CONTEMPORARY AND INTERDISCIPLINARY SCIENTIFIC APPROACHES IN FISHERIES AND AQUACULTURE

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PROF. DR. ALİ BİLGİLİ

BİDGE Yayınları

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PREFACE

Rapid increase in global population and decrease of natural stocks to a significantly lower level, arises the importance of aquaculture industry in terms of ensuring the food security. The shift of sea cage farms from coastal areas to offshore in recent decades has brought with the need for complex ecological, environmental and operational management. Monitoring of fish welfare and assessment of environmental interactions cannot be sustainably carried out with traditional visual counting and sampling methods due to variable hydrodynamic conditions and the mass of offshore cage systems. Acoustic telemetry, electronic tagging and monitoring techniques which have been used in marine ecological and fisheries management studies are coming to the forefront in overcoming these methodological limitations. This chapter has discussed frequencies and acoustic signal propagation, acoustic receivers, acoustic tags, environmental monitoring, deployment of receivers and mooring methodology, interaction between sea cages and wild species, fish behaviour and fish welfare, and fish escapes and recapture strategies, with supporting quotations from scientific sources.

Rapid population growth and the decline of wild capture fisheries stocks have led to significant growth in global aquaculture. Recently, commercial mussel farms operating in the central zone of Izmir Bay have reported a new biological threat undermining this production process. The managers of the mussel farms in Izmir Bay noted that, the rayed Erythrean mussel, *Brachidontes pharaonis* (P. Fischer, 1870), an invasive Lessepsian bivalve of Red Sea origin, has begun rapidly colonizing suspended longline units and spat collectors in extremely high densities. Lacking any commercial value, this species exerts severe spatial and nutritional competitive pressure on *M. galloprovincialis*, threatening the sustainability of regional bivalve aquaculture. This chapter has addressed biological

and physiological characteristics of *Brachidontes pharaonis*, ecological impacts and biotic competition in the Aegean sea, ecological threats to mussel aquaculture through a synthesis of key scientific studies.

Fish and seafood products are highly susceptible to quality deterioration because of their high water activity, relatively high moisture content, near-neutral muscle pH, endogenous enzymes, spoilage microorganisms, and oxidation-sensitive lipids. These characteristics make the control of microbial growth, protein degradation and lipid oxidation particularly important during chilled storage and processing. *Aloe vera* gel has attracted increasing interest as a potential ingredient in edible coatings and active packaging systems because of its film-forming characteristics and the presence of bioactive constituents. However, its preservation performance depends on the composition and processing of the *Aloe vera* preparation, the coating formulation, the target seafood product and the storage conditions. Therefore, *Aloe vera* should be considered a potential preservation component rather than a universally effective natural preservative. This section has provided the chemical and technological properties of *Aloe vera*, its effects on shelf life in fish and shellfish, its combinations with biopolymer films, its value-added product development potential, safety-regulatory aspects, and sustainability perspective based on current literature.

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BÖLÜM 1

ACOUSTIC TELEMETRY IN AQUACULTURE

EVRİM KURTAY[1]

1. INTRODUCTION

Rapid increase in global population and decrease of natural stocks to a significantly lower level, arises the importance of aquaculture industry in terms of ensuring the food security. The shift of sea cage farms from coastal areas to offshore in recent decades has brought with the need for complex ecological, environmental and operational management. Monitoring of fish welfare and assessment of environmental interactions cannot be sustainably carried out with traditional visual counting and sampling methods due to variable hydrodynamic conditions and the mass of offshore cage systems.

Acoustic Telemetry, electronic tagging and monitoring techniques which have been used in marine ecological and fisheries management studies are coming to the forefront in overcoming these methodological limitations. Thanks to its superior technical capability, acoustic telemetry based on the transmission of sound waves underwater has started to use in aquaculture facilities particularly in marine environments (Hussey et al., 2015: 1255642).

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Basically, acoustic telemetry is monitoring aquatic species via transmitters that implanted in an individual by a surgical or external method and receivers that record these specific signals emitted from the transmitters (Cooke et al., 2013: 5).

With the adaptation of "Precision Fish Farming" approach in the aquaculture sector (Føre et al., 2018: 176), the use of acoustic telemetry has not been limited to monitoring wild populations, but also has become a direct part of the aquaculture production processes. This technology offers valuable solutions in aquaculture primarily in three main areas:

Individual behaviour and Welfare Monitoring: with the help of acoustic sensor tags (depth, accelerometer, temperature, tilt) the vertical distribution of fish within the sea cage, their dial swimming speed variations, and stress responses are monitored in real-time and feeding strategies and aquaculture conditions can be optimized in terms of welfare implementations.

Interaction of Wild and Aquaculture Stocks: Sea cages, due to the mass of nutrients and organic waste around them, function as artificial aggregating areas (FADs – Fish Aggregating Devices) (Dempster et al., 2010: 237) attracting wild fish populations in the surrounding area. Acoustic monitoring can help spatial and temporal usage dynamics of these wild species around the facility.

Fish Escapes and Distribution Dynamics: Fish escapes caused by storms or structural disruption create ecological risks for native stocks such as genetic contamination, disease transmission and trophic competition. Acoustic telemetry enables recovery and management strategies by determining the dispersal rates, habitat preferences and side fidelity of escapees (Skilbrei & Jørgensen, 2010: 107).

2. METHODOLOGY AND TECHNICAL INFRASTRUCTURE

2.1 Frequencies and Acoustic Signal Propagation

Since the transmission of sound waves underwater directly affected from the environment in terms of propagation loss, attenuation, and noise levels; frequency selection that will be used is notable (Hussey et al., 2015: 1255642).

*69 kHz Frequency Band***:** This frequency is the industry standard in aquaculture facilities. It offers an ideal balance between medium to long range capability distances up to 500-1000 meters in open water and monitoring medium to large sized fishes such as tuna, seabass, seabream etc.

180 kHz Frequency Band: These higher-frequency systems are preferred, especially in inland waters and high-resolution positioning systems (HRPS) within a receiver network. Despite its short range, it offers the advantage of high data transmission speed and managing multipath complexity in confined spaces.

2.2 Acoustic Receivers

Receivers are basically listening via the hydrophone and record the emitted pings from the transmitters 7/24 from the locations that they are deployed. The hydrophones are omni-directional and listen pings 360-degree area. To track the underwater positions of tagged aquatic organisms, receivers equipped with internal synchronization tags are used for fine scale positioning. This internal synchronization tags ensures the time synchronization and correct the clock drift between the receivers. Thanks to recent developments, new generation acoustic receivers enable data transmission from underwater; thus, data can be collected without physically bringing the receiver to the surface. In addition, receivers

can be linked to a surface or land unit which farmers can monitor the data in real time.

2.3 Acoustic tags

Acoustic tags in various size and dimensions are implemented intraperitoneally in body cavity by surgical method or externally according to the organism's size. These tags are codded tags and each has a unique ID code which allows hundreds of individuals to be uniquely identified at the same frequency. Tags can be produced with various internal sensors such as pressure sensor which detects depth, tri-axial accelerometers which detects swimming activity and temperature which detects ambient temperature (Li et al., 2024: 357).

2.4 Environmental monitoring

For monitoring further environmental parameters, acoustic environmental sensors can be used. These sensors can be deployed like receivers at desired locations within sea cage farms and record various environmental parameters in real time such as temperature, dissolved oxygen, salinity, turbidity, chlorophyll-a, particulate organic matter and also tilt (e.g. Innovasea aquaMeasure).

