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REVIEW

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Pumpkin as a natural feed additive in livestock production: A review

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ABSTRACT. The livestock industry is currently facing several significant challenges, including high feed costs, restrictions on antibiotic use, and growing consumer demand for high-quality animal products. Consequently, there is increasing interest in identifying alternative feed ingredients that promote animal health and enhance productivity. Pumpkin (*Cucurbita* spp.) has emerged as a promising natural feed additive due to its favourable nutritional profile, including proteins, unsaturated fatty acids, vitamins, minerals, and bioactive compounds. This review aims to examine the potential applications of pumpkin in livestock nutrition, with a focus on its impact on animal health, growth performance, product quality, and sustainability. Studies have indicated that the inclusion of pumpkin and its derivatives (fruit, seeds, oil, and green parts) in the diets of ruminants, swine, poultry, and rabbits can improve feed efficiency, meat, milk, and egg composition, and support immune function. In addition, pumpkin seeds demonstrates antiparasitic properties, while pumpkin oil exerts antioxidant and metabolic regulatory effects. Although further research is needed to determine optimal inclusion levels and processing methods, current evidence suggests that pumpkin could be a viable alternative to conventional protein sources. Its integration into livestock feeding strategies is consistent with current trends in sustainable agriculture, offering both economic and environmental advantages while improving animal welfare and food quality.

Introduction

The contemporary livestock production industry is driven by the need for continuous improvement in feeding methodologies, with the objective of increasing productivity and optimising animal welfare. In the context of rising feed costs and restrictions on antibiotic use, the search for alternative nutritional solutions has become increasingly important. Meeting the dietary demands of high-yielding livestock requires the provision of feed that is not only sufficient in quantity but also of consistently high quality. From an economic perspective, feed represents the most significant expense in livestock production, accounting for approximately 80–85% of total animal maintenance costs. Poland is a net importer of plant-based protein, with imports covering over 75% of domestic demand. Soybean meal is the primary component of this protein, with annual imports reaching around 2.5 mln t. This meal, used in compound feeds, is the most expensive component and require substitution once legislation banning the use of genetically modified feed in animal nutrition takes effect. As a result, ongoing research is focused on identifying alternative protein sources in livestock breeding, including previously unused materials such as herbs, weeds, and orchard waste. In parallel, there is increasing emphasis on improving the quality of meat, milk, and eggs through nutritional interventions, in response to consumer expectations regarding final product quality. Herd health, closely linked to nutrition, is also a key area of concern. Inadequate diets have been associated with disruptions in intestinal microflora composition (Nguyen et al., 2024), which often leads to weaken immunity and, consequently, the proliferation of environmental bacteria, contributing to the development of metabolic diseases and infections.

The primary objective of large-scale livestock farming is to maximise economic returns through the implementation of intensive production systems. Animals reared under such conditions must be characterised by high fertility, fecundity, and productivity, and be well-suited to their specific production purpose. To improve rearing efficiency, livestock farmers often resort to synthetic health products, particularly antibiotics, which, in addition to their therapeutic effects, also exhibit growth-stimulating properties. However, the widespread use of antibiotics in animal nutrition, also as growth promoters, has raised serious concerns. The most critical issue is the emergence of antibiotic-resistant strains, which develop as bacteria adapt to repeated antibiotic exposure, resulting in so-called 'superbugs' that are increasingly difficult to treat. These resistant strains can be transmitted to humans through the consumption of contaminated meat, direct contact with animals or environmental routes such as soil and water. In addition, antibiotic residues may persist in animal products such as meat, milk and eggs. When consumed, these residues may trigger allergic reactions and tissue or cause organ dysfunctions. Moreover, they may contribute to the selection of antibiotic-resistant bacterial strains within the human body (Algammal et al., 2023).

In response to growing problems regarding antibiotic resistance, Regulation (EU) 2019/4 of the European Parliament and of the Council, dated 11 December 2018, has banned the use of antibiotics as growth promoters in EU countries from 2006 onwards. However, data collected in 2022 indicate that approximately 20% of EU member states still use antibiotics to increase livestock production (Ghimpeșteanu et al., 2022). It is widely recognised that young animals during the growth period are particularly susceptible to infections. As a result, farmers apply antibiotics to reduce losses and limit the spread of disease (Falcão-e-Cunha et al., 2007). Antibiotics exhibit high resistance to degradation, and most are excreted in active form through faeces and urine, contributing to environmental contamination (Falcão-e-Cunha et al., 2007).

The global efforts to reduce antibiotic use in livestock production has intensified research into effective alternative solutions that can sustain animal health and productivity. Proposed substitutes include probiotics, prebiotics, organic acids, yeast and sodium butyrate, along with various herbs and their bioactive extracts (Kocher et al., 2004). The bacteriostatic, antifungal, and coccidiostatic properties of herbs such as oregano (*Origanum vulgare*), thyme (*Thymus vulgaris* L.), fennel (*Foeniculum vulgare* Mill.), and black caraway (*Nigella sativa*) have been demonstrated by numerous studies (Dorman and Deans, 2000; Mitsch et al., 2004; El-Bagir et al., 2010; Benlemlih et al., 2014).

The use of natural additives in animal nutrition is gaining popularity due to growing consumer health awareness, animal welfare protection and environmental sustainability. Consumers are increasingly seeking food products that are natural and free from chemical substances, including antibiotics. Natural additives, such as herbs, probiotics, prebiotics and essential oils are considered safer alternatives, as they do not leave harmful residues in meat, milk or eggs. These compounds contribute to animal health by enhancing the immune system, improving digestion and reducing oxidative stress, thereby minimising the reliance on antibiotics. As antibiotic resistance remains one of the greatest public health concerns, there is a strong incentive for producers to adopt alternatives that do not contribute to the emergence of drug-resistant bacterial strains (Pandey et al., 2019). Additionally, natural additives align with the 'clean label' trend, reflecting consumer preference for food products with simple and transparent ingredient lists, which increases the acceptance of products containing such additives. In animal nutrition, they play an important role in sustainable agriculture by helping reduce the environmental footprint of livestock production. Unlike synthetic antibiotics, which can pollute soil and water, natural substances such as plant extracts are biodegradable and do not leave persistent residues in the environment. They support animal welfare by promoting health and reducing the need for aggressive pharmaceutical treatments, consistent with the principles of sustainable and ethical farming. Moreover, certain natural additives, such as probiotics, can improve digestion efficiency, which in turn facilitate the reduction of greenhouse gas emissions, including methane produced by ruminants. Cultivation of botanical feed additives additionally contributes to on-farm biodiversity, creating synergies between animal nutrition and agroecological systems. This integrated approach demonstrates how natural additives can simultaneously enhance animal health, product quality, and environmental sustainability while supporting the economic viability of livestock operations (Arsenos and Vouraki, 2023; Gabriel et al., 2024).

Pumpkin (*Cucurbita* spp.) is attracting growing attention as an alternative nutritional supplement, with both its fruits and seeds recognised as valuable components in livestock diets. The fruit is rich in bioactive compounds, including carotenoids, vitamins, and unsaturated long-chain fatty acids, which support animal health and improve the quality of animal products. Pumpkin pulp stimulates digestive function, bile secretion, fluid balance, and immune response. Pumpkin seeds in turn are particularly valued for their high protein and mineral content, as well as their antiparasitic properties, which protect against various parasites, including worms and tapeworms. Moreover, pumpkin seeds have demonstrated immune-modulating effects, potentially improving animal welfare and reduced reliance on synthetic health products. As a forage crop, pumpkin produce high yields with low input requirements and can be cultivated in less favourable growing conditions. Current research increasingly focuses on the utilisation of various pumpkin plant parts, including fruit, roots, flowers, leaves, and seeds in livestock nutrition (Valdez-Arjona and Ramírez-Mella, 2019).

This article presents a comprehensive review of existing literature on the use of pumpkin in livestock nutrition, with particular emphasis on its impact on animal health, production parameters, and product quality. To this end, an extensive review of both Polish and international scientific sources was carried out. The literature was obtained from reputable databases, including Google Scholar, EBSCO, ScienceDirect, PubMed, Scopus, Web of Science, and Wiley Online Library. The analysis covered scientific publications, research reports, and meta-analyses addressing the chemical composition, nutritional value, and potential health benefits of pumpkin in the context of livestock production.

Cultivation history

The pumpkin (*Cucurbita* spp.) is a member of the family Cucurbitaceae and is cultivated widely across the world. Archaeological evidence shows it was grown as early as 5500 BC, when it was considered a sacred plant by the indigenous peoples of South and Central America (Colagar and Souraki, 2012; Ahmad and Khan, 2019). Historically, its fruits were mainly used for medicinal purposes. More recent studies indicate that pumpkin was also valued in the folk medicine of many cultures for its therapeutic properties, particularly in treating digestive problems, improving skin condition, and strengthening the immune system (Colagar and Souraki, 2012; Ahmad and Khan, 2019). Pigmentation analysis of pumpkin seeds has helped identify the crop's origins, with Dhiman et al. (2009) suggesting Guatemala, Central Mexico, or Colombia as likely centres of domestication. The earliest documented mention of pumpkin in European culinary traditions dates back to antiquity, when it was introduced to Europe by Sephardic Jews living in the region now known as Italy. Pumpkin was consumed raw with wine to relieve constipation, and when prepared with honey, it was considered a delicacy. In traditional Middle Eastern medicine, pumpkin juice was used to manage sleep disorders (Koc-Karwowska and Stanczuk, 2014). However, this knowledge gradually faded over the centuries, only to re-emerge in Europe following the voyages of Christopher Columbus at the turn of the 16th century. This period was characterised by a resurgence of interest in ancient Greco-Roman traditions, reviving historical uses of pumpkin (Zdrojewicz et al., 2016).

Today, pumpkin is primarily associated with North America and the USA - a connection that is historically well founded. Since the earliest European settlements in the New World, pumpkin has been an essential companion to the colonists, and records indicate that it was the first wild plant to be domesticated in the region. However, when European explorers, including Captain John Smith, first encountered it, the plant had already undergone centuries of cultivation and modification by Indigenous peoples, resulting in a form far different from its original wild state. For the early settlers, pumpkin was not only a practical food source but also came to symbolise resilience, adaptation, and a connection to the new land. It was seen as a representation of cultural identity and historical continuity, reflecting both survival in unfamiliar conditions and reliance on the natural resources of the New World (Ott, 2013).

