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The Effect of Dietary Incorporation of Olive Oil Extraction By-Products on Production Performance and Carcass Traits in Nile Tilapia (*Oreochromis niloticus*): A Comprehensive Review

Mohamed Omar Abdalla *[1], Amna Ali Alhadad [2], Ayiman Mohammed Basheer
[1,2,3]Department of Biology, Faculty of Education, Bani Waleed University, Bani Waleed, Libya.
mohamed.salem@bwu.edu.ly

تأثير دمج منتجات مخلفات استخلاص زيت الزيتون في علائق أسماك البلطي النيلي (*Oreochromis niloticus*) على أداء الإنتاج وصفات الذبيحة: مراجعة شاملة

محمد عمر عبدالله *[1] أمنة علي الحداد [2]، إيمان محمد بشير [3]
[3.2.1] قسم الأحياء، كلية التربية، جامعة بني وليد، بني وليد، ليبيا

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الملخص:
تقتضي الحاجة إلى الاستزراع المائي المستدام تحديد موارد علفية بديلة للتغلب على القيود الاقتصادية والبيئية المرتبطة بالمكونات التقليدية مثل مسحوق السمك وكسب فول الصويا. وفي الوقت نفسه، تنتج صناعة زيت الزيتون كميات كبيرة من المنتجات الثانوية - وهي تفل الزيتون(OP) ، ومياه صرف معاصر الزيتون (OMW)، وأوراق الزيتون - (OL) والتي يشكل التخلص منها تحديات بيئية كبيرة بسبب محتواها العالي من مركبات البوليفينول والحمل العضوي. تقدم هذه المخطوطة تركيبًا نقديًا للبحوث المعاصرة حول تعزيز قيمة هذه المنتجات الثانوية للزيتون (OBPs) كمكونات غذائية وظيفية في علائق أسماك البلطي النيلي (*Oreochromis niloticus*).تتميز المنتجات الثانوية للزيتون باحتوائها على مصفوفة معقدة من الألياف والبروتين المتبقي، والأهم من ذلك، تشكيلة متنوعة من المركبات النشطة بيولوجيًا بما في ذلك مركبات الفينول (مثل الهيدروكسي تايروسول، أوليوروبين) والدهون غير المشبعة. يشير تحليل التلوي للدراسات التجريبية إلى أن الدمج الغذائي المعتدل (5-15٪) للمنتجات الثانوية للزيتون المعالجة بشكل مناسب يمكن أن يعزز المعايير التقنية الحيوانية مثل زيادة الوزن (WG) ومعدل تحويل الغذاء(FCR) ، وذلك من خلال تحسين صحة الأمعاء، وهضم المغذيات، والكفاءة الأيضية. علاوة على ذلك، تُظهر المنتجات الثانوية للزيتون تأثيرات إيجابية عميقة على جودة الذبيحة، حيث تقوم بتعديل ملف الأحماض الدهنية لشرائح اللحم لتكوين أكثر صحة وغني بالأحماض الدهنية الأحادية غير المشبعة (MUFAs) وتعزيز الاستقرار التأكسدي بسبب خصائصها المضادة للأكسدة القوية. تخلص هذه المراجعة إلى أن الدمج الاستراتيجي للمنتجات الثانوية

للزيتون المعالجة في علائف البلطي يُمثل نموذجًا للاقتصاد الحيوي الدائري، حيث يخفف في الوقت نفسه من التأثير البيئي للنفايات الزراعية الصناعية ويعزز استدامة وجدوى إنتاج الاستزراع المائي الاقتصادية.

الكلمات الدالة: تفل الزيتون، مصادر بروتين بديلة، الأحماض الدهنية، مضادات الأكسدة، الاستزراع المائي.

Abstract

The imperative for sustainable aquaculture necessitates the identification of alternative feed resources to circumvent the economic and environmental constraints associated with conventional ingredients such as fishmeal and soybean meal. Simultaneously, the olive oil industry generates substantial quantities of by-products—olive pomace (OP), olive mill wastewater (OMW), and olive leaves (OL)—whose disposal poses significant ecological challenges due to their high polyphenolic content and organic load. This manuscript provides a critical synthesis of contemporary research on the valorization of these olive by-products (OBPs) as functional dietary components in feeds for Nile tilapia (Oreochromis niloticus). OBPs are characterized by a complex matrix of fiber, residual protein, and, most notably, a diverse profile of bioactive compounds including phenolics (e.g., hydroxytyrosol, oleuropein) and unsaturated lipids. A meta-analysis of empirical studies indicates that moderate dietary inclusion (5-15%) of appropriately processed OBPs can enhance zootechnical parameters such as weight gain (WG) and feed conversion ratio (FCR), primarily through the amelioration of gut health, nutrient digestibility, and metabolic efficiency. Furthermore, OBPs exert profound positive effects on carcass quality, modulating the fillet's fatty acid profile towards a healthier composition rich in monounsaturated fatty acids (MUFAs) and enhancing oxidative stability post-harvest due to their potent antioxidant properties. This review concludes that the strategic integration of processed OBPs into tilapia aquafeeds constitutes a paradigm of circular bioeconomy, simultaneously mitigating the environmental impact of agro-industrial waste and enhancing the sustainability and economic viability of aquaculture production.

Keywords: Olive pomace, Alternative protein sources, Fatty acid profile, Antioxidants; aquaculture.

1. Introduction

Global aquaculture, as the fastest-growing food production sector, is entrusted with the critical mandate of supplying animal protein to an escalating global population, projected to reach 9.7 billion by 2050 (FAO, 2022). However, the sustainability of this sector is intrinsically challenged by its reliance on finite and costly conventional feed ingredients, particularly fishmeal and soybean meal, which constitute 50-70% of total production expenses and raise concerns regarding resource competition and ecological footprint (Arslan et al., 2018; Salem et al., 2022). This economic and environmental imperative has catalyzed intensive research into the development of unconventional, nutrient-rich, and low-cost alternative feedstuffs (Salem, 2025; Salem & Mohamed, 2025).

In parallel, the olive oil industry, predominantly located in the Mediterranean basin, is a major generator of organic waste, producing approximately 9-10 million tons of olive pomace (OP), over 10 million m³ of olive mill wastewater (OMW), and significant quantities of olive leaves (OL) annually (European Commission, 2017; Roig et al., 2006). The disposal of these by-products presents a formidable environmental management challenge, characterized by high chemical oxygen demand (COD), phytotoxicity, and elevated concentrations of phenolic compounds, which can lead to soil degradation and aquatic pollution if not managed appropriately (Abdala et al., 2025; Salem et al., 2024). Paradoxically, this very chemical composition underpins their value. OBPs are not merely waste; they represent reservoirs of dietary fiber, protein, and, most significantly, a spectrum of bioactive molecules with demonstrated antioxidative, antimicrobial, and anti-inflammatory properties (Obied et al., 2005; Salem & Lakwani, 2024).

Nile tilapia (*Oreochromis niloticus*) is a globally significant aquaculture species, ranked as the second most farmed finfish worldwide, prized for its rapid growth, tolerance to diverse environmental conditions, and omnivorous feeding habit (El-Sayed, 2019; Ina-Salwany et al., 2023). This physiological plasticity renders it an ideal biological model for evaluating the efficacy of unconventional feed ingredients such as OBPs. The integration of OBPs into tilapia diets represents a synergistic innovation, offering a dual-resolution strategy: alleviating the environmental burden of olive waste disposal while providing a sustainable, functional, and cost-effective feed component for aquaculture. This manuscript aims to meticulously review, analyze, and synthesize the current body of evidence regarding the effects of dietary OBPs on key production parameters (growth performance, feed utilization) and carcass traits (proximate composition, fatty acid profile, oxidative stability) in Nile tilapia, thereby providing a comprehensive resource for researchers, nutritionists, and industry stakeholders.

2. Chemical and Nutritional Composition of Olive By-Products

The nutritional valorization of OBPs is contingent upon a precise understanding of their heterogeneous composition, which is influenced by a multitude of factors including olive cultivar (*Olea europaea* L.), geographic origin, climatic conditions, maturity at harvest, and the extraction technology employed (e.g., traditional press, 2-phase, or 3-phase decanters) (Boskou, 2006; Salem, 2024). Subsequent processing methods further dictate their final nutritional quality and applicability in aquafeeds.

Olive Pomace (OP): OP, also termed "olive cake," is the solid residue comprising skin, pulp, and fragmented stones. Its nutritional profile is highly variable but is generally characterized by high crude fiber (25-45% Dry Matter (DM)), moderate crude protein (5-10% DM), and a residual lipid fraction (2-10% DM) predominantly composed of oleic acid (C18:1n9), the hallmark monounsaturated fatty acid of olive oil (Molina-Alcaide & Yáñez-Ruiz, 2008; Salem et al., 2021). Its most significant value, however, lies in its rich content of bioactive compounds. These include secoiridoids (e.g., hydroxytyrosol, tyrosol), lignans (e.g., pinoresinol), and pentacyclic triterpenic acids (e.g., maslinic and oleanolic acid), which collectively confer potent antioxidant and anti-inflammatory capacities (Pérez-Jiménez et al., 2014; Obied et al., 2005). The specific composition is detailed in Table 1.

Olive Mill Wastewater (OMW): This aqueous effluent is characterized by an extremely high organic load (COD can exceed 100 g/L), containing soluble sugars, organic acids (e.g., acetic, citric), polyalcohols, minerals, and a high concentration of water-soluble polyphenols (Paraskeva et al., 2007). Its direct application is prohibitive due to its strong phytotoxicity, high moisture content (>80%), and acidity. However, advanced valorization technologies such as evaporation, membrane filtration (ultrafiltration, nanofiltration), or encapsulation can transform OMW into a stable powder or extract concentrated in hydroxytyrosol and other simple phenolics, making it suitable for animal nutrition (Paraskeva et al., 2007; Zbakh & El Abbassi, 2012).

Olive Leaves (OL): Often obtained from tree pruning and harvesting operations, OL are a remarkably concentrated source of bioactive compounds. The secoiridoid oleuropein is the predominant phenolic, constituting up to 6-9% of dry leaf matter, alongside verbascoside, luteolin-7-glucoside, and apigenin-7-glucoside (Sahin & Bilgin, 2018). OL also contain appreciable levels of protein (~9-12% DM), fiber, and essential minerals such as calcium and potassium. They are widely recognized for their potent antimicrobial, antioxidative, and hypolipidemic properties (Amhamed et al., 2023; Salem, 2024).

A primary limitation for the direct inclusion of raw OP in monogastric animal diets is its high lignin and cellulose content, which can impair nutrient digestibility and act as an anti-nutritional factor (Özdemir et al., 2018). Consequently, pre-processing techniques are often employed to enhance their nutritional value, palatability, and safety for fish. These include:

Drying: Sun-drying or oven-drying to reduce moisture and inhibit microbial spoilage.

Solid-State Fermentation: Using fungi (e.g., *Aspergillus niger*, *Pleurotus* spp.) or bacteria to degrade lignin and fiber, increase protein content, and reduce phenolic toxicity (Mahommed et al., 2025).

Solvent Extraction: To remove residual oil, resulting in a defatted meal with higher protein concentration.

Enzymatic Treatment: Supplementation with exogenous enzymes (e.g., cellulase, xylanase, β-glucanase) to break down non-starch polysaccharides and improve nutrient availability (Øverland et al., 2013).

Table 1: Typical Proximate Composition and Key Bioactive Compounds in Different Olive By-Products (Dry Matter Basis)

Component (%) / Bioactive Compound	Olive Pomace (OP)	Olive Mill Wastewater (OMW) Powder	Olive Leaves (OL)	References
Dry Matter	85-95%	92-97%	90-95%	(Molina-Alcaide & Yáñez-Ruiz, 2008; Paraskeva et al., 2007; Sahin & Bilgin, 2018)
Crude Protein	5 - 10	4 - 8	9 - 12	(Nefzaoui, 1997; Salem & Mohamed, 2025; Molina-Alcaide & Yáñez-Ruiz, 2008)
Crude Lipid	2 - 10	1 - 5	3 - 6	(Salem et al., 2021; Ahwaas et al., 2025)
Crude Fiber	25 - 45	2 - 8	18 - 25	(Molina-Alcaide & Yáñez-Ruiz, 2008; Martin Garcia et al., 2003)
Ash	4 - 8	8 - 15	7 - 10	(Molina-Alcaide & Yáñez-Ruiz, 2008; Salem, 2022)
Nitrogen-Free Extract	~30-50	~60-80	~45-60	(Calculated)
Total Phenolics (g GAE/kg)	10 - 30	50 - 150	40 - 90	(Obied et al., 2005; Pérez-Jiménez et al., 2014; Taamalli et al., 2012)
Hydroxytyrosol	0.1 - 0.5	5 - 15	0.5 - 2.0	(Pérez-Jiménez et al., 2014; Salem, 2024; Salem et al., 2024)
Oleuropein	Low	Low	60 - 90 g/kg	(Sahin & Bilgin, 2018; Romani et al., 2011)

3. Impact on Production Performance

The zootechnical effects of OBPs on Nile tilapia are not monolithic but are profoundly influenced by an intricate interplay of factors: the type of by-product, the processing method employed, the inclusion level within the diet, and the life stage of the fish.

3.1. Growth Performance

A consensus emerging from the literature suggests that moderate inclusion levels of processed OP (typically between 5% and 15% of the diet) are generally well-tolerated by Nile tilapia, with no adverse effects on final body weight, weight gain (WG), and specific growth rate (SGR) (Abdel-Warith et al., 2019; Davies et al., 2022; Çağırgan & Tanrıverdi, 2001). In several studies, these metrics were significantly improved compared to control groups fed standard diets (Ünal et al., 2009). The proposed mechanisms for this enhancement are multifaceted and interconnected:

Digestive Enzyme Stimulation: Bioactive phenolics in OBPs are hypothesized to stimulate the secretion of pancreatic and brush-border digestive enzymes (e.g., protease, amylase, lipase), thereby enhancing the breakdown and absorption of nutrients (Salem & Mohamed, 2025; Hamad et al., 2024).

Gut Microbiota Modulation: The antimicrobial properties of compounds like oleuropein and hydroxytyrosol can suppress potentially pathogenic gut bacteria (e.g., *Aeromonas* spp., *Vibrio* spp.) while promoting beneficial genera (e.g., *Lactobacillus*, *Bacillus*), leading to a more favorable gut microbiome (Salem et al., 2025; Bilen et al., 2020).

Intestinal Morphology Improvement: A healthier gut environment often translates to improved intestinal morphology, including increased villus height, villus width, and absorptive surface area, which facilitates enhanced nutrient uptake (Kiron, 2012; Bisignano et al., 1999).

However, a clear dose-dependent negative response is observed at high inclusion levels (often >20% for unprocessed or poorly processed OP) (Hassaan et al., 2013; Yılmaz et al., 2012). This growth depression is primarily ascribed to:

Anti-Nutritional Factors (ANFs): Particularly tannins, which can form indigestible complexes with dietary proteins and glycoproteins, reducing protein digestibility and bioavailability (Makkar, 2003; Mueller-Harvey, 2006).

Reduced Palatability: The bitter taste associated with certain phenolics can lead to decreased voluntary feed intake (Glencross et al., 2005).

High Fiber Content: Excessive fiber can increase feed bulk, reduce nutrient density, and accelerate gut passage rate, limiting the time available for digestion and absorption (Amirkolaie, 2011).

3.2. Feed Utilization Efficiency

One of the most consistent positive findings is an improvement in feed conversion ratio (FCR) at moderate inclusion levels. Fish fed diets containing 5-15% OP frequently demonstrate a lower FCR, indicating that less feed is required to produce a unit of biomass gain (Abdel-Warith et al., 2019; Taştan & Salem, 2021). This improved efficiency is likely a direct consequence of the enhanced gut health and nutrient digestibility mentioned above, alongside the potential metabolic effects of polyphenols that may improve energy utilization and reduce maintenance costs associated with inflammation and oxidative stress (Salem, 2017; Salem et al., 2023). Furthermore, dietary fiber, when included at optimal levels, may contribute to better satiety and regulation of feed passage rate, further optimizing digestion (Krogdahl et al., 2005). A summary of performance responses to varying inclusion levels is presented in Table 2.

Table 2: Summary of Effects of Dietary Olive Pomace (OP) Inclusion on Nile Tilapia Production Performance

Inclusion Level (% of Diet)	Processing Method	Effect on Growth	Effect on FCR	Key Observations	References
≤ 10%	Dried, Ground	No effect or significant improvement	Significantly improved	Improved gut morphology, enhanced enzyme activity.	(Abdel-Warith et al., 2019; Hamad et al., 2024; Bisignano et al., 1999)
10 - 15%	Dried, Ground/Defatted	Generally no adverse effect	Improved or unchanged	Optimal for fatty acid profile modification. Potential for improved growth.	(Davies et al., 2022; El-Sayed et al., 2020; Tosi et al., 2023)
15 - 20%	Dried, Ground	Reduced or unchanged	Unchanged or worsened	Reduced feed intake often observed. Requires processing.	(Yılmaz et al., 2012; Meneguz et al., 2016)
> 20%	Unprocessed or poorly processed	Significantly reduced	Worsened	Marked reduction in palatability and protein digestibility.	(Hassaan et al., 2013; Ghanawi et al., 2021)

4. Impact on Carcass Characteristics and Meat Quality

Beyond growth performance, the incorporation of OBPs significantly influences the quality attributes of the final product, aligning with consumer demands for healthier, higher-quality, and more stable aquatic foods.

4.1. Proximate Composition

The majority of studies report that the inclusion of OBPs at optimized levels (≤15%) does not significantly alter the moisture, crude protein, or total lipid content of Nile tilapia fillets (Abdel-Warith et al., 2019; Glencross, 2009). This indicates that the fundamental nutritional integrity and yield of the muscle tissue are preserved, which is crucial for consumer acceptance and market value.

4.2. Fatty Acid Profile

This represents one of the most remarkable and beneficial impacts of OBP inclusion. Diets supplemented with OP consistently lead to a significant and favorable modification of the fillet's fatty acid composition. There is a marked increase in health-promoting monounsaturated fatty acids (MUFAs), specifically oleic acid (C18:1n9), which is the principal fatty acid in olive oil (El-Sayed et al., 2020; Salem, 2023). This occurs primarily through the direct deposition of dietary lipids from the OP into fish tissues. The resulting fillet boasts a fatty acid profile reminiscent of the heart-healthy Mediterranean diet, potentially enhancing its nutritional value and appeal to health-conscious consumers (Martínez et al., 2013). Some studies also report an increase in certain polyunsaturated fatty acids (PUFAs), such as linoleic acid (C18:2n6), though the effect on long-chain n-3 PUFAs (eicosapentaenoic acid, EPA, and docosahexaenoic acid, DHA) is less consistent and is highly dependent on the fatty acid composition of the base diet and other lipid sources (Falch et al., 2005; Tocher, 2003). The changes in fillet fatty acid profile are quantified in Table 3.

4.3. Oxidative Stability and Shelf-Life

The high concentration of natural antioxidants (phenolic compounds) in OBPs plays a crucial dual role:

In Vivo Antioxidant Enhancement: Dietary polyphenols from OBPs are absorbed and augment the fish's endogenous antioxidant defense systems (e.g., by upregulating the activity of superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx)), thereby reducing oxidative stress at the cellular level. This may divert energy from combating inflammation towards growth and improve overall fish health (Salem, 2017; Sahan et al., 2020).

Post-Mortem Shelf-Life Extension: The residual antioxidants deposited in the muscle tissue provide a powerful protective effect against lipid peroxidation, which is the primary cause of rancidity and quality deterioration in seafood. Consequently, fillets from fish fed OBP-supplemented diets exhibit significantly reduced levels of thiobarbituric acid reactive substances (TBARS)—a key marker of lipid oxidation—during refrigerated and frozen storage, thereby extending the product's shelf-life and maintaining its sensory quality (color, odor, flavor) for longer periods (Salem & Salem, 2023; NRC, 2011).

Table 3: Modifications in the Fatty Acid Profile (% of total fatty acids) of Nile Tilapia Fillets Fed Diets Containing Olive Pomace (OP)

Fatty Acid	Control Diet (0% OP)	10% OP Inclusion	15% OP Inclusion	Change Trend	Nutritional Implication	References
C16:0 (Palmitic)	20 - 25%	18 - 22%	17 - 21%	↓ SFA	Reduced saturated fat content	(El-Sayed et al., 2020; Salem, 2021)
C18:1n9 (Oleic)	25 - 35%	35 - 45%	40 - 50%	↑ MUFA	Cardioprotective, improves lipid stability	(Salem, 2023; Simopoulos, 2002)
C18:2n6 (Linoleic)	15 - 20%	16 - 22%	15 - 20%	↔ or Slight ↑ n-6 PUFA	Essential fatty acid	(Falch et al., 2005; Salem, 2017)
EPA + DHA	3 - 8%	3 - 7%	2 - 6%	↔ or Slight ↓ n-3 PUFA	Depends on base diet; requires monitoring	(Tocher, 2003; Salem, 2023)
n-3/n-6 Ratio	~0.5 - 1.5	~0.4 - 1.2	~0.3 - 1.0	↓	Potential decrease; can be managed with n-3 sources	(Salem, 2025; Kadak & Salem, 2020)

5. Discussion and Synthesis of Findings

The synthesis of available research robustly supports the hypothesis that processed olive by-products, particularly dried and defatted olive pomace, are a viable and beneficial alternative ingredient in diets for Nile tilapia. Their successful implementation is not a simple substitution but a strategic formulation choice, predicated on the adherence to moderate inclusion levels (≤15%) and the application of appropriate processing technologies to mitigate the negative effects of fiber and anti-nutritional factors.

The mechanisms underpinning the observed benefits are interconnected and operate on multiple physiological levels:

1. **Gut Health Promotion:** The bioactive compounds in OBPs act as prebiotics (fueling beneficial bacteria) and antimicrobials (suppressing pathogens), fostering a favorable and stable gut microbiome. This, in turn, improves intestinal integrity and function, which translates directly to enhanced digestion and absorption of nutrients (Salem, 2024; Krogdahl et al., 2005).
2. **Systemic Antioxidant Enhancement:** The potent antioxidant activity of OBPs' phenolic compounds provides a systemic reduction in oxidative damage, improves overall fish health and welfare, and crucially, confers stability to the final product, reducing spoilage and waste (Salem, 2017; Aprahamian et al., 2021).
3. **Nutrient Synergy and Economic Benefit:** OBPs provide not only energy and protein but also essential minerals, vitamins, and bioactive lipids, partially displacing more expensive conventional ingredients without compromising nutritional adequacy or growth performance, thus reducing feed costs (Salem, 2017; Salem & Moammer, 2024).

The tangible improvement in carcass quality—specifically the enrichment with MUFAs and the extended shelf-life—adds significant value to farmed tilapia. These addresses evolving market trends towards health-conscious consumption and reduces food waste, creating a more sustainable and profitable value chain from farm to fork.

6. Conclusion and Recommendations

6.1. Conclusion

The strategic incorporation of processed olive oil extraction by-products into Nile tilapia feed formulations presents a compelling and multi-faceted opportunity to advance the sustainability of both the aquaculture and olive oil industries. This comprehensive review confirms that at optimized inclusion levels (5-15%), processed olive pomace does not inhibit and can potentially enhance growth performance and feed efficiency (Abdel-Warith et al., 2019; Davies et al., 2022). More significantly, it confers substantial qualitative benefits to the final product by creating a healthier lipid profile (MUFA-enriched) and enhancing the oxidative stability of tilapia fillets through its natural antioxidant content (El-Sayed et al., 2020; Salem, 2023). This approach epitomizes the principles of a circular bioeconomy, transforming an environmental liability into a valuable feed resource that simultaneously reduces aquaculture's ecological footprint and operational costs (Salem et al., 2024; Amhamed et al., 2023).

6.2. Recommendations

Based on the critical analysis presented, the following recommendations are proposed:

For Aquaculture Practitioners: Processed olive pomace (dried, and preferably defatted or fermented) can be safely and beneficially included in commercial tilapia diets at levels of up to 10-15% to reduce feed costs and produce a premium, health-enhancing product with improved shelf-life (Davies et al., 2022; Abdel-Warith et al., 2019).

For Researchers: Future investigations should prioritize:

- **Standardizing Processing Protocols:** Optimizing cost-effective techniques like solid-state fermentation or enzymatic treatment to maximize nutrient bioavailability and consistently neutralize anti-nutritional factors across different OBP batches (Mahommed et al., 2025; Øverland et al., 2013).
- **Comprehensive Long-Term Studies:** Conducting large-scale, long-term trials to assess the effects on reproductive performance, immune competence, disease resistance, and overall fillet sensory quality (Aprahamian et al., 2021; Kiron, 2012).
- **Economic and Environmental Quantification:** Performing detailed economic analysis and Life Cycle Assessment (LCA) to rigorously quantify the full economic and environmental benefits of integrating OBPs into commercial aquafeeds (Salem et al., 2024; Amirkolaie, 2011).
- **Exploring Synergies:** Investigating the synergistic effects of combining different OBPs (e.g., OP with OMW extract or OL powder) or with other functional ingredients (e.g., probiotics, prebiotics) to create next-generation functional feeds (Lakwani & Salem, 2024; Taştan & Salem, 2021).

For Industry and Policymakers: Fostering collaboration between the olive oil and aquaculture sectors is essential to develop efficient logistics, processing hubs, and supply chains for OBPs (European Commission, 2017). Policymakers should encourage this synergy through incentives for waste valorization and sustainable practices, ensuring a consistent and high-quality feed ingredient for the market (Ina-Salwany et al., 2023).

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