2.5 Deployment of Receivers and Mooring Methodology

Environmental noise generated by motors of vessels, feeding machines, metal construction vibrations (chains, shackles etc.) directly affect receiver performance. Also turbidity, salinity, net structure of sea cages and biomass of cultured fish affect the performance of receivers. Therefore, before deployment of actual receiver array in aquaculture facilities requires a range testing. Receiver locations and their distances from each other are evaluated and acoustic receiver infrastructure is deployed in the most efficient way according to these results. The deployment of receivers can be in various array designs according to farmers desired data collection

for the cage system. To reveal the wild species approaching direction to the cage system or escapees leaving route from the cage receivers can be deployed in a radial row design which is a curtain like array covering each other's range. Some receivers may be deployed sub-surface (below 3-5 meters from the sea surface) to avoid harsh wave energy with buoys, chains and moorings. Farmers also avoid deploying acoustic receivers to the vicinity of sea cages' chains and ropes otherwise the structure of sea cages may reflect the pings or has a shadowing affect.

3. INTERACTION BETWEEN SEA CAGES AND WILD SPECIES

Acoustic telemetry can be used as a key feature for farmers to evaluate and manage the wild aquatic organisms which are in an interaction with sea cage systems. Due to high and constant nutrient flow generated from aquaculture operations in sea cage systems attract wild fish populations and both pelagic and demersal wild fish species aggregates around sea cage farms (Dempster et al., 2010: 237). These aggregated species can use the sea cage system as residently, transiently or migratory. Relatively small fish species such as sparidae and carangidae exhibits site fidelity and they spent their lifetime around the cages feeding with the waste feed from the sea cages. Some other big pelagics or demersal species occurs around sea cages at a certain time of the day, approaches to the cage system vertically or horizontally according to feeding times of the day (Arechavala-Lopez et al., 2010: 127). Big pelagics such as Bluefin tuna, sharks, swordfish also can occur around sea cages. According to the results of the scientific studies; data obtained via acoustic tags provides farm managers with precise information, showing that wild individuals approach the enclosure bottom during feeding times to consume leftover feed, and retreat to the stream shade or deeper water layers around the facility during non-feeding hours (Arechavala-Lopez, 2010: 127).

4. FISH BEHAVIOUR AND FISH WELFARE

One of the key determinants of sustainable aquaculture production and product quality is the welfare in industrial aquaculture. Stocking density, physiochemical changes in the vertical water column (temperature, dissolved oxygen, light penetration, turbidity etc.), feeding strategies and operational interventions (sizing, vaccination, net change etc.) create significant stress factors for fish. In traditional aquaculture management, welfare and biomass monitoring are mostly limited to macroscopic observations sampled biometric measurements or surface camera systems. However, these methods do not fully reflect the group dynamics and individual variations in the deep cage structures. Sensor based acoustic telemetry technology central to the "Precision Fish Farming" (PFF) approach, provides a strategic solution to these limitations (Fore et al., 2018: 176). Acoustic tags used in aquaculture cage monitoring systems not only provide individual identification and location data, but also biometric data via their highly sensitive sensors. Pressure sensors records the fishes dial swimming depths and migrations in the sea cages on a 24/7 basis. Tri-axial accelerometers provide data of instant swimming speed or acceleration of fish and also tail-beat frequency which ensures to calculate energy consumption of fish (Muñoz et al., 2020: 645). Temperature sensors detect the environmental temperature to which the fish is exposed, it enables the identification of thermal comfort zones.

These sensor data function as Operational Welfare Indıcators (OWIs), directly reflecting the physiological stress status of the fish. For instance, sudden bursts of activity derived from accelerometer tags indicate acute stress or escape behaviour, while prolonged drops in activity levels suggest hypoxic responses due to chronic stress or low dissolved oxygen levels (Muñoz et al., 2020: 645).

The other key feature of acoustic telemetry in aquaculture is to determine individual area usage of fishes in the cage. Acoustic Positioning Systems are used to determine three dimensional swimming paths of cultured fish in the cages. This system makes it possible to calculate the position of tagged individuals with centimetre scale accuracy. Hierarchical structures, such as the occupying of high quality micro habitats (e.g., high-currents and oxygen rich regions) by dominant individuals and pushing of recessive individuals towards the lower portion of cage are clearly confirmed via telemetry systems. Based on these results, the positive effects of welfare-enhancing practices such as shade structures, artificial shelters, or underwater lighting added to the cages on fish distribution are quantified (Muñoz et al., 2020: 645).

5. FISH ESCAPES AND RECAPTURE STRATEGIES

Fish escapes from sea cages resulting from operational accidents, structural material fatigue, severe storm events or predator attacks (such as seals, dolphins, sharks) that tearing nets pose significant ecological and economic threats (Serra-Llinares 2013: 107). These escapees introduce ecological risks to native stocks and coastal ecosystems including genetic introgression, diseases transmission and trophic imbalances. Acoustic telemetry studies demonstrate that during the first few hours following an escape, individuals exhibit circular or erratic movement patterns around the cage structure; however, following an initial 24 to 48-hour period, driven by prevailing currents and instinctive shelter-seeking behaviour, they rapidly disperse along coastal corridors. To minimize the ecological damage caused by escaped fish and to mitigate economic losses for farmer, early intervention strategies can be developed by acoustic telemetry method. By combining signal intensity data from acoustic tags with real-time hydrodynamic and current modelling during an escape event, the probable routes and

aggregation points of the escaped school are predicted, enabling concentrated recapture operations in these high-probability zones.

6. CONCLUSION

Acoustic telemetry has transitioned from an ecological research tool into an valuable component of modern, sustainable aquaculture management and "Precision Fish Farming" (PFF). By linking the macro-scale environmental interactions and micro-scale individual fish behaviour, acoustic telemetry systems—supported by multi-sensor tags, high-resolution positioning networks, and real-time environmental sensors—provide significant operational efficiency in aquaculture facilities. Developments in sensors, battery longevity and artificial intelligence-driven analytics will further enhance the capacity to monitor fish welfare, mitigate wild-farmed interactions, and reduce escape risks. Integration of acoustic telemetry into offshore aquaculture protocols will ease a more resilient, transparent, and ecologically harmonious blue economy.

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BÖLÜM 2

AN INVASIVE ALIEN LESSEPSIAN BIVALVE AS A THREAT ON MUSSEL AQUACULTURE IN THE AEGEAN SEA: *Brachidontes pharaonis* (Fischer, 1870)

1. EVRİM KURTAY

Introduction

Rapid population growth and the decline of wild capture fisheries stocks have led to significant growth in global aquaculture (Cardia & Lovatelli, 2015:593; Lucas, Southgate & Tucker, 2019:1). According to Food and Agriculture Organization (FAO) data, global aquaculture production surpassed capture fisheries for the first time in 2020, reaching 130.9 million tonnes (FAO, 2024). Turkey holds a pioneering and strategic position in the Mediterranean basin's marine aquaculture sector, which is heavily dominated by finfish species such as European seabass (*Dicentrarchus labrax* Linnaeus, 1758), gilthead seabream (*Sparus aurata* Linnaeus, 1758), and rainbow trout (*Oncorhynchus mykiss* Walbaum, 1792) (BSGM, 2026). However, in recent years, technological advancements and the

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implementation of modern longline systems have led to a rapid expansion of suspended bivalve aquaculture along the Turkish coastline. By the end of 2024, the number of licensed mussel farms nationwide reached 53, and with production heavily concentrated in Izmir (14 licenced mussel farms), the Aegean Sea has become a strategic location for bivalve production in Turkey (BSGM, 2025).

