabbit nutrition should be reframed around caecotrophy-centred functional feeding because caecotrophy connects diet structure, caecal fermentation, microbial nutrient recycling, fusus coli function and meat quality. Structural fibre, particle size, balanced starch and protein, probiotics, prebiotics, macroalgae, phytogenic additives, antioxidants and lipid supplements may all contribute, but evidence strength differs. Probiotics show stronger support for growth than mortality reduction, macroalgae remain undervalidated in rabbits, and PUFA enrichment requires antioxidant protection. Future studies should move beyond performance endpoints and directly assess caecotrophy, caecal fermentation, microbiota, cecotroph composition and meat oxidative stability.

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