Bioactive Phytochemistry, Therapeutic Potential and Nutrient Digestibility of Turmeric, Ginger, Garlic and Onion in Farm Animal Nutrition

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Abstract

Phytogenic agents are plant-derived feed additives rich in bioactive compounds that are increasingly used in animal nutrition to enhance growth performance, nutrient utilisation and overall health status. Owing to restrictions on antibiotic growth promoters, phytogenic additives have gained attention as sustainable alternatives because of their antioxidant, antimicrobial, anti-inflammatory and immunomodulatory properties, which improve gut health, feed efficiency and immune function in farm animals. Their application in poultry, ruminants, rabbits and aquaculture species has been associated with improved nutrient digestibility, reduced oxidative stress and enhanced animal welfare, thereby supporting safer and more sustainable livestock production systems. Turmeric (Curcuma longa), ginger (Zingiber officinale), garlic (Allium sativum), and onion (Allium cepa) are globally utilised culinary botanicals with increasing scientific recognition as functional feed additives in livestock production. The progressive restriction of antibiotic growth promoters has intensified research interest in phytogenic alternatives capable of enhancing nutrient digestibility, gut health, immune competence, and productivity in farm animals. This review synthesises recent advances in understanding the nutritional composition, bioactive phytochemistry, and therapeutic potential of these four botanicals, with particular emphasis on their influence on nutrient digestibility in poultry, ruminant, porcine and rabbit. Although they contribute modest amounts of macronutrients and micronutrients, their primary functional value lies on specialised phytochemicals such as curcuminoids, gingerols, shogaols, organosulfur compounds, flavonoids, and fructans. These bioactives exert antioxidant, anti-inflammatory, antimicrobial, immunomodulatory, and gut-modulatory effects through molecular pathways involving Nrf2, NF-κB, MAPK, and modulation of gastrointestinal microbiota. Experimental evidence demonstrates improvements in apparent digestibility coefficients, feed conversion efficiency, intestinal morphology, digestive enzyme activity, rumen fermentation efficiency, and resistance to oxidative and inflammatory stress. However, challenges persist regarding phytochemical variability, bioavailability limitations—particularly for curcumin—and the need for species-specific dosing strategies. By integrating phytochemical mechanisms with digestive physiology and production outcomes, this review highlights turmeric, ginger, garlic, and onion as promising natural tools for improving nutrient utilisation and sustainability in modern livestock systems.

Keywords: Phytogenic feed additives; Curcumin; Gingerols; Organosulfur compounds; Livestock nutrition.

Running Title: Herbal supplementation in farm animals.

Phytochimie bioactive, potentiel thérapeutique et digestibilité des nutriments du curcuma, du gingembre, de l'ail et de l'oignon dans l'alimentation des animaux d'élevage

Résumé

Les agents phytogéniques sont des additifs alimentaires d'origine végétale riches en composés bioactifs, de plus en plus utilisés en nutrition animale pour améliorer les performances de croissance, l'utilisation des nutriments et l'état de santé général. En raison des restrictions imposées aux antibiotiques de croissance, les additifs phytogéniques ont attiré l'attention en tant qu'alternatives durables grâce à leurs propriétés antioxydantes, antimicrobiennes, anti-inflammatoires et immunomodulatrices, qui améliorent la santé intestinale, l'efficacité alimentaire et la fonction immunitaire chez les animaux d'élevage. Leur utilisation *chez les volailles, les ruminants, les lapins et les espèces aquacoles a été associée à une meilleure digestibilité des nutriments, à une réduction du stress oxydatif et à un bien-être animal accru, favorisant ainsi des systèmes de production animale plus sûrs et plus durables. Le curcuma (Curcuma longa), le gingembre (Zingiber officinale), l'ail (Allium sativum) et l'oignon (Allium cepa) sont des plantes culinaires utilisées dans le monde entier et de plus en plus reconnues scientifiquement comme additifs alimentaires fonctionnels dans la production animale. La restriction progressive des antibiotiques utilisés comme facteurs de croissance a renforcé l'intérêt des chercheurs pour les alternatives phytogéniques capables d'améliorer la digestibilité des nutriments, la santé intestinale, la compétence immunitaire et la productivité chez les animaux d'élevage. Cette revue synthétise les avancées récentes dans la compréhension de la composition nutritionnelle, de la phytochimie bioactive et du potentiel thérapeutique de ces quatre plantes, en mettant particulièrement l'accent sur leur influence sur la digestibilité des nutriments chez la volaille, les ruminants, les porcs et les lapins. Bien qu'ils n'apportent que de faibles quantités de macronutriments et de micronutriments, leur principale valeur fonctionnelle réside dans des composés phytochimiques spécialisés tels que les curcuminoïdes, les gingérols, les shogaols, les composés organosulfurés, les flavonoïdes et les fructanes. Ces composés bioactifs exercent des effets antioxydants, anti-inflammatoires, antimicrobiens, immunomodulateurs et modulateurs de la fonction intestinale par le biais de voies moléculaires impliquant Nrf2, NF-κB, MAPK et la modulation du microbiote gastro-intestinal. Les données expérimentales démontrent des améliorations au niveau des coefficients de digestibilité apparente, de l'indice de conversion alimentaire, de la morphologie intestinale, de l'activité des enzymes digestives, de l'efficacité de la fermentation ruminale et de la résistance au stress oxydatif et inflammatoire. Cependant, des défis persistent concernant la variabilité phytochimique, les limites de biodisponibilité — en particulier pour la curcumine — et la nécessité de stratégies de dosage spécifiques à chaque espèce. En intégrant les mécanismes phytochimiques à la physiologie digestive et aux résultats de production, cette revue met en avant le curcuma, le gingembre, l'ail et l'oignon comme des outils naturels prometteurs pour améliorer l'utilisation des nutriments et la durabilité dans les systèmes d'élevage modernes.*

Mots-clés : Additifs alimentaires phytogéniques ; Curcumine ; Gingérols ; Composés organosulfurés ; Nutrition animale.

Introduction

The global livestock industry is increasingly required to improve productivity while responding to growing concerns around antimicrobial resistance, environmental sustainability, animal welfare, and rising consumer preference for naturally derived food products. These pressures have driven a shift towards more sustainable production strategies that reduce reliance on synthetic chemotherapeutics and support healthier food systems (Hossain et al., 2022; Windisch et al., 2022; Zhu et al., 2020). Historically, antibiotic growth promoters (AGPs) were widely used in animal agriculture to enhance feed efficiency, growth rate and disease resistance; however, their extensive use contributed to the emergence of antimicrobial resistance, prompting regulatory restrictions and bans in many regions (Aletor, 2014; Sahoo et al., 2021; Windisch et al., 2022). However, their prolonged and indiscriminate use has contributed to the emergence of antimicrobial-resistant pathogens, prompting regulatory bans or restrictions in many regions, including the European Union and parts of Asia and Africa (Sahoo *et al.,* 2021; Windisch *et al.,*2022).

