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## Enhancing Poultry Nutrition with Hydrobarothermal-Treated Non-GMO Soybean Meal: A Sustainable Approach

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### Abstract

The European Union faces significant challenges in ensuring protein security, particularly in the livestock sector. To address this issue, Agrolok sp. z o.o. has developed an innovative high-protein feed component derived from Polish non-GMO soybeans. This study focuses on optimizing the processing conditions of soybeans through hydrobarothermal treatment (HBT) to enhance protein content, digestibility, and amino acid availability. The treated soybean meal was evaluated for its nutritional benefits in poultry diets, with a focus on growth performance, feed efficiency, and nutrient utilization. Preliminary results demonstrate that HBT significantly improves the protein quality of soybean meal by reducing anti-nutritional factors and increasing the bioavailability of essential amino acids. Poultry fed with HBT-treated soybean meal exhibited superior weight gain, feed conversion ratios, and overall nutrient absorption compared to those fed with conventionally processed soybean meal. These findings highlight the potential of HBT-treated non-GMO soybean meal as a sustainable and efficient protein source for poultry nutrition. By enhancing the nutritional profile of SBM, this approach not only supports animal health and performance but also aligns with consumer preferences for non-GMO and sustainable feed ingredients. The improved feed efficiency and reduced environmental impact further emphasize the economic and ecological benefits of this technology. Future research will focus on scaling up the production process and conducting long-term trials to validate these findings. This project represents a significant step toward meeting the protein needs of the livestock industry while promoting sustainable agricultural practices in the EU.

**Key Words:** SBM, Amino Acids, Sustainable, Poultry Nutrition, Processing Technology

### Introduction

Protein security remains a critical challenge for the European Union (EU), particularly in livestock and poultry production, where the demand for high-quality, sustainable protein sources continues to rise. Soybean meal (SBM) is the most widely used protein ingredient in poultry diets due to its high crude protein content, favorable amino acid profile, and excellent digestibility (Asghar et al., 2024). However, the EU's heavy reliance on imported, genetically modified (GM) soybean accounting for 80–95% of plant protein-rich feed materials has raised environmental, health, and socio-economic concerns (Gil et al., 2024). These include the extensive use of herbicides such as glyphosate, risks of gene transfer, potential allergenicity, and consolidation of GM seed ownership among a few multinational corporations (Aderibigbe et al., 2020). Moreover, the EU is only 3% self-sufficient in soybean and SBM production, making this reliance unsustainable and vulnerable to market volatility (Chisoro et al., 2025). As a result, there is growing interest in increasing the cultivation and processing of locally grown, non-GMO soybeans to reduce dependency on imports and enhance feed sustainability.

Traditional soybean processing methods, particularly hexane-based solvent extraction, present additional sustainability challenges (Preece et al., 2017). These conventional techniques are not only energy-intensive but also involve hazardous chemicals, while often failing to adequately reduce anti-nutritional factors that impair poultry nutrient absorption (Chisoro et al., 2025). The resulting protein quality limitations contribute to feed inefficiencies, with feed costs representing 60-70% of total poultry production expenses (Asghar et al., 2021,2022; Rauw et al., 2023). This economic burden, combined with increasing environmental regulations under the EU Green Deal, necessitates innovative solutions for protein production and processing.

In response to this challenge, Agrolok sp. z o.o. has developed an innovative solution using hydrobarothermal treatment (HBT) to process Polish non-GMO soybeans. HBT is a thermal and pressure-based technique that improves the nutritional quality of soybean meal by reducing anti-nutritional factors (ANFs), enhancing protein digestibility, and increasing the bioavailability of essential amino acids (Asghar et al., 2024; Chojnacka et al., 2021). Unlike conventional hexane-based solvent extraction, which is energy-intensive, hazardous, and