Mussel farming in Turkey relies entirely on longline culture utilizing natural spat (juvenile) collection methods of the native Mediterranean mussel (*Mytilus galloprovincialis* Lamarck, 1819) (Lök, 2000:93). Unlike finfish aquaculture, hatchery-based seed production is not common; instead, farms deploy fibrous collector ropes into the water column to capture settling wild mussel spat. The timing of collector deployment is an absolute determinant of commercial viability. Early deployment exposes the collector ropes to intense biofouling pressure by non-target epibiotic organisms, which rapidly cover the collectors and prevent mussel larvae from settling. Conversely, delayed deployment risks missing peak larval settlement waves, leading to low stocking densities and production deficits (Beer & Southgate, 2006:424).

Recently, commercial mussel farms operating in the central zone of Izmir Bay have reported a new biological threat undermining this production proccess. The managers of the mussel farms in Izmir Bay noted that, The rayed Erythrean mussel, *Brachidontes pharaonis* (P. Fischer, 1870), an invasive Lessepsian bivalve of Red Sea origin, has begun rapidly colonizing suspended longline units and spat collectors in extremely high densities (personal communication). Lacking any commercial value, this species exerts severe spatial and nutritional competitive pressure on M. galloprovincialis, threatening the sustainability of regional bivalve aquaculture.

BIOLOGICAL AND PHYSIOLOGICAL CHARACTERISTICS OF *Brachidontes pharaonis*

Belonging to the family *Mytilidae*, *Brachidontes pharaonis* is a small-sized, dimorphic bivalve native to the Indian Ocean and the Red Sea (Fuchs, 1878) (Table 1). Following the opening of the Suez Canal in 1869, it became one of the earliest documented Lessepsian migrants in the Mediterranean, first recorded off Port Said, Egypt (Fuchs, 1878:25). Over subsequent decades, the species expanded along the Levantine Sea, colonizing the coasts of Lebanon (Gruvel & Moazzo, 1931:437), Israel (Haas, 1937:275), Sicily (Di Geronimo, 1971:847), Syria, Cyprus, Greece (Kinzelbach, 1985:273) and eventually establishing extensive populations along the southern and western coasts of Turkey (Doğan, Önen & Öztürk, 2007:461). Its introduction and vector pathways within the Mediterranean are attributed to a combination of pelagic larval transport via current systems, ship hull fouling, and ballast water translocation (Terranova et al., 2006:89).

Table 1. Scientific classification of B. pharaonis

Kingdom	Animalia
Phylum	Mollusca
Class	Bivalvia
Order	*Mytilida*
Family	*Mytilidae*
Genus	*Brachidontes*
Species	*Brachidontes pharaonis*

Morphologically, B. pharaonis features an elongated, trapezoidal equivalve shell structure that reaches a maximum length of approximately 40 mm. The shell expands posteriorly from the umbo, and its outer surface is characterized by prominent, bifurcating radial ribs that coarsen toward the crenulated margins. The external coloration ranges from dark brown to blackish-brown, while the internal surface displays a glossy purple tint (Abd-Ellah, 2025:165). Anatomically, it mirrors typical mytilid architecture, utilizing a specialized foot to secrete strong byssal threads that securely anchor

the organism to hard substrata, natural reefs, and artificial aquaculture infrastructure (Abd-Ellah, 2025:165). It relies on a pair of lamellate ctenidia (gills) to simultaneously manage respiration and suspension feeding, filtering particulate organic matter from the water column and directing it to the digestive glands (Abdel Razek et al., 2017:265).

In addition to exhibiting rapid growth rates under optimal conditions, it possesses an exceptionally broad tolerance to extreme fluctuations in seawater temperature and salinity (Sarà, Romano & Mazzola, 2008:e8). Its euryhaline and eurythermal capabilities enable individuals to withstand harsh intertidal and infralittoral conditions where fluctuating salinity and intense solar radiation limit native macrobenthic distribution (Sarà, Romano & Mazzola, 2008:e8; Battiata et al., 2024:381). Furthermore, its high tolerance to organic enrichment and moderate environmental degradation allows it to thrive in anthropogenically altered environments, including sheltered bays, harbors, and aquaculture facilities (Çınar et al., 2017:613).

ECOLOGICAL IMPACTS AND BIOTIC COMPETITION IN THE AEGEAN SEA

The introduction and proliferation of *B. pharaonis* in the Aegean Sea have caused significant shifts in benthic community dynamics (Çınar et al., 2017:613). The species forms extremely dense, multi-layered aggregates or continuous beds on available hard substrates. Population density records highlight its overwhelming dominance, reaching up to 16,550 individuals/m² in Malta (Bonnici et al., 2012:153), 25,000 individuals/m² in Sicily (Sarà, Romano & Mazzola, 2008:e8), 30,000 individuals/m² in Israel (Rilov, Benayahu & Gasith, 2004:347), and exceeding 40,000 individuals/m² in parts of the Turkish coast (Doğan, Önen & Öztürk, 2007:461).

This high-density crowding triggers severe competitive exclusion (Çınar et al., 2017:613). Historical ecological assessments demonstrate that B. pharaonis has partially or entirely displaced native littoral and infralittoral species. A primary example is the native dwarf mussel *Mytilaster minimus*, which shares the exact ecological niche on Mediterranean rocky shores (Gruvel & Moazzo, 1931:437). Due to its superior filtration efficiency, higher byssal

attachment strength, and rapid growth, the invasive bivalve quickly overgrows and smothers *M. minimus* colonies, altering the structural complexity of local macrobenthic fauna (Gruvel & Moazzo, 1931:437).

In suspended aquaculture systems, this competitive pressure transfers directly to the commercially cultured Mediterranean mussel (*Mytilus galloprovincialis*). Suspended longlines provide an artificial extension of infralittoral hard substrata, offering a clean, high-flow environment away from benthic predators. When B. pharaonis larvae settle alongside or directly onto *M. galloprovincialis*, they trigger intense asymmetric competition for both space and food (Figure 1). Because both species are filter-feeders relying on the same size spectrum of phytoplankton and particulate organic matter (POM), the high density of *B. pharaonis* can locally deplete food availability. This nutritional competition suppresses the metabolic efficiency of the native species, weakening its ecological dominance in the water column.

Figure 1. Invasive *B. pharaonis* mussels on Mediterranean mussel farm's longline cultivation system.



ECONOMIC THREATS TO MUSSEL AQUACULTURE

The negative economic impact of *B. pharaonis* on commercial longline mussel facilities take effect across several stages of the production cycle:

Spat Collection Failure: Because *B. pharaonis* acts as an aggressive biofouling agent, its uncontrolled settlement on fibrous collector ropes limits the surface area which is for the commercial target, *M. galloprovincialis*. When collector ropes are dominated by this invasive species, the survival and attachment rates of

Mediterranean mussel spat drop sharply, resulting a shortage of seed material for subsequent grow-out phases.

Growth Suppression and Lower Condition Index: Severe spatial crowding and intense nutritional competition directly disturb the morphometric and physiological development of the Mediterranean mussel. Sharing nutritional mass can cause a significant reduction in the shell growth rates of *M. galloprovincialis* and a decline in meat yield (low condition index). Thus, mussels harvested from heavily fouled lines may finaleze with drastically reduced commercial value.

Increased Biomechanical Load and Structural Risk: The biomass of attached of tightly clustered *B. pharaonis* individuals imposes an immense weight load on longline configurations. This additional weight increase reduces the system's buoyancy, forcing farmers to invest in additional high-density polyethylene (HDPE) support buoys. During stormy or high-energy wave conditions typical of open areas in the Aegean Sea, this excessive weight

drastically elevates structural tension which may lead rope breakage and mass product loss.