Phytogenic agents, also known as phytobiotics or botanical feed additives, are naturally derived plant products incorporated into animal diets to improve growth performance, nutrient utilisation, health status and product quality. These agents include herbs, spices, essential oils and plant extracts rich in bioactive compounds such as polyphenols, flavonoids, alkaloids and organosulphur compounds. The growing restriction on antibiotic growth promoters in livestock production has increased interest in phytogenic additives as safer and sustainable alternatives. Phytogenic compounds exert antioxidant, antimicrobial, anti-inflammatory and immunomodulatory effects, thereby enhancing gut health, digestive enzyme activity and feed efficiency in farm animals. In poultry, ruminants, rabbits and aquaculture species, phytogenic supplementation has been associated with improved nutrient digestibility, enhanced immune responses and reduced oxidative stress. Consequently, phytogenic feed additives are increasingly recognised as important components of modern animal nutrition strategies aimed at promoting productivity, animal welfare and food safety (Ajanaku et al., 2022; Faniyi et al., 2021; Hossain et al., 2022).

In response, phytogenic feed additives—plant-derived materials incorporated into animal diets—have emerged as viable alternatives. Among the wide range of medicinal and culinary plants investigated for animal nutrition, phytogenic feed additives such as oregano (*Origanum vulgare*), thyme (*Thymus vulgaris*), rosemary (*Rosmarinus officinalis*), cinnamon (*Cinnamomum verum*), fenugreek (*Trigonella foenum-graecum*), moringa (*Moringa oleifera*), neem (*Azadirachta indica*), clove (*Syzygium aromaticum*) and black pepper (*Piper nigrum*) have also demonstrated notable biological activities and are widely explored as alternatives to synthetic growth promoters. Within this broader phytogenic spectrum, turmeric (*Curcuma longa*), ginger (*Zingiber officinale*), garlic (*Allium sativum*) and onion (*Allium cepa*) remain particularly prominent due to their long-standing dietary use, well-documented safety profiles and broad-spectrum pharmacological properties (Li et al., 2021). These botanicals are widely available, culturally accepted and economically accessible across both developed and developing regions, which enhances their practical relevance for inclusion in smallholder and intensive livestock production systems where cost-effective and sustainable feed solutions are essential.

Beyond their culinary roles, these plants are rich sources of secondary metabolites with profound biological activities. Curcuminoids in turmeric, gingerols and shogaols in ginger, and organosulfur compounds and flavonoids in garlic and onion have been shown to modulate oxidative stress, inflammation, immune responses, and microbial populations within the gastrointestinal tract (Hewlings and Kalman, 2017; Mao *et al.*, 2019; Lanzotti, 2020). These processes are intimately linked to nutrient digestibility and feed utilisation, which are central determinants of animal performance and production efficiency.

Digestive efficiency in farm animals is governed by complex interactions between diet composition, digestive enzyme secretion, intestinal morphology, microbial ecology, and host metabolic regulation. Disruptions to gut homeostasis—whether due to pathogenic infection, oxidative stress, or inflammatory responses—can significantly impair nutrient absorption and utilisation. Consequently, phytogenic compounds capable of stabilising gut environments and enhancing digestive function represent valuable nutritional tools.

Although numerous studies have explored the effects of individual botanicals on growth performance and health indices, comprehensive synthesis linking phytochemical composition, mechanistic pathways, and nutrient digestibility across multiple animal species remains limited. This review therefore aims to:

(i) examine the nutritional composition of turmeric, ginger, garlic, and onion;

(ii) analyse their defining phytochemical constituents and molecular mechanisms;

(iii) evaluate experimental evidence on their effects on nutrient digestibility and digestive physiology in farm animals; and

(iv) identify challenges, knowledge gaps, and future research priorities for their effective application in livestock nutrition.

Nutritional Composition of Turmeric, Ginger, Garlic, and Onion

Proximate Composition

The proximate composition of turmeric (*Curcuma longa*), ginger (*Zingiber officinale*), garlic (*Allium sativum*) and onion (*Allium cepa*) varies considerably depending on several factors, including plant variety, soil fertility, climatic conditions, stage of maturity at harvest, and post-harvest processing methods such as drying, milling or extraction. In addition, whether these botanicals are used in fresh, dried or powdered form can markedly influence their moisture content, fibre levels, ash composition and concentration of bioactive constituents. Such variability is not merely a compositional concern but has direct implications for their biological efficacy when applied as phytogenic feed additives in animal nutrition, as differences in nutrient density and phytochemical concentration can alter their antioxidant, antimicrobial and metabolic effects across livestock species (Akhila et al., 2022; Li et al., 2021; Mao et al., 2019).

Turmeric and ginger rhizomes, particularly when dried, are characterised by relatively high dry matter content, commonly exceeding 85%. Carbohydrates constitute the dominant macronutrient fraction, typically accounting for 60–70% of dry matter (Mao *et al.,* 2019; Akhila *et al.,* 2022). These carbohydrates comprise both starch and non-starch polysaccharides, including cellulose and hemicellulose, which contribute to dietary energy and fibre supply. Although their direct caloric contribution to livestock diets is limited due to low inclusion rates, these carbohydrate fractions influence gut motility and microbial fermentation dynamics.

Crude protein content in turmeric and ginger generally ranges between 6 and 10% on a dry matter basis, reflecting the presence of structural and enzymatic proteins. Ether extract levels are comparatively low, usually below 5%, consisting mainly of essential oils and lipid-soluble phytochemicals. Dietary fibre content is moderate to high, particularly in turmeric, due to its fibrous rhizome structure. This fibre fraction may slow digesta transit time and promote favourable microbial activity, thereby indirectly enhancing nutrient digestibility.

In contrast, garlic and onion bulbs are characterised by very high moisture content, often exceeding 85% in fresh form, resulting in lower concentrations of macronutrients on a fresh-weight basis. When dried, however, their nutrient density increases substantially. Carbohydrates remain the predominant macronutrient, primarily in the form of simple sugars such as glucose and fructose, as well as fructans, which function as fermentable dietary fibre (Slimestad *et al.,* 2007). Crude protein content is generally low, typically ranging from 3 to 6% of dry matter, while lipid content is minimal.

Although garlic and onion contribute only marginally to the overall nutrient supply when included at typical dietary levels, their fermentable carbohydrate fractions—particularly fructans—play an important functional role in gut health modulation. These non-digestible carbohydrates act as prebiotic substrates that selectively stimulate the growth and activity of beneficial intestinal microbiota, including lactic acid-producing bacteria. This microbial shift enhances fermentation processes within the hindgut, resulting in increased production of short-chain fatty acids such as acetate, propionate and butyrate, which are essential for maintaining intestinal epithelial integrity, regulating luminal pH and supporting nutrient absorption. Through these pathways, garlic and onion indirectly improve gut ecosystem stability, reduce pathogenic bacterial colonisation and enhance overall feed efficiency and nutrient utilisation in farm animals (Lanzotti, 2020; Slimestad et al., 2007; Kumari et al., 2022).

