Research Progress on the Application of Citrus Pomace in Animal Feed: Postprint

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Abstract

Citrus peel residue is a by-product of the citrus processing industry, accounting for 45%-60% of the fresh weight of citrus fruits. It is nutritionally rich, containing abundant fiber, pigments, antioxidant substances, and other components, and demonstrates significant utilization value in animal nutrition and immunity. Utilizing citrus peel residue as feed can not only improve animal production performance, promote immune function, and enhance livestock product quality, but also address the environmental pollution it causes, reduce feed costs, and alleviate the competition for grain resources between humans and livestock. Therefore, this article reviews the nutritional characteristics of citrus peel residue and its application in the diets of ruminants and monogastric animals, with the aim of providing a reference for research on the application of citrus peel residue in animal production.

Full Text

Research Progress on the Application of Citrus Pulp in Animal Feed

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Abstract

Citrus pulp, a by-product of the citrus processing industry, accounts for 45%-60% of fresh citrus weight. Rich in nutrients, fiber, pigments, and antioxidant substances, it holds significant value for animal nutrition and immunity.

Utilizing citrus pulp as feed can improve animal growth performance, enhance immune function and product quality, mitigate environmental pollution from waste disposal, reduce feed costs, and alleviate competition between humans and livestock for grain resources. This review synthesizes current knowledge on the nutritional characteristics of citrus pulp and its application in diets for ruminants and monogastric animals, providing a reference for future research and practical implementation in animal production.

Keywords: citrus pulp; animal feed; growth performance; meat quality

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With rising living standards in China, demand for animal-derived foods continues to grow steadily. However, the country' s grain supply and demand balance remains chronically strained, making the development of grain-saving animal husbandry essential for ensuring adequate livestock product supply. Developing feed resources from economic crop by-products not only transforms waste into valuable resources and reduces feed costs to improve farmers' economic returns, but also mitigates environmental problems caused by by-product accumulation. This approach holds significant research and practical importance for developing sustainable, grain-efficient livestock production.

Citrus ranks as the world' s leading fruit crop, with annual global production reaching approximately 100 million tons. China contributes 25% of world citrus production, making it one of the major citrus-producing nations. Beyond fresh consumption, a substantial portion of citrus is processed for juice and canned products, generating large quantities of pulp by-products consisting primarily of peel, seeds, mesocarp, and residual pulp. These by-products are rich in carbohydrates, vitamins, minerals, fats, and proteins. In countries with advanced citrus processing industries such as the United States and Brazil, citrus pulp has been widely utilized in ruminant diets. In China, however, limited research and technological constraints have restricted its use primarily to pectin extraction, traditional Chinese medicine (dried tangerine peel), and minimal feed applications, with most pulp being discarded or landfilled. This practice not only wastes valuable resources but also creates serious environmental pollution, posing significant challenges for the citrus industry and environmental management. Consequently, developing scientific and rational solutions for citrus pulp utilization has become an urgent priority for stakeholders.

Recent research on comprehensive citrus pulp utilization has expanded both domestically and internationally, focusing primarily on two aspects: extraction of functional components such as essential oils, pectin, and dietary fiber; and biological conversion for ethanol fuel, feed, food, and additive production. This review emphasizes the nutritional characteristics of citrus pulp and its effects on animal health, production performance, and product quality when used as a feed ingredient, providing a reference for future research on citrus pulp feed development.

1. Utilization Methods and Nutritional Characteristics of Citrus Pulp

Currently, three primary methods exist for utilizing citrus pulp as animal feed: fresh feeding, drying and pelleting, and fermentation treatment. Due to obvious seasonal and regional limitations, fresh feeding cannot serve as the main utilization pathway, making drying/pelleting and fermentation the predominant production methods.