In 1621, the colonists who had arrived in Plymouth, Massachusetts, aboard the *Mayflower*, faced a particularly harsh winter, which resulted in the demise of nearly half of them from starvation and hypothermia during their initial year in the New World. The settlers received crucial assistance from Native Americans, who taught them hunting techniques and agricultural practices, including pumpkin cultivation. The following spring brought a successful harvest, prompting the colonists to host a celebratory feast in gratitude for their Native American allies. This event was later commemorated in 1863, when President Abraham Lincoln declared Thanksgiving Day a national holiday. Modern celebrations of this holiday in the United States are extremely popular, with pumpkin featuring prominently in traditional dishes and desserts. The most iconic elements of the meal are roast turkey, symbolising the settlers' survival through wild game hunting, and pumpkin pie, a traditional dessert also known as Thanksgiving pie (Wallendorf and Arnould, 1991).

Pumpkin is most commonly associated with October 31, the date of Halloween. This tradition stems from an Irish legend about a cunning man named Jack, who tricked the devil and was condemned to wander eternally with only a hollowed turnip lantern holding a glowing coal to light his way. When Irish immigrants brought this tale to America, the native pumpkin – larger and easier to carve – replaced the turnip, giving rise to the jack-o'-lantern. These carved pumpkins became a staple of Halloween decor, symbolising both folklore and the autumn harvest. The pumpkin's cultural significance extends beyond decoration. It appears in art and literature, most famously in Washington Irving's The Legend of Sleepy Hollow (1820), where the Headless Horseman hurls a flaming pumpkin as a mock head. Today, Halloween is one of the most commercially significant holidays associated with pumpkin, contributing to its growing popularity in many parts of the world, including Europe (Rogers, 2002; Levinson et al., 1992).

In the USA, competitive pumpkin growing has evolved into a celebrated tradition, where farmers compete for prestigious titles such as 'largest pumpkin' and 'largest pumpkin pie'. These contests often include ceremonial events like the selection of a 'Miss Pumpkin Show Queen'. The tradition originated in Circleville, Ohio, home to the E. Sears Canning Company, a major pumpkin producer, and the site of the largest pumpkin festival in the country (Ott, 2002). In 2023, Travis Gienger of Anoka, Minnesota, set a new national record by growing a pumpkin weighing 1 246.9 kg, surpassing the previous world record of 1 226 kg held by Italian competitor Stefano Cutrupi in 2021 (https://slate.com/human-interest/2023/10/giant-largest-pumpkin-world-record-2023.html).

Pumpkin is a self-pollinating annual plant, reaching a height of up to 1.5 m. It produces creeping or twining vines on the ground, which facilitate climbing and propagation. Agriculturally, pumpkin species are monoecious, typically characterised by extensive above-ground vine growth (Colagar and Souraki, 2012). The genus includes several species such as *Cucurbita moschata*, *Cucurbita pepo*, *Cucurbita maxima*, *Cucurbita mixta*, *Cucurbita facifola*, and *Telfairia occidentalis*. Among these, *Cucurbita moschata* (musk pumpkin), *Cucurbita maxima* (giant pumpkin), and *Cucurbita pepo* (common pumpkin), are the most commonly cultivated worldwide (Caili et al., 2006). Pumpkin cultivation typically begins in late May or early June, with harvest taking place in October, once the fruit reaches optimal size and bright orange colour. The crop is relatively easy to cultivate, as it adapts well to a variety of soil types and climatic conditions. Moreover, pumpkins require limited pesticide use, making them well suited to organic farming systems (Rekiel et al., 2019). Although pumpkin currently has a limited economic significance in Poland, its popularity has been gradually increasing. This phenomenon can be attributed to several factors, including the influence of Western culture, the popularisation of American and British holidays, and growing interest in healthy eating and organic farming (Telesiński et al., 2014).

Chemical composition and biological properties

Pumpkin is widely used in both the food and pharmaceutical industries due to its high content of nutrients and bioactive compounds, including fatty acids, proteins, phytosterols, polyphenols, carotenoids, and cucurbitacins. Numerous studies have confirmed that the various pumpkin components exhibit a range of health-promoting properties, such as antioxidant, anti-inflammatory, hypoglycaemic, and antineoplastic effects. All parts of the plant, i.e. roots, flowers, leaves, fruits, and seeds are usable and valued for their high levels of bioactive antioxidants. These bioactive compounds help neutralise free radicals and reactive oxygen species, potentially reducing risks of cancer, cardiovascular diseases, neurodegenerative disorders, and eye conditions (Kulczyński et al., 2020). Pumpkin flowers demonstrate particular therapeutic efficacy, especially in wound treatment involving high inflammatory responses. In addition, pumpkin flower infusions have been shown to have a soothing effect on sore throats and tonsillitis (Colagar and Souraki, 2012).

Pumpkin fruits are low in calories (~26 kcal per 100 g), fat and protein, yet they are rich in carbohydrates, minerals, and vitamins. Their distinctive orange colour results from high concentrations of carotenoids, specifically α-carotene (3100 µg/100 g) and β-carotene (4016 µg/100 g). In addition, pumpkin is a good source of potassium, phosphate, and calcium. The chemical composition of pumpkin fruit is given in Table 1.

Table 1. Nutritional composition of raw pumpkin flesh (per 100 g)

Nutrient[a]	Amount
Water, g	91.60
Energy, KJ	109.00
Carbohydrates, g	6.50
Dietary fibre, g	0.50
Fats, g	0.10
Saturated fats, g	0.05
Monounsaturated fats, g	0.01
Polyunsaturated fats, g	0.01
Protein, g	1.00
Vitamin A, µg	426.00
α-Carotene, µg	4026.00
β-Carotene, µg	3100.00
Thiamine (vitamin B_1), mg	0.05
Riboflavin (vitamin B_2), mg	0.11
Niacin (vitamin B_3), mg	0.60
Pantothenic acid (vitamin B_5), mg	0.30
Pyridoxine (vitamin B_6), mg	0.06
Folic acid (vitamin B_9), µg	16.00
Vitamin C, mg	9.00
Vitamin E, mg	1.06
Calcium (Ca), mg	21.00
Iron (Fe), mg	0.80
Magnesium (Mg), mg	12.00
Phosphorus (P), mg	44.00
Potassium (K), mg	340.00
Sodium (Na), mg	1.00
Zinc (Zn), mg	0.32

[a] data obtained from USDA National Nutrient Database for Standard Reference

Carotenoids (β-carotene, lutein and zeaxanthin) and B vitamins present in pumpkin has been demonstrated to support cognitive function and protect against neurodegenerative disorders such as Alzheimer's disease (Zhu et al., 2019). Among these compounds, β-carotene and lutein play a crucial role in maintaining health in both animals and humans. As a precursor to vitamin A, β-carotene is essential for good vision, particularly in low-light conditions (Zhu et al., 2019), and contributes to immune function, reproductive health, and cellular protection due to its strong antioxidant activity. In animals, it supports ovarian function, improve reproductive efficiency and mitigates oxidative stress, providing particular benefits in intensive production systems. Regular consumption of pumpkin, a rich source of β-carotene, has also been associated with a reduced risk of macular degeneration (Ma and Lin, 2010). Lutein, known for its antioxidant properties, protects visual health by reducing the risk of macular degeneration. Beyond its visual benefits, lutein strengthens immune system, decreases oxidative damage and enhances pigmentation of animal-derived products, for example, intensifying the yellow coloration of egg yolks in poultry and the orange flesh of certain fish species (Kijlstra et al., 2012).

In addition to its high carotenoid content, pumpkin flesh also contains polyphenols and vitamin C, which help neutralise free radicals, potentially lowering the risk of chronic conditions such as heart disease and certain types of cancer (Kim et al., 2012). Polyphenols are potent antioxidants that protect cellular structures from oxidative damage, contributing to improved immune function and overall health in animals. Vitamin C, another strong antioxidant, further enhances immune responses, protecting cells from oxidative damage, and supporting collagen synthesis – vital for skin and tissue integrity (Bertelli et al., 2021).

Pumpkin, due to its high water and fibre content, is believed to support intestinal health by improving peristalsis and preventing constipation. Moreover, the presence of pectin in pumpkin may contribute to blood glucose regulation (Mishra et al., 2020), with studies indicating its potential benefits for managing type 2 diabetes (Batool et al., 2022). Chen et al. (2005) demonstrated that the administration of pumpkin fruit powder, rich in D-chiro-inositol, increased insulin levels, and lowered blood glucose concentrations. Additionally, regular pumpkin consumption may help reduce the risk of kidney damage.

Pumpkin seeds are a rich source of tocopherols, carotenoids, terpenoids, terpenes (cucurbitacin), alkaloids (moschatin), squalenes, phytosterols, phenols, coumarins, provitamins, pigments, unsaturated fatty acids, flavonoids, and proteins. They also provide significant amounts of magnesium, iron, calcium, potassium, phosphorus, and various micronutrients (Dotto and Chacha, 2020). The detailed chemical composition of dried pumpkin seeds is presented in Table 2. Nutritional analysis has revealed that pumpkin seeds

Table 2. Nutritional composition of dried pumpkin seeds (per 100 g)

Nutrient[a]	Amount
Water, g	2.23
Energy, KJ	2340.00
Carbohydrates, g	10.07
Dietary fibre, g	6.00
Fats, g	49.00
Saturated fats, g	8.66
Monounsaturated fats, g	16.20
Polyunsaturated fats, g	21.00
Protein, g	30.02
Vitamin A, µg	16.00
α-Carotene, µg	1.00
β-Carotene, µg	1.00
Thiamine (vitamin B_1), mg	0.27
Riboflavin (vitamin B_2), mg	0.15
Niacin (vitamin B_3), mg	4.99
Pantothenic acid (vitamin B_5), mg	0.75
Pyridoxine (vitamin B_6), mg	0.14
Folic acid (vitamin B_9), µg	58.00
Vitamin C, mg	1.90
Vitamin E, mg	2.18
Calcium (Ca), mg	46.00
Iron (Fe), mg	8.82
Magnesium (Mg), mg	592.00
Phosphorus (P), mg	1230.00
Potassium (K), mg	809.00
Sodium (Na), mg	7.00
Zinc (Zn), mg	7.81

[a] data obtained from USDA National Nutrient Database for Standard Reference

contain 41.59% fat, 25.4% protein, 25.19% carbohydrates, and 5.34% fibre (Gohari-Ardabili et al., 2011).