Comparative table summarising the proximate composition of key phytogenic additives (*Curcuma longa*, *Zingiber officinale*, *Allium sativum* and *Allium cepa*) as reported by different authors (Table 1). Values are presented in ranges where studies differ, reflecting natural variability due to variety, processing and analytical methods.

Table 1: Proximate composition of turmeric (*Curcuma longa*), ginger (*Zingiber officinale*), garlic (*Allium sativum*) and onion (*Allium cepa*) (dry weight basis)

Plant	Moisture (%)	Crude protein (%)	Ether extract (%)	Crude fibre (%)	Ash (%)	Carbohydrate (%)	Source
Turmeric rhizome	8–12	6.3–9.4	4.5–7.8	6.0–9.2	5.0–7.5	65–75	**Akhila et al. (2022); Li et al. (2021)**
Turmeric powder	6–10	7.0–10.2	5.0–8.0	5.5–8.5	6.0–8.0	60–70	**Prasad & Aggarwal (2011); Li et al. (2021)**
Ginger rhizome	78–85 (fresh)	7.5–10.5	3.0–6.0	4.0–7.0	5.5–8.0	70–80 (dry basis)	**Mao et al. (2019); Muhammad et al. (2025)**
Ginger powder	8–12	8.0–11.0	4.0–7.5	5.0–8.0	5.0–7.0	60–72	**Mao et al. (2019)**
Garlic bulb (fresh)	60–70	5.5–7.5	0.5–2.0	1.5–3.5	1.0–2.5	20–30	**Bayan et al. (2014); Dalhat et al. (2018)**
Garlic powder	5–10	16–18	1.5–3.0	2.0–4.0	3.0–5.0	65–75	**Lanzotti (2020); Kodera et al. (2017)**
Onion bulb (fresh)	85–92	1.2–2.5	0.1–0.5	1.0–2.0	0.5–1.2	5–10	**Slimestad et al. (2007)**
Onion powder	6–10	7.0–10.0	0.5–1.5	3.0–5.0	2.5–4.5	70–80	**Kumari et al. (2022); Lanzotti (2020)**

Table 2: Summary comparison of phytogenic additives (average proximate profile)

Phytogenic additive	Protein (%)	Fibre (%)	Lipid (%)	Ash (%)	Functional implication in animal nutrition
Turmeric	6–10	5–9	4–8	5–8	Antioxidant-rich; supports liver and gut health
Ginger	7–11	4–8	3–7	5–8	Enhances digestion and immune modulation
Garlic	6–18	2–4	0.5–3	1–5	Strong antimicrobial and lipid-lowering effects
Onion	1–10	1–5	0.1–1.5	0.5–4.5	Prebiotic-rich; supports gut microbiota balance

Source: Adapted from **Mao et al. (2019); Muhammad et al. (2025)**

The proximate composition profiles demonstrate clear inter-species and inter-processing variability among phytogenic additives. Garlic and onion exhibit comparatively lower lipid and fibre fractions in their fresh forms but show increased nutrient density upon dehydration due to moisture loss. Conversely, turmeric and ginger display higher fibre and carbohydrate fractions, which contribute to their functional roles in gastrointestinal modulation. Importantly, these compositional differences influence not only nutrient availability but also the concentration of bioactive compounds responsible for antioxidant, antimicrobial and immunomodulatory effects (Table 1 & 2). Such variability underscores the need for standardised processing and dosage calibration when incorporating phytogenic additives into livestock feeding systems to ensure reproducible physiological responses.

Mineral and Vitamin Composition

In addition to macronutrients, turmeric, ginger, garlic, and onion provide a range of essential minerals and vitamins that support metabolic, enzymatic, and immune functions in farm animals. Although these micronutrients are unlikely to meet dietary requirements at typical supplementation levels, their presence may exert synergistic effects that enhance physiological resilience and nutrient utilisation.

Potassium is particularly abundant in garlic and onion, reflecting their role in plant osmotic regulation. Potassium contributes to acid–base balance, nerve conduction, and muscle function in animals. Turmeric and ginger contain appreciable amounts of calcium, magnesium, and phosphorus, which are essential for skeletal development, enzyme activation, and energy metabolism (Dalhat *et al.,* 2018). Trace elements such as iron, manganese, zinc, and copper are present in varying concentrations, supporting haemoglobin synthesis, antioxidant enzyme systems, and immune competence.

Garlic is recognised as a notable dietary source of selenium, an essential trace mineral involved in glutathione peroxidase activity and cellular antioxidant defence (Bayan *et al.,* 2014). Selenium availability from garlic may enhance antioxidant status and reproductive performance, particularly in regions where dietary selenium is marginal.

Vitamin content differs markedly among these botanicals, reflecting their diverse phytochemical profiles and physiological roles in animal nutrition. Onion is a notable dietary source of vitamin C, which contributes to antioxidant defence mechanisms and supports immune modulation through the scavenging of reactive oxygen species and enhancement of leukocyte function. Garlic contains appreciable levels of B-complex vitamins, including thiamine, riboflavin and pyridoxine, which are essential cofactors in carbohydrate metabolism, energy production and nervous system functioning. In contrast, turmeric and ginger provide relatively small but biologically relevant quantities of fat-soluble vitamins such as vitamin E and vitamin K, which contribute to membrane stability, coagulation processes and antioxidant protection. Collectively, these vitamin fractions complement the major bioactive compounds in these spices, reinforcing their multifunctional roles in oxidative balance, metabolic regulation and immune enhancement in farm animals (Li et al., 2021; Mao et al., 2019; Ajanaku et al., 2022).

Overall, while the nutritional contribution of these botanicals is secondary to their phytochemical effects, their mineral and vitamin profiles complement their functional roles in enhancing digestive efficiency, immune competence, and metabolic stability.

Comparative tables summarising the vitamin and mineral composition of turmeric (*Curcuma longa*), ginger (*Zingiber officinale*), garlic (*Allium sativum*) and onion (*Allium cepa*), compiled from multiple authors (Tables 3 and 4). Values are presented as ranges to reflect natural variation due to cultivar, soil type, maturity stage, and processing methods.