Escalating Operational and Labor Costs: Struggling heavy biofouling requires intensive manual or mechanical intervention. Farmers must implement frequent cleaning schedules, using manual or automated industrial declumping machines to strip the invasive bivalves from the lines. This kind of operations significantly increases fuel consumption, vessel runtime, and labor expenses. which can lead to narrow profit margin.

CONCLUSION

Brachidontes pharaonis represents a significant biological barrier to the expanding bivalve aquaculture industry in the Aegean Sea. Its physiological tolerance, yearround reproductive capacity, and aggressive colonization behavior allow it to effectively exploit artificial suspended culture systems and directly compete with the economically valuable *Mytilus galloprovincialis*.

To retain the sustainability of the mussel farming industry, reactive operations must be replaced by proactive defense management frameworks. Mechanical cleaning after settlement of invasive *B. pharaonis* is economically unsustainable. Instead, proactive biofouling mitigation schedules should be integrated into regional aquaculture protocols. By adjusting collector deployment timing to specific biologic and hydrographic windows when invasive larval settlement pressure naturally drops, farmers can mitigate the initial biofouling and ensure optimal substrate availability for native spats. Continuous monitoring of invasive species abundance and local environmental dynamics across Izmir Bay is imperative to protect Turkey's strategic marine aquaculture industry.

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BÖLÜM 3

USE OF ALOE VERA IN AQUACULTURE: SHELF LIFE, PACKAGING AND PRODUCT DEVELOPMENT PRACTICES

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Introduction

Fish and seafood products are highly susceptible to quality deterioration because of their high water activity, relatively high moisture content, near-neutral muscle pH, endogenous enzymes, spoilage microorganisms, and oxidation-sensitive lipids. These characteristics make the control of microbial growth, protein degradation and lipid oxidation particularly important during chilled storage and processing (Gram & Huss, 1996: 121, Gram & Dalgaard, 2002: 262, Kurek et al., 2024: 1417). Aloe vera gel has attracted increasing interest as a potential ingredient in edible coatings and

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active packaging systems because of its film-forming characteristics and the presence of bioactive constituents. However, its preservation performance depends on the composition and processing of the Aloe vera preparation, the coating formulation, the target seafood product and the storage conditions. Therefore, Aloe vera should be considered a potential preservation component rather than a universally effective natural preservative (Hamman, 2008: 1599; Maan et al., 2021: 329, Kurek et al., 2024: 1417). This section discusses the chemical and technological properties of aloe vera, its effects on shelf life in fish and shellfish, its combinations with biopolymer films, its value-added product development potential, safety-regulatory aspects, and sustainability perspective based on current literature. In seafood preservation, the concept of shelf life is not limited solely to the time the product remains unspoiled; it also refers to the time interval during which the product maintains its nutritional value, safety, sensory acceptance, and economic value. Therefore, when evaluating natural preservative applications, oxidative stability, color, texture, water loss, odor formation, and consumer preference should be considered together with microbiological limits. Aloe vera may contribute to a multi-parameter quality-preservation strategy because it can be incorporated into film-forming systems and contains compounds associated with antioxidant and other bioactive properties. Nevertheless, these potential functions should be evaluated using product-specific microbiological, chemical, physical and sensory measurements rather than assumed from the composition of the plant material alone (Maan et al., 2021: 329, Sánchez et al., 2020: 1248, Kurek et al., 2024: 1417). The clean label trend, driven by consumers' avoidance of synthetic additives and increased awareness of the environmental impact of food packaging, has made plant-based gel and biopolymer-based protection systems more visible. Aloe vera's advantage lies in its long-standing use in food, cosmetics, and pharmaceuticals; however, this familiarity does not

substitute for scientific evaluation. For high-risk foods such as seafood, every new coating system needs to be validated in terms of safety, dosage, sensory impact, and regulatory aspects (Ahlawat & Khatkar, 2011: 525; EFSA, 2024: 5090). Aquatic foods provide high-quality protein and a range of essential nutrients, including long-chain omega-3 fatty acids in many species. Recent assessments emphasize the nutritional and sustainability importance of aquatic foods within global food systems. Consequently, reducing quality deterioration and post-harvest losses can contribute to more efficient utilization of aquatic food resources. Current FAO assessments indicate that aquaculture should be considered not only as a source of protein but also as a nutrient-dense and important component of sustainable food systems. Therefore, reducing post-harvest losses in aquaculture is important not only economically but also in terms of food security and the right to nutrition (FAO, 2024; Golden et al., 2021: 315). Fish and other aquatic products can spoil more quickly than slaughtered animal meats due to their high water activity, muscle structure close to neutral pH, free amino acids, and oxidation-sensitive polyunsaturated fatty acids. While traditional approaches such as cold chain, hygienic processing, modified atmosphere, or vacuum packaging extend shelf life, consumer preference for clean-label and natural preservatives has increased interest in plant-based coating and active packaging technologies (Gram & Huss, 1996: 121, Gram & Dalgaard, 2002: 262, Kurek et al., 2024: 1417).

Aloe vera (Aloe barbadensis Miller) is a succulent plant classified in the Asphodelaceae family in current botanical classification. The gel-like inner part of the leaf contains a high percentage of water, as well as polysaccharides, phenolic compounds, vitamins, minerals, and organic acids, primarily acemannan. These components form the basic chemical basis that explains Aloe vera's moisture-retaining, film-forming, antioxidant,

and antimicrobial properties (Hamman, 2008: 1599; Rodríguez et al., 2010: 305).

Chemical and Functional Properties of Aloe Vera

Leaf Structure and Critical Points in Terms of Processing

Mixing the latex layer and the gel portion in the aloe vera leaf is one of the most important quality and safety issues in food applications. While the inner gel is mostly associated with the polysaccharide and water phase, the latex fraction is considered riskier in terms of anthraquinone glycosides. The Aloe vera leaf consists principally of an outer rind, a latex-containing layer and an inner gel fraction. For food applications, the inner gel is generally the relevant fraction, whereas latex and whole-leaf materials require particular attention because they may contain hydroxyanthracene derivatives such as aloin. Accordingly, separation of the gel from latex, followed by appropriate filtration, stabilization and microbiological quality control, is important for the production of standardized food-grade Aloe vera preparations (Ramachandra & Srinivasa Rao, 2008: 502; Ahlawat & Khatkar, 2011: 525; EFSA, 2018: 5090). Aloe vera gel is predominantly water, while the relatively small dry-matter fraction contains polysaccharides and other compounds that contribute to its technological properties. Acemannan and related polysaccharide fractions have been associated with the viscosity and film-forming characteristics of Aloe vera gel. Because processing can alter the composition of the final material, fresh gel, stabilized gel, concentrated preparations and dried powders should not be assumed to have identical technological properties (Hamman, 2008: 1599; Maan et al., 2021: 329).

Antioxidant, Antimicrobial and Barrier Mechanisms

The antioxidant potential of Aloe vera in seafood applications should be evaluated in relation to the formation of lipid-

oxidation products. However, the observed effect is influenced not only by the antioxidant constituents of Aloe vera but also by oxygen permeability, water activity, lipid composition, storage temperature, light exposure and the characteristics of the coating matrix. Therefore, complementary indicators such as peroxide value, TBARS or other validated oxidation indices, together with sensory evaluation, should be considered when assessing antioxidant performance (Maan et al., 2021: 329, Kurek et al., 2024: 1417, Waris & Pilavtepe-Celik, 2025: 1). However, antioxidant capacity is not solely dependent on the presence of total phenolic compounds; oxygen permeability within the matrix, water activity, fatty acid composition, storage temperature, and light exposure also affect the result. Microbial growth is a major contributor to the deterioration of chilled seafood, and the dominant spoilage microbiota may vary with species, temperature, packaging atmosphere and storage conditions. Aloe vera-based coatings may contribute to controlling microbial deterioration when their formulation provides suitable barrier or bioactive properties; however, such effects must be demonstrated experimentally for the specific coating and product. General knowledge of seafood spoilage microbiota should therefore be distinguished from direct evidence of Aloe vera antimicrobial activity (Gram & Huss, 1996: 121, Gram & Dalgaard, 2002: 262, Kurek et al., 2024: 1417).