The primary fatty acids detected in pumpkin seed oil are linoleic acid (LA, C18:2 n-6), oleic acid (C18:1), stearic acid (C18:0), and palmitic acid (C16:0). Together, they account for approximately 95% of the total fatty acid content, with the unsaturated fatty acids (linoleic and oleic) comprising around 75%. Oleic acid (C18:1) is known for its beneficial effects on cardiovascular health, as well as its anti-inflammatory and neuroprotective properties. Pumpkin seed oil inclusion in a balanced diet has been associated with improved outcomes in chronic and metabolic disorders. At the cellular level, oleic acid supports membrane integrity and facilitates efficient signal transmission, potentially promoting brain and nervous system function. In addition, oleic acid (C18:1) has demonstrated the ability to improve insulin sensitivity, suggesting a potential role in preventing type 2 diabetes (De Souza and Mente, 2015; Frega and Mozzon, 2017). Linoleic acid (LA, C18:2 n-6) is one of the most important n-6 polyunsaturated fatty acids with a number of biological functions in the human body. As a precursor for eicosanoid synthesis, it plays a key role in regulating vasodilation, blood pressure, and inflammatory response (Yang et al., 2015). Additionally, LA contributes to lipid metabolism optimisation, cardiovascular protection, and serves as a structural component of brain cell membranes, supporting cognitive function and neuronal integrity (Lichtenstein and Deckelbaum, 2001; Harris and Von Schacky, 2004). Pumpkin seeds also contain trace amounts of linolenic acid (ALA, C18:3 n-3), which, together with linoleic acid (LA, C18:2 n-6), belongs to the group of essential unsaturated fatty acids (EFAs). These EFAs cannot be synthesised endogenously in humans and must therefore be obtained through dietary sources. The potential role of n-3 polyunsaturated fatty acids in the prevention of cardiovascular disease has been a subject of extensive research. Numerous studies have demonstrated their ability to significantly reduce the risk of heart disease, vascular embolism, and hypertension (Dotto and Chacha, 2020). The cardioprotective properties of n-3 polyunsaturated fatty acids (PUFAs) are primarily attributed to their ability to modulate lipid metabolism by lowering serum triglyceride levels and increasing high-density lipoprotein (HDL) cholesterol (Shibabaw, 2021). In addition, these fatty acids show anti-inflammatory properties by inhibiting the production of pro-inflammatory cytokines, such as interleukin-6 (IL-6) and tumour necrosis factor-alpha (TNF-α), while simultaneously promoting the synthesis of anti-inflammatory mediators, including resolvins and protectins (Das, 2021). These fatty acids have also been shown to stabilise heart rhythm by modulating ion channels in cardiac cells, thereby reducing the risk of arrhythmias (Drenjančević and Pitha, 2022). Their vasodilatory properties are attributed to the stimulation of endothelial nitric oxide production, which in turn promotes arterial relaxation and normal blood pressure. Moreover, regular consumption of n-3 PUFAs has been associated with reduced platelet aggregation, thereby lowering the risk of thrombus formation and vascular embolism (Golanski et al., 2021).

Pumpkin seeds contain up to 35% protein in certain varieties, comprising a complete amino acid profile that includes all nine essential amino acids, making them a valuable alternative protein sources for human and animal nutrition (Jafari et al., 2012). Studies have shown that protein isolated from pumpkin seeds has a very high bioavailability and digestibility, comparable to that of soybean protein (Rezig et al., 2013). The presence of amino acids like tryptophan helps neutralise free radicals, thereby reducing oxidative stress and risk of age-related diseases. In addition, these proteins demonstrate chelating properties, facilitating the elimination of toxic metals, such as cadmium and lead. High levels of methionine and phenylalanine support the production of antibodies and the activity of enzymes essential to immune function. This favourable chemical composition, combined with antioxidant and chelating activity, position pumpkin seed protein as a viable substitute for conventional protein sources in human diets and animal feed formulations (Singh and Kumar, 2024).

Pumpkin seeds contain vitamin E in the form of four isomers – α, β, γ, and δ tocopherols and tocotrienols, differentiated by methyl group positioning on their chromanol rings. The most abundant is γ-tocopherol, followed by α-tocopherol and δ-tocopherol. Both tocopherols and tocotrienols are potent antioxidants of natural origin, capable of inactivating highly reactive free radicals (Azzi, 2019). Thus, they protect cellular lipids from peroxidation, and their subsequent degradation. It has been hypothesised that tocopherols may also possess a pro-oxidant function by reducing the content of certain harmful metals in tissues, though this activity is highly dependent on dietary tocopherol intake. Tocotrienols have been shown to exert anticholesterolemic, neuroprotective, cardioprotective, and anticancer effects (Saito and Yoshida, 2019).

One of the main benefits of the bioactive compounds found in pumpkin is their strong antioxidant activity. Carotenoids such as β-carotene and lutein neutralise free radicals, thereby protecting cells from oxidative damage. A precursor to vitamin A (β-carotene), is particularly effective in scavenging singlet oxygen and reducing cellular damage, while lutein protects eye tissues and supports vision health. Tocopherols (vitamin E) are lipid-soluble antioxidants integrated into cell membranes, where they protect fatty acids from peroxidation and help maintain cellular integrity. Pumpkin also contains polyphenols, another group of antioxidants that neutralise reactive oxygen species and stabilise cellular structures (Mohamed Ahmed et al., 2024). In addition to their antioxidant effects, these compounds modulate cellular signalling pathways, regulate inflammatory processes, and modulate gene expression (Sakthivel et al., 2022). Carotenoids can enhance the expression of genes involved in antioxidant defence mechanisms (Sakthivel et al., 2022), while PUFAs, particularly omega-3 fatty acids, exert anti-inflammatory effects. Omega-3 fatty acids reduce the production of pro-inflammatory cytokines, supporting cellular homeostasis and reducing chronic inflammation linked to metabolic disorders in animals (Calder, 2017). Pumpkin also contributes to gut health through its dietary fibre, which acts as a prebiotic to stimulate beneficial bacteria like *Lactobacillus* and *Bifidobacterium*, improving digestion and nutrient absorption. Polyphenols further enhance gut integrity by strengthening tight junction proteins and reducing the risk of gut permeability. In addition, both carotenoids and polyphenols have antimicrobial properties, inhibiting the growth of pathogenic bacteria such as *Escherichia coli* and *Salmonella* (Nieto et al., 2024).

Many individuals diagnosed with type 1 or type 2 diabetes avoid pumpkin seeds due to concerns related to their high carbohydrate content. However, a study conducted in rats has revealed that pumpkin seeds may actually exert blood sugar-lowering effects. A diet supplemented with pumpkin seeds did not result in elevated blood levels of glucose, lipids, triglycerides, or cholesterol (Sedigheh et al., 2011).

Other studies have demonstrated that pumpkin seeds can lower alanine aminotransferase (ALT) and aspartate aminotransferase (AST) enzyme activities, which are key markers used in the diagnosis and management of liver disease (Makni et al., 2010). The seeds also improve overall immunity, liver function and support the physiological activity of multiple organs, including the liver, gallbladder, prostate, and testes (Hussain et al., 2022b). Pumpkin seeds also show potential in preventing bladder disorders and reducing cancer risk. Notably, their high concentration of bioactive carotenoids with potent antioxidant properties has been linked to protective effects against brain cancer (Syed et al., 2019).

Folk medicine and ongoing scientific research indicate that pumpkin consumption exerts a positive effect on reproductive health (Batool et al., 2022). This is largely attributed to the high zinc content in pumpkin seeds, which is essential for male germ cell development (Aghaei et al., 2013). Pumpkin seeds also improve sexual stimulation, arousal, ejaculatory function, and latency (IsHak et al., 2017). Moreover, pumpkin extract has been shown to significantly reduce the proportion of sperm with primary and secondary conformational defects (Shaban and Sahu, 2017). As a result, research into the use of pumpkin for the prevention and treatment of male infertility has intensified in recent years (Shaban and Sahu, 2017). Aghaei et al. (2013) investigated the protective effects of pumpkin seed extract on sperm parameters, blood biochemical markers, and epididymal histology in rats treated with cyclophosphamide, a chemotherapeutic. The study involved four groups of Wistar rats: a control group receiving saline, a group treated only with cyclophosphamide (100 mg/kg), and two additional groups receiving cyclophosphamide along with pumpkin seed extract at different doses (300 and 600 mg/kg). Results demonstrated that cyclophosphamide administration significantly reduced semen quality, while co-treatment with 300 mg pumpkin seed extract markedly increased total antioxidant capacity (TAC). Histopathological examination of the epididymis revealed cyclophosphamide-induced epididymal damage, including vacuolisation, altered epithelial thickness, and fibromuscular layer changes, and variations in the diameter of epididymal tubules in the tail region. Pumpkin seed extract administration significantly ameliorated these harmful effects, suggesting its potential as a protective agent. Mohammadi et al. (2014) further demonstrated that the combined treatment with ginger and pumpkin seed extract not only improved these histopathological markers but also accelerated germ cell proliferation within the seminal ducts and supported spermatogenic recovery following cyclophosphamide exposure.

The membrane that separates the seed coat from the kernel serves as a natural barrier against microbial and fungal pathogens. This structure contains cucurbitacins, bioactive compounds with demonstrated anti-parasitic, anti-microbial, and anti-cancer properties. Cucurbitacins are safe for human consumption, as they are not absorbed in the gastrointestinal tract and do not irritate the intestinal mucosa. For this reason, they are considered suitable for use in traditional medicine for the control of gastrointestinal parasites. These compounds penetrate parasitic organisms and induce paralysis by affecting their nervous system. Scientific reports indicate that regular consumption of pumpkin seeds containing cucurbitacins may offer long-term protection against parasites, such as armed and unarmed tapeworms, pinworms, roundworms, and duodenal hookworms. In addition to their antiparasitic properties, cucurbitacins also support the functioning of the digestive system by stimulating secretion of gastric, pancreatic, and intestinal juices while promoting bile production, digestion, and protecting the liver (Zdrojewicz et al., 2016; Kumar et al., 2023). Cucurbitacins also exhibit anti-inflammatory activity, which may be particularly relevant in chronic conditions such as rheumatoid arthritis or inflammatory bowel disease. This effect is attributed to its ability to inhibit transcription factors such as NF-κB, which play a key role in regulating inflammatory processes. This NF-κB suppression mechanism reduces oxidative stress and limits tissue damage caused by chronic inflammation (Rocha et al., 2005).

Recent research efforts have focused on elucidating anticancer properties of cucurbitacins. Studies demonstrate their ability to interfere with cancer cell cycles, particularly inducing G2/M phase arrest and promoting apoptosis in various malignancies including breast, lung, and skin cancers (Dąbek et al., 2021). Additionally, certain cucurbitacin derivatives have been found to modulate signalling pathways implicated in angiogenesis, potentially restricting tumour vascularisation and nutrient supply. Preliminary findings suggest that cucurbitacins may act synergistically with certain chemotherapeutic agents by increasing their efficacy while reducing treatment-related toxicity (Park et al., 2025; Si et al., 2019). Figure 1 summarises these health-promoting properties of pumpkin-derived compounds.

The bioactive compounds present in pumpkin show significant potential in dietetics and metabolic disease prevention. Pumpkin seed oil, rich in polyunsaturated fatty acids and tocopherols, may help reduce oxidative stress and improve lipid profiles. Minerals contained in various parts of the pumpkin plant support reproductive function and improve fertility. Current research explores pumpkin extracts' ability to regulate body weight and lipid metabolism for managing obesity and type 2 diabetes. The wide range of health-promoting properties of pumpkin have led to its incorporation into both human nutrition and dietary supplements. Its bioactive constituents demonstrate therapeutic potential across various diseases, positioning it as a valuable resource for pharmaceutical and nutraceutical applications. Pumpkin-based products also serve as natural alternatives to synthetic medications in livestock health management, supporting both animal welfare and agricultural productivity.

Economic aspects of using pumpkin by-products in livestock feed

The incorporation of pumpkin by-products, such as seeds, seed oil, and pulp, into livestock feeds presents several economic advantages for both farmers and feed producers. These benefits stem from the relatively low cost of these by-products, their high nutritional value, and positive impact on ani-

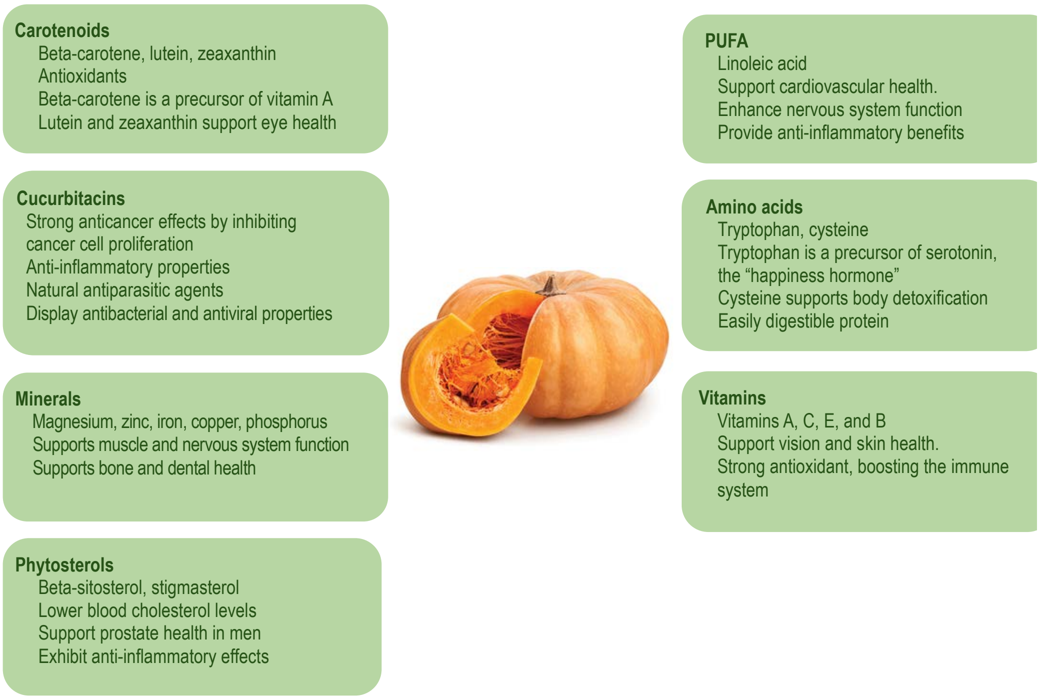

Figure 1. Bioactive compounds contained in pumpkin and their effects on health (Hussain et al., 2022a)

mal health and productivity. The economic aspects of using pumpkin by-products in animal nutrition can be assessed through several key factors, including cost reduction, value addition, improved animal performance, and market potential (Gavril Rațu et al., 2024).

The utilisation of pumpkin by-products in livestock feed offers significant cost advantages, primarily through the substitution of expensive conventional ingredients (Wadhwa et al., 2013). In the pumpkin processing industry, materials such as leaves, stems, pulp, and seed cake are often regarded as waste (Villamil et al., 2023), making them economically attractive feed alternatives. By partially substituting more expensive protein sources like soybean meal or energy sources, such as maize, with pumpkin by-products, producers can reduce expenses without compromising nutritional quality (Parrini et al., 2023). At present, pumpkin by-products are not widely commercialised by feed companies, which contributes to their relatively high prices. For example, the cost of pumpkin seed cake, a readily digestible ingredient rich in high-quality protein, ranges from 5 to 20 PLN per kg in Poland, depending on the source. This price is several times higher than the cost of soybean meal, which is approximately 2.20–2.70 PLN per kg in Poland, or 0.296 USD on global markets (https://www.investing.com/commodities/us-soybean-meal). However, in addition to its nutritional function, pumpkin seed cake also provides additional health benefits for livestock.

The nutritional enrichment provided by pumpkin by-products in livestock feed represents a significant value-added benefit. Pumpkin seeds are a rich source of protein, essential fatty acids, particularly linoleic acid (LA C18:2 n-6), vitamins, such as vitamin E, and essential minerals, including zinc and magnesium. Pumpkin seed oil is of particular value due to its potent antioxidant properties, reducing reliance on synthetic additives. The natural antioxidants in pumpkin seed oil help protect animal cells from oxidative damage, while the essential fatty acids support cellular membrane integrity and overall health. Studies demonstrate that this nutritional profile improves animal health, feed efficiency, and production outcomes (Villamil et al., 2023; Gavril Rațu et al., 2024).

Research indicates that diets supplemented with pumpkin derivatives improve growth performance, including weight gain, feed conversion ratios, and reproductive health (Achilonu et al., 2018). The high zinc content in pumpkin seeds specifically increases poultry fertility and hatchability rates. Additionally, the natural antioxidants found in pumpkin seed oil help reduce oxidative stress, a key factor in maintaining overall animal wellbeing. These health benefits translate directly into production advantages, as healthier livestock exhibit superior performance parameters and require fewer veterinary interventions, ultimately reducing operational costs for producers (Dowidar et al., 2020).

The utilisation of pumpkin by-products in livestock feed aligns with sustainable agricultural practices, and can improve the marketability of livestock products. This approach supports circular economy principles by minimising waste and enhance resource efficiency. As consumers are increasingly prioritising sustainability, feeds containing natural ingredients, such as pumpkin by-products, can be marketed as environmentally friendly options (Jiao et al., 2021). Moreover, the increasing demand for organic and natural livestock products represents a lucrative opportunity for producers to market meat, eggs, or milk from animals fed pumpkin-based feeds as premium foods. Such products can be promoted as 'enhanced' or 'functional', with the latter category achieving higher market prices (Hussain et al., 2022a).

A cost-benefit analysis confirms the economic feasibility of utilising pumpkin by-products in livestock rations. The relatively low acquisition cost of these by-products in comparison to conventional feed ingredients, combined with minimal processing requirements (typically just drying, grinding, or oil extraction), ensures cost-effectiveness (Noh et al., 2022). Their inclusion in feed generates multiple revenue streams through improved livestock productivity, product quality, and the potential for premium pricing of value-added animal products. When combined with the direct feed cost savings and animal health benefits, these factors result in a high return on investment.

Pumpkin in ruminant nutrition

Pumpkin seeds are characterised by a high content of fats, protein, and bioactive compounds, making them an interesting alternative to conventional feed components such as soybean meal or rapeseed meal (Kuchtík et al., 2015). In addition, pumpkin seed cake, a by-product of oil pressing, is receiving growing research interest due to its potential impact on rumen fermentation, milk composition, and meat quality in ruminants (Li et al., 2021; Antunović et al., 2018). The inclusion of pumpkin in ruminant diets has also been associated with alterations in the fatty acid profile of milk and meat, which is relevant both to animal health and the nutritional value of animal products for consumers (Klir et al., 2017; Halik et al., 2018). Additionally, the use of cattle manure as fertiliser has been demonstrated to significantly increase pumpkin fruit yield, seed production, and fruit chemical composition. This creates an opportunity for farmers to make efficient use of livestock waste, establishing a closed-loop system between pumpkin cultivation and cattle farming (Ansari et al., 2017).

The study by Li et al. (2021) investigated pumpkin seed cake as a soybean meal replacement in dairy cow rations at two inclusion levels: 50 and 100% substitution. Results demonstrated no significant differences ($P > 0.05$) in key performance metrics between control and experimental groups. These parameters included rumen degradation and fermentation, milk yield, dry matter (DM) intake, and apparent total digestive tract digestibility. Additionally, nitrogen partitioning between milk, faeces, and urine remained unaltered between the groups. These findings are significant because they show that pumpkin seed cake can be used as a high-quality, locally sourced alternative to imported protein, reducing dependence on feed imports. The high protein content and favourable amino acid profile of pumpkin seeds ensures an adequate nitrogen supply for rumen microbes, supporting efficient protein utilisation. Although the rumen bacterial diversity index was not significantly affected by the change in feed composition, the study revealed a shift in the rumen microbial population, characterised by an increased relative abundance of *Firmicutes* and *Tenericutes*, bacterial groups associated with effective fibre degradation. This microbial changes enhanced fibre digestion efficiency, explaining the improved neutral detergent fibre digestibility observed in animals fed pumpkin-based diets. Supplementation with seed cake resulted in a linear decrease in the abundance of *Ruminococcus*, while the population of *Prevotella* showed a linear decreasing trend. The antioxidant properties of pumpkin compounds, particularly polyphenols, also play a role in maintaining rumen health by protecting rumen epithelial cells from oxidative stress, particularly under intensive production conditions. Research indicates that in addition to seeds, other pumpkin components, including the fruit and whole plant material, can be effectively incorporated into ruminant feeding regimens.

Halik et al. (2018) investigated the effects of pumpkin silage supplementation in dairy cow diets on milk quality. The study included four experimental groups: a control group fed grass and maize silage with concentrate, a group receiving the same diet plus 400 mg/day of synthetic β-carotene, a group with 40% of maize silage replaced by pumpkin silage (providing equivalent β-carotene), and a group with 60% maize silage replaced by pumpkin silage. Results showed the highest concentrations of α-carotene, β-carotene, lutein and violaxanthin in the 60%

pumpkin silage group, along with elevated PUFA and n-3 fatty acid content. The antioxidant properties of carotenoids improved milk quality by protecting its lipid fraction from oxidation, making the milk more beneficial for consumers. The improved fatty acid profile and carotenoid enrichment are attributed to the direct absorption and transfer of pumpkin's high PUFA content and fat-soluble carotenoids into milk fat.

Antunović et al. (2018) examined the effects of 10 and 15% inclusion of pumpkin seed cake on production performance, meat quality, and health parameters in 70-day-old *Merinolandschaf* lambs. Results showed no significant differences in slaughter performance, meat colour, or lipid profile. However, lambs fed diets containing pumpkin seed cake showed a higher concentration of linoleic acid (LA C18:2 n-6) in meat lipids resulting in an increased n-6/n-3 ratio compared to the control group. Despite this, the antioxidant properties of carotenoids and tocopherols in pumpkin contributed to improved oxidative stability of the meat. The total contents of saturated fatty acids (SFAs), monounsaturated fatty acids (MUFAs), and PUFAs did not differ between groups. The findings suggest that pumpkin seed cake supplementation can positively influence meat fatty acid composition while maintaining oxidative stability, which may lead to better colour retention and extended shelf life of lamb meat.

Aranda Aguirre et al. (2024) evaluated the effects of chia and pumpkin seed supplementation (61 g/kg DM) in dairy sheep diets on nutrient intake and digestibility, milk yield, and milk composition. The study found no significant impact on body weight or DM intake between control and treatment groups. However, the supplemented diets improved neutral detergent fibre and lignin digestibility compared to the control. Pumpkin seed inclusion enhanced milk yield, fat-corrected milk production, and feed conversion efficiency. The experimental rations reduced milk palmitic acid (C16:0) content while showing a tendency to increase γ-linolenic acid (GLA, C18:3 n-6) and α-linolenic acid (ALA, C18:3 n-3) concentrations.

Tacuri Vera (2024) investigated the use of pumpkin as an antiparasitic agent in lamb nutrition by comparing a control group with a group receiving 0.45 kg/day/animal of pumpkin seed supplementation. Results showed reduced body weight in supplemented lambs, potentially linked to decreased feed intake. The study concluded that the dietary supplementation had no significant effect on parasite infestation levels, which could be related to the reduced feed intake observed in the experimental group. Similarly, Matthews et al. (2016) found that administration of pumpkin seeds (5 g/kg body weight) or pumpkin seed oil (2 ml/kg body weight) had no significant impact on antiparasitic resistance in kids and lambs. The level of parasite infection did not differ significantly between dietary groups. Although the direct antiparasitic effects of pumpkin were limited, its high antioxidant content may still provide indirect benefits by enhancing the immune response and increasing the animals' resilience to parasitic infections.

Klir et al. (2017) investigated the effect of feeding pumpkin seed cake (160 g/kg feed) to lactating goats and found no significant impact on milk yield or chemical composition. The study reported reduced levels of linoleic acid (LA, C18:2 n-6) and docosapentaeonic acid (DPA, C22:5 n-3) in milk, while eicosapentaenoic acid (EPA, C20:5 n-3) levels remained unchanged. As a result, the LA/ALA ratio was lower in supplemented group, and total n-6 fatty acids decreased compared to control. In a related study, Boldea et al. (2021) used 1.24 kg of pumpkin seed cake per goat daily and observed no effect on milk yield but a 25% increase in PUFA and FAME content compared to the control. The milk from goats fed pumpkin seed cake also had significantly higher CLA levels.

Maselema et al. (2021) studied the impact of dietary supplementation with full-fat pumpkin seed meal on the fattening performance and semen quality in pasture-raised male Malawian goats. Thirty goats were divided into three groups: one grazed without supplementation, another supplemented with pumpkin seed meal (500 g/animal before grazing), and a third supplemented with soybean meal. The soybean meal group had higher feed intake than the pumpkin seed meal group. Both supplemented groups achieved higher slaughter weights and average daily gain compared to the unsupplemented group. The pumpkin seed meal group had the largest scrotal circumference. Additionally, their semen had higher pH values, greater total and progressive sperm motility, and higher sperm concentration compared to the other groups. These effects were directly linked to the role of PUFAs in maintaining cell membrane fluidity and protecting sperm cells from oxidative damage. Zinc in pumpkin seed meal supports spermatogenesis, sperm motility, and membrane stability in reproductive cells. Tocopherols (vitamin E) further contribute by protecting testicular cells from oxidative stress and enhancing sperm viability, while carotenoids provide addi-

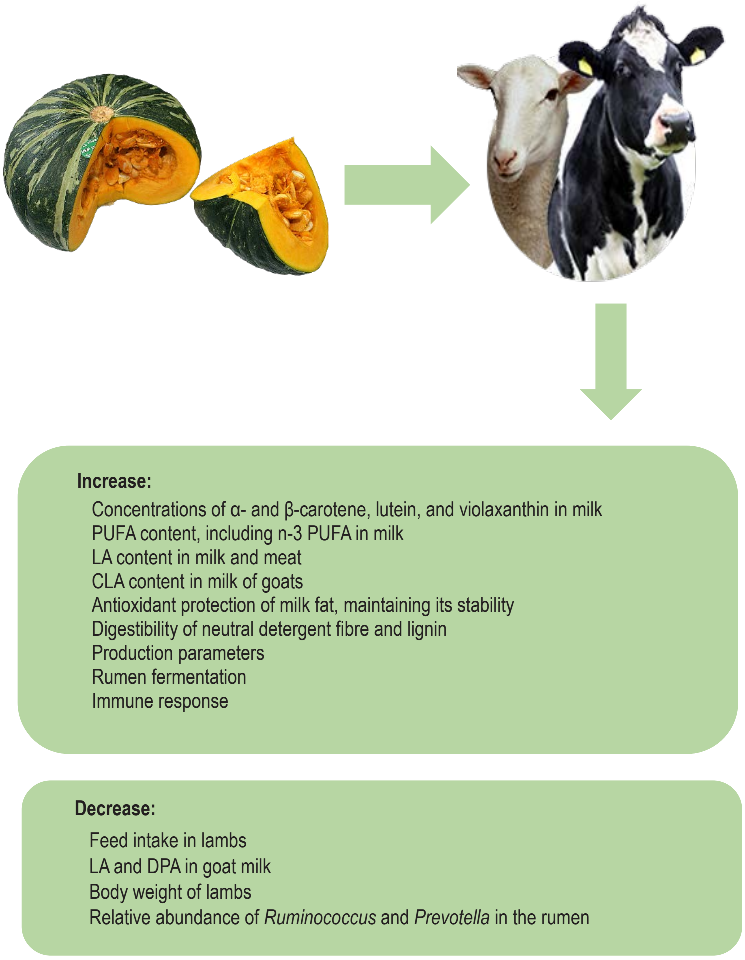

Figure 2. Effects of bioactive substances contained in pumpkin on ruminant performance, health and product characteristics

PUFA – polyunsaturated fatty acids, CLA – conjugated linoleic acid, DPA – docosapentaeonic acid, LA – linoleic acid

tional antioxidant protection in reproductive tissues (Ziamajidi et al., 2023; Marín de Jesús et al., 2024).

The influence of bioactive compounds found in pumpkin seeds on ruminant productivity, product quality, and health is illustrated in Figure 2.

The research presented here confirms the beneficial effects of pumpkin and its derivatives on rumen fermentation, milk composition, milk fat nutritional value, and meat quality. Studies have also validated the positive influence of pumpkin on reproductive performance in ruminants. Pumpkin seed cake has been demonstrated to be an effective alternative for traditional protein sources such as soybean meal, maintaining production performance while improving the fatty acid profile of milk and meat. Dietary inclusion of pumpkin may additionally improve fibre digestibility and feed conversion efficiency in ruminants. However evidence regarding potential antiparasitic properties of pumpkin remains inconclusive and requires further investigation. Overall, the use of pumpkin in ruminant nutrition not only increases feed diversity but may also improve the nutritional value of animal products, aligning with the current trend of seeking alternative locally sourced feed alternatives.

Pumpkin in pig nutrition

Modern pig nutrition increasingly emphasises the identification of alternative feed ingredients to replace conventional components such as soybean meal or maize (Parrini et al., 2023). In this context, pumpkin has emerged as a promising candidate, though its utilisation in pig diets remains relatively limited. Current research has primarily examined fermented pumpkin fruit or post-production waste, such as vines and leaves, which could be incorporated into traditional pig feeding system.

In a study by Danilov et al. (2024), the addition of pumpkin seed cake to the feed at 4%/t (initial fattening phase) and 7%/t (later phase) had no negative effect on health, production performance, and carcass quality of fattening pigs (Yorkshire × Landrace × Duroc), as well as economic performance indicators. Compared to the control group, pigs fed pumpkin seed cake achieved a 2.3% higher average daily gain (789 g) and 2.1% better feed conversion. These improvements can be ascribed to the high-quality protein and energy-rich unsaturated fats in pumpkin seeds, which facilitate efficient muscle development and metabolism. Chemical meat analysis revealed increased intramuscular fat content, likely increasing tenderness and juiciness, with elevated oleic (C18:1) and linoleic (C18:2 n-6) acid levels contributing to improved fat deposition. Blood biochemical parameters remained physiologically normal, confirming no adverse metabolic effects. Carcass analysis showed a higher dressing percentage reduced backfat thickness ($6/7^{th}$ thoracic vertebra), and a trend toward larger *longissimus dorsi* muscle area. These changes may result from optimised nutrient utilisation supporting the anti-inflammatory properties of bioactive compounds present in pumpkin seeds.

De Castro et al. (2023) examined the effects of supplementing fattening pig rations with 5 and 10% pumpkin seed meal on production traits and antiparasitic resistance. While the additive did not significantly influence weight gain or feed conversion efficiency, it demonstrated notable antiparasitic properties. The researchers observed a reduction in gastrointestinal parasite load, evidenced by decreased counts of parasite eggs and oocysts in faeces. This antiparasitic effect was likely mediated by cucurbitacins and other secondary metabolites found in pumpkin seeds, which interfere with parasite development and reproduction.

Medina-González et al. (2019) replaced 0, 15, and 30% of conventional pig feed with fermented pumpkin. Although the addition of fermented pumpkin had no significant effect on body weight, a marked reduction in diarrhoea incidence was observed. Furthermore, pig mortality decreased from 10% in the control group to 0% in groups receiving fermented pumpkin. The fermentation process has been shown to increase nutrient bioavailability of nutrients and to generate organic acids, e.g. lactic acid, which lower gut pH, suppress pathogenic bacteria, and support intestinal health. Moreover, the prebiotic fibre content of pumpkin likely contributed to a balanced gut microbiota, thereby reducing the incidence of digestive disorders.

Vlaicu et al. (2019) conducted a study to analyse the effects of dietary supplementation with flaxseed meal and grape seed meal (5 and 1%, respectively) versus pumpkin waste (5%) in growing-finishing pigs (60–100 kg). The pumpkin waste group demonstrated significantly higher average daily feed intake compared to both the control and flaxseed/grape seed groups, likely due to the palatability-enhancing properties of pumpkin by-products. No significant differences were observed in feed conversion ratio between the treatment groups. However, fibre digestibility was significantly lower in the pumpkin waste group, reflecting the high fibre content of this by-product material. The maintained feed conversion ratio, despite reduced fibre digestibility, suggests potential for the strategic incorporation of pumpkin waste in swine diets when properly balanced.

Another study focused on the effects of including cassava leaf meal with provitamin A, pumpkin stalks, and moringa leaf meal at a 10% inclusion rate in pig rations on pork quality, growth performance, and lipid profile, using a conventional full-feed ration as the control. (Ekpo et al., 2022). Pigs fed moringa leaf meal showed the highest weight gain among all treatment groups, while cassava leaf meal and pumpkin stalks also enhanced growth performance over the control diet. All experimental diets increased daily feed intake without compromising feed conversion efficiency. The pumpkin stalk formulation improved lipid metabolism, reducing total cholesterol, triglycerides, low-density lipoprotein (LDL), and very low-density lipoprotein (VLDL) while increasing HDL levels in pork. Sensory evaluation ranked moringa-fed pork highest for juiciness and tenderness, with pumpkin stalk-fed meat also receiving favourable scores. These plant by-products improved both production efficiency and meat quality when incorporated at 10% inclusion levels (Ekpo et al., 2022).

The effects of bioactive compounds found in pumpkin seeds on the productivity, product quality, and health of pigs are summarised in Figure 3.

The studies discussed here indicate that various forms of processed pumpkin can be used in swine nutrition, with measurable effects on animal health and production outcomes. Pumpkin supplementation has been shown to improve feed digestibility, modify meat composition, and strengthen immune function, including a reduction in diarrhoea incidence. Fermented pumpkin formulations appear particularly beneficial in promoting animal health, while the use of pumpkin waste has been linked to improved nutrient bioavailability. Current evidence suggests that the incorporation of pumpkin into pig diets does not compromise production efficiency; however, the limited number of studies and their methodological variations highlight the need for further research to determine the most effective forms and inclusion levels in swine nutrition.

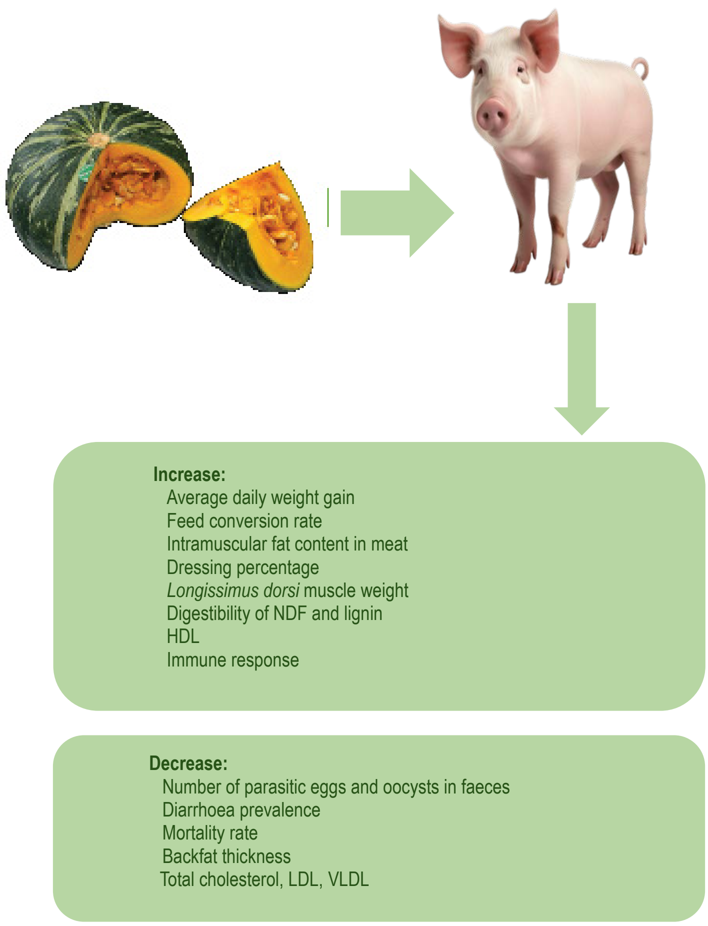

Figure 3. Effects of bioactive substances contained in pumpkin on pig performance, health and product characteristicsNDF – neutral detergent fibre, HDL – High-density lipoprotein, LDL – Low-density lipoprotein, VLDL – very low-density lipoprotein

Pumpkin in poultry nutrition

The scientific literature demonstrates that pumpkin and its by-products are increasingly utilised in poultry nutrition as alternative protein sources in complete feed mixtures. Studies most often employ pumpkin seeds, which can be a substitute for co ventional protein ingredients. Research to date indicates that supplementing poultry diets with plant-derived components, such as herbs or vegetable oils, can positively influence both production parameters and poultry product quality (Jachimowicz et al., 2022; El-Sabrout et al., 2024). Consequently, the inclusion of pumpkin and its by-products into poultry feed rations appears to be a promising nutritional approach for supporting animal health and improving product characteristics in the poultry sector. In backyard or organic production systems, there is also potential to utilise other parts of the pumpkin plant, as poultry are often fed with succulent roughage such as root crops. Pumpkin fruit, a valuable source of carotenoids, has been shown to improve egg yolk pigmentation, thereby increasing their attractiveness to consumers (Karadas et al., 2006).

A study involving 160 laying hens assessed the effects of different levels of pumpkin seed meal (0, 3.3, 6.6, and 10%) in the diet on health status and egg quality parameters (Martínez et al., 2012, Martínez-Aguilar et al. 2012).The results showed that the additive had no adverse effect on the health of hens. The 10% supplementation significantly improved egg nutritional quality, increasing yolk n-3 fatty acids from 454 mg/100 g to 1095 mg/100 g while reducing cholesterol content by 10%. These changes resulted from the high α-linolenic acid (ALA, C18:3 n-3) content in pumpkin seeds and the hypocholesterolaemic action of phytosterols and PUFAs. The results demonstrate that pumpkin seed meal can effectively improve the fatty acid profile of eggs without compromising laying performance.

El-Saadany et al. (2022) evaluated the effects of dietary supplementation with pumpkin (PK) and garden cress (GC) seed oils on the physiological and productive performance of laying hens (360 birds, 24 weeks old). The birds were randomly assigned to four groups: a control group fed a basal diet, and three treatment groups receiving 0.5% PK oil, 0.5% GC oil, or a 0.25% PK + 0.25% GC oil combination for eight weeks. The oil-supplemented groups showed significant improvements in blood biochemical parameters, including reduced cholesterol and triglyceride levels, while also enhancing productive performance through increased egg production and egg weight. These effects can be attributed to the unsaturated lipid content and bioactive phytochemicals present in pumpkin seed oil that modulate lipid metabolism and hepatic enzyme expression. The supplementation also improved antioxidant status, as evidenced by elevated superoxide dismutase (SOD) activity and reduced malondialdehyde (MDA) levels, as well as enhanced immune markers, including globulin, lymphocytes, and heterophils. These effects are linked to the tocopherols and phenolic compounds in pumpkin, which help neutralise free radicals and stimulate lymphocyte proliferation. In addition, the fatty acid profile of egg yolks improved, as demonstrated by higher levels of oleic and linoleic acids.

Vlaicu and Panaite (2022) examined the effects of adding 9% pumpkin seed meal to laying hen diet on performance, egg quality, fatty acid profile, cholesterol content, antioxidant levels, and shelf life. The addition of pumpkin seed meal significantly reduced average daily feed intake but had no meaningful impact on other performance parameters. Eggs from the experimental group contained higher concentrations of polyunsaturated fatty acids, particularly α-linolenic acid (ALA, C18:3 n-3) and linoleic acid (LA, C18:2 n-6), along with lower arachidonic acid (C20:4 n-6) levels and a reduced n-6/n-3 ratio compared to the control group. The inclusion of pumpkin seed meal led to an 11.31% reduction in egg yolk cholesterol and a 10.38% decrease in whole egg cholesterol. This decrease was likely due to the competition between plant sterols and dietary cholesterol for micellar incorporation, thereby limiting cholesterol absorption. Furthermore, eggs from hens fed the experimental diets contained significantly higher levels of polyphenols and antioxidants, which prolonged shelf life over 28 days at both refrigerated (5 °C) and ambient (21 °C) temperatures while delaying lipid oxidation and protein denaturation. This finding indicates that phenolic antioxidants derived from pumpkin may stabilise egg components during storage, resulting in improved egg quality and safety. The study also found that pumpkin-supplemented feed led to a higher Haugh unit values after 28 days of storage at 21 °C and a lower egg protein pH throughout the storage period at both temperatures, confirming pumpkin's antioxidant properties.