Table 3: Mineral composition of selected phytogenic additives (mg/100 g dry weight)

Phytogenic additive	Calcium (Ca)	Potassium (K)	Magnesium (Mg)	Iron (Fe)	Zinc (Zn)	Phosphorus (P)	Source
Turmeric (*Curcuma longa*)	150–250	1500–2100	150–200	20–35	2–4	250–350	**Akhila et al. (2022); Li et al. (2021)**
Ginger (*Zingiber officinale*)	80–150	1200–1800	120–180	10–25	1–3	150–300	**Mao et al. (2019); Muhammad et al. (2025)**
Garlic (*Allium sativum*)	180–400	400–1000	20–60	1.5–5	1–2	40–80	**Bayan et al. (2014); Dalhat et al. (2018)**
Onion (*Allium cepa*)	20–80	100–300	10–25	0.2–1.5	0.1–0.5	20–50	**Slimestad et al. (2007); Kumari et al. (2022)**

Table 4: Vitamin composition of phytogenic additives (mg/100 g fresh or dry weight depending on study)

Phytogenic additive	Vitamin C	Vitamin E	Vitamin K	B1 (Thiamine)	B2 (Riboflavin)	B6 (Pyridoxine)	Source
Turmeric (*Curcuma longa*)	0.5–2.0	1.5–3.5	0.5–1.5	0.05–0.1	0.02–0.08	0.1–0.2	**Li et al. (2021); Akhila et al. (2022)**
Ginger (*Zingiber officinale*)	1.0–5.0	0.5–2.5	0.1–0.5	0.02–0.1	0.02–0.1	0.1–0.3	**Mao et al. (2019); Muhammad et al. (2025)**
Garlic (*Allium sativum*)	10–35	0.1–0.5	0.5–1.2	0.2–0.7	0.1–0.3	0.5–1.2	**Bayan et al. (2014); Lanzotti (2020)**
Onion (*Allium cepa*)	7–20	0.1–0.4	0.2–0.8	0.03–0.2	0.02–0.1	0.2–0.6	**Slimestad et al. (2007); Kumari et al. (2022)**

Table 5: Summary comparison of mineral–vitamin richness index (qualitative ranking)

Phytogenic additive	Mineral density	Vitamin density	Antioxidant vitamin strength	Functional implication in livestock
Turmeric	High	Moderate	Moderate	Strong antioxidant & hepatoprotective effects
Ginger	High	Moderate	Moderate–High	Digestive stimulant & anti-inflammatory effects
Garlic	Moderate	High	High (vitamin C, B-complex synergy)	Immune enhancement & antimicrobial action
Onion	Low–Moderate	Moderate	High (vitamin C + flavonoids)	Immune modulation & gut health support

Source: Adapted from Mao et al. (2019); Muhammad et al. (2025)

The mineral and vitamin profiles of these phytogenic additives demonstrate clear nutritional complementarity. Turmeric and ginger are particularly rich in macro-minerals such as potassium, calcium and phosphorus, which are essential for enzymatic function, osmotic balance and skeletal development. Garlic and onion, in contrast, exhibit relatively lower mineral density but higher functional vitamin contributions, particularly vitamin C and B-complex vitamins, which are critical for immune modulation, energy metabolism and oxidative balance (Table 3, 4 & 5). The combined presence of these micronutrients, alongside their phytochemical constituents, enhances their suitability as multifunctional feed additives in livestock systems, where they contribute not only to nutrition but also to physiological resilience and disease resistance.

Bioactive Phytochemistry

Turmeric (Curcuma longa)

The biological activity of turmeric is largely attributed to a group of polyphenolic compounds collectively known as curcuminoids, comprising curcumin, demethoxycurcumin, and bisdemethoxycurcumin. Among these, curcumin is the most abundant and biologically active constituent, accounting for approximately 70–80% of total curcuminoid content (Li *et al.,* 2021). Curcuminoids are responsible for the characteristic yellow pigmentation of turmeric and are widely recognised for their potent antioxidant and anti-inflammatory properties.

At the cellular level, curcuminoids modulate multiple signalling pathways associated with oxidative stress, inflammation, and immune regulation. Curcumin acts as a scavenger of reactive oxygen species and upregulates endogenous antioxidant enzymes, thereby protecting tissues from oxidative damage. In the gastrointestinal tract, these effects preserve epithelial integrity and support optimal absorptive function, which is critical for nutrient utilisation.

In addition to curcuminoids, turmeric contains a complex mixture of volatile oils rich in sesquiterpenes, including ar-turmerone, α-turmerone, and β-turmerone. These compounds contribute to antimicrobial activity by disrupting microbial membranes and inhibiting enzyme systems. Evidence suggests that the volatile oil fraction may act synergistically with curcuminoids, enhancing their stability and biological efficacy. Such synergy is particularly relevant in animal nutrition, where consistent biological responses are essential for practical application (Hewlings & Kalman, 2017; Gupta et al., 2013).

Ginger (*Zingiber officinale*)

Ginger's phytochemical profile is dominated by phenolic compounds collectively known as gingerols, shogaols, and paradols. Fresh ginger contains high concentrations of gingerols, particularly 6-gingerol, which is considered the primary bioactive component. During drying, storage, or thermal processing, gingerols undergo dehydration to form shogaols, which often exhibit greater antioxidant and anti-inflammatory potency (Mao *et al.,* 2019).

These phenolic compounds exert multiple biological effects, including stimulation of digestive secretions, enhancement of gut motility, and modulation of inflammatory responses. Gingerols and shogaols have been shown to increase pancreatic enzyme activity, thereby improving the digestion of proteins, carbohydrates, and lipids. Their antioxidant properties also protect gastrointestinal tissues from oxidative damage, supporting nutrient absorption (Platel & Srinivasan, 2004; Ali et al., 2008; Shukla & Singh, 2007).

Ginger also contains essential oils composed of monoterpenes and sesquiterpenes such as zingiberene and β-bisabolene. These volatile compounds contribute to antimicrobial activity within the gastrointestinal tract, suppressing pathogenic microorganisms while allowing beneficial commensals to flourish. The combined actions of phenolics and essential oils make ginger a particularly effective phytogenic additive for improving digestive efficiency and gut health (Grzanna et al., 2005; Ali et al., 2008; Nikkhah Bodagh et al., 2019).

Garlic (Allium sativum)

Garlic is distinguished by its exceptionally rich content of organosulfur compounds, which are responsible for its characteristic aroma and potent biological activity. The primary precursor compound, alliin, is stored in intact garlic cells and is enzymatically converted to allicin upon tissue disruption. Allicin is highly reactive and unstable, rapidly decomposing into a range of sulfur-containing compounds, including diallyl disulfide, diallyl trisulfide, ajoene, and S-allyl cysteine (Kodera *et al.,* 2017).

These organosulfur compounds exhibit strong antimicrobial activity against a wide range of bacteria, fungi, and protozoa by inhibiting thiol-containing enzymes and disrupting microbial metabolism. In the context of animal nutrition, this antimicrobial action contributes to reduced pathogenic pressure in the gut, improved microbial balance, and enhanced nutrient availability.

Garlic compounds also possess antioxidant and immunomodulatory properties, supporting immune competence and reducing inflammatory stress. In ruminant systems, garlic-derived sulfur compounds have been shown to suppress methanogenic archaea, improving feed efficiency and reducing methane emissions. This dual nutritional and environmental benefit underscores garlic's significance as a multifunctional phytogenic feed additive (Ankri & Mirelman, 1999; Busquet et al., 2005; Patra, 2012).