The barrier effect is the third mechanism that enhances the practical value of aloe vera in aquaculture. Edible coatings can modify the transfer of oxygen and moisture between the seafood surface and its surrounding environment. The magnitude of this barrier effect depends on coating composition, thickness, water content and storage conditions. Excessively thick or poorly optimized coatings may also adversely affect appearance, surface texture or sensory acceptance; therefore, coating thickness and

formulation should be optimized together with preservation performance (Maan et al., 2021: 329, Kurek et al., 2024: 1417).

In composite systems formed with biopolymers such as chitosan, gelatin, and collagen, the mechanisms complement each other. Chitosan provides an antimicrobial and film-forming scaffold; gelatin and collagen contribute to film integrity; and aloe vera strengthens the active phase with its antioxidant/moisture-retaining properties. Composite systems containing Aloe vera and biopolymers such as chitosan or fish gelatin provide a potential approach for combining film-forming properties with bioactive functions. Studies on fish gelatin–Aloe vera and Aloe vera–chitosan films demonstrate the technical feasibility of such combinations. Nevertheless, their industrial suitability should be determined through product-level performance, stability, sensory, safety and scale-up studies rather than inferred solely from film characterization (Chin et al., 2017: 128, Sánchez et al., 2020: 1248, Kaur et al., 2024: 242). The antioxidant effect of aloe vera cannot be reduced to a single component. The antioxidant properties reported for Aloe vera preparations have been associated with several classes of constituents, including phenolic compounds and other bioactive fractions. However, the contribution of individual constituents depends on the plant material, extraction or stabilization procedure and final formulation. Consequently, antioxidant activity measured in Aloe vera extracts or films should not automatically be equated with equivalent antioxidant protection in a seafood product (Hamman, 2008: 1599, Rodríguez et al., 2010: 305, Sánchez et al., 2020: 1248). This effect is monitored in aquaculture products, particularly through changes in TBARS/MDA, peroxide values, and sensory odor (Rodríguez et al., 2010: 305, Waris & Pilavtepe-Celik, 2025: 1).

The antimicrobial effect should be evaluated in conjunction with the surface barrier formed by phenolics, saponins, organic

acids, and the gel matrix. The direct lethal effect is not the same for all types of microorganisms; however, the coating can slow the growth of spoilage microorganisms such as Pseudomonas, Shewanella, and Photobacterium on the product surface by limiting oxygen passage and surface contamination (Gram & Dalgaard, 2002: 262, Kurek et al., 2024: 1417). The film-forming property of Aloe vera makes it valuable in terms of active packaging. However, pure Aloe vera films are generally limited in terms of mechanical strength and water vapor barrier. Therefore, combining it with biopolymers such as chitosan, fish gelatin, collagen, alginate, and carrageenan stands out as a more viable approach (Chin et al., 2017: 128, Maan et al., 2021: 329, Kaur et al., 2024: 242).

Table 1. Main bioactive components of aloe vera gel and their technological equivalents in terms of aquaculture.

Component group	Key components	Technical impact on aquaculture	References
Polysaccharides	Acemannan, glucomannan, pectic fractions	Contributes to viscosity, water retention, film matrix, and surface barrier formation.	Hamman, 2008; Maan et al., 2021
Phenolics and chromones	Aloin, aloe-emodin, phenolic acids	Contributes to free radical scavenging capacity; latex-derived anthraquinones should be controlled for safety.	Hamman, 2008; EFSA, 2018; EFSA, 2024
Vitamins	Vitamin C, Vitamin E, beta-carotene, B vitamins	May support antioxidant defense; its effect depends on gel processing conditions and concentration.	Rodríguez et al., 2010; Ahlawat & Khatkar, 2011
Minerals	Ca, Mg, K, Na, Zn, Fe	Contributes to the nutritional and technological profile; should not be interpreted as the sole main mechanism for extending shelf life.	Hamman, 2008; Ahlawat & Khatkar, 2011

Component group	Key components	Technical impact on aquaculture	References
Organic acids and saponins	Traces of malic/citric acid, saponins	May contribute to antimicrobial effect through pH environment and cell membrane interactions.	Maan et al., 2021; Kaur et al., 2024
Enzymes	Catalase, peroxidase, amylase, etc.	Plays a role in plant biochemistry; stability in food application depends on heat treatment and storage conditions.	Ramachandra & Srinivasa Rao, 2008; Hamman, 2008

Source: Compiled from the references listed in the table.

Spoilage Mechanisms in Seafood and the Effect of Aloe Vera on Shelf Life

Microbiological and Biochemical Spoilage

The type of spoilage microorganisms varies depending on the storage atmosphere and temperature. While Shewanella and Pseudomonas species may be prominent in fresh seafood stored on ice, Photobacterium phosphoreum and lactic acid bacteria may become more dominant under modified atmosphere or vacuum packaging conditions. The composition and activity of seafood spoilage microbiota vary with storage temperature, packaging atmosphere and product characteristics. Consequently, the preservation performance of an Aloe vera-based coating may also vary according to the packaging system and storage conditions. Comparative experiments under standardized conditions are therefore required before generalizing the effectiveness of a specific Aloe vera formulation (Gram & Huss, 1996: 121, Gram & Dalgaard, 2002: 262, Kurek et al., 2024: 1417). TVB-N is widely used as an indicator of protein and nitrogenous-compound deterioration in fish. Aloe vera coatings may influence the rate of TVB-N development when they contribute to controlling microbial growth or modifying mass transfer at the product surface. However, the magnitude of this effect depends on the formulation, initial microbial quality, storage

temperature and product characteristics, and should therefore be demonstrated experimentally (Bekhit et al., 2021: 280, Waris & Pilavtepe-Celik, 2025: 1). However, the coating effect may be limited when the storage temperature is high or the initial contamination level is high. Therefore, the application should be considered in conjunction with good hygiene practices and an uninterrupted cold chain (Waris & Pilavtepe-Celik, 2025: 1, Oğuzhan Yıldız, 2026: 118).

The main processes that limit shelf life in seafood are microbial proliferation, breakdown of proteins and nitrogen compounds, lipid oxidation, enzymatic changes, and loss of sensory quality. Cold storage slows down these processes; however, it is not sufficient on its own since psychrotrophic microorganisms can also grow at low temperatures. Therefore, natural coating systems such as aloe vera should be considered as a complementary barrier that supports the cold chain, rather than a replacement for it (Gram & Huss, 1996: 121, Gram & Dalgaard, 2002: 262).

Lipid Oxidation and Sensory Deterioration

Lipid oxidation is not only a chemical quality issue; it is also one of the main causes of odor, taste, and color changes that lead consumers to reject the product. Oxidation control is central to shelf-life strategy, especially in oily species such as salmon, trout, mackerel, and sardines. Polyunsaturated fatty acids such as EPA and DHA are important nutritional components of many aquatic foods, but their high degree of unsaturation also makes them susceptible to oxidative deterioration. Lipid oxidation may contribute to rancid odors and flavors, discoloration and other quality losses. Aloe vera-based coatings have therefore been investigated as potential approaches for controlling oxidative deterioration in seafood, although the magnitude of the effect depends on the formulation, fish species and storage conditions (Fofandi & Tanna, 2020: 1438, Waris

& Pilavtepe-Celik, 2025: 1). Delay of sensory degradation is often more meaningful to the consumer than numerical chemical parameters. Sensory quality is an important component of seafood shelf-life assessment because changes in odor, appearance, color and texture may determine consumer acceptance even when chemical indicators remain within acceptable ranges. Aloe vera-containing coatings may influence these characteristics, but the direction and magnitude of the effect depend on coating composition and application conditions. In formulations containing essential oils, aroma intensity should be evaluated particularly carefully because antimicrobial or antioxidant benefits may be accompanied by sensory effects (Jamali et al., 2023: 93, Oğuzhan Yıldız, 2026: 118).

Polyunsaturated fatty acids such as EPA and DHA found in fish oil are valuable for human health; however, these fatty acids are quite susceptible to oxidation. Lipid oxidation can cause rancidity, fishy odor, discoloration, and consumer rejection by forming hydroperoxides, aldehydes, ketones, and volatile compounds. Aloe vera's antioxidant capacity is particularly important in this regard, especially for oily fish species (Waris & Pilavtepe-Celik, 2025: 1).

Table 2. Quality parameters monitored in aquaculture products and possible effects of aloe vera applications.

Parameters	Meaning in terms of quality	Potential effects of aloe vera application	References
TVB-N	Volatile basic nitrogen fraction resulting from microbial/enzymatic breakdown of proteins and nitrogen compounds.	Aloe vera coating can reduce microbial growth and oxygen exposure, thereby slowing down the growth rate.	Bekhit et al., 2021; Waris & Pilavtepe-Celik, 2025
TMA-N	An indicator of fishy odor associated with the reduction of TMAO to TMA by spoilage bacteria.	Suppression of microorganisms such as Shewanella, Photobacterium, and Pseudomonas can	Gram & Huss, 1996; Gram & Dalgaard, 2002

Parameters	Meaning in terms of quality	Potential effects of aloe vera application	References
		delay TMA formation.	
TBARS/MDA	Follows the secondary products of lipid oxidation; particularly critical in fish rich in EPA-DHA.	The antioxidant effect from phenolics and vitamins can slow down oxidative rancidity.	Kurek et al., 2024; Waris & Pilavtepe-Celik, 2025
pH	Tenses to rise when basic metabolites increase during storage.	When the microbial load is reduced, the pH increase may occur more slowly.	Fofandi & Tanna, 2020; Oğuzhan Yıldız, 2026
Color	Surface oxidation, pigment change, and water loss affect consumer perception.	A semi-permeable film can support gloss by reducing oxygen exposure and surface drying.	Kurek et al., 2024; Waris & Pilavtepe-Celik, 2025
Texture	Proteolysis and water loss cause softening/loosening of muscle tissue.	The coating can reduce moisture loss and protein degradation; gelatin/chitosan combinations excel in texture protection.	Feng et al., 2016; Kurek et al., 2024
Sensory perception	Odor, appearance, color, and texture together determine shelf life.	While combinations of aloe vera and oil/extract are effective, the essential oil scent may limit consumer acceptance.	Jamali et al., 2023; Oğuzhan Yıldız, 2026

Source: Compiled from the references listed in the table.

Application Methods

Aloe vera can be applied to aquaculture products in various formats including dipping, spraying, edible coating, composite film, and active packaging. Dipping is a relatively simple approach for laboratory-scale experiments because it allows direct contact between the coating formulation and the product surface. For scale-up, however, coating uptake, solution stability, hygiene, viscosity,

process speed and coating uniformity need to be controlled. In the dipping method, the viscosity, pH, and solid content of the coating solution determine the amount of film that will remain on the product surface. Very low viscosity may result in insufficient coating; very high viscosity may leave a thick, sticky, and consumer-noticeable layer on the surface. Therefore, the coating solution should be characterized not only in terms of its components but also in terms of its rheological properties (Maan et al., 2021: 329, Kurek et al., 2024: 1417).

Spraying methods may be more controlled from an industrial perspective; however, spray pressure, nozzle diameter, product surface area, and drying time affect homogeneity. In particular, the formation of coatings of different thicknesses on the fillet surface can cause variations in shelf-life performance within the same batch. Therefore, coating uptake and surface distribution should be measured in pilot-scale studies (Kurek et al., 2024: 1417).

In active film applications, aloe vera is placed not directly on the product surface, but inside the packaging material. In active packaging systems, Aloe vera-derived components can be incorporated into a polymeric film or coating matrix rather than being applied directly to the food surface. Such systems may provide opportunities for controlled interaction between the active components and the packaged product. However, migration, release kinetics, food-contact safety and the stability of the active compounds must be evaluated before practical application (Kaur et al., 2024: 242, Kurek et al., 2024: 1417). However, the migration of active ingredients to the surface in contact with the product must be measured, and it must be demonstrated that the packaging is safe in terms of aloin/hydroxyanthracene derivatives (EFSA, 2024; Kaur et al., 2024: 242).

Aloe vera can be used alone or in combination with carriers such as essential oil, plant extract, chitosan, gelatin, or collagen.

However, combinations that provide a stronger antimicrobial effect do not always mean higher consumer acceptance. In formulations containing essential oils, the dominance of odor, taste, and aroma can limit the shelf-life advantage; therefore, the optimum dose, sensory threshold, and consumer panel should be evaluated together (Jamali et al., 2023: 93, Oğuzhan Yıldız, 2026: 118).

Table 3. Main application methods of aloe vera in aquaculture.

Method	Application Description	Advantages	Limitations	References
Dipping	Brief immersion of fillet or piece products in coating solution	Provides homogeneous surface coating; practical for laboratory work.	Solution dilution and the risk of cross-contamination require control in the industry.	Maan et al., 2021; Kurek et al., 2024
Spraying	Spraying the coating solution onto the surface	Offers lower coating solution consumption and in-line application possibilities.	Surface roughness and spraying parameters affect coating thickness.	Kurek et al., 2024
Edible coating	Creating a thin, consumable barrier layer on the product	Reduces oxygen/moisture transfer; can carry active ingredients.	Mechanical strength and sensory neutrality must be optimized.	Maan et al., 2021; Waris & Pilavtepe-Celik, 2025
Active film	Usage of aloe vera in chitosan, gelatin, collagen or alginate matrix	Combines shelf life and packaging function.	Migration, aloin level, regulations, and cost must be considered together.	Chin et al., 2017; Kaur et al., 2024
Nanoemulsion/	Incorporation of aloe vera or essential oils	Has the potential for controlled	Scaling up, toxicology, and consumer	Kong et al., 2022;

Method	Application Description	Advantages	Limitations	References
nanoencapsulation	into nanoscale carrier systems	release and dose reduction.	perception must also be validated.	Jamali et al., 2023

Source: Compiled from the references listed in the table.

Experimental Applications in Fish and Shellfish

Applications in fish fillets

Waris and Pilavtepe-Celik (2025) investigated Aloe vera gel as a treatment for refrigerated sea bass and evaluated chemical, physical and sensory quality parameters during cold storage. Their findings support the potential of Aloe vera gel as a preservation treatment in sea bass; however, the specific contribution of antioxidant and antimicrobial mechanisms should be distinguished from the overall observed quality changes. Monitoring quality parameters together during cold storage reveals that Aloe vera should be evaluated not on a single criterion but on a multidimensional quality preservation basis (Waris & Pilavtepe-Celik, 2025: 1).

