

Orange peels as a second-generation feedstuff to produce a new feed ingredient for dairy sheep.

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Introduction

In an effort to enhance sustainability and reduce their carbon footprint, industries are increasingly exploring waste valorization strategies as an alternative to conventional waste treatment. Simultaneously, food insecurity is escalating at an alarming rate, necessitating innovative solutions to optimize resource utilization. Within this context, the global demand for animal-derived products continues to rise, influenced by shifting consumer preferences, animal welfare considerations, and climatic challenges. Sheep farming, in particular, faces significant sustainability challenges, including dependency on imported, high-cost feedstuffs that are subject to market fluctuations, thereby limiting farm resilience. Additionally, forage scarcity due to environmental disturbances disrupts rumen fermentation dynamics, leading to reduced productivity and compromised animal welfare. To address these challenges, food by-products have emerged as viable alternative feed sources due to their nutritional value and widespread availability, particularly in the Mediterranean region. Among these, fiber-rich fruit by-products offer a promising substitute for conventional feeds, enhancing the long-term sustainability and competitiveness of the livestock sector.

Despite the annual production of over 17 million tons of food by-products from processing alone, only 10% is repurposed for industrial applications such as animal feed production. In particular, global orange juice production reached approximately 1.53 million metric tons in 2022/2023, with Mediterranean countries—Spain, Italy, Greece, Egypt, Turkey, and Morocco—contributing approximately 24% of total global production. Juice extraction generates substantial residues, including peel (flavedo and albedo), pulp (juice sac residue), rag (membranes and cores), and seeds, which collectively account for 50–60% of the fruit's total weight. This translates to an estimated 0.76–0.92 million metric tons of orange by-products rich in soluble sugars, pectin, proteins, hemicelluloses, and cellulose fibers. Orange peels, in particular, exhibit high organic matter digestibility (~85%) and substantial energy content, making them a promising animal feed component, especially when subjected to bioprocessing techniques such as solid-state fermentation and enzymatic hydrolysis.

Methodology

This study aimed to evaluate the utilization of orange peels from a Greek orange juice industry as a high-value secondary feedstuff for dairy sheep within a circular economy framework. The investigation assessed the impact of orange peel supplementation on feed intake, productivity, milk composition, and the quality characteristics of dairy products, specifically yoghurt.

Results and discussion

The proposed valorization strategy included a saccharification step for the orange peels and an aerobic fermentation process for the liquid residue, both optimized using factorial design methodologies. Saccharification optimization was based on pectinolytic and cellulolytic enzyme concentrations and solid loading, while fermentation parameters were adjusted for nutrient supplementation, yeast-to-glucose ratio, and pH control. Under optimal conditions, the final feedstuff consisted of solid residues derived from orange peel saccharification (50°C, 24 h, 7.5% solids loading, Pectinex 25 µL/g TS, CellicCTec3 25 µL/g TS), combined with harvested yeast cultivated aerobically on orange peel hydrolysate (30°C, 24 h, supplemented with nutrients, yeast-to-glucose ratio 0.02). The formulated feed underwent drying to ensure stability, yielding a product with a 23.11% increase in in vitro organic matter digestibility and a threefold increase in protein content.

To evaluate its efficacy, both enzymatically hydrolyzed (processed) orange peels (POP) and unprocessed orange peels (UOP) were incorporated into the diets of two groups of twelve multiparous Chios breed dairy ewes at a rate of 11% dry matter. A control group of twelve ewes received a conventional diet. The animals were housed in

separate pens, monitored weekly by a veterinarian, and fed isoenergetic and isonitrogenous rations formulated to meet their nutritional requirements. Each ewe received 1.6 kg of concentrates, 1.3 kg of alfalfa hay, and 0.3 kg of wheat straw daily, with feed intake monitored and refusals collected and weighed daily over an 84-day feeding period.

Biweekly milk production and composition analyses were conducted according to ICAR recommendations. Consolidated milk samples, collected during morning and afternoon milking sessions, were analyzed for fat, protein, lactose, and total solids using an automatic infrared milk analyzer (MilkoScan™, Foss). The incorporation of POP and UOP as partial replacements for sunflower meal and wheat bran resulted in:

- Increased feed palatability and consumption by ewes
- Enhanced milk yield
- Improved milk composition (higher fat and protein content)
- Reduced milk oxidative modification capacity
- Enriched polyunsaturated fatty acid content in milk
- Decrease in rumen methanogenic bacteria, contributing to a lower environmental footprint.

Bulk tank milk collected throughout the lactation period was used to produce four batches of yoghurt, which were subsequently analyzed for proximate composition. Yoghurt derived from UOP and POP diets exhibited higher protein and fat content compared to the control, with no significant differences observed in fat nutritional indices. Despite variations in total phenolic content, antioxidant activity remained statistically unchanged across treatments. Textural analysis revealed greater firmness and cohesiveness in UOP-derived yoghurt, while the whiteness index remained stable during storage, preserving the desirable visual attributes of traditional sheep milk yoghurt. Syneresis levels were comparable across all groups, indicating no adverse effects on yoghurt stability. Sensory evaluation confirmed high acceptability for yoghurts produced from both experimental diets.

Further analysis indicated that dietary supplementation with orange peels, particularly in their unprocessed form, significantly influenced yoghurt composition, resulting in:

- Lower moisture content ($p < 0.01$)
- Higher ash content ($p < 0.05$)
- Increased protein content ($p < 0.05$)
- Elevated fat content ($p < 0.05$)
- No significant effect on carbohydrate content ($p > 0.05$)

Processed orange peel supplementation enhanced feed digestibility, while unprocessed peels promoted higher acetic acid production in the rumen, thereby increasing milk fat composition. Both treatments positively influenced yoghurt composition without adverse effects on quality.

Conclusion

These findings underscore the potential of orange peels as a sustainable feed additive, offering a viable waste valorization strategy without compromising the nutritional, functional, or sensory properties of dairy products. The integration of orange peels into dairy sheep diets enhances productivity while contributing to circular economy practices in the livestock sector. This approach not only mitigates agricultural waste but also promotes sustainable animal nutrition, reinforcing the viability of alternative feed resources in ruminant production systems.