Onion (Allium cepa)

Onion phytochemistry is characterised by high concentrations of flavonoids, particularly quercetin and its glycosides, as well as sulfur-containing cysteine sulfoxides such as isoalliin. Quercetin is a potent antioxidant and anti-inflammatory compound that modulates cellular signalling pathways involved in oxidative stress and immune responses (Slimestad *et al.,* 2007).

Sulfur compounds in onion contribute to antimicrobial activity and influence gut microbial composition. Additionally, onion is rich in fructans, which function as prebiotic substrates for beneficial bacteria. Fermentation of these fructans in the hindgut results in the production of short-chain fatty acids, supporting epithelial health and enhancing nutrient absorption.

Collectively, the flavonoid and sulfur fractions of onion contribute to improved gut health, stabilised microbial ecosystems, and enhanced digestive efficiency, reinforcing its value as a complementary phytogenic additive in livestock diets (Roberfroid, 2007; Geboes et al., 2006; Slavin, 2013).

Comparative tables summarising the major bioactive compounds of turmeric (*Curcuma longa*), ginger (*Zingiber officinale*), garlic (*Allium sativum*) and onion (*Allium cepa*), compiled from multiple authors (Tables 6 and 7). Values are presented as dominant compound classes and representative molecules, since concentrations vary widely with cultivar, extraction method and processing conditions.

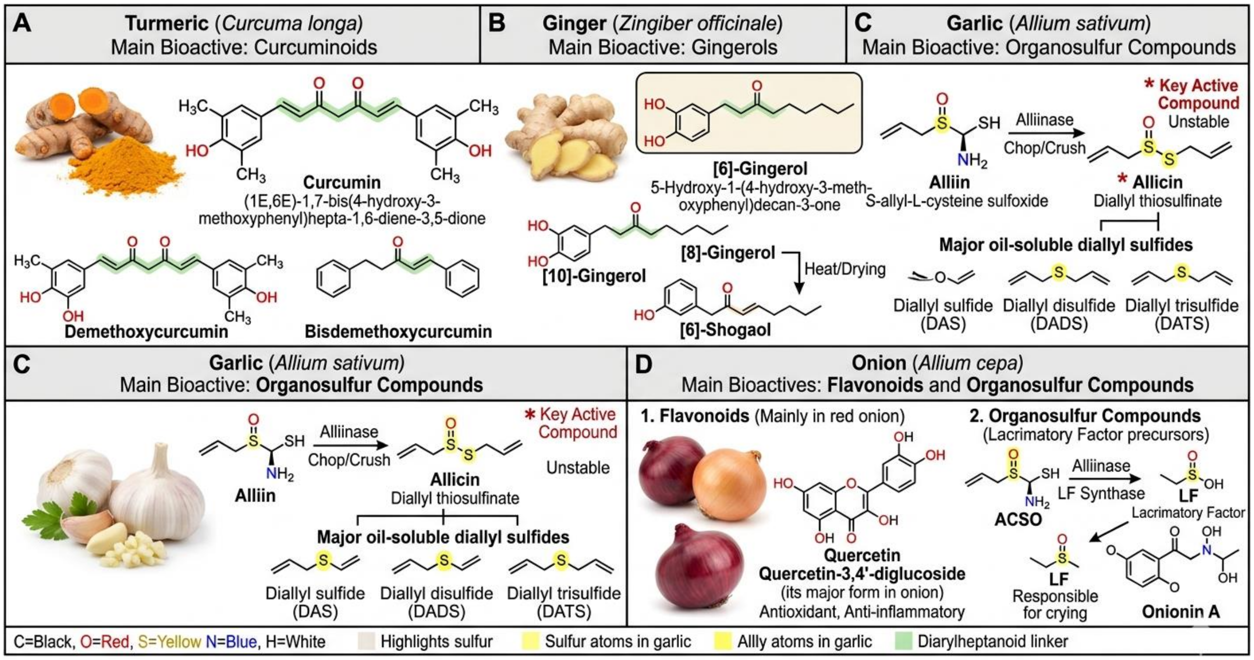

Figure 2A–D. Key Bioactive Compounds and Their Representative Structures from Turmeric, Ginger, Garlic, and Onion.

Table 6: Major bioactive compounds in turmeric and ginger (Zingiberaceae family)

Phytogenic additive	Major bioactive class	Key compounds identified	Reported biological activities	Source
Turmeric (*Curcuma longa*)	Curcuminoids	Curcumin, demethoxycurcumin, bisdemethoxycurcumin	Antioxidant, anti-inflammatory, hepatoprotective, antimicrobial	**Li et al. (2021); Hewlings & Kalman (2017); Giordano & Tommonaro (2019)**
Turmeric	Volatile oils	Turmerone, atlantone, zingiberene	Immunomodulatory, neuroprotective, anti-carcinogenic	**Zorofchian Moghadamtousi et al. (2014); Li et al. (2021)**
Ginger (*Zingiber officinale*)	Phenolic compounds	Gingerols (6-, 8-, 10-gingerol), shogaols, paradols	Antioxidant, anti-inflammatory, hypolipidaemic	**Mao et al. (2019); Alolga et al. (2022)**
Ginger	Volatile oils	Zingiberene, bisabolene, citral	Antimicrobial, digestive stimulant	**Mao et al. (2019); Muhammad et al. (2025)**

Table 7: Major bioactive compounds in garlic and onion (Allium species)

Phytogenic additive	Major bioactive class	Key compounds identified	Reported biological activities	Source
Garlic (*Allium sativum*)	Organosulphur compounds	Allicin, alliin, ajoene, diallyl disulfide	Antimicrobial, hypocholesterolaemic, antioxidant	**Bayan et al. (2014); Kodera et al. (2017)**
Garlic	Water-soluble sulfur amino acids	S-allyl cysteine (SAC)	Hepatoprotective, immunomodulatory, anti-diabetic	**Kodera et al. (2017); Lanzotti (2020)**
Onion (*Allium cepa*)	Flavonoids	Quercetin, kaempferol, isorhamnetin	Antioxidant, anti-inflammatory, vasoprotective	**Slimestad et al. (2007); Lanzotti (2020)**
Onion	Organosulphur compounds	Thiosulfinates, cepaenes	Antimicrobial, anti-thrombotic	**Kumari et al. (2022); Lanzotti (2020)**

Table 8: Functional classification of phytogenic bioactive compounds

Phytogenic additive	Phenolics/flavonoids	Sulfur compounds	Volatile oils	Key dominant activity in animal systems
Turmeric	High	Low	Moderate	Anti-inflammatory & antioxidant regulation
Ginger	High	Low	High	Gut health modulation & lipid metabolism
Garlic	Moderate	Very high	Moderate	Immune stimulation & antimicrobial defence
Onion	High	High	Low–Moderate	Antioxidant protection & vascular health

Source: Adapted from Kodera et al. (2017); Lanzotti (2020)

The phytogenic additives examined exhibit distinct but complementary bioactive profiles that underpin their physiological effects in animal systems. Turmeric is dominated by curcuminoids, particularly curcumin, which regulate inflammatory signalling pathways and oxidative stress responses. Ginger contains a high concentration of phenolic compounds such as gingerols and shogaols, which contribute to its metabolic and digestive enhancing properties. In contrast, garlic and onion are characterised by sulphur-containing organosulphur compounds and flavonoids, which exert strong antimicrobial, hypolipidaemic and immunomodulatory effects (Tables 6, 7 & 8; Figures 2A-D). The synergy between phenolic-rich (turmeric, ginger) and sulphur-rich (garlic, onion) phytogenics provides a mechanistic basis for their combined use in livestock nutrition, where they collectively enhance gut health, immune competence and metabolic stability across species.