Studies on trout show that Aloe vera can also be used as an essential oil or nanoemulsion carrier. This approach can enhance the effectiveness of natural ingredients; however, the distinctive aroma of essential oils and consumer acceptance are critical limitations. Especially in species with characteristic aromas, such as trout, the sensory compatibility of the formulation is as important as its chemical success (Jamali et al., 2023: 93, Oğuzhan Yıldız, 2026: 118).

Studies on tilapia and mackerel show that Aloe vera can be evaluated in species with different fat percentages and muscle structures. However, direct comparison of results can be misleading when interspecies comparisons are made without standardizing initial pH, fat percentage, microbial flora, fillet thickness, and

packaging conditions (El-Chaghaby et al., 2024: 987, Fofandi & Tanna, 2020: 1438).

In recent years, studies on the use of Aloe vera in aquaculture have increased. In a study conducted on sea bass, Aloe vera gel coating was identified as a natural antioxidant that slowed down quality loss in fish slices stored at 4 ± 1 °C. The study is quite important because it considers chemical quality indicators, color, texture, and sensory properties together (Waris & Pilavtepe-Celik, 2025: 1).

The combination of aloe vera gel and essential oils in rainbow trout is noteworthy. In a study with patchouli essential oil, Oğuzhan Yıldız (2026) investigated a composite coating containing Aloe vera gel and patchouli essential oil on rainbow trout fillets during refrigerated storage. The combined treatment affected microbiological and chemical quality parameters, while essential-oil concentration also influenced sensory acceptance. Because Aloe vera and patchouli oil were applied together, the individual contribution of Aloe vera cannot be determined from the combined treatment alone. This result demonstrates that sensory balance and market acceptance, as well as laboratory parameters, are crucial in the product development phase (Oğuzhan Yıldız, 2026: 118). Jamali et al. (2023) investigated an Aloe vera-based edible coating containing a ginger essential-oil nanoemulsion for refrigerated trout fillets. The combined formulation was associated with improved control of microbial and chemical deterioration. However, because ginger essential oil was an active component of the formulation, the observed preservation effect should not be attributed exclusively to Aloe vera. Further studies comparing Aloe vera alone, ginger essential oil alone and the combined formulation would be necessary to determine their individual and possible synergistic effects. The use of nanoemulsions can improve the dispersion and persistence of active ingredients on the surface; however, food safety, scalability,

and cost considerations must also be validated (Jamali et al., 2023: 93, Kong et al., 2022: 555).

The combination of Aloe vera and lemongrass extract was examined for antioxidant properties and lipid oxidation in Nile tilapia fillets; Aloe vera coating on Indo-Pacific king mackerel parts has been evaluated as an application that slows down quality deterioration in cold storage. Studies conducted directly on Nile tilapia and Indo-Pacific king mackerel provide product-specific evidence that Aloe vera-containing coatings can influence selected quality parameters during refrigerated storage. However, the formulations also differed in their composition and application conditions; therefore, these findings should be interpreted as species- and formulation-specific evidence rather than as proof of a universal shelf-life extension effect for seafood (El-Chaghaby et al., 2024: 987, Fofandi & Tanna, 2020: 1438).

Evaluation in terms of shellfish

Major spoilage problems in shrimp and other shellfish include melanosis, microbial growth, protein breakdown, and water loss. The antioxidant and barrier properties of aloe vera could theoretically be useful in this regard; however, studies directly with shellfish are limited (Kurek et al., 2024: 1417).

Chitosan is already a strong natural coating agent in shellfish because chitin/chitosan obtainable from shellfish by-products is compatible with aquaculture technology. Direct studies on the use of Aloe vera coatings in shrimp, crab and lobster appear to be more limited than studies on fish fillets. Chitosan and other marine-derived biopolymers have nevertheless been widely investigated as coating materials for seafood, providing a potential matrix into which Aloe vera could be incorporated. Therefore, Aloe vera–chitosan systems represent a promising research hypothesis for shellfish preservation, but their effects on melanosis, microbial

growth, water loss and sensory quality require direct experimental validation (Kurek et al., 2024: 1417, Kaur et al., 2024: 242). Although numerous studies exist on chitosan, alginate, gelatin, and essential oil-based coatings in shellfish, publications examining the direct use of Aloe vera in shrimp, crab, or lobster are more limited compared to fish fillets. Therefore, when writing about Aloe vera applications for shellfish, phrases such as 'high potential' and 'need for validation' should be used instead of a definite claim of increased shelf life. Since chitosan and marine biopolymers provide a strong foundation in shellfish, adding Aloe vera as an antioxidant/film-supporting component to this matrix is a realistic hypothesis for future studies (Kurek et al., 2024: 1417, Kaur et al., 2024: 242).

Table 4. Experimental use of aloe vera and related biopolymer systems in aquaculture.

Product/Model	Application	Conditions and monitored parameters	Key findings	References
Sea Bass (Dicentrarchus labrax)	Aloe vera gel coating	4 ± 1 °C, 13 days; TVB-N, MDA/TBARS, pH, color, texture and sensory analysis.	Chemical degradation was slowed compared to the control; natural antioxidant capacity was highlighted.	Waris & Pilavtepe-Celik, 2025
Rainbow Trout	Aloe vera gel + 1-2% patchouli essential oil	4 ± 1 °C, 12 days; microbiology, TVB-N, TBARS, pH and sensory acceptance.	Coatings suppressed microbial and chemical degradation; 2% oil showed a stronger effect, but odor perception was limiting.	Oğuzhan Yıldız, 2026
Rainbow Trout	Aloe vera-based coating + ginger	4 °C, 12 days; microbial, chemical and	Nanoemulsion coating extended shelf life and preserved	Jamali et al., 2023

Product/Model	Application	Conditions and monitored parameters	Key findings	References
	essential oil nanoemulsion	sensory quality.	sensory acceptance in cold storage.	
Nile Tilapia Fillets	Edible coating containing aloe vera + lemongrass extract	Cold storage; antioxidant activity and lipid oxidation indicators.	Antioxidant properties were supported, and it was shown that TBARS accumulation could be reduced.	El-Chaghaby et al., 2024
Indo-Pacific King Mackerel Pieces	Aloe vera coating	Cold storage; pH, chemical and sensory quality.	Coating slowed quality degradation and was associated with a more stable pH profile.	Fofandi & Tanna, 2020
Fish Gelatin Film Model	Fish gelatin + Aloe vera gel	Film characterization; physical, functional and antioxidant properties.	Aloe vera addition increased the active packaging potential in fish gelatin films.	Chin et al., 2017; Sánchez et al., 2020
Chitosan-Aloe Vera Film Model	Chitosan + Aloe vera gel	Mechanical, barrier, thermal, antioxidant and antimicrobial analysis.	The combination was evaluated as a strong candidate for sustainable active packaging.	Kaur et al., 2024

Source: Compiled from the references listed in the table.

Aloe Vera-Based Edible Films and Active Packaging Systems

The goal in film systems is not simply to produce a durable material; the material must also exhibit appropriate oxygen and water vapor permeability for the product, be applicable without tearing, adhere to the product surface, and not create a negative perception when noticed by the consumer. Meeting these criteria

often requires combination with other biopolymers for aloe vera-based films (Maan et al., 2021: 329, Kurek et al., 2024: 1417).

Fish gelatin provides a relevant marine-derived film-forming matrix for seafood packaging, while Aloe vera can be incorporated as a bioactive component. Studies on fish gelatin films containing Aloe vera have demonstrated the technical feasibility of this combination and reported functional properties relevant to active packaging. However, the water sensitivity and mechanical properties of gelatin-based films require optimization through formulation variables such as plasticizer concentration, crosslinking and film thickness (Chin et al., 2017: 128, Sánchez et al., 2020: 1248). The addition of aloe vera can impart antioxidant properties to these films; however, due to the water-sensitive nature of fish gelatin, the moisture barrier and mechanical resistance should be optimized with plasticizer ratio, crosslinking, and film thickness (Chin et al., 2017: 128, Sánchez et al., 2020: 1248).

In chitosan-aloe vera films, an enhanced antimicrobial effect is expected; however, the dissolution of chitosan in an acidic environment and its potential to affect taste/odor in some products should be considered. Furthermore, discussions about chitosan-related allergenicity mean that consumers with shellfish allergies should pay attention to product labels before consuming the product (Kaur et al., 2024: 242, Wang et al., 2021: 1).

Smart packaging systems can transform aloe vera-based films into materials that are not only protective but also informative. Films combined with anthocyanins or pH-sensitive indicators can convert pH changes caused by increased TVB-N into color signals. This approach can enhance the perception of freshness in seafood (Bekhit et al., 2021: 280, Kurek et al., 2024: 1417).

Food packaging is no longer seen as merely passive materials separating the product from the external environment. Active

packaging can support shelf life by acting on oxygen, moisture, microbial load, or oxidative reactions on the product surface. In rapidly perishable foods such as seafood, edible coating and active film systems offer significant advantages when used in conjunction with cold chain and hygienic processing (Kurek et al., 2024: 1417).

Although aloe vera gel has the potential to form films, it may have limitations in terms of mechanical strength, water vapor barrier and structural stability in film applications alone. Therefore, combining Aloe vera with biopolymers such as chitosan, fish gelatin, collagen, alginate and carrageenan is a more realistic application route. Composites created with fish gelatin and collagen are also valuable in that they can transform the by-products of the aquaculture industry into packaging materials (Chin et al., 2017: 128, Rajabimashhadi et al., 2023: 544). Chitosan and Aloe vera can be combined to produce composite films with potentially complementary functional properties. Kaur et al. (2024) reported antioxidant, antimicrobial, thermal and barrier-related characteristics for an Aloe vera/chitosan film, supporting the technological feasibility of this combination. Reviews of chitosan–gelatin films further demonstrate the importance of polymer composition and processing conditions in determining film performance; however, these studies should not be interpreted as direct evidence of improved preservation in Aloe vera-treated seafood (Kaur et al., 2024: 242; Wang et al., 2021: 1). While chitosan adds mechanical and microbial resistance to the matrix with its antimicrobial and film-forming properties; Aloe vera can support the system with its antioxidant capacity and moisture retention properties. Kaur et al.'s 2024 study shows that Aloe vera/chitosan films are promising for sustainable food preservation in terms of antioxidant, antimicrobial, thermal and barrier properties (Kaur et al., 2024: 242).

Table 5. Biopolymer combinations that can be used in aloe vera-based film and packaging systems.

Film/coating system	Technological role	Advantages	Limitations	References
Pure Aloe vera film	Polysaccharide-based transparent/edible film.	Natural, biodegradable, moisture-retaining.	Mechanical strength and water vapor barrier may be limited.	Maan et al., 2021
Aloe vera-chitosan	Chitosan matrix + aloe gel	Antimicrobial and barrier effect is enhanced.	Acetic acid use, taste/odor and pH effects should be optimized.	Kaur et al., 2024; Wang et al., 2021
Aloe vera-fish gelatin	Fish gelatin matrix + aloe gel	Suitable for active packaging compatible with fish by-products.	Moisture sensitivity and plasticizer level should be controlled	Chin et al., 2017; Sánchez et al., 2020
Aloe vera-collagen	Collagen film + aloe bioactives	Attractive for circular bioeconomy and marine by-product valorization.	Collagen source, extraction conditions and standardization are important.	Rajabimashhadi et al., 2023; Coppola et al., 2021
Aloe vera-alginate	Aloe gel or extract in algal matrix	Good film integrity and oxygen barrier potential.	Calcium crosslinking and water sensitivity should be optimized.	Maan et al., 2021; Kurek et al., 2024
Aloe vera-carrageenan	Red algae polysaccharide + aloe	Transparency and gel structure advantage	Proof of direct application in seafood is limited; validation is required.	Kurek et al., 2024

Film/coating system	Technological role	Advantages	Limitations	References
Aloe vera + essential oil/nanoemulsion	Aloe-based essential oil transport	Antimicrobial/antioxidant effect may be enhanced.	Essential oil aroma, release rate and regulatory limits are determining factors.	Kong et al., 2022; Oğuzhan Yıldız, 2026

Source: Compiled from the references listed in the table.

Developing Value-Added and Functional Aquaculture Products

The marketing appeal of Aloe vera in value-added products does not eliminate the need for scientific evidence. For a formulation to be presented as 'functional', it is not enough for it to simply contain Aloe vera; the biological effect must be preserved within the product matrix, present in an edible dose, and evaluated within the framework of a health claim that complies with regulations (Rodríguez et al., 2010: 305, EFSA, 2024). In products such as fish burgers and fish patties, Aloe vera may be considered as a potential functional ingredient or coating component because of its reported film-forming and moisture-related properties. However, excessive incorporation may alter product structure, cooking loss, texture, color or sensory acceptance. Therefore, the optimum Aloe vera concentration should be established experimentally using product-specific measurements such as cooking yield, texture profile, color, lipid oxidation, microbiological quality and sensory acceptance. Evidence from fish gelatin–chitosan coatings demonstrates the potential of biopolymer systems to reduce quality deterioration in refrigerated fish, but it should not be interpreted as direct evidence of an Aloe vera effect in fish burgers or patties (Feng et al., 2016: 283, Maan et al., 2021: 329). In products like fish burgers and meatballs, the water-holding capacity of aloe vera is theoretically advantageous. However, excessive gel addition can lead to loose

structure, high moisture release, or noticeable stickiness during cooking. Therefore, the aloe ratio should be tested gradually in product development studies and evaluated together with quality control analyses such as texture profile analysis, cooking loss, color, and sensory scores (Maan et al., 2021: 329, Feng et al., 2016: 283).

The effect of aloe vera on surimi products is more complex. Protein gelation is sensitive to pH, salt, and water phase balance. Controlled experiments are needed in this regard, as The application of Aloe vera to surimi and fish-gel products remains a research hypothesis rather than an established technological practice. Because surimi gelation is strongly influenced by pH, ionic strength, water content, protein concentration and processing conditions, Aloe vera incorporation may alter the gel matrix depending on its concentration and composition. Future experiments should therefore evaluate gel strength, whiteness, water-holding capacity, folding ability and sensory acceptance under standardized processing conditions (Kurek et al., 2024: 1417).

The use of aloe vera in value-added seafood is an area where direct experimental evidence is more limited. Therefore, recommendations for fish burgers, fish patties, surimi, smoked fish, and omega-3 fatty acid-enriched products should be presented as product development hypotheses, not definitive results, as shelf-life studies have mostly been conducted on fillet or piece products (Maan et al., 2021: 329, Kurek et al., 2024: 1417).

In ground products such as fish burgers and patties, the risk of lipid oxidation and microbial spoil is high due to the increased surface area. Aloe vera can be considered as a natural ingredient that can provide moisture retention and antioxidant support; however, the optimal usage rate should be verified with cooking yield, texture, color, and sensory acceptance tests. In these products, using aloe vera as a thin coating based on chitosan/gelatin may be a more

appropriate approach rather than adding it directly to the dough (Feng et al., 2016: 283, Wang et al., 2021: 1).

While the water retention and oxidation control potential of Aloe vera is interesting for surimi and fish gel products, its effect on protein gelation must be measured. The effect of Aