

SUNFLOWER PROTEIN CONCENTRATE IN ANIMAL NUTRITION: A SCOPING REVIEW OF NUTRITIONAL VALUE, PROCESSING, AND TRADE

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Abstract

Sunflower protein concentrate (SPC) is gaining recognition as a high-quality, plant-based protein source in animal nutrition due to its favorable amino acid profile, high digestibility, and functional feed properties. This scoping review synthesizes current research on SPC's nutritional composition, processing methods, and international trade dynamics, with a particular focus on Ukraine's growing role as a producer and exporter. Technological advancements such as dehulling, decellulosing, and membrane fractionation have significantly enhanced SPC's suitability for poultry and swine diets, while research on ruminants, aquaculture, and rabbits remains limited. The review also addresses broader challenges – such as climate-induced variability in seed quality, the lack of harmonized quality standards, and logistical constraints during geopolitical disruptions – that influence the development and application of SPC. By integrating evidence across disciplines, this work highlights the need for further research, regulatory alignment, and standardization to support the global scaling of SPC as a sustainable and functional feed ingredient.

Keywords: sunflower protein concentrate, high-protein sunflower meal, animal nutrition, feed ingredient quality, scoping review, Ukraine, feed processing technologies, global feed trade, poultry, aquaculture

INTRODUCTION

The demand for sustainable and efficient feed ingredients in poultry diets has led to a reliance on soybeans, one of the primary plant-based protein sources. Soybeans provide a high-quality protein that supports the rapid growth of poultry (Acheampong-Boateng *et al.*, 2016; Janocha *et al.*, 2022). However, as Okoro *et al.* (2017) noted, it is essential to identify alternative protein sources that are both cost-effective and available to reduce competition between human food needs and livestock feed requirements.

Recently, there has been a growing interest in incorporating alternative protein sources into poultry diets, mainly by-products derived from

sunflower (*Helianthus annuus L.*) (Iegorov *et al.*, 2023). This trend has been driven by several factors, including the rising costs of soybeans and their derivatives, as well as the impacts of climate change on agricultural production (Ditta and King, 2017; Simović *et al.*, 2024; Such *et al.*, 2024). Heat treatment often processes soy products, but does not eliminate anti-nutritional factors. Overprocessing can even form insoluble carbohydrate-protein complexes complicated for birds to digest and absorb (Banti and Bajo, 2020; Arsov *et al.*, 2024; Zubko *et al.*, 2022).

Plant-based feed ingredients are increasingly favoured over those of animal origin due to environmental concerns. While animal-based feeds



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are widely used, they are generally less sustainable than plant-based alternatives (Bryant, 2022). Moreover, excessive inclusion of soy products in poultry diets has been linked to digestive issues, such as flatulence, reduced feed digestion rates, imbalanced intestinal microbiota, and impaired immune system development. These challenges highlight the need for alternative protein sources to replace soybean meal (Deng and Kim, 2024; Marchal *et al.*, 2024).

In response to these challenges, SPC has emerged as a promising feed ingredient. This high-protein product, derived from the by-products of sunflower oil production, offers numerous advantages. It is nutritionally rich, cost-effective, and environmentally sustainable, making it an ideal alternative to soybean meal (Igorov *et al.*, 2023). Its adoption is particularly notable in Europe, where sustainable agricultural practices are increasingly prioritized (Pitera and Otchenashko, 2022).

Ukraine, one of the world's leading producers of sunflower seeds and oil, is strategically positioned to supply sunflower protein concentrate to meet Europe's growing demand. With its abundant production capacity and expertise, Ukraine is pivotal in addressing the global need for sustainable protein sources (Melnyk *et al.*, 2018).

The review offers a comprehensive overview of SPC's nutritional profile, processing technologies, and trade relevance, focusing on Ukraine's strategic contribution to the European feed industry during the 2022–2025 geopolitical crisis. It also outlines key areas of scientific uncertainty and research needs.

This scoping review aims to synthesize available evidence on the nutritional value, processing methods, and export potential of SPC in animal nutrition. It includes peer-reviewed and industry sources published between 1995 and 2025 and covers poultry, swine, ruminants, and aquaculture.

Given the diverse applications of SPC and the interdisciplinary nature of the available literature, a scoping review was selected as the most suitable method.

MATERIALS AND METHODS

1. Scoping Review Framework

This study follows the methodological principles of a scoping review outlined by Arksey and O'Malley (2005) and refined by Levac *et al.* (2010). This approach was selected due to the interdisciplinary nature of the topic, which involves animal nutrition, feed processing technologies, and international feed market dynamics.

2. Search Strategy And Databases

A systematic search was conducted across Web of Science, Scopus, PubMed, ScienceDirect, and Google Scholar, covering 1995 to 2025. The following keywords were used in various Boolean combinations: “sunflower protein concentrate”, “SPC”, “sunflower meal protein”, “animal feed protein alternatives”, “SPC poultry”, and “SPC digestibility”. Over 100 peer-reviewed publications were initially retrieved through targeted searches for qualitative analysis.

3. Eligibility criteria and screening

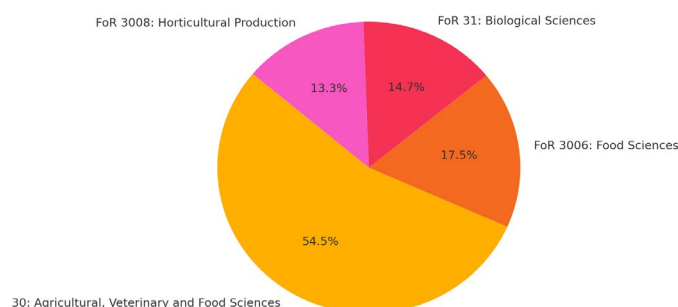
Publications were selected based on their relevance to monogastric and ruminant nutrition, availability in English or Ukrainian, clear distinction between SPC and conventional SFM, and publication in peer-reviewed journals. Studies without performance data, duplicates, non-scientific sources, and inaccessible full texts were excluded. After screening, approximately 70 studies were retained for in-depth thematic analysis.

4. Bibliometric mapping via Dimensions (supplementary)

In addition to the scoping review, a broad bibliometric mapping was performed using Dimensions.ai. A search covering 1995–2025 with the terms “sunflower protein concentrate”, “high-protein sunflower meal”, and related synonyms retrieved 2,532 publications.

These were categorized by Fields of Research (FoR) using the ANZSRC 2020 classification, with the following distribution:

Distribution of Publications by Field of Research (ANZSRC 2020)



1: Distribution of 2532 publications by Field of Research (FoR) based on ANZSRC 2020 classification. Data retrieved from Dimensions, June 2025.

- FoR 30 – Agricultural, Veterinary and Food Sciences: 2,344 publications
- FoR 3006 – Food Sciences: 755
- FoR 31 – Biological Sciences: 632
- FoR 3008 – Horticultural Production: 573
- FoR 3004 – Crop and Pasture Production: 546

RESULTS AND DISCUSSION

Physicochemical and Functional Characteristics of Sunflower Protein Concentrate

Sunflower meal is a by-product of sunflower oil extraction, and its protein content can vary significantly depending on the processing method and the presence of hulls (Mohammadabadi *et al.*, 2007). Depending on the processing methods applied to sunflower seeds (or sunflower meal/sunflower cake) – particularly in terms of dehulling and defatting – various product designations can be found in the scientific literature. These include sunflower meal, dehulled sunflower meal, SPC, high-protein sunflower meal, and sunflower seed meal. Each term reflects differences in fibre content, protein concentration, and the extent of processing, affecting the final product's nutritional and functional characteristics.

High-protein SFM is typically produced through dehulling and air classification processes to concentrate the protein fraction (Vidosavljević *et al.*, 2019).

SPC is a high-quality feed ingredient valued for its rich content of essential amino acids, including lysine, methionine, and glutamic acid (Lovatto *et al.*, 2018). It is produced by defatting sunflower seeds, followed by extraction and concentration processes that create an optimal protein profile suitable for livestock and poultry diets. The unique properties of SPC include its high water and oil absorption capacity, which enhances its stability and functionality in animal feed. These characteristics allow it to create balanced, nutrient-dense diets, meeting the nutritional needs of livestock. Moreover, its natural antioxidant properties help preserve animal health, positively influencing productivity and product quality in farming. As a sustainable plant-based alternative to animal proteins, SPC aligns with Europe's increasing emphasis on environmentally friendly agricultural practices (Salgado *et al.*, 2011).

Sunflower seeds and SPC contain proteins with excellent nutritional properties. These proteins fall into two main categories, accounting for about 95% of the total protein in sunflower seeds. The first category is 11S-globulins, helianthinins, constituting 60–70% of the protein content. The second category, 2S-albumin, or sunflower albumin, makes up 20–30% of the total proteins (González-Pérez and Vereijken, 2007; Zilic *et al.*, 2010). A challenge associated with

SFM, a precursor to SPC, is its high fibre content, which can negatively impact the growth of young birds due to their limited digestive capacity. Excessive fibre reduces the exchangeable energy in feed, slowing growth rates. A technological solution to this issue involves separating the husk, the primary fibre source, from the kernel during processing. This refinement significantly enhances the nutritional value of sunflower-based feed products (Sredanovic *et al.*, 2011).

Despite its slightly lower lysine content than soybean proteins, SPC offers nutritional and functional properties comparable to other legumes, solidifying its role as a competitive alternative in animal feed formulations (González-Pérez and Vereijken, 2007). Additionally, sunflower seeds are a rich source of α -tocopherol (vitamin E), with concentrations reaching 608 mg/kg. This provides antioxidant benefits that support livestock health and the oxidative stability of feed formulations (Azizi *et al.*, 2018).

Environmental conditions, particularly climate change, influence the protein content of sunflower seeds. Water stress can alter the composition and size of seeds, affecting both protein content and shelling efficiency. Such challenges underscore the importance of adaptive agricultural practices to maintain the consistent quality of sunflower-based products (Dauguet *et al.*, 2015).

Nutritional Value and Amino Acid Profile

1. Protein content and quality

Sunflower protein concentrate typically contains between 42–44% crude protein, significantly higher than SM, which contains approximately 33–35% protein. This protein concentration makes SPC suitable for monogastric diets requiring high-protein, low-fiber feed (Iegorov *et al.*, 2023).

Ukraine's processing advancements have enabled consistent production of high-quality SPC, optimizing protein levels and making the concentrate a competitive alternative to other plant-based proteins. Studies reveal that SPC derived from Ukrainian sunflower seeds often reaches protein levels around 44%, reflecting the crop's genetic potential and optimal growing conditions (Melnik *et al.*, 2018).

2. Amino acid profile and digestibility

SPC's amino acid profile includes essential amino acids such as methionine and threonine, which are critical for growth and metabolic function in livestock. These amino acids are present at higher SPC levels than SM, enhancing animal nutritional value and reducing the need for synthetic amino acid supplements (Yegorov *et al.*, 2019; Pfarr *et al.*, 2018).

However, the lysine content in SPC remains lower compared to soybean meal, which is considered a benchmark protein source for monogastric animals (González-Pérez and Vereijken, 2007). As lysine is

typically the first limiting amino acid in cereal-based diets for poultry and swine, its deficiency can impair muscle development and feed conversion efficiency (Pfarr *et al.*, 2018). Therefore, diets, including SPC, may require supplementation with crystalline lysine or combination with lysine-rich ingredients to maintain optimal animal performance.

The digestibility of SPC is notably high, with studies showing approximately 85–90% digestibility. This high digestibility benefits monogastric animals like poultry and swine, which require nutrient-dense, easily digestible protein sources (Salgado *et al.*, 2012).

To better understand how Ukrainian products align with international sunflower by-products, the following table provides a cross-country comparison.

In addition to national data, comparative profiles of SPC from other major producers (Germany, Spain, Brazil) were included to contextualize the nutritional value of Ukrainian products within the global feed market. Tab. I summarizes the proximate composition and amino acid profiles of high-protein sunflower concentrates from different countries.

Recalculated nutrient profiles of SPC from various countries (on a dry matter basis) reveal notable differences in crude protein and amino acid content. German SPC showed the highest protein level (54.6%), while Ukrainian and Serbian samples ranged from 45–50%, reflecting defatting and hull removal variations. Brazilian products were higher in fat, likely due to less intensive oil extraction.

I: Nutritional value of sunflower high-protein by-products from different countries on dry matter basis

Parameters	Ukraine, (Proglot datasheet)	Brazil, (Lovatto <i>et al.</i> , 2017)	Germany, (Rosenfelder <i>et al.</i> , 2016)	Spain, (Dadalt <i>et al.</i> , 2016)
Ash, %	6,29	7,74	10,02	10,13
Crude fat, %	1,07	7,01	0,00	0,00
Crude protein, %	49,17	57,34	53,56	53,40
Crude fibre, %	10,79	-	-	-
Non-essential amino acids, g/kg				
Glycine	28,69	-	31,14	27,74
Alanine	21,47	-	22,74	22,70
Tyrosine	13,45	-	-	11,40
Cysteine	8,29	-	8,84	8,44
Proline	21,30	-	22,84	31,36
Aspartic acid	44,49	-	48,81	46,16
Glutamic acid	91,79	-	103,56	102,85
Serine	21,62	-	23,06	25,11
Essential amino acids, g/kg				
Histidine	13,14	10,82	13,58	14,69
Threonine	18,47	17,23	20,26	17,43
Arginine	40,29	34,46	45,26	44,30
Valine	22,80	27,42	26,62	22,48
Methionine	10,80	-	-	8,99
Phenylalanine	22,33	20,28	24,89	22,26
Isoleucine	19,35	-	22,20	17,54
Leucine	30,99	31,52	34,27	31,25
Lysine	18,71	18,28	20,47	19,08
Tryptophan	6,24	-	7,65	-

SPC samples from Ukraine include data from the State Scientific Research Institute (Lviv) and MHP Group; international references include products analyzed by Evonik (Germany), CCPA (France), and Bangkok Animal Research Center (Thailand)

German and Spanish samples also contained more indispensable amino acids such as leucine, lysine, and arginine, suggesting higher nutritional density linked to genetics and processing. However, many datasets lack complete amino acid profiles, complicating direct comparison and meta-analysis. In addition, inconsistent reporting of secondary parameters like fibre fractions and anti-nutritional factors limits comprehensive functional evaluation. Therefore, while informative, cross-country comparisons should be interpreted with methodological caution.

Production Methods and Technological Aspects

Sunflower seed consists of an outer husk and an inner kernel. Dehulling, the process of removing the outer husk before oil extraction, directly impacts the protein content of the resulting meal. Sunflower variety significantly affects hullability and protein content, influencing the final meal quality (Dauguet *et al.*, 2016).

SPC can be produced through several industrial and experimental methods, each with specific effects on protein yield, purity, and bioavailability. The most common approaches include ethanol or hexane solvent extraction, aqueous extraction, alkaline or enzymatic solubilization, and membrane-based separation technologies such as ultrafiltration or nanofiltration. These methods remove non-protein components such as fibre, sugars, and anti-nutritional factors, increasing protein content and improving digestibility. Recent research has also focused on optimizing fractionation processes to enhance sunflower meal's protein content and nutritional value, paving the way for higher-quality SPC (Vidosavljević *et al.*, 2019). Studies have demonstrated that SPC supports effective weight gain and improves feed efficiency across different animal species, making it a versatile and valuable choice in animal agriculture (Povod *et al.*, 2022).

A decellulosed sunflower meal refers to a sunflower meal that has undergone a process to reduce its fibre content. Reducing cellulose content enhances the meal's digestibility and nutritional value, making it more suitable for specific animal diets (Levic *et al.*, 2005).

According to Ritala *et al.* (2017), membrane separation has emerged as a promising green technology to isolate functional plant proteins with minimal structural denaturation. Meanwhile, González-Pérez and Vereijken (2007) highlight that ethanol extraction remains widely used at scale for its cost-effectiveness and relatively simple integration into oilseed processing chains.

In Ukraine, local feed manufacturers and oil processing enterprises apply multi-stage production schemes that combine solvent extraction and physicochemical purification. These often involve press cake defatting, hydrothermal treatment, and ultrafiltration of protein-rich extracts. However, peer-reviewed literature describing the processing parameters used in Ukrainian SPC manufacturing is

currently limited. Comparative studies are needed to benchmark local protocols against standardized methods used in the European Union or North America.

The choice of processing method directly affects the functional properties of SPC (e.g., solubility, emulsification, heat stability), its nutritional profile, and its applicability in animal diets – especially for monogastric species. Therefore, further optimization and harmonization of production technologies are essential for scaling SPC as a sustainable feed ingredient (Yarovyi, 2021).

In summary, dehulling and decellulosing are crucial processes that enhance the nutritional value of sunflower meal. Dehulling increases the protein content, while decellulosing improves digestibility, making sunflower meal a versatile and valuable component in animal feed formulations (Dauguet *et al.*, 2016; Levic *et al.*, 2005).

Variability in protein content can affect the extrusion process and physical quality of extruded feed (Banjac *et al.*, 2021).

Experimental Findings in Animal Nutrition

Despite the increasing interest in SPC, most available studies have been conducted on poultry and swine. At the same time, research involving other livestock and aquaculture species, such as ruminants, fish, and rabbits, remains scarce or fragmentary. This highlights a significant knowledge gap regarding the broader applicability of SPC across diverse animal production systems, both in Ukraine and globally.

1. Poultry

SFM can be a valuable protein source in poultry diets, especially in regions where soybean meal is expensive or unavailable (Ditta and King, 2017).

SPC has demonstrated high efficacy in poultry diets, particularly for broilers, due to its rich amino acid profile, which is essential for muscle development. Experiments replacing soybean meal with SPC in broiler diets showed impressive results. In one study, substituting 70% of soybean meal with SPC resulted in a 20.3% increase in final live weight and a 14.8–15.3% reduction in feed conversion costs per gain unit (Gavilej *et al.*, 2020). For broilers, high-quality decellulosed sunflower meal is recommended to maximize benefits (Levic *et al.*, 2005). For young quails, diets enriched with SPC led to an average weight gain increase of 15–18% compared to control groups. Feed conversion ratios also improved by 10–12%, indicating that less feed was required to achieve weight gains similar to traditional protein sources (Pitera and Otchenashko, 2022). However, the fibre content of SFM should be minimized through dehulling to improve its digestibility and utilization in broiler diets (Levic *et al.*, 2005). Replacing up to 50% of soybean meal with SPC reduced feed costs by 12% without compromising growth rates. Daily weight gains of quails on SPC-enriched diets were comparable to

those on standard soybean diets, ensuring steady growth while lowering overall expenses (Pitera and Otchenashko, 2022a). Enzyme supplementation can also improve nutrient digestibility when undecorticated SFM in layer chick diets (Fafiolu *et al.*, 2015).

The benefits of SPC were also observed in laying quails, where diets containing SPC increased hatching rates by 7–9% compared to control groups. Eggshell thickness improved by 5–7%, and average egg mass increased by 3–4%, critical factors for improved hatching success and productivity in meat-type quails (Pitera and Otchenashko, 2023).

2. Swine

SPC has also proven an effective and cost-efficient alternative to soybean meal in swine production. Partial replacement of soybean meal with SPC significantly reduced feed costs per unit of weight gain, improved feeding efficiency, and lowered overall production costs. Moreover, SPC positively impacted the fattening qualities of pigs, making it an excellent choice for large-scale pig farming. Studies have shown that replacing soybean meal with high-protein sunflower meal can improve the survival of piglets (Povod *et al.*, 2022a).

Studies have shown that partially substituting soybean meal with SPC led to a 3.64% reduction in feed costs per kilogram of weight gain and a 5.37% improvement in feed conversion efficiency. Total feeding costs were reduced by up to 4.57% with complete replacement. Pigs on SPC-enriched diets exhibited up to 31.2 points in fattening quality indices, further demonstrating SPC's nutritional and economic viability as a sustainable feed alternative (Povod *et al.*, 2022).

3. Fish

Sunflower seed meal has been evaluated as a protein source in diets for various fish species, including silver catfish and tilapia (Lovatto *et al.*, 2018; Olvera-Novoa *et al.*, 2002). Studies on silver catfish have explored sunflower protein concentrate (SMPC) as a sustainable ingredient, replacing animal protein with plant-based protein (Lovatto *et al.*, 2018). Tilapia fingerlings have shown good growth and feeding efficiency when fed diets containing 10% to 20% sunflower seed meal as a replacement for fishmeal protein (Olvera-Novoa *et al.*, 2002). Studies on carp have shown that growth performance and nutritive value can be maintained with diets containing moderate levels of sunflower seed meal (Meriç and Demir, 2012).

5. Ruminants

In lamb rations, sunflower seed meal can serve as a protein source similar to coconut meal (Wijayanti *et al.*, 2020).

Several studies have evaluated the use of SFM in dairy cows and goats, demonstrating acceptable levels of digestibility, feed intake, and milk production

(e.g., Oliveira *et al.*, 2018; Geraseev *et al.*, 2023; Mirza *et al.*, 2004). However, it is important to distinguish between SFM and sunflower protein concentrate (SPC). Despite its increasing application in monogastric nutrition, studies are lacking in focusing on SPC use in ruminants.

While conventional SFM and sunflower seed meal (SSM) have been investigated in ruminant diets with encouraging results, particularly in dairy cows, the use of SPC remains largely undocumented in peer-reviewed literature. A study by Paengkoum (2007) demonstrated that inclusion of SSM at 20–30% in the concentrate significantly improved dry matter intake, nutrient digestibility, and milk fat yield in lactating cows, highlighting the potential of sunflower-derived ingredients in bypass protein supply. However, specific trials involving SPC, which differs in its processing and protein density, are still lacking in the scientific domain. It is known that some farms experiment with SPC inclusion in dairy cow rations, and anecdotal feedback suggests improvements in milk yield and overall animal condition. Yet such practices are seldom disclosed publicly due to commercial confidentiality, market competition, and limited access to formulation details. Consequently, determining recommended SPC inclusion levels, ration structures, or performance benchmarks remains a challenge. Further targeted research is needed to validate the efficacy of SPC in ruminant feeding systems.

Experimental studies on SPC have consistently highlighted its effectiveness as a high-quality feed component for poultry and swine, enhancing productivity and health. The demonstrated benefits, including cost savings, improved feed efficiency, and enhanced growth metrics, underscore SPC's potential as a sustainable and economically viable alternative to traditional protein sources in livestock farming. However, the lack of research on other animal species allows further studies to explore the full scope of SPC's applicability.

Export Dynamics and Ukraine's Role in the SPC Market

Ukraine remains a global leader in sunflower cultivation and oilseed processing, accounting for nearly 30% of global sunflower production in peak years (Melnyk *et al.*, 2018; Vasylykivska *et al.*, 2021; Makarchuk, 2022; Puttha *et al.*, 2023). Favourable agro-climatic conditions, high-yield hybrids, and processing infrastructure have positioned Ukraine as a major producer and exporter of SPC.

Since 2019, SPC in Ukraine has been manufactured under nationally certified technical specifications, standardizing key quality metrics such as protein content, fibre levels, and microbiological safety. For export, SPC is labelled as “sunflower meal” in compliance with EU feed ingredient classifications (DSTU 4638:2007; Iegorov *et al.*, 2023), ensuring compatibility with European Feed Manufacturers' Federation (FEFAC) requirements.

Economic and Environmental Implications of Sunflower Protein Concentrate Exports

SPC offers cost-effective, locally produced protein for the European feed industry amid rising soybean prices and supply risks. Its adoption supports EU strategic goals for sustainable agriculture, as sunflower-based proteins have a substantially lower carbon footprint than imported soybean meal, which is often associated with deforestation and long-haul transport (Filho and Egea, 2021; Rakita *et al.*, 2023).

The EU-Ukraine Deep and Comprehensive Free Trade Area (DCFTA) agreement further enhances the competitiveness of Ukrainian SPC by reducing tariffs and facilitating streamlined regulatory alignment (Dzyad and Pashchenko, 2022; Baryshpolets and Devadoss, 2021). These factors collectively support the increased integration of Ukrainian SPC into European poultry and swine feed formulations.

Challenges and Shortcomings in Current Applications

In 2023, Ukraine experienced a nationwide soybean shortage due to export blockades, disrupted imports, and high international demand. Many feed manufacturers were unable to source sufficient volumes of soybean meal at affordable prices (Zakharchuk *et al.*, 2022; Voora *et al.*, 2024; Kulakova *et al.*, 2023; Pavlenko *et al.*, 2023; Ostashko, 2023; Wellington *et al.*, 2023). In this context, sunflower protein concentrate (SPC) rapidly emerged as a critical substitute in poultry and pig feed formulations (Barboza Martignone *et al.*, 2024; Kapelista *et al.*, 2023).

SPC was integrated into emergency diets across various production systems, often without complete nutritional rebalancing or prior feeding trials. Industry reports and field observations indicate that SPC was also used in young ruminant rations in

multiple regions of Ukraine (Voronetska and Yurchuk, 2023; Kapelista *et al.*, 2023; Nehrey and Trofimtseva, 2022; Brovdi, 2022). While this shift demonstrated the practical utility of SPC during supply crises, it also revealed a lack of structured research on species-specific tolerances, nutrient interactions, and long-term outcomes – particularly for ruminants, where no peer-reviewed SPC studies exist.

These developments highlight the urgent need for evidence-based formulation guidelines, evaluation of SPC's bypass protein potential in ruminants, and clearer regulatory standards to support future feed system resilience under geopolitical or supply-driven shocks.

Research Gaps and Future Directions

Existing research on SPC mainly focuses on monogastric animals, particularly poultry and swine (Fafiolu *et al.*, 2015; Povod *et al.*, 2022; Povod *et al.*, 2022a). Data on the use of SPC in ruminants – especially as a source of bypass protein – and in aquaculture is almost entirely lacking (Paengkoum, 2007). In fish, available studies often examine sunflower meal rather than SPC, which limits conclusions. In addition, the effects of SPC on gut microbiota, immune function, reproductive performance, and long-term productivity are poorly understood. Most studies originate from a limited number of countries and rely on specific processing technologies, making their findings difficult to generalize. Future research should investigate in vivo use of SPC in ruminants and fish, including digestibility, nitrogen retention, feed conversion efficiency, gut microbiota response, and metabolic indicators. It is also important to compare different SPC production technologies, assess their impact on protein purity and amino acid bioavailability, establish unified quality standards for trade, and evaluate the carbon footprint of SPC production (Lovatto *et al.*, 2018; Olvera-Novoa *et al.*, 2002).

CONCLUSION

This review positions SPC as more than just a nutritional component – it is a strategic feed ingredient shaped by technological progress, geopolitical context, and the evolving needs of sustainable agriculture. The intersection of processing innovation, trade policy, and species-specific feed demands underscores SPC's potential to redefine protein sourcing in animal nutrition. Its broader adoption, however, will depend on scientific validation beyond poultry and swine, regulatory alignment across markets, and the development of consistent quality standards. By mapping current knowledge and gaps, this work sets the foundation for a more diversified and resilient global feed system.

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