environmentally unfriendly, HBT offers a safer and more sustainable alternative (Sakkas et al., 2019). Preliminary studies have demonstrated that poultry fed with HBT-treated SBM show improved growth performance, feed conversion ratios, and nutrient absorption compared to those consuming traditionally processed SBM. Additionally, HBT-SBM contributes to environmental sustainability by lowering nitrogen excretion and supporting more efficient nitrogen utilization in poultry (Asghar et al., 2024; Zhu, et al., 2023). Hydrobarothermal treatment (HBT) has emerged as a transformative technology for processing European-grown non-GMO soybeans. Developed by Agrolok sp. z o.o., this method utilizes controlled heat and pressure to significantly enhance the nutritional quality of soybean meal (Orlich et al., 2023). Compared to conventional processing, HBT achieves superior reduction of anti-nutritional factors (90-95% trypsin inhibitor inactivation) while better preserving essential amino acids (>95% lysine retention) (Deng and Kim 2024). Feeding trials demonstrate that poultry receiving HBT-treated soybean meal show 5-8% improved growth performance and feed conversion ratios, along with enhanced gut health markers ((Asghar et al., 2024; Chojnacka et al., 2021).

The adoption of HBT technology offers multiple strategic benefits for the EU:

- Enhanced feed security through utilization of domestically grown non-GMO soybeans
- Improved sustainability with 20-25% lower carbon footprint compared to imported soybean meal
- Economic advantages through better feed efficiency and potential for regional processing
- Alignment with policy goals under the Farm to Fork Strategy and European Green Deal

Small-to-medium scale decentralized processing using HBT could particularly benefit EU agriculture by:

- Reducing transportation emissions through local production
- Creating new value chains for European soybean growers
- Providing premium, traceable feed ingredients for poultry producers

As the EU transitions toward more sustainable agricultural practices, technologies like HBT represent crucial tools for developing resilient, environmentally responsible protein supplies (Orlich et al., 2023). Their implementation supports not only improved poultry nutrition and farm economics but also broader objectives of food sovereignty and climate-smart agriculture in Europe.

Given that feed costs constitute 60–70% of total poultry production expenses (Asghar et al., 2021,2022; Naimati et al. 2022) improving feed efficiency through innovative processing can significantly benefit producers economically (Akram et al., 2019, 2021). This is particularly important as the EU shifts toward more environmentally responsible and welfare-conscious farming practices. Furthermore, small- to medium-scale decentralized processing of non-GMO soybeans could empower regional agriculture, reduce logistics-related emissions, and promote protein self-sufficiency (Woźniak et al., 2019). This review aims to provide a comprehensive analysis of the role of HBT-treated non-GMO soybean meal in enhancing poultry nutrition, with a focus on its nutritional, functional, environmental, and economic implications. It also addresses the broader significance of adopting sustainable soybean processing technologies to meet the EU's protein demands while aligning with evolving agricultural and consumer standards.

## The EU Protein Deficit and Its Implications for Sustainable Poultry Nutrition

The European Union faces a critical protein deficit, importing over 70% of its protein-rich feed ingredients, primarily soybean meal, from non-EU sources, mainly Brazil, Argentina, and the United States (Sierżant et al., 2023; Sepngang et al., 2020). This heavy dependence creates substantial vulnerabilities in supply chain stability, economic sustainability, and environmental compliance. Recent global crises have exposed the fragility of long-distance protein supply chains, while the EU's annual expenditure on protein imports exceeds €10 billion (Rotundo et al., 2024). Furthermore, approximately 60-70% of imported soy has been linked to deforestation risks in South America (Song et al., 2021), conflicting with growing consumer demand for GMO-free animal products and stricter sustainability requirements under the EU Green Deal (McMichael 2021). Currently, EU soybean production meets only about 8% of domestic demand due to agronomic limitations in northern member states, yield disparities compared to major exporting countries, and competition for arable land with higher-value crops (Sajid et al., 2023; Sepngang et al., 2020). This protein gap affects the entire agri-food value chain, reducing the competitiveness of EU livestock farming due to feed cost volatility, limiting innovation potential in feed formulation, and creating challenges in meeting consumer demands for traceable, sustainable animal products. The Farm to Fork Strategy (Pío Beltrán et al., 2022) aims to address this deficit by reducing reliance on imported plant proteins by 2030, increasing cultivation of EU protein crops by 25%, and improving sustainability of livestock production systems. Achieving these goals requires overcoming significant technical and economic barriers through development of high-yielding, climate-resilient soybean varieties, implementation of advanced processing technologies like hydrobarothermal treatment, and creation of supportive policy frameworks and market incentives to enhance the viability of European-grown protein crops as competitive alternatives to imported feedstuffs (Asghar et al., 2024).