1.1 Fresh Citrus Pulp

The nutrient composition of fresh citrus pulp varies considerably, primarily depending on citrus variety and processing methods. Calculated on a 90% dry matter basis, fresh citrus pulp typically contains: nitrogen-free extract 55.3%-71.6%, crude protein 6.4%-10.7%, crude fat 2.2%-12.6%, crude fiber 7.8%-18.5%, crude ash 3.1%-11.9%, calcium 0.34%-1.68%, and phosphorus 0.07%-0.27%. Additionally, fresh citrus pulp contains various mineral elements and vitamins, including iron, copper, zinc, manganese, B vitamins, vitamin E, vitamin C, and carotenoids. However, its high moisture content and abundant sugars make it prone to spoilage and decay, creating difficulties in transport and storage that severely limit its utilization.

1.2 Dried Citrus Pulp

Dried citrus pulp is produced by reducing moisture content to approximately 12% through indirect or direct drying methods. Production can employ either natural sun-drying or mechanical processing. Natural sun-drying is limited by production scale and inconsistent product quality, making it unsuitable for large-scale application. Mechanical processing is therefore the preferred method. This approach involves chopping fresh pulp into approximately 0.6 cm particles, mixing with 0.2%-0.5% lime powder by weight, reacting until the color turns light gray, then pressing and optionally adding back concentrated syrup before drying to below 10% moisture, cooling, and grinding or pelleting. Drying and pelleting represent the primary utilization method in foreign countries. Dried citrus pulp contains high concentrations of pectin (22%-40%), a high calcium-to-phosphorus ratio (3.5±1.7), crude protein (7.2±0.2)%, crude fat (3.0±1.0)%, neutral detergent fiber (19.3±1.3)%, and acid detergent fiber (16.9±2.0)%. Due to its rich nutrient content, dried citrus pulp is widely used as a ruminant feed ingredient to replace grain concentrates at high proportions without negatively affecting production performance.

Furthermore, dried citrus pulp contains bioactive substances with antioxidant functions, including polyphenols, flavonoids, terpenes, citric acid, and carotenoids, which may influence animal antioxidant capacity. Although dried citrus pulp serves as an excellent ruminant feed and has been extensively used for beef and dairy cattle in major citrus-producing countries like Brazil and the United States, its low protein content, strong bitter taste, and poor palatability somewhat limit its application in animal feed.

1.3 Fermented Citrus Pulp

The presence of substantial bitter compounds, poor palatability, and low protein content in citrus pulp have historically limited its application in animal production. Microbial fermentation offers a method to modify citrus pulp by reducing bitter compounds, increasing protein content, and balancing amino acids. Research on microbial fermentation of citrus pulp has a considerable history both domestically and internationally.

Li et al. used yeast to ferment citrus pulp for feed production, determining optimal conditions as: temperature 30°C, initial pH 5, and fermentation time of 4 days. Following fermentation, yeast cell count reached 926 million per gram of citrus pulp (dry matter basis), while crude protein increased significantly from 8.17% pre-fermentation to 28.06%. Yin et al. and Guo et al. investigated microbial strains, supplementary materials, and process conditions for producing high-protein feed from fermented citrus pulp. Their research indicated that when *Aspergillus niger*, *Aspergillus oryzae*, and *Saccharomyces fibuligera* were mixed at a 2:3:1 ratio, with a substrate containing 85% citrus pulp and 15% wheat bran, 70% moisture content, and inoculation rate of 0.4 mL/g, crude protein content increased from 10.37% pre-fermentation to 34.40% post-fermentation. Zhu et al. studied waste utilization of citrus pulp for single-cell protein feed production, finding that maximum key amino acid production occurred with a 1:1 ratio of *Aspergillus niger* to *Saccharomyces cerevisiae*, 20% inoculation rate, 60 g/L citrus pulp, and 21 g/L urea after 5 days fermentation. Under these conditions, threonine, methionine, and lysine contents reached 2.03×10^{3}, 3.58, and 1.49×10^{2} g/L respectively, accounting for 14.77% of total amino acids.

2.1.1 Effects on Ruminant Growth Performance

Citrus pulp contains substantial digestible crude fiber and pectin that can provide energy for ruminants, partially replacing grain feeds such as corn. Extensive research on citrus pulp in ruminant diets has demonstrated effects on growth performance and rumen fermentation. Cribbs et al. investigated the effects of dried citrus pulp on feedlot performance of crossbred heifers, finding that partial replacement of corn with dried citrus pulp reduced the risk of rumen acidosis. However, due to palatability factors, dry matter intake, average daily gain, and feed efficiency decreased as dietary dried citrus pulp inclusion increased. Peixoto et al. reported that citrus pulp supplementation in lamb diets did not affect nutrient intake, digestibility, rumen pH, or ammonia nitrogen content, suggesting that citrus pulp could completely replace corn or be included up to 26.5% of dietary dry matter. Gholizadeh et al. examined the effects of replacing barley with dried citrus pulp on growth performance of 85–90 day-old Saanen dairy goats, using dried citrus pulp to replace 0%, 7%, and 14% of dietary barley. Results showed that increasing dried citrus pulp inclusion reduced dry matter intake and daily gain while increasing feed efficiency, rumen fluid pH, and plasma urea nitrogen. However, apparent digestibility of dry matter, acid detergent fiber, neutral detergent fiber, and crude protein did not differ significantly from the control group. Li studied the effects of citrus pulp on growth performance of fattening Simmental crossbred bulls, finding that when dried citrus pulp inclusion reached 15%-25% of dietary dry matter, no significant effects on beef cattle growth performance occurred, but at 35% inclusion, growth performance and economic benefits decreased significantly. These results indicate that ensiled citrus pulp can be used as roughage for fattening cattle at up to 20% of dietary dry matter, while dried citrus pulp can partially replace corn and soybean meal in concentrates at up to 25% of dietary dry matter. Gouvêa et al. investigated citrus pulp effects on fattening cattle, reporting that supplementation increased dry matter intake without significantly affecting dressing percentage, ribeye area, or rumen pH, suggesting no negative impact on growth performance. However, the lack of significant rumen pH increase indicates it may not reduce acidosis risk. These inconsistent results may relate to citrus pulp source, processing method, basal diet, and animal breed, requiring further investigation. Additionally, research indicates that feeding lambs diets containing 74.5% citrus pulp caused rumen parakeratosis, while dairy cows fed large amounts of citrus pulp died from type IV hypersensitivity reactions. These findings demonstrate that citrus pulp can serve as an effective ruminant feed ingredient for growth and development, but inclusion should be controlled within appropriate ranges, generally not exceeding 20%. Storage methods and feeding forms also require careful attention to avoid negative effects on animal performance.

2.1.2 Effects on Ruminant Product Quality and Antioxidant Capacity

Animal bodies contain numerous free radicals that are highly reactive and damaging due to their ability to denature macromolecules through lipid peroxidation. Citrus pulp contains bioactive compounds including flavonoids, polyphenols, citric acid, and carotenoids that scavenge free radicals and block oxidation by inhibiting free radical chain propagation, thereby protecting cell membranes from oxidative damage. Research indicates that dietary citrus pulp supplementation may enhance animal antioxidant capacity and improve product quality by reducing lipid oxidation and increasing milk fat percentage. Scerra et al. investigated the effects of ensiled citrus pulp diets on growth performance and meat quality of 63-day-old weaned lambs, finding no significant difference in carcass weight between treatment and control groups. Compared with controls, the treatment group showed better carcass muscle conformation, significantly reduced fat content, increased moisture content, and higher lean percentage (though not significantly different), with no difference in final muscle pH. These results demonstrate that ensiled citrus pulp can replace conventional roughage and partial concentrate without negatively affecting carcass and meat quality. Santos et al. examined citrus pulp effects on milk quality in Holstein dairy cows, reporting that 18% dietary citrus pulp increased monounsaturated fatty acids and decreased saturated fatty acids in milk fat. At inclusion levels of 9%-18% of dietary dry matter, total milk polyphenols and flavonoids increased, along with significantly enhanced ferric-reducing antioxidant power. López et al. found that replacing 61% of dietary corn with citrus pulp in dairy goat diets did not significantly affect dry matter intake or milk yield but significantly increased milk fat percentage, indicating no adverse effects on lactation performance. Gravador et al. reported that citrus pulp replacing partial barley in lamb diets significantly reduced protein radicals and carbonyl compounds while preserving sulfhydryl compounds and slowing protein oxidation rates in meat stored aerobically for 6 days, demonstrating that dietary citrus pulp reduces meat protein oxidation. Yuan investigated the effects of dried tangerine peel supplementation in Holstein dairy cows, finding that compared with controls, dry matter intake increased by 3.80% and milk yield by 2.15%, with significantly higher serum total protein, albumin, and alanine aminotransferase levels. Malondialdehyde content decreased by 5.10%, superoxide activity increased by 35.08%, and glutathione peroxidase activity improved significantly. These results indicate that dried tangerine peel supplementation enhances dairy cow performance by increasing dry matter intake, milk yield, and milk protein content while reducing free radical production and enhancing antioxidant capacity. Inserra et al. studied the effects of partial replacement of barley concentrate with dried citrus pulp on meat quality of weaned lambs, reporting that dried citrus pulp supplementation significantly reduced lipid oxidation in meat stored aerobically for 6 days without affecting meat color parameters, demonstrating a natural and feasible method to enhance meat antioxidant capacity. Romero-Huelva et al. found that dietary inclusion of citrus pulp by-products did not negatively affect milk yield or composition in dairy goats but reduced saturated fatty acids while increasing monounsaturated and polyunsaturated fatty acids. These results collectively demonstrate that citrus pulp supplementation in ruminant diets can improve meat and milk quality while enhancing antioxidant capacity in both animals and products. The primary mechanism likely involves transfer of polyphenols and flavonoids from citrus pulp to animal tissues and milk, thereby improving antioxidant capacity. The relationship between total phenolic content and ferric-reducing antioxidant power requires further investigation.

2.2.1 Application of Citrus Pulp in Pig Diets

2.2.1.1 Application in Piglet Diets Citrus pulp contains abundant citric acid compounds that may improve feed utilization efficiency in pig diets. However, due to poor palatability and nutritional imbalance, research on citrus pulp in pig diets has focused primarily on growing-finishing pigs, with relatively few studies on piglets and gestating sows. Recent research indicates that appropriate dietary fiber supplementation promotes digestive system development and prevents digestive disorders in piglets. Wang reported that 8% fermented citrus pulp in weaned piglet diets improved growth performance, promoted intestinal villus development, reduced crypt depth, enhanced digestive capacity, and improved nutrient utilization. Almeida et al. investigated the interactive effects of dietary crude protein level and dried citrus pulp inclusion on growth performance, small intestinal morphology, and hindgut fermentation in 21-day-old weaned piglets. Their results showed that 7.5% dried citrus pulp supplementation did not significantly affect growth performance or intestinal morphology. However, feeding high-protein diets containing 7.5% dried citrus pulp for 7 or 28 days significantly increased the acetate-to-propionate ratio in the hindgut. These findings indicate that appropriate citrus pulp inclusion enhances digestive capacity and growth performance in weaned piglets, though optimal inclusion levels and forms require further research due to limited studies in piglets.

2.2.1.2 Application in Growing-Finishing Pig Diets Citrus pulp is nutrient-rich and contains various antimicrobial and antioxidant bioactive substances. Research demonstrates that citrus pulp supplementation in growing-finishing pig diets promotes growth, improves feed conversion efficiency, reduces backfat thickness and cholesterol content, and improves gut microbiota. Zhao investigated the feeding effects of single-cell protein feed from citrus pulp on growing pigs, finding that under isoenergetic and isoprotein conditions, replacing 50% or 100% of dietary rapeseed meal (8%) with fermented summer orange pulp did not adversely affect growth performance or serum total protein, albumin, globulin content, or albumin-to-globulin ratio in 38–50 kg growing pigs. The 50% replacement group showed significantly reduced serum urea nitrogen and improved dietary protein and dry matter digestibility while reducing feed costs. Cerisuelo et al. studied the effects of ensiled citrus pulp on growth performance, gut microbiota, and meat quality in finishing pigs, reporting that ensiled citrus pulp supplementation reduced feed intake and daily gain during the first 4 weeks but had no significant effect thereafter. Supplementation significantly reduced fecal *Enterobacteriaceae* populations without affecting *Lactobacillus* counts and showed trends toward reduced backfat thickness and increased oleic acid content in subcutaneous fat. Moset et al. investigated ensiled citrus pulp inclusion (0, 50, 100, 150 g/kg) in finishing pig diets on carcass quality and intestinal microflora. Results showed that citrus pulp supplementation significantly reduced digestible energy but linearly increased neutral and acid detergent fiber digestibility. Increasing citrus pulp inclusion significantly reduced fecal *Enterobacteriaceae* and *Lactobacillus* populations and linearly decreased dressing percentage, while polyunsaturated fatty acid content in subcutaneous fat decreased quadratically. However, at 100 g/kg inclusion, citrus pulp had no significant effects on nutrient digestibility, dressing percentage, or subcutaneous fatty acid content. Watanabe et al. studied citrus pulp supplementation in finishing pigs (83.7±5.1 kg), finding quadratic effects on daily gain and days to reach 130 kg body weight, with optimal inclusion levels of 10.79%–10.97%. Citrus pulp had no significant effect on serum urea and triglyceride levels but showed quadratic effects on serum cholesterol. These results demonstrate that appropriate citrus pulp inclusion does not adversely affect growth performance or meat quality in growing-finishing pigs. The polyphenols and flavonoids in citrus pulp may enhance non-specific immunity and humoral immune function while reducing harmful gut microorganisms, thereby improving feed conversion efficiency. Consequently, appropriate citrus pulp supplementation in production can save feed costs and increase economic benefits.

2.2.2 Application of Citrus Pulp in Poultry Diets

2.2.2.1 Effects on Poultry Production Performance Citrus pulp is commonly processed into peel powder for poultry diet formulation. Numerous studies demonstrate that citrus peel powder supplementation promotes growth, improves weight gain rate, and enhances feed conversion efficiency, primarily by increasing apparent metabolic rates of crude protein, crude fat, crude fiber, and crude ash. Huang et al. reported that 3% citrus peel powder in broiler diets increased survival rate by 0.4%, significantly improved average weight gain and feed utilization, increased economic benefits by 13%, produced orange-yellow skin color, and improved processed meat flavor. Nazok et al. reported that citrus pulp inclusion below 12% in laying hen diets did not significantly affect feed intake, egg number, egg mass, feed-to-egg ratio, body weight, yolk index, or yolk color, but 16% inclusion significantly reduced feed intake and egg number while increasing feed-to-egg ratio. Yang et al. fed 1–21 day-old Sichuan white geese diets containing 0%, 2%, 4%, 6%, 8%, and 10% citrus pulp, investigating effects on growth performance and serum biochemical indices. Results showed that citrus pulp inclusion below 10% did not significantly affect serum biochemical indices, while 6% inclusion significantly reduced feed-to-gain ratio and 8% inclusion significantly increased serum high-density lipoprotein content. Considering these factors, 6% citrus pulp inclusion in 1–21 day-old Sichuan white goose diets optimally promotes growth performance. Chen et al. fed 32-day-old yellow-feathered broilers diets containing 3.5%, 3.0%, and 2.5% citrus peel powder for 35 days, finding that 3.5% inclusion produced the best results: feed-to-gain ratio of 3.09 (11.71% lower than control), feed conversion efficiency 13.27% higher than control, average weight gain of 0.9345 kg (11.72% higher than the control’ s 0.8365 kg), economic benefits 27.35% higher than control, and weight gain cost reduced by 0.55 yuan/kg. These results demonstrate that citrus pulp supplementation in poultry diets promotes growth and improves production performance, with optimal inclusion below 10% as higher levels produce adverse effects. Therefore, further research is needed on the regulatory mechanisms of citrus pulp on poultry growth and development and optimal inclusion levels before widespread application.