Mechanisms Underpinning Digestive and Therapeutic Effects

Table 9. Mechanisms underpinning digestive and therapeutic effects of selected phytogenic feed additives

Botanical source	Major bioactive compounds	Primary molecular / physiological targets	Key digestive and therapeutic effects	Supporting references
Turmeric *Curcuma longa*	Curcumin, demethoxycurcumin, bisdemethoxycurcumin	Nrf2 activation; NF-κB inhibition; bile secretion	Enhanced antioxidant enzyme activity; reduced intestinal inflammation; improved villus integrity; increased lipid digestibility	**Hewlings and Kalman (2017); Giordano and Tommonaro (2019)**
Ginger *Zingiber officinale*	Gingerols, shogaols, zingerone	Digestive enzyme stimulation; microbial membrane disruption; antioxidant pathways	Increased pancreatic amylase and protease secretion; improved gut motility; enhanced nutrient breakdown and absorption	**Mao *et al.* (2019)**
Garlic *Allium sativum*	Allicin, diallyl sulfide, ajoene	Microbial enzyme inhibition; suppression of methanogens; NF-κB modulation	Reduced pathogenic bacterial load; improved gut microbial balance; enhanced feed efficiency and energy utilisation	**Aletor (2014); Windisch *et al.* (2022)**
Onion *Allium cepa*	Quercetin, flavonoids, fructans	Antioxidant signalling; prebiotic fermentation; inflammatory pathway suppression	Improved intestinal barrier function; increased short-chain fatty acid production; enhanced nutrient absorption	**Zorofchian Moghadamtousi *et al*. (2014)**

The beneficial effects of turmeric (*Curcuma longa*), ginger (*Zingiber officinale*), garlic (*Allium sativum*), and onion (*Allium cepa*) on nutrient digestibility and animal health are mediated through multiple, interrelated biochemical, physiological, and microbial mechanisms. These mechanisms operate synergistically to enhance gastrointestinal functionality, preserve intestinal integrity, and optimise nutrient utilisation across diverse farm animal species (Table 9).

A central mechanism involves the regulation of oxidative balance within the gastrointestinal tract. Intensive livestock production systems expose animals to various stressors, including high metabolic demand, environmental stress, pathogenic challenge, and dietary transitions, all of which promote excessive generation of reactive oxygen species (ROS). Elevated oxidative stress compromises intestinal epithelial cells, disrupts tight junction proteins, and impairs nutrient absorption. Bioactive compounds in turmeric, ginger, garlic, and onion play a crucial role in counteracting these effects through activation of the nuclear factor erythroid 2–related factor 2 (Nrf2) signalling pathway. Activation of Nrf2 promotes transcription of antioxidant response element–dependent genes encoding endogenous antioxidant enzymes such as superoxide dismutase, catalase, glutathione peroxidase, and heme oxygenase-1 (Hewlings and Kalman, 2017). This enhanced antioxidant defence protects intestinal tissues from oxidative injury, preserves epithelial barrier integrity, and maintains optimal absorptive capacity.

In parallel, these botanicals exert pronounced anti-inflammatory effects by modulating pro-inflammatory signalling pathways, particularly nuclear factor-kappa B (NF-κB). Chronic or excessive intestinal inflammation reduces villus height, increases crypt depth, and diverts nutrients away from growth and production towards immune responses. Curcumin, gingerols, quercetin, and organosulfur compounds inhibit NF-κB activation by suppressing upstream kinases and preventing nuclear translocation of inflammatory transcription factors (Giordano and Tommonaro, 2019). Consequently, the expression of pro-inflammatory cytokines such as tumour necrosis factor-α, interleukin-1β, and interleukin-6 is reduced. Lower inflammatory burden within the gut environment facilitates improved villus architecture, enhanced brush-border enzyme activity, and more efficient nutrient absorption (Pluske et al., 1997; Gu et al., 2002; Liu et al., 2018).

Another critical mechanism underpinning improved digestibility is the antimicrobial activity of these phytogenic compounds. The gastrointestinal tract harbours a complex microbial ecosystem that plays a fundamental role in digestion, fermentation, immune modulation, and pathogen exclusion. Dysbiosis, characterised by overgrowth of pathogenic microorganisms, impairs digestive efficiency and increases nutrient losses. Allicin and related sulfur compounds from garlic and onion disrupt thiol-containing enzymes essential for microbial metabolism, leading to growth inhibition or cell death of pathogenic bacteria. Similarly, curcumin and gingerols interfere with microbial membrane integrity, inhibit quorum sensing, and suppress biofilm formation (Zorofchian Moghadamtousi *et al.,* 2014; Mao *et al.,* 2019).

Importantly, these antimicrobial effects are often selective rather than indiscriminate. While pathogenic bacteria such as Escherichia coli, Salmonella spp., and Clostridium perfringens are suppressed, beneficial commensal microorganisms—including Lactobacillus and Bifidobacterium species—are relatively preserved or even promoted. This selective modulation stabilises gut microbial ecosystems, enhances fermentation efficiency, and improves production of short-chain fatty acids, which serve as energy substrates for intestinal epithelial cells (Table 10).

Digestive enzyme stimulation represents an additional mechanism contributing to improved nutrient utilisation. Ginger and garlic, in particular, have been shown to stimulate secretion of salivary, gastric, pancreatic, and intestinal enzymes, including amylase, protease, lipase, and trypsin. Enhanced enzyme activity accelerates feed breakdown, increases nutrient availability, and reduces undigested substrates entering the hindgut, thereby limiting pathogenic fermentation (Aletor, 2014).

Collectively, the antioxidant, anti-inflammatory, antimicrobial, microbiota-modulating, and enzyme-stimulatory properties of turmeric, ginger, garlic, and onion create a favourable gastrointestinal environment that supports efficient digestion, improved nutrient absorption, and enhanced overall animal performance.