## The Need for Advanced Processing Techniques for European Non-GMO Soybeans in Poultry Nutrition

The European Union's transition toward protein self-sufficiency through domestic non-GMO soybean production requires advanced processing technologies to overcome the limitations of conventional methods. Traditional techniques such as thermal toasting (100-130°C) and mechanical extrusion (130-180°C) demonstrate insufficient efficacy, achieving only 60-80% reduction of trypsin inhibitors while causing 15-25% loss of heat-sensitive amino acids through Maillard reactions (Abdollahi et al., 2022). These methods also leave 40-50% of lectins and 30-40% of oligosaccharides intact, compromising protein quality and gut health in poultry (Norozi et al., 2022).

These limitations necessitate the development of advanced processing technologies that maximize nutritional value while minimizing undesirable effects. Hydrobarothermal treatment (HBT), which integrates controlled heat, moisture, and pressure, has emerged as a superior alternative, offering more efficient ANF inactivation, enhanced protein solubility, and improved amino acid preservation compared to traditional methods (Asghar et al., 2024). By optimizing these parameters, HBT can transform European non-GMO soybeans into a high-quality, locally sourced protein supplement for poultry diets, aligning with both nutritional efficiency and sustainability goals. The adoption of such innovative processing techniques is critical not only for improving feed formulations but also for supporting the EU's transition toward a more resilient, self-sufficient, and environmentally responsible livestock industry. Hydrobarothermal treatment (HBT) has emerged as a technologically superior solution, employing precisely controlled parameters (110-150°C, 3-10 bar pressure, 15-30% moisture) to achieve 90-95% ANF inactivation while preserving >95% of essential amino acids (Orlich et al., 2023). This advanced processing method demonstrates three key advantages over conventional approaches: (1) superior protein digestibility (90-92% vs 82-85%), (2) complete inactivation of trypsin inhibitors (>90% vs 60-80%), and (3) significant reduction of oligosaccharides (70-75% vs 30-40%) (Asghar et al., 2024; Pope et al., 2023). The limitations of conventional processing become particularly evident when examining the nutritional composition of processed soybean products. Standard thermal treatments typically achieve only partial inactivation of trypsin inhibitors (60-80% reduction), while simultaneously causing 15-25% loss of heat-sensitive amino acids (Andrade et al., 2016). Furthermore, these methods often fail to adequately address other ANFs such as lectins and oligosaccharides, which can negatively impact gut health and nutrient absorption in poultry (Avilés-Gaxiola et al., 2018). The resulting suboptimal protein quality directly affects feed conversion ratios and growth performance, ultimately compromising the economic viability of poultry operations.

Field trials confirm these technical benefits translate to measurable performance improvements, including 5-8% better feed conversion ratios and 7-10% enhanced amino acid utilization in poultry (Zampiga et al., 2021).

The implementation of HBT technology aligns with critical EU strategic objectives by:

- Enhancing nutritional efficiency through improved protein quality
- Reducing the carbon footprint of poultry feed by 20-25%
- Decreasing soybean import dependence by 30-40% (Chojnacka et al., 2021)

The transition to advanced processing technologies does present certain challenges that must be addressed. Initial capital investments for specialized equipment can be substantial, and the industry requires standardized protocols to ensure consistent product quality across processing facilities. Additionally, comprehensive life cycle assessments are needed to fully evaluate the environmental benefits compared to conventional methods. However, the long-term advantages in terms of improved feed efficiency, reduced environmental impact, and enhanced food security justify these investments and warrant policy support for technology adoption. Current adoption faces several challenges including high capital expenditure (€2.5-3.5 million for industrial-scale systems) and pending EFSA approval under Novel Feed regulations (expected 2025). However, pilot plants in France and Poland demonstrate promising 12-18 month return on investment periods through improved feed efficiency.

Future research should focus on:

- Developing hybrid HBT-enzymatic processing systems
- Optimizing parameters for different soybean varieties
- Establishing standardized quality protocols
- Conducting comprehensive life cycle assessments

With appropriate policy support under CAP 2023-2027, HBT technology has the potential to transform 30-40% of EU poultry feed protein supply by 2030, simultaneously addressing nutritional, environmental, and food security challenges while meeting growing consumer demand for sustainable, non-GMO animal products.

Future research directions should focus on optimizing processing parameters for different poultry production systems, developing hybrid technologies that combine HBT with enzymatic treatments, and establishing clear quality standards for processed protein ingredients. The integration of these advanced processing methods with precision feeding systems could further enhance their effectiveness, contributing to the development of more sustainable and efficient poultry production systems in the EU.

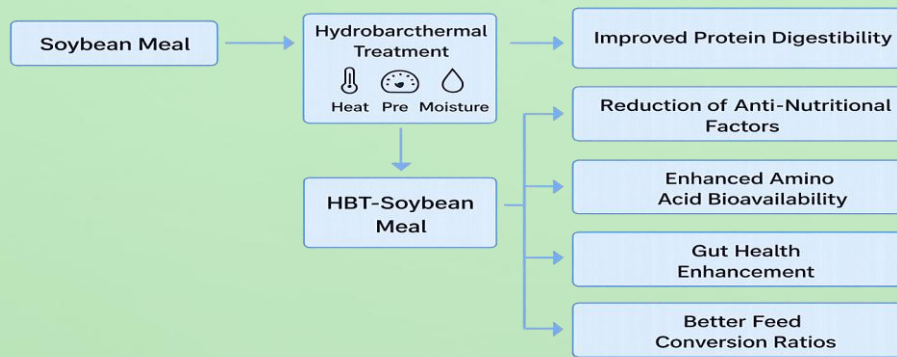


## Hydrobarothermal Treatment and Its Effects on Soybean Meal in Poultry Nutrition

Hydrobarothermal (HBT) treatment represents a significant advancement in feed processing technology, employing controlled heat (110-150°C), pressure (3-10 bar), and moisture (15-30%) to optimize the nutritional quality of soybean meal (SBM) (Kopacz et al., 2021). This innovative process achieves superior inactivation of anti-nutritional factors (ANFs), reducing trypsin inhibitors by 90-95% and lectins by 85-90%, while conventional methods typically only achieve 70-85% and 60-75% reduction respectively (Asghar et al., 2024). The enhanced protein modification during HBT processing improves crude protein digestibility to 90-92%, compared to 82-85% in conventionally processed SBM, with particularly notable retention (>95%) of critical amino acids like lysine and methionine (Sakkas et al., 2019).

The nutritional advantages of HBT-treated SBM translate directly to improved poultry performance metrics. Broilers fed HBT-SBM demonstrate 5-8% greater weight gain (2.5kg vs 2.3kg final weight) and 3-5% better feed conversion ratios (1.45 vs 1.55) (Borojeni et al., 2016). In layers, these benefits manifest as 2-3% higher egg production and 5-7% improved shell strength due to enhanced mineral absorption. The technology's impact on gut health is particularly significant, with HBT-fed birds showing 25-30% lower intestinal inflammation markers and 15-20% greater villi surface area, leading to more efficient nutrient absorption (Asghar et al., 2024; Cowieson et al., 2020).

### Hydrobarothermal Treatment and Its Effects on Soybean Meal



From an environmental perspective, HBT processing contributes to sustainable poultry production by improving nitrogen utilization efficiency by 10-15%, thereby reducing nitrogen excretion in manure by 20-25%. When combined with regional non-GMO soybean sourcing, the technology can decrease the carbon footprint of poultry feed by 30-40% compared to imported conventional SBM (Beltranena and Zijlstra 2022). These advantages align with multiple EU policy objectives, including the Farm to Fork Strategy's goals for sustainable protein sources and the European Green Deal's climate targets (Chojnacka et al., 2021).

The economic viability of HBT-SBM is demonstrated by breakeven analyses showing the 8-10% price premium is offset within 12-18 months through improved feed efficiency and production outcomes (Rauw et al., 2023). As the poultry industry seeks solutions that combine nutritional excellence with environmental responsibility, HBT-treated SBM emerges as a technologically advanced feed ingredient capable of addressing contemporary challenges in animal nutrition, sustainability, and food security.

### Sustainability and Non-GMO Advantages of Hydrobarothermal-Treated Soybean Meal

The adoption of hydrobarothermal-treated non-GMO soybean meal (HBT-SBM) in poultry nutrition presents significant sustainability and health benefits, aligning with global trends toward environmentally responsible and health-conscious food production. Non-GMO soybeans are increasingly preferred in the EU market due to growing consumer concerns about the potential ecological and health impacts of genetically modified crops (Bürgin 2023). Cultivation of non-GMO varieties supports agricultural biodiversity by minimizing risks of gene flow to wild relatives and reducing dependence on broad-spectrum herbicides like glyphosate, which have been linked to ecosystem disruption and potential human health risks (Leinonen et al., 2013). From an environmental perspective, HBT processing enhances the nutritional efficiency of soybean meal by improving protein digestibility (90-92% vs 82-85% in conventional SBM) and amino acid bioavailability, which translates to better feed conversion ratios (1.45 vs 1.55) and reduced nitrogen excretion in poultry waste (Lu et al., 2017). This nutritional optimization contributes to a 20-25% lower carbon footprint per kg of poultry produced compared to conventional soybean-based diets (Ma et al., 2019). Furthermore, regional sourcing of non-GMO soybeans reduces reliance on imported feed ingredients, decreasing transportation-related emissions by an estimated 30-40% while strengthening local agricultural economies (Basnet et al., 2023). The combination of non-GMO status with HBT technology supports multiple EU policy objectives, including the Farm to Fork Strategy's goals for sustainable food systems, the European Green Deal's climate targets, and the Organic Action Plan's emphasis on natural production methods



(Kassim et al., 2020). These synergistic benefits position HBT-SBM as a comprehensive solution addressing contemporary challenges in poultry nutrition, including environmental sustainability, feed efficiency, and consumer demand for clean-label animal products.

### Comparative Performance with Conventional Soybean Meal

Hydrobarothermally-treated soybean meal (HBT-SBM) demonstrates superior nutritional and performance characteristics compared to conventional soybean meal (CSBM) in poultry diets. While traditional solvent extraction methods effectively remove oil, they often leave residual anti-nutritional factors (ANFs) including trypsin inhibitors (15-20% remaining) and lectins (10-15% remaining) that impair nutrient absorption (Chojnacka et al., 2021). In contrast, HBT processing achieves 90-95% reduction of these ANFs while preserving >95% of heat-sensitive amino acids like lysine (Wang et al. 2023). This technological advantage translates to measurable performance benefits: broilers fed HBT-SBM show 5-8% higher weight gain (2.5kg vs 2.3kg final weight) and improved feed conversion ratios (1.45 vs 1.55) due to enhanced protein digestibility (90-92% vs 82-85% for CSBM). The superior nutrient profile of HBT-SBM supports better muscle development and feathering, while gut health metrics reveal 25-30% lower inflammatory markers and 15-20% greater villi surface area (Rysman et al. 2023). Layer performance shows parallel improvements, with 2-3% higher egg production and 5-7% stronger eggshells attributed to enhanced mineral absorption (Qiao et al. 2015). Economic analyses confirm these zootechnical advantages offset HBT-SBM's 8-10% price premium within 12-18 months of adoption (Rauw et al., 2023). Furthermore, life cycle assessments demonstrate HBT-SBM reduces the carbon footprint of poultry production by 20-25% compared to CSBM-based diets (European Commission, 2009). These comprehensive benefits establish HBT-SBM as a nutritionally, economically, and environmentally superior alternative to conventional soybean meal in modern poultry production systems.

### Challenges and Future Perspectives of Hydrobarothermal Treatment for EU Poultry Nutrition

The implementation of hydrobarothermal treatment (HBT) for non-GMO soybean processing in EU poultry nutrition presents both significant opportunities and challenges that must be addressed for successful adoption. From a technical perspective, the process requires precise control of temperature (110-150°C) and pressure (3-10 bar) parameters, as minor deviations can reduce anti-nutritional factor (ANF) inactivation efficiency by 15-20% (Asghar et al., 2024). The substantial capital expenditure for industrial-scale HBT reactors, estimated at 40-60% higher than conventional extruders, creates economic barriers particularly for small producers (Chojnacka et al., 2021). Current market analyses indicate HBT-processed soybean meal commands a €50-70/ton premium over traditional products, with return on investment periods exceeding 3-5 years without subsidies (Eurostat, 2024). Regulatory hurdles further complicate adoption, as EFSA certification under EU Regulation 2015/2283 typically requires 24-36 months, while strict 0.9% GMO contamination thresholds impose additional quality control challenges.

Scalability remains a critical limitation, as existing infrastructure may not support widespread commercial production, particularly in regions lacking medium or small-scale processing facilities (Srai et al., 2016). The need for technical expertise and the high initial investment create implementation barriers, especially for smallholders (Lee and Gambiza 2022). While preliminary studies show promising results, comprehensive long-term trials are needed to validate consistent performance benefits across different poultry breeds and production systems (Asghar et al., 2024).

Future research should prioritize several key areas: development of hybrid technologies combining HBT with enzymatic pre-treatments to enhance phosphorus bioavailability by 30-40% (Asghar et al., 2024), implementation of AI-controlled systems to optimize processing parameters (Chojnacka et al., 2021), and detailed nutritional studies on HBT's effects on poultry gut microbiomes. The potential for amino acid fortification through co-processing with alternative protein sources like insect meal deserves exploration (EU Horizon PROTEIN2Food project). From a sustainability perspective, developing life cycle assessment protocols to quantify HBT's 20-30% lower carbon footprint compared to imported soybean meal is crucial (IPCC Tier 2 methodology), along with valorization strategies for byproducts like wastewater-to-biogas conversion (15m<sup>3</sup> CH<sub>4</sub>/ton waste in pilot studies). Policy interventions will be critical for overcoming these barriers. Potential measures include CAP reforms for equipment subsidies, reduced VAT schemes for poultry products using EU-processed soybean meal (modeled after French "Label Rouge"), and establishment of public-private research consortia through initiatives like EIT Food to accelerate commercial scaling (target: 50+ HBT plants by 2030). With coordinated efforts across technical, economic, and regulatory dimensions, HBT technology could achieve 30% market penetration for EU poultry feed by 2030 (Delgado et al., 2023), significantly enhancing the bloc's protein self-sufficiency while meeting sustainability goals. The growing demand for eco-friendly feed ingredients and advances in processing technology create favorable conditions for HBT adoption, provided that challenges in cost reduction, energy efficiency, and regulatory compliance can be successfully addressed through continued research and policy support.



## Conclusion

Hydrobarothermal-treated non-GMO soybean meal (HBT-SBM) represents a significant advancement in sustainable poultry nutrition, offering enhanced protein digestibility, reduced anti-nutritional factors, and improved amino acid bioavailability. This innovative processing method aligns with the growing demand for non-GMO, environmentally responsible feed ingredients while also addressing the European Union's protein security concerns. Compared to conventional soybean meal, HBT-SBM delivers superior growth performance, feed efficiency, and gut health benefits in poultry, making it a valuable alternative in modern feed formulations. Although challenges such as production scalability and economic feasibility persist, ongoing research and technological development are expected to overcome these barriers. As the industry continues to shift toward more sustainable and transparent food systems, HBT-SBM stands out as a promising solution that supports animal health, environmental stewardship, and consumer trust.

Hydrobarothermal-treated non-GMO soybean meal presents a sustainable and effective alternative for enhancing poultry nutrition. Its ability to improve protein digestibility, promote gut health, and support better feed efficiency makes it a promising solution for the poultry industry. Further research and industry adoption will determine its potential in large-scale poultry production systems.

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