2.2.2.2 Effects on Poultry Product Quality As a feed ingredient, citrus peel powder contains abundant carotenoids that increase pigment deposition in skin and egg yolk, enhancing flavor and palatability while providing antimicrobial health benefits, improving meat quality, increasing laying performance, and deepening yolk color. Lei et al. added 2.5% citrus peel powder to 45-week-old Roman laying hen diets, finding after 42 days that the treatment group increased egg production by 5.23% compared with controls, demonstrating that citrus peel powder as a feed additive promotes nutrient deposition, stimulates follicle maturation, and increases ovulation to improve production efficiency. Hu et al. fed 61-week-old laying hens diets containing 1% dried tangerine peel powder for 6 weeks, reporting that compared with controls, egg production rate increased by 2.54%, feed intake increased by 1.28%, average egg weight and feed-to-egg ratio decreased by 0.06% and 1.48% respectively, broken egg rate decreased by 1.20%, Haugh unit and egg specific gravity increased by 10.73% and 0.94% respectively, yolk color improved by 12.89%, shell color, shell thickness, and yolk index increased by 2.60%, 3.39%, and 5.26% respectively, and shell and albumen proportions increased by 1.68% and 3.83% respectively. Egg crude protein content increased significantly, while crude fat decreased by 9.42% and crude ash decreased by 7.95%. These results demonstrate that dried tangerine peel improves laying hen performance and egg quality. Wang et al. fed 1-day-old broilers diets containing 1.5% and 2.5% citrus peel powder, finding that treatment groups showed significantly higher feed-to-gain ratio, feed conversion efficiency, average weight gain, feed apparent metabolic rate, and body composition nutrient content compared with controls, with substantially improved economic benefits. Lei et al. studied the effects of 2.5% citrus peel powder on nitrogen, calcium, and phosphorus metabolism in late-laying hens, reporting that the treatment group showed significantly improved nitrogen apparent metabolic rate, calcium apparent metabolic rate of 65.79% (3.49% higher than the control' s 62.30%), and phosphorus apparent metabolic rate of 46.39% (1.13% lower than the control' s 47.52%). Lanza et al. investigated citrus pulp in ostrich diets, finding that supplementation reduced muscle crude fat content, increased polyunsaturated fatty acid content, and decreased cooking loss and crude ash content. Compared with controls, ostriches fed citrus pulp showed significantly higher final muscle pH and lower saturated and monounsaturated fatty acid content. These results indicate that citrus pulp in ostrich diets does not adversely affect meat quality and can reduce feed costs. Overall, appropriate citrus pulp supplementation improves poultry product quality and economic benefits, making it a viable feed ingredient in poultry production.

3. Summary

In summary, appropriate inclusion of citrus pulp in animal diets can improve animal production performance and product quality, conserve feed resources, reduce feed costs, and increase economic benefits while mitigating environmental pollution from citrus waste disposal, thereby providing clear ecological advantages. However, due to factors such as poor palatability and substantial nutritional variation, standardized optimal inclusion levels for different animal species and growth stages have not been established, and inclusion forms vary considerably. Consequently, further research is needed on citrus pulp application in animal diets. Additionally, citrus pulp contains functional substances including essential oils, pectin, citrus pigments, limonoids, flavonoids, and alkaloid compounds, suggesting potential applications beyond feed ingredient use as feed attractants, colorants, and antioxidants. Research in these areas requires further deepening.

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Note: Figure translations are in progress. See original paper for figures.