Table 10. Antimicrobial and Microbiota-Modulating Actions Relevant to Nutrient Digestibility

Phytogenic compound	Mode of antimicrobial action	Targeted microbial groups	Digestive implication
Allicin	Inhibition of thiol-containing enzymes	E. coli, Salmonella, methanogenic archaea	Reduced pathogenic competition; improved nutrient availability
Curcumin	Disruption of membrane integrity; quorum sensing inhibition	Gram-positive and Gram-negative pathogens	Stabilised gut microbiota; improved fermentation efficiency
Gingerols	Increased membrane permeability	Enteric pathogens	Reduced intestinal inflammation; enhanced nutrient retention
Fructans (garlic, onion)	Selective fermentation (prebiotic effect)	Lactobacillus, Bifidobacterium spp.	Increased SCFA production; improved gut epithelial health

Source: Adapted from Valenzuela-Grijalva et al., 2017; Abd El-Hack et al., 2020; Windisch et al., 2008

Effects on Nutrient Digestibility in Farm Animals

Poultry

In poultry production, nutrient digestibility is a major determinant of growth performance, feed efficiency, and profitability due to the rapid growth rate and high metabolic demand of modern broiler and layer strains. Numerous studies have demonstrated that dietary inclusion of turmeric, ginger, garlic, and onion positively influences apparent digestibility coefficients of crude protein, ether extract, and metabolizable energy in poultry diets. These improvements are primarily attributed to enhanced digestive enzyme activity, improved intestinal morphology, and stabilisation of gut microbial populations (Muhammad *et al.*, 2025).

Turmeric supplementation has been consistently associated with increased villus height and villus-to-crypt ratio in the duodenum, jejunum, and ileum, indicating an expansion of absorptive surface area. Improved intestinal architecture facilitates greater nutrient uptake and contributes to improved feed conversion efficiency. Curcumin also enhances bile secretion and lipid digestion, thereby increasing ether extract digestibility and energy utilisation.

Ginger exerts pronounced effects on digestive physiology through stimulation of pancreatic enzyme secretion and acceleration of gastrointestinal motility. Enhanced amylase and protease activity improves starch and protein digestion, while its antioxidant properties protect intestinal tissues from oxidative stress induced by high-energy diets. Garlic and onion further contribute by reducing pathogenic bacterial load, lowering intestinal inflammation, and promoting a more favourable microbial balance (Table 11). These combined effects translate into improved nutrient retention, reduced feed wastage, and enhanced growth performance in broilers and laying hens.

Table 11. Effects of Turmeric, Ginger, Garlic, and Onion on Nutrient Digestibility in Poultry

Additive	Digestibility parameters affected	Intestinal effects	Performance implication	References
Turmeric	↑ Crude protein, ↑ ether extract, ↑ ME	Increased villus height; improved villus-crypt ratio	Improved feed conversion ratio; enhanced growth	Muhammad *et al.* (2025)
Ginger	↑ Protein and starch digestibility	Increased pancreatic enzyme secretion; improved motility	Better weight gain; reduced feed wastage	Mao *et al.* (2019)
Garlic	↑ Protein and fat digestibility	Reduced pathogenic bacteria; improved gut integrity	Enhanced nutrient retention	Aletor (2014)
Onion	↑ Energy utilisation	Prebiotic fermentation; improved epithelial health	Improved laying performance and growth	Zorofchian Moghadamtousi *et al.* (2014)

Ruminants

In ruminant production systems, nutrient digestibility is governed largely by rumen fermentation processes, which are mediated by complex microbial consortia responsible for fibre degradation, microbial protein synthesis, and volatile fatty acid production. Phytogenic compounds from garlic, onion, ginger, and turmeric influence rumen microbial ecology and fermentation efficiency, thereby affecting overall nutrient utilisation (Table 12).

Garlic and onion are particularly effective in modulating rumen microbial populations. Organosulfur compounds selectively inhibit methanogenic archaea and protozoa, leading to reduced methane production and improved energy retention. Lower methane losses enhance feed efficiency by redirecting energy towards productive functions such as growth and milk synthesis. Additionally, suppression of protozoa reduces predation on rumen bacteria, thereby increasing microbial protein flow to the small intestine (Windisch *et al.*, 2022).

Ginger and turmeric influence fibre digestibility by enhancing the activity of fibrolytic bacteria and stabilising rumen fermentation patterns. Their antioxidant properties mitigate oxidative stress within the rumen environment, which can otherwise impair microbial activity. Improved neutral detergent fibre and acid detergent fibre digestibility have been reported in small ruminants and cattle supplemented with ginger or turmeric, accompanied by increased production of acetate and propionate, key precursors for milk fat synthesis and gluconeogenesis.

Overall, the modulation of rumen fermentation by these botanicals contributes to improved nutrient utilisation, reduced environmental impact, and enhanced sustainability of ruminant production systems.

Table 12. Effects on Rumen Fermentation and Nutrient Utilisation in Ruminants

Botanical additive	Rumen microbial effect	Fermentation outcome	Nutritional implication
Turmeric	Antioxidant stabilisation of rumen environment	Balanced VFA production (acetate, propionate)	Enhanced milk and growth performance
Garlic	Suppression of methanogenic archaea and protozoa	Reduced methane emission; increased microbial protein flow	Improved feed efficiency and energy retention
Onion	Similar organosulfur effects to garlic	Enhanced microbial balance	Improved digestibility of fibre and protein
Ginger	Stimulation of fibrolytic bacteria	Increased NDF and ADF degradation	Improved fibre utilisation

Source: Adapted from Windisch et al. (2022).

Pigs and Rabbits

In monogastric mammals such as pigs and rabbits, nutrient digestibility is closely linked to gut health, enzyme secretion, and microbial balance. Dietary inclusion of turmeric, ginger, garlic, and onion has been shown to improve apparent digestibility of protein, fat, and energy in these species by reducing intestinal inflammation, enhancing enzyme activity, and suppressing pathogenic microorganisms.

Garlic and onion are particularly effective due to their high content of fructans, which function as prebiotic substrates for beneficial gut bacteria. Fermentation of fructans in the hindgut produces volatile fatty acids, including acetate, propionate, and butyrate, which serve as energy sources for intestinal epithelial cells and promote mucosal health. Improved gut integrity enhances nutrient absorption and reduces the incidence of post-weaning diarrhoea in pigs (Table 13).

Ginger supplementation stimulates gastric and pancreatic secretions, improving feed digestion and reducing undigested substrates entering the large intestine. Turmeric contributes through its anti-inflammatory and antioxidant effects, which protect intestinal tissues from dietary and environmental stressors. In rabbits, these combined effects lead to improved nutrient retention, enhanced growth performance, and reduced mortality associated with enteric disorders.

Across poultry, ruminants, pigs, and rabbits, the evidence indicates that turmeric, ginger, garlic, and onion improve nutrient digestibility through species-specific mechanisms that converge on enhanced gut function, microbial balance, and metabolic efficiency. Their strategic use therefore represents a viable nutritional approach for improving productivity in antibiotic-free livestock systems.

Table 13. Effects on Nutrient Digestibility in Pigs and Rabbits

Species	Additive	Primary mechanism	Digestibility outcome	Health implication
Pigs	Garlic	Prebiotic fructan fermentation	↑ Protein and energy digestibility	Reduced post-weaning diarrhoea
Pigs	Ginger	Enzyme stimulation; anti-inflammatory action	Improved feed digestion	Enhanced growth performance
Rabbits	Turmeric	Antioxidant and anti-inflammatory effects	Improved nutrient retention	Reduced enteric disorders
Rabbits	Onion	SCFA production via hindgut fermentation	Enhanced fibre utilisation	Improved gut health and survival

Source: Adapted from (Bayan *et al.*, 2014; Hewlings and Kalman, 2017; Windisch *et al.* 2022).

Production and Therapeutic Implications

Beyond their demonstrated effects on nutrient digestibility, turmeric (Curcuma longa), ginger (Zingiber officinale), garlic (Allium sativum), and onion (Allium cepa) exert broad production-enhancing and therapeutic effects that are highly relevant to modern livestock systems. Improved nutrient utilisation often translates directly into enhanced growth performance, as evidenced by increased body weight gain, improved feed conversion ratio, and reduced days to market reported across poultry, pig, rabbit, and ruminant production systems (Windisch *et al.,* 2022). These performance benefits are particularly valuable in antibiotic-free feeding programmes, where maintaining productivity remains a major challenge.

One of the most significant production-related advantages of these botanicals is their capacity to enhance immune competence. Bioactive compounds such as curcumin, gingerols, allicin, and quercetin modulate both innate and adaptive immune responses by regulating cytokine production, enhancing phagocytic activity, and supporting lymphocyte proliferation (Hewlings and Kalman, 2017; Bayan *et al.,* 2014). Improved immune status reduces disease incidence and severity, thereby lowering mortality rates and veterinary intervention costs. In poultry and pigs, dietary supplementation with garlic and turmeric has been associated with reduced pathogen load, particularly Escherichia coli and Salmonella species, contributing to improved flock and herd health (Muhammad *et al.,* 2025).

Reproductive performance also benefits from the inclusion of these botanicals in animal diets. Oxidative stress is a major contributor to impaired fertility, embryonic loss, and reduced semen quality in breeding animals. The potent antioxidant properties of curcuminoids, ginger phenolics, and onion flavonoids protect reproductive tissues from oxidative damage, thereby supporting hormonal balance, gamete integrity, and embryonic development (Giordano and Tommonaro, 2019). Studies in rabbits and small ruminants have reported improvements in conception rates, litter size, and offspring viability following supplementation with turmeric- or garlic-based diets, highlighting their potential role in reproductive management strategies.

Another critical production implication relates to enhanced resilience against environmental and metabolic stressors. Heat stress, in particular, poses a substantial threat to livestock productivity in tropical and subtropical regions. Phytogenic compounds in ginger, turmeric, and onion have been shown to attenuate heat stress–induced oxidative damage, stabilise cellular membranes, and regulate stress-related hormones, thereby preserving feed intake and metabolic efficiency under adverse conditions (Zhu *et al.,* 2020). This property is especially relevant for poultry and dairy animals, where heat stress can severely compromise performance and welfare.

From a sustainability perspective, the multifunctional properties of these botanicals support reduced dependence on synthetic growth promoters, antioxidants, and chemotherapeutic agents. Their integration into livestock diets aligns with global efforts to promote environmentally responsible production systems, improve animal welfare, and meet consumer demand for naturally produced animal products. Furthermore, their widespread availability and relatively low cost—particularly in developing countries—make them attractive options for both commercial and smallholder farming systems.

Limitations and Research Gaps

Despite the substantial body of evidence supporting the beneficial effects of turmeric, ginger, garlic, and onion in animal nutrition, several limitations and research gaps constrain their widespread and consistent application in livestock production systems. One of the most prominent challenges is the considerable variability in phytochemical composition associated with differences in plant cultivar, geographical origin, agronomic practices, maturity at harvest, and post-harvest processing. Such variability can lead to inconsistent biological responses and complicates the establishment of standardised dosing recommendations (Lanzotti, 2020).

Bioavailability represents another critical limitation, particularly for curcumin, which exhibits poor solubility, rapid metabolism, and limited intestinal absorption. These properties significantly reduce its systemic availability and may partially explain the variability observed across experimental studies. Although strategies such as nano-formulation, encapsulation, and combination with bioavailability enhancers have shown promise, their application in livestock nutrition remains limited and often cost-prohibitive (Hewlings and Kalman, 2017).

Dose optimisation and species-specific responses also remain inadequately defined. Inclusion levels that are beneficial in one species or production stage may be ineffective or even detrimental in another. High inclusion rates of garlic or onion, for instance, have been associated with reduced palatability and potential haematological disturbances in some animal species. This underscores the need for carefully controlled dose–response studies that account for species, age, physiological status, and production objectives.

Furthermore, many available studies are of short duration and focus primarily on growth performance and basic digestibility indices. There is a relative scarcity of long-term, large-scale trials assessing reproductive outcomes, lifetime productivity, product quality, and potential residual effects. Interactions between phytogenic additives and other dietary components, such as probiotics, enzymes, and organic acids, also remain poorly understood.

Addressing these limitations will require multidisciplinary research approaches integrating phytochemistry, animal physiology, microbiology, and nutritional modelling. Such efforts are essential for translating experimental findings into practical, evidence-based feeding strategies.

Conclusion and Future Perspectives

Turmeric, ginger, garlic, and onion represent a unique group of multifunctional phytogenic resources with significant potential to enhance nutrient digestibility, animal health, and productivity in farm animal systems. Although their direct contribution to dietary nutrients is modest, their rich phytochemical composition underpins a wide range of biological activities, including antioxidant, anti-inflammatory, antimicrobial, immunomodulatory, and gut-regulatory effects. These mechanisms collectively improve digestive efficiency, stabilise gastrointestinal ecosystems, and support optimal metabolic and physiological function.

The evidence reviewed in this manuscript demonstrates that dietary inclusion of these botanicals can positively influence growth performance, feed conversion efficiency, immune competence, reproductive outcomes, and resilience to environmental stressors across multiple livestock species. Importantly, their use aligns with global efforts to reduce reliance on antibiotic growth promoters and synthetic additives, thereby contributing to safer, more sustainable, and consumer-acceptable animal production systems.

Future research should prioritise the standardisation of botanical preparations, optimisation of inclusion levels, and development of advanced delivery systems to enhance bioavailability, particularly for compounds such as curcumin. Long-term, species-specific studies are needed to evaluate cumulative effects on productivity, health, and product quality, as well as potential interactions with other functional feed additives. Greater integration of molecular techniques, including gut microbiome profiling and nutrigenomics, will further elucidate mechanisms of action and facilitate precision nutrition approaches.

In conclusion, turmeric, ginger, garlic, and onion offer substantial promise as natural additives for improving nutrient utilisation and resilience in livestock. Their strategic and evidence-based incorporation into animal feeding programmes has the potential to support sustainable intensification of animal agriculture while safeguarding animal health, environmental integrity, and public confidence in animal-derived foods.

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