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Corn Steep Liquor in Poultry Nutrition: Impacts on Performance, Metabolism, and Immunity

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ABSTRACT Corn steep liquor (CSL), a by-product of the corn wet-milling process, has been increasingly explored as an alternative feed ingredient in poultry nutrition. Rich in highly digestible proteins, organic acids, and bioactive compounds, CSL has been studied primarily as a partial replacement for soybean meal (SBM), offering a sustainable and cost-effective solution to the rising prices and supply fluctuations of conventional protein sources. Beyond its nutritional value, the lactic acid and other organic acids naturally present in CSL may enhance gut health, modulate lipid metabolism, and improve immune responses, positioning it as a potential alternative to antibiotic growth promoters. This review synthesizes evidence on CSL supplementation in poultry diets, focusing on its nutritional composition, effects on growth performance, and multifaceted physiological impacts. Moderate inclusion levels, typically 3－10% in broilers, up to 20% in layers, and ≤5% in turkeys, support growth performance, improve nutrient digestibility, enhance hepatic lipid regulation, strengthen humoral immunity, and reduce oxidative stress. However, excessive inclusion (>10－15%) has been linked to metabolic disturbances, mild mucosal irritation, reduced immune organ weights, and nephrotoxic effects associated with elevated serum uric acid. Collectively, these findings indicate that CSL can serve not only as a functional protein source but also as a gut health promoter with immunomodulatory benefits. Nevertheless, precise dose optimization is crucial to maximize its benefits while avoiding potential adverse effects. Future research should focus on elucidating the mechanisms underlying its bioactive effects, defining long-term safety thresholds, and optimizing diet formulations for different poultry species and production phases.

(Key words: alternative feed ingredients, corn by-products, corn steep liquor, lactic acid, protein source)

INTRODUCTION

Feed costs account for approximately 70% of total production costs in the poultry industry, making them one of the most significant economic considerations. Among conventional feed ingredients, corn and SBM are the primary components used in commercial poultry diets. However, the continuous rise in prices and fluctuations in supply have raised concerns regarding the long-term sustainability of these ingredients (Van Immerseel et al., 2017). While energy supply is a crucial factor in formulating poultry diets, ensuring an adequate balance of essential nutrients such as amino acids (AA) and crude protein (CP) is fundamental to maximizing growth efficiency and overall productivity. Since protein sources represent a substantial portion of feed costs, improving protein utilization and exploring alternative ingredients with comparable nutritional value have become central objectives in poultry nutrition research (Beski et al., 2015).

In the wet-milling process, corn is steeped and fermented, producing various by-products, among which corn steep liquor (CSL) is notable (Wet, 2006). CSL is a valuable by-product of the wet-milling process, characterized by its high concentrations of small peptides, free AA, fermentable sugars, vitamins, trace minerals, and organic acids (Liggett and Koffler, 1948; Zhou et al., 2022). It is a viscous, light to dark brown liquid with an ensiled aroma and naturally acidic properties (Mirza and Mushtaq, 2006). Unlike many other feed ingredients, CSL contains negligible amounts of fat, fiber, and silica (Gupta et al., 1990), making it highly digestible. Moreover, it serves as a rich source of biologically active compounds that enhance feed palatability and may contribute to improved growth performance (Camp et al., 1957; Waldroup and Rutherford, 1971). Lactic acid, which constitutes approximately 10 to 30% of CSL on a dry basis, is the primary organic acid formed through microbial fermentation. This organic acid is largely present in the form

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of potassium lactate salts, which contribute to CSL's acidifying properties and potential benefits for gut health (Liggett and Koffler, 1948).

These characteristics are similar to the functions traditionally attributed to antibiotic growth promoters (AGPs). In the past, AGPs were widely used to enhance productivity and suppress intestinal pathogens. However, their use has been restricted in response to changing consumer demand and stricter regulations. Consequently, CSL, as a naturally derived material, has gained attention as a sustainable alternative resource with the potential to promote gut health and improve productivity simultaneously.

This review aims to summarize the research findings and practical applications of CSL as a poultry feed ingredient, with a focus on its nutritional composition, physiological effects, and potential benefits as an alternative to antibiotic growth promoters. By synthesizing current knowledge, this study seeks to provide a comprehensive understanding of CSL's role in poultry nutrition and its implications for sustainable feed formulation. The impacts of CSL supplementation on poultry production performance are summarized in Table 1, and its effects on physiological responses are presented in Table 2.

IMPACT OF CORN STEEP LIQUOR SUPPLEMENTATION ON PRODUCTION PERFORMANCE

1. Broilers

CSL supplementation in broiler diets has been extensively evaluated, with studies exploring various inclusion levels, processing methods (liquid vs. dried), and replacement strategies for conventional protein sources such as SBM and fish meal. Early trials demonstrated that low-level CSL inclusion could improve body weight (BW) in broiler chicks. Camp et al. (1957) reported that the inclusion of 3−10% liquid CSL in diets based on yellow corn and SBM significantly enhanced BW of Lancaster × New Hampshire broiler chicks, with no further benefit beyond 3%, suggesting that a low inclusion level is sufficient to provide the unidentified growth factors present in CSL. Similarly, CSL dried on corn germ meal or corn gluten feed also preserved these growth-promoting effects, indicating that the drying process does not compromise CSL's bioactive components. Subsequent studies assessed CSL as a partial substitute for plant- and animal-based proteins. Russo and Heiman (1959b) demonstrated that replacing 5% of corn meal and SBM with CSL (23% CP) increased BW in White Leghorn cockerels, regardless of feed form (pelleted or crumbled), although feed conversion ratio (FCR) remained unaffected. Interestingly, CSL could partially replace animal-derived protein sources such as condensed fish solubles and dried whey, fully restoring broiler body weight gain (BWG) and FCR (Russo and Heiman, 1959a). Moreover, Russo et al. (1960) found that fermentation improved CSL's efficacy; fermented corn solubles yielded better feed efficiency compared with unfermented counterparts, highlighting the importance of fermentation-derived organic acids.

Dried CSL has also been evaluated in broilers. Tsang and Schaible (1960) reported that 3% dried CSL improved BW in White Plymouth Rock cockerels after 8 weeks, while replacing fish meal with 1.5−3.0% dried CSL enhanced BWG and improved FCR at 5 weeks of age. Likewise, Waldroup et al. (1970) observed that dried CSL inclusion up to 15% had no negative effects on BWG, feed intake (FI), or FCR; however, higher levels (20−25%) reduced BW and FI while increasing FCR. These detrimental effects were likely due to excessive dietary acidity or nutrient imbalance rather than palatability, as FI was not markedly lower in high-CSL diets. Recent studies have further clarified the inclusion threshold for CSL in broiler diets. Yazdanyar et al. (2015) showed that CSL inclusion above 10% negatively impacted BWG, FI, and FCR, likely due to high diet viscosity and lactic acid levels causing digestive discomfort. In contrast, moderate inclusion (≤10%) improved growth performance, possibly by acidifying the gut environment and enhancing nutrient digestibility. Ullah et al. (2018) similarly reported that 10% CSL yielded the highest BWG and best FCR in Hubbard × Hubbard broilers, while 15% CSL maintained BWG but did not further improve feed efficiency.

The beneficial effects of moderate CSL supplementation during the starter phase have been consistently observed. For instance, Ebrahimpour et al. (2022) found that 4% dried CSL enhanced FI and BWG in Ross 308 broilers during the first 10 days, likely due to improved palatability and gut health

Table 1. Impact of corn steep liquor supplementation on production performance in poultry

A. Broilers

Breed	CSL level & replacement	Key response	Reference
Lancaster × New Hampshire chicks	3−10% CSL	↑ BW; No effect on FCR	Camp et al. (1957)
Broilers	2.5, 5.0, 7.5, 10.0, 15.0% CSL inclusion replaced yellow corn, SBM	No effect on BW, FI, FCR	Waldroup et al. (1970)
	20, 25% CSL (yellow corn, SBM)	↓ BW, ↑ FCR; No effect on FI	
Ross 308	20, 30, 40% CSL inclusion replaced SBM, corn, soybean oil	↓ FI, BWG; ↑ FCR; ↓ liver & immune organs	Yazdanyar et al. (2015)
Hubbard × Hubbard unsexed broilers	5, 10, 15% CSL inclusion replaced rice broken, canola meal, SBM	↓ BWG (5% of CSL) ↑ BWG (10, 15% of CSL) ↓ FI (5% of CSL) ↑ FI (10, 15% of CSL) ↑ FCR (5% of CSL) ↓ FCR (10% of CSL)	Ullah et al. (2018)
Ross 308	2−6% CSL	↑ BWG, FI (days 0−10); no effect on BWG, FI, FCR	Ebrahimpour et al. (2022)
Hubbard broilers	3−12% CSL (with Enzose)	↑ BWG, FI; ↓ FCR (3% of CSL); ↓FI (6, 9, 12% of CSL); ↓ BWG, ↑ FCR (12% of CSL)	Tauqir et al. (2022)

FCR, feed conversion ratio; FI, feed intake; BWG, body weight gain; CSL, corn steep liquor; SBM, soybean meal; BW, body weight.

B. Layers

Breed	CSL level & replacement	Key response	Reference
Layers	2.5−25% CSL inclusion replaced yellow corn, SBM	No effect on HDEP, EW, FCR, HU, yolk color	Waldroup and Rutherford (1971)
Babcock hens	5−20% CSL inclusion replaced yellow corn, SBM	↑ HU; no effect on HDEP, EW, FI, eggshell thickness, egg mass	Waldroup and Hazen (1979)
Single comb white leghorn females	2.5−20% CSL inclusion replaced ground yellow corn, SBM	↑ HU (10, 20%); ↓ liver/plasma lipids (20%), ↓ BWG (20%); no effect on HDEP, FI, EW, HU (2.5, 5%)	Lilburn and Jensen (1984)
Hy-line brown	5, 30 g/kg	(30 g/kg of CSL) ↑ HDEP, EM, EW ↓ FCR	Lee et al. (2025)

CSL, corn steep liquor; SBM, soybean meal; HDEP, hen-day egg production; EW, egg weight; FCR, feed conversion ratio; HU, Haugh units; FI, feed intake; BWG, body weight gain; EM, egg mass.

C. Turkeys

Breed	CSL level & replacement	Key response	Reference
Turkey breeder hens	5, 10, 15, 20% CSL inclusion replaced yellow corn, SBM, alfalfa meal	No effect on HDEP, FCR, fertility, hatchability	Waldroup and Rutherford (1971)
Large white turkeys	2.5, 5% CSL inclusion replaced ground yellow corn, dehulled SBM	↑ BW, FI, FCR	Potter and Shelton (1978)

CSL, corn steep liquor; SBM, soybean meal; HDEP, hen-day egg production; FCR, feed conversion ratio; BW, body weight; FI, feed intake.

Table 2. Impact of corn steep liquor supplementation on physiological response in poultry

A. Metabolic and hepatic effects

Breed	CSL level	Response	Reference
Single comb white leghorn hens (Babcock)	2.5–20% CSL inclusion replaced ground yellow corn, SBM	↓ Liver & plasma lipids; no effect on liver weight	Lilburn and Jensen (1984)
Ross 308 broilers	20–40% CSL inclusion replaced SBM, corn, soybean oil	↓ Liver, Bursa of Fabricius, spleen, gizzard weight	Yazdanyar et al. (2015)
Ross 308 broilers	1, 2 cc/kg CSL	↓ Plasma TG, ↑ HDL-C (1 cc/kg, day 42)	Hamidifard et al. (2023)

CSL, corn steep liquor; SBM, soybean meal; TG, Triglycerides; HDL-C, high-density lipoprotein cholesterol.

B. Immune and antioxidant responses

Breed	CSL level	Response	Reference
Ross 308	4–10% CSL inclusion replaced SBM, feather meal	↑ GPX, FRAP(8.5%); ↑ MDA (10%)	Atabak et al. (2021)
Ross 308	2–6% CSL	↑ Antibody titers (ND, IB, AI); no effect on LAB/coliform	Ebrahimpour et al. (2022)
Ross 308	1–2 cc/kg liquid CSL	↑ Humoral response to AI vaccine	Hamidifard et al. (2023)

CSL, corn steep liquor; SBM, soybean meal; GPX, glutathione peroxidase; FRAP, ferric reducing ability of plasma; MDA, plasma malondialdehyde; ND, Newcastle disease; IB, Infectious bronchitis; AI, Avian influenza; LAB, lactic acid bacteria count.

C. Digestive physiology and gut health

Breed	CSL level	Response	Reference
Hubbard × Hubbard unsexed broilers	5–15% CSL	↑ DM, CP digestibility; no effect on CF digestibility	Ullah et al. (2018)
Hubbard broilers	3–12% CSL + Enzose	↑ DM, CP, EE digestibility; no effect on CF digestibility	Tauqir et al. (2022)
Ross 308 broilers	1–2 cc/kg liquid CSL	↑ pH in gizzard, ↑ ileum weight (2 cc/kg), ↓ pH in ileum (1 cc/kg); no effect on villus/crypt	Hamidifard et al. (2023)

CSL, corn steep liquor; DM, dry matter; CP, crude protein; CF, crude fiber; EE, ethyl este.

D. Organ development and adverse effects

Breed	CSL level	Response	Reference
Ross 308 broilers	20–40% CSL	↓ Bursa, spleen, gizzard weight	Yazdanyar et al. (2015)
Hubbard × Hubbard unsexed broilers	5–15% CSL	↑ Crop hypertrophy & hyperplasia; no effect on necrosis in renal tubules	Ullah et al. (2018)
Ross 308	1–2 cc/kg liquid CSL	↑ H:L ratio (2 cc/kg)	Hamidifard et al. (2023)

CSL, corn steep liquor; H:L, heterophils to lymphocytes ratio.

from CSL's organic acids. However, long-term inclusion beyond the starter phase did not produce additional growth benefits. Similarly, Hamidifard et al. (2023) reported that low-dose liquid CSL (1 cc/kg) numerically improved BW and FI during the first 21 days without significantly affecting overall performance, supporting the notion that early-life gut acidification contributes to initial growth responses. Overall, evidence suggests that CSL inclusion at 3–10% supports growth and feed efficiency in broilers, likely through unidentified growth factors, lactic acid-driven gut acidification, and improved nutrient digestibility. However, excessive levels (>15%) can impair performance, potentially due to metabolic stress and reduced nutrient utilization.

2. Laying Hens

In laying hens, CSL supplementation has been primarily evaluated for its effects on egg production, internal and external egg quality, and long-term metabolic health. Early investigations by Waldroup and Rutherford (1971) showed that dried CSL (31.5% CP, 7.8% lactic acid) could replace up to 25% of yellow corn and SBM in layer diets without negatively affecting hen-day egg production (HDEP), egg weight (EW), FCR, or Haugh units (HU). Interestingly, prolonged feeding (48 weeks) with 10−25% CSL improved HU and yolk color due to increased dietary xanthophyll levels. Further studies confirmed CSL's positive impact on internal egg quality. Waldroup and Hazen (1979) reported that Babcock hens receiving 20% dried CSL showed significantly improved HU scores, indicating enhanced albumen integrity. However, in older hens (>12 months in production), high CSL inclusion (20%) occasionally reduced HDEP, likely due to the stress associated with dietary changes and handling.

Long-term trials by Lilburn and Jensen (1984) evaluated CSL (2.5−20.0%) in Single Comb White Leghorn hens. CSL supplementation improved HU scores at 10−20% inclusion levels without affecting HDEP, EW, or FI. Interestingly, hens fed CSL exhibited reduced liver lipid content and relative liver weight, suggesting improved lipid metabolism. These findings highlight CSL's potential dual benefit in layers: enhancing albumen quality while supporting hepatic lipid regulation. In summary, CSL inclusion up to 20% can be safely used in laying hen diets to maintain egg production and improve internal egg quality, particularly HU scores. However, caution is advised in older layers where dietary stress may transiently affect egg production at very high inclusion levels.

Moreover, a recent study demonstrated that supplementing dried CSL at a moderate level (3% of the diet) in Hy-Line Brown hens improved laying performance, including higher HDEP, egg mass (EM), and feed efficiency during the later weeks of the trial, while 0.5% CSL showed no significant effects (Lee et al., 2025). Significantly, CSL supplementation did not alter external or internal egg quality parameters such as eggshell thickness, strength, albumen height, HU, or yolk color. These results suggest that a 3.0% inclusion of CSL can partially replace SBM without compromising egg quality, while providing additional benefits to production performance.

3. Turkeys

The use of CSL in turkeys has been less extensively studied, but available data indicate similar responses to those observed in broilers. Waldroup and Rutherford (1971) investigated CSL in turkey breeder hens and found that dried CSL (5−20%) replacing yellow corn, SBM, and alfalfa meal did not affect HDEP, FCR, fertility, or hatchability, indicating its safety and acceptability in breeder diets. In meat-type turkeys, Potter and Shelton (1978) evaluated the inclusion of 2.5% and 5.0% corn fermentation solubles in Large White turkeys over seven weeks. CSL supplementation improved BW by 6.6% (2.5% CSL) and 8.4% (5.0% CSL) and increased FI by 6.7% and 10.2%, respectively. However, feed efficiency slightly declined at the higher inclusion level (5.0%), suggesting a threshold beyond which CSL's benefits on FI and BW may not translate into improved FCR. Thus, CSL can be used in turkey diets at low-to-moderate levels (≤5%) to improve growth performance and FI without compromising reproductive performance or egg quality in breeder hens.

IMPACT OF CORN STEEP LIQUOR SUPPLEMENTATION ON PHYSIOLOGICAL RESPONSE

1. Metabolic and Hepatic Effects

CSL supplementation has been shown to influence lipid metabolism and liver health in poultry. In laying hens, Lilburn and Jensen (1984) reported that feeding liquid CSL for four to six months significantly reduced liver and plasma lipid levels compared to basal diets. In Babcock layers, the highest inclusion level of CSL resulted in a marked decrease in hepatic lipid accumulation, while Shaver layers fed 5%, 10%, or 20% CSL exhibited significantly lower liver lipid content than the controls. Interestingly, relative liver weight was unaffected in one trial but was reduced considerably in birds receiving the highest CSL inclusion in another, suggesting that CSL may modulate hepatic lipid metabolism through its bioactive compounds. Similar trends were observed in broilers. Yazdanyar et al. (2015) found that inclusion levels above 10% in Ross 308 broilers reduced relative liver weight, indicating possible alterations in metabolic activity or nutrient partitioning at higher dietary acidity levels. Moreover, Hamidifard et al. (2023) observed reduced plasma triglycerides and elevated high-density lipoprotein cholesterol (HDL-C) in birds receiving 1 cc/kg liquid CSL, likely due to the actions of CSL-derived organic acids and lactic acid bacteria in modulating bile acid metabolism and cholesterol homeostasis. Collectively, these findings suggest that moderate CSL inclusion supports lipid metabolism and may prevent excessive hepatic lipid deposition. In contrast, too high levels may lead to altered liver morphology or metabolic stress.

2. Immune and Antioxidant Responses

CSL supplementation also modulates immune function and oxidative status. Ebrahimpour et al. (2022) demonstrated that broilers fed 6% dried CSL had significantly higher antibody titers against Newcastle disease (ND), infectious bronchitis (IB), and avian influenza (AI), implying that CSL-derived organic acids may improve gut microbiota balance and stimulate both mucosal and humoral immunity. In addition, CSL's high CP content likely supports immunoglobulin synthesis. Antioxidant effects were also reported by Atabak et al. (2021), finding that diets containing 8.5% dried CSL increased glutathione peroxidase (GPX) and ferric reducing ability of plasma (FRAP) while reducing lipid peroxidation markers, indicating improved oxidative stress resilience. Similarly, Hamidifard et al. (2023) showed enhanced humoral immune responses to AI vaccination at day 42 in birds supplemented with liquid CSL, although early vaccination titers were not significantly different. These findings collectively highlight CSL's role in supporting immune responsiveness and mitigating oxidative stress, likely through its organic acids, bioactive peptides, and potential prebiotic effects on gut microbiota.

3. Digestive Physiology and Gut Health

The influence of CSL on gut physiology and nutrient digestibility appears dose-dependent. Ullah et al. (2018) reported that broilers fed 5% and 10% CSL exhibited significantly higher dry matter (DM) and CP digestibility during the starter phase, likely due to CSL's high soluble protein content improving nutrient availability. Ether extract (EE) digestibility was also enhanced at moderate inclusion levels. However, beyond the starter phase, further improvements were not observed, suggesting early-life benefits may be more pronounced. Similar findings were noted by Tauqir et al. (2022), where birds fed 3% CSL had the highest DM, CP, and EE digestibility, while higher inclusion levels did not confer additional benefits. Moreover, Hamidifard et al. (2023) showed that liquid CSL supplementation lowered the pH of ileal digesta, supporting an acidifying effect that can inhibit pathogenic bacteria and promote beneficial microbial colonization. Interestingly, while villus height (VH), crypt depth (CD), and the VH:CD ratio were not significantly altered, a numerically lower VH in CSL-fed birds suggested a reduced pathogen load and decreased intestinal cell turnover. Overall, moderate CSL inclusion may enhance early gut health by improving nutrient digestibility and lowering gut pH, thereby creating a more favorable intestinal environment.

4. Organ Development and Potential Adverse Effects

High CSL inclusion can induce adverse effects on organ development and tissue integrity. In Ross 308 broilers, Yazdanyar et al. (2015) observed that inclusion levels above 10% significantly reduced the relative weights of the liver, Bursa of Fabricius, spleen, and gizzard, indicating potential impacts on immune organ development and mechanical digestion. Similarly, Ullah et al. (2018) reported that birds fed 15% CSL exhibited moderate-to-severe hypertrophy and hyperplasia of the crop mucosa, likely due to persistent irritation from the low dietary pH. Histological changes included swelling of enterocytes, leukocyte infiltration in intestinal intervillous spaces, and extensive necrosis of renal tubular epithelial cells, suggesting nephrotoxicity related to increased uric acid accumulation from CSL's high non-protein nitrogen content. Interestingly, while hematological parameters such as erythrocyte count, leukocyte count, hemoglobin concentration, and erythrocyte sedimentation rate (ESR) remained unaffected, serum uric acid levels rose significantly with increasing CSL inclusion. Hamidifard et al.

(2023) also found a transient increase in heterophil-to-lymphocyte (H:L) ratio at 14 days with higher CSL doses, suggesting mild stress responses, although this effect diminished over time. Despite these changes, carcass yield and giblet weights were largely unaffected at moderate inclusion levels (Tauqir et al., 2022), indicating that low-to-moderate CSL inclusion remains safe. Overall, while moderate inclusion supports organ development and immune function, excessive levels may induce crop irritation, renal stress, and reduced immune organ size.

CONCLUSION

This review consolidates current evidence on CSL as a viable alternative protein source in poultry nutrition. CSL provides highly digestible proteins and peptides, as well as organic acids and bioactive compounds that modulate gut health, nutrient metabolism, and immune responses. Across broilers, layers, and turkeys, the optimal inclusion level is species- and production-phase-dependent. In broilers, low to moderate inclusion (3－10%) improves BWG, gut health, and nutrient digestibility, whereas excessive levels (>15%) may induce metabolic stress and compromise performance. In layers, CSL up to 20% supports egg production and enhances internal egg quality, particularly albumen integrity, while modulating hepatic lipid metabolism. In turkeys, inclusion levels ≤5% improve growth performance and FI without adversely affecting reproductive parameters. Beyond production outcomes, moderate supplementation improves hepatic lipid regulation, enhances nutrient digestibility, augments humoral immunity, and mitigates oxidative stress, reflecting its multifaceted functional benefits.

From a practical perspective, dried CSL offers advantages in terms of storage stability and ease of handling but is generally more costly compared with its liquid form. Moreover, the nutritional composition and functional properties of CSL can vary depending on the corn source and wet-milling process, leading to inconsistencies in its efficacy. These findings underscore the importance of dose optimization and quality control to maximize the nutritional and functional benefits of CSL while minimizing potential adverse effects, such as tissue irritation, nephrotoxicity, or metabolic imbalances, at high inclusion levels. Overall, CSL represents a promising functional feed ingredient that can partially replace conventional protein sources, such as SBM. However, further research is warranted to clarify its bioactive mechanisms, establish long-term safety thresholds, and refine dietary strategies for consistent application in modern poultry production systems.

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