Pumpkin seeds can be incorporated into broiler diets without compromising performance. In one trial, Martínez-Aguilar et al. (2010) supplemented broiler rations with 10% whole pumpkin seeds and observed no significant changes in carcass traits or dressing percentage. Conversely, Aguilar et al. (2011) found that adding 33 or 66 g/kg of pumpkin-seed flour increased both live body weight and breast-muscle yield, an effect likely related to improved protein quality and amino acid availability from pumpkin seeds, supporting muscle deposition.

In an experiment conducted by Zinabu et al. (2019), broiler diets were supplemented with 1% Indian honeybush seed, 1% pumpkin-seed meal, or a 1% mixture of both. All three treatments significantly increased feed intake and weight gain vs. the control, while the feed conversion ratio improved (i.e., declined). The authors attributed these responses to enhanced nutrient digestibility and palatability resulting from the lipid content of pumpkin seed meal. Birds receiving pumpkin-seed meal, alone or in combination with honeybush, also recorded the highest slaughter yields and dressing percentages. In a related study, Hajati et al. (2011) supplemented hen diets with pumpkin seed oil at 5 and 10 g/kg. This intervention significantly reduced blood serum levels of total cholesterol and triglycerides, though no notable changes were detected in the meat chemical composition, indicating that pumpkin oil may down-regulate hepatic lipid synthesis and alter lipoprotein metabolism while preserving carcass quality. In a study by Tabari et al. (2016), broiler chickens were fed diets supplemented with either pumpkin seed oil (0.5 g/kg), or a combination of pumpkin seed oil and nettle (*Urtica* L.) extract (0.5 g/kg each), to assess effects on their intestinal microflora. Both treatments significantly lowered intestinal *Escherichia coli* counts. Birds receiving pumpkin-seed oil alone also showed a numerical, though non-significant, rise in *Lactobacillus* populations. These positive changes are thought to stem from the antimicrobial activity of phenolics and fatty acids in pumpkin, which can suppress pathogen development and selectively stimulate beneficial microbial strains.

Reda et al. (2024) evaluated the dose-dependent effects of pumpkin seed oil supplementation (0.50, 1.0, 1.5, and 2.0 ml/kg feed) on growth performance, carcass characteristics, digestive enzyme activity, blood biochemistry, and caecal microbiota in broiler chickens. The highest weight gain was observed at 1.0 and 2.0 ml oil/kg feed, and the optimal feed conversion ratio was achieved at 1.0 ml/kg. Dietary pumpkin seed oil significantly increased intestinal lipase, amylase, and protease activities, while simultaneously lowering plasma activities of AST and ALT together with concentrations of creatinine, urea, and uric acid. These findings are consistent with the hepato- and renoprotective properties of pumpkin-derived bioactive compounds. No significant alterations were observed in the proportion of offal, internal organs, or slaughter performance. However, supplementation elevated HDL-cholesterol and reduced total cholesterol, triglycerides, and VLDL- and LDL-cholesterol fractions, confirming the lipid-regulating capacity of pumpkin-derived sterols and unsaturated fats. The oil supplementation increased the abundance of *Lactobacillus* spp. and decreased *Salmonella* spp., coliforms, and *E. coli* in the caecum. Moreover, pumpkin seed oil enhanced antioxidant capacity (TAC, SOD) and reduced malondialdehyde (MDA) content. Dose-dependent improvements were observed in immune parameters, including elevated total protein, globulins, IgA, IgG, and complement component C3. Collectively, these results suggest that pumpkin seed oil promotes humoral immune response and oxidative stability, likely mediated by its fatty acids and antioxidant compounds.

Lotfi et al. (2021) explored how pumpkin seed oil and sunflower, alone or combined with vitamin E, affected rooster reproductive performance. Over 60 days, birds received one of six diets: control, 2% pumpkin seed oil, 2% sunflower oil, control plus 200 mg/kg vitamin E, 2% pumpkin seed oil plus vitamin E, and 2% sunflower oil plus vitamin E. The group receiving pumpkin seed with vitamin E showed significant improvements in sperm concentration, total and progressive motility, viability, and cell membrane integrity, along with reduced lipid peroxidation. This group also displayed the lowest percentage of sperm with DNA damage early in the study, whereas the sunflower oil with vitamin E group had the highest DNA damage by day 40. Testosterone levels were unaffected, though luteinising hormone and follicle-stimulating hormone levels varied. The results indicate that pumpkin seed oil combined with vitamin E may enhance rooster fertility, potentially through antioxidant mechanisms that preserve sperm quality.

A study in 22-week-old Japanese quail evaluated dietary vitamin E (150 or 200 mg/kg) and pumpkin seed oil (15 or 30 ml/kg) as performance enhancers (Al-Salhie et al., 2017). The birds (120 quails, aged 22 weeks) were randomly assigned to five dietary groups, with three replicates each. The control received a basal diet, while experimental groups were supplemented with either 150 or 200 mg/kg vitamin E, or 15 or 30 ml/kg pumpkin seed oil. Supplementation with 200 mg/kg vitamin E significantly improved egg production parameters, including hen-day egg production percentage, egg number, and weight, compared to the control group. Moreover, reproductive performance markers such as gonad weight, testicular development, and serum levels of testosterone, oestrogen, follicle-stimulating hormone, and luteinising hormone were also improved. Both concentrations of pumpkin seed oil (15 and 30 ml/kg) improved most measured parameters compared to controls, with 30 ml/kg showing comparable efficacy to 200 mg/kg vitamin E. These effects were attributed to pumpkin seed phytoestrogenic compounds and antioxidant tocopherols, indicating that both supplements can effectively increase quail productivity and reproductive performance through similar physiological pathways.

The effect of bioactive compounds found in pumpkin seeds on the productivity, product quality, and health of poultry is illustrated in Figure 4.

The present literature review demonstrates the broad potential applications of pumpkin and its products for broilers and layers reared in intensive, organic, or backyard systems. Pumpkin seeds, rich in protein and fatty acids, represent a valuable feed ingredient that positively influences egg quality, fatty acid profile, cholesterol content, and antioxidant properties of poultry products. Pumpkin seed oil has been shown to improve intestinal health, immune status, and lower cholesterol and triglyceride levels. Importantly, existing studies report no adverse effects on bird health or production performance following dietary inclusion of pumpkin seeds. Therefore, replacing part of conventional rations with pumpkin meal or oil offers a sustainable route to higher-quality poultry products without compromising productivity.

Pumpkin in rabbit nutrition

The field of rabbit nutrition research is increasingly focusing on the potential health-promoting and functional properties of plant components, and growing evidence indicates that pumpkin seeds, seed oil, and even the green aerial parts can improve rabbit health and performance. Pumpkin seeds

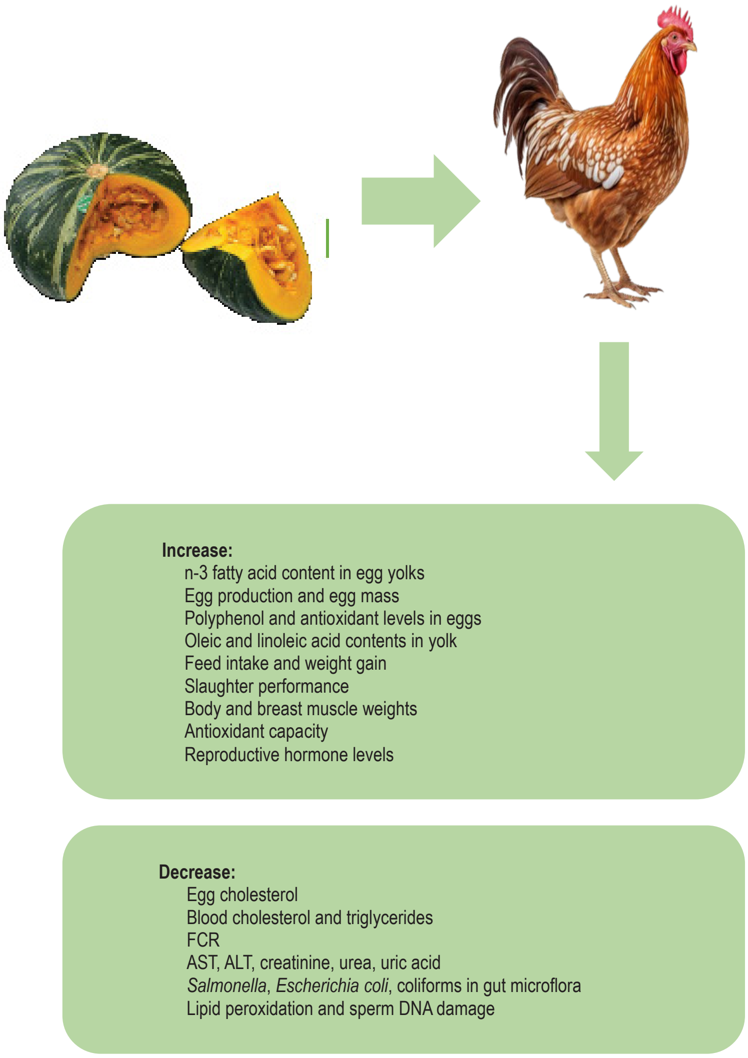

Figure 4. Effects of bioactive substances contained in pumpkin on poultry performance, health and product characteristics
FCR – feed conversion ratio, AST – aspartate transaminase, ALT – alanine transaminase

provide essential nutrients, including fats, proteins, and bioactive compounds that influence metabolic and reproductive parameters. The seed oil shows antioxidant properties that enhance immunity and protect cells from oxidative stress. On the other hand, pumpkin green parts, typically agricultural by-products, offer substantial nutritional value due to their high protein and mineral content. In rabbit husbandry, various forms of pumpkin supplementation improve health status, reproductive parameters, and meat quality. Scientific studies outlined below consistently demonstrate multiple benefits, including improved antioxidant capacity, lipid metabolism, and digestive functions.

Bakeer et al. (2021) examined the effects of pumpkin seed oil (*Cucurbita moschata*) supplementation on reproductive performance and serum antioxidant capacity in male and female rabbits. The study evaluated serum testosterone and oestradiol levels, breeding performance, litter characteristics, and semen quality. Supplementation with 0.5% pumpkin seed oil increased total serum antioxidant capacity and reduced malondialdehyde levels in both sexes, indicating the antioxidant effect of the oil mediated by its tocopherol and polyphenol content. In males, the treatment decreased semen abnormalities while showing no effect on female reproductive parameters such as litter size and birth weight. These results suggests improved spermatogenesis and sperm membrane integrity, likely a consequence of the combined action of unsaturated fatty acids and antioxidant compounds. Bakeer (2021) demonstrated that dietary supplementation with pumpkin seed oil (5 g/kg diet) significantly enhanced serum amylase, lipase, and protease activities, as well as improved mean body weight in rabbits. Collectively, moderate dietary inclusion of pumpkin seed oil stimulated the secretion of key digestive enzymes (amylase, lipase, protease), thereby enhancing nutrient assimilation, energy utilisation, and feed digestion.

A study by Abdelnour et al. (2023) demonstrated the beneficial effects of pumpkin seed oil supplemented with feed on reducing heat stress risk in rabbits. Animals exposed to high ambient temperatures (38 °C) received pumpkin seed oil at 0.5, 1.0, and 2.0 ml/kg feed. The incorporation of up to 2 ml/kg of this oil enhanced growth, immune function, enzymatic defences against free radicals, digestive enzyme activity, and caecal microbiota balance. Phenolic compounds and fibre present in pumpkin supported gastrointestinal health by stimulating the proliferation of beneficial bacterial and inhibiting the growth of potentially harmful species, leading to improved body weight and overall health under suboptimal conditions. Additionally, supplementation at 1.0 and 2.0 ml/kg increased haemoglobin levels and decreased white blood cell counts, likely due to improved iron absorption and antioxidant protection of red blood cells.

Recent research by Abou-Shehema et al. (2023) has revealed the effects of dietary pumpkin seed powder supplementation (0.05, 0.1, and 0.2%) in growing rabbits. The 0.1% inclusion level yielded optimal results, significantly improving final body weight, body weight gain, feed conversion ratio, performance index, and economic efficiency compared to other groups. This outcome was likely related to the high nutrient density, improved feed palatability, and bioactive lipids supporting energy balance. Both the 0.1 and 0.2% supplemented groups showed increased serum albumin with reduced globulins, along with significantly lower total cholesterol, LDL, and triglycerides levels. The hypolipidemic effect of the diet can be attributed to pumpkin phytosterols and PUFAs, which inhibit cholesterol absorption and promote lipid catabolism. Additionally, pumpkin seed meal addition markedly reduced caecal *E. coli* population, accompanied by an increase in the abundance of *Lactobacillus* spp., confirming its antimicrobial and prebiotic properties promoting gastrointestinal health and competitive pathogen exclusion.

Nworgu et al. (2008) supplemented weaned rabbits with fluted pumpkin (*Telfairia occidentalis*) leaf extract at 0, 50, 100, and 150 ml/l water for 10 weeks. The extract, rich in crude protein (30.5%) and minerals (ash 8.4–10.9%), significantly improved weight gain (62.9% higher than controls at 150 ml/l) and feed conversion, likely due to enhanced nutrient digestibility from fibre-bound phenolic compounds that promote gut motility and microbiota balance. Supporting these findings, Wafar et al. (2017) reported no adverse effects of pumpkin leaf inclusion in rabbit diets on organ weights (liver, lung, kidney, heart, spleen), confirming the safety of pumpkin fibrous green parts as a feed supplement even at higher inclusion rates.

In a study on the use of pumpkin seed oil (0.5%) and *Nigella sativa* seed oil (0.5%), Ragab et al. (2013) investigated their effects both separately and in combination (0.025% each) on rabbit blood biochemistry. The researchers reported no significant differences in organ weights (liver, kidney, heart, lung, spleen, head, or bile), meat quality characteristics (pH, colour, tenderness, water retention capacity) or blood morphology between experimental groups However, ALT activity was lower in groups receiving either oil alone compared to controls. All oil-supplemented groups had reduced blood lipid levels, with the *Nigella sativa* group showing the lowest triglyceride values. Total cholesterol, HDL, and LDL fractions decreased in all supplemented groups, with the most marked LDL reduction recorded in the *Nigella sativa*-fed rabbits, although this group also displayed the lowest HDL levels. The combination treatment produced the most favourable lipid-lowering effects. These metabolic improvements resulted from the combined antioxidant and lipid-regulating properties of both oils, which modulate liver enzymes and lipid transport proteins, while maintaining normal organ development and meat quality parameters.

Ekpo et al. (2019) investigated the effects of feeding rabbits with green pumpkin parts (5 and 10%), a by-product from fruit harvests. The study revealed significant lipid-modulating effects, with the 10% supplementation group showing the most pronounced reduction in meat cholesterol levels. This hypocholesterolaemic effect was attributed to the plant sterols and fibre content of pumpkin vines. Haematological analysis demonstrated increased haemoglobin and red blood cell counts in the 10% group, though both supplemented groups showed decreased mean corpuscular haemoglobin (MCH) and mean corpuscular volume (MCV), likely due to the vine iron and vitamin C content influencing erythropoiesis. The supplementation significantly improved blood lipid profiles, reducing total cholesterol, triglycerides, and LDL cholesterol while increasing HDL cholesterol. These effects suggest comprehensive modulation of lipid metabolism

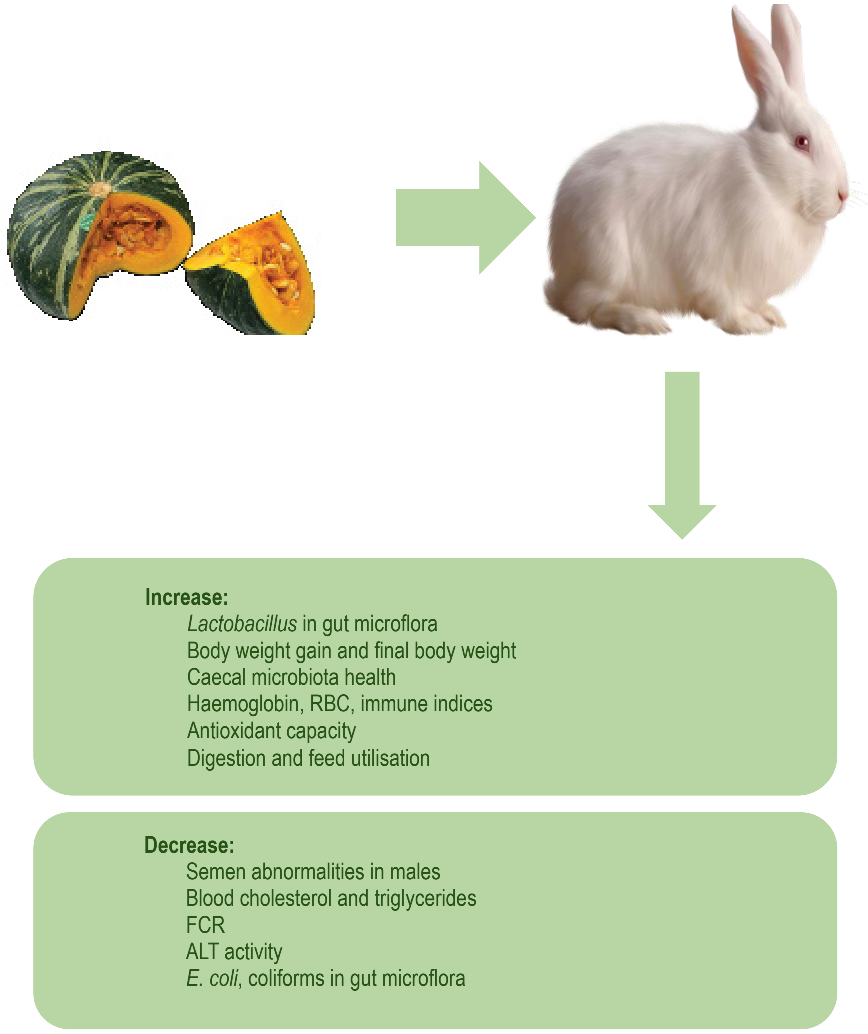

Figure 5. Influence of bioactive substances contained in pumpkin on rabbit performance, health and product characteristics
RBC – red blood cells, FCR – feed conversion ratio, ALT – alanine transaminase

through enhanced bile acid excretion and altered lipoprotein synthesis pathways. The findings highlight pumpkin green parts as a valuable by-product for improving both the nutritional quality of rabbit meat and overall metabolic function.

The effects of bioactive compounds contained in pumpkin seeds on the productivity, product quality, and health of rabbits are presented in Figure 5. The research results presented herein indicate that pumpkin seed oil, seeds, and green plant parts provide many beneficial properties for rabbit nutrition, improving health and production efficiency. The addition of pumpkin to rabbit feed mixtures can improve metabolic parameters, support digestive functions, and strengthen immunity. Pumpkin seed oil, in particular, exhibits strong antioxidant properties that reduce oxidative stress and improve the antioxidant status of the body. Pumpkin in various forms also positively influences growth, body condition, and blood lipid profile in rabbits. Collectively, these studies unequivocally demonstrate that pumpkin and its derivatives can be a valuable component in rabbit nutrition, promoting their welfare and optimising breeding performance.

Conclusions

Pumpkin shows significant potential as a feed component used in livestock nutrition. Its fruit, seeds, oil, and green parts are rich in valuable nutrients and bioactive compounds that can positively affect animal health and performance. Extensive research has validated the antioxidant, anti-inflammatory, hypoglycaemic, and lipid metabolism-promoting properties of pumpkin. Considering its high protein, unsaturated fatty acid, vitamin, and mineral content, pumpkin presents a compelling alternative to conventional feed ingredients such as soybean meal or rapeseed meal. The present literature review demonstrate the positive effects of pumpkin on meat, milk, and egg quality, as well as reproductive health in livestock. In light of the growing interest in alternative feed sources and sustainable feeding strategies, further research is needed to fully explore and utilise pumpkin's potential in modern animal production.

Conflict of interest

The Authors declare that there is no conflict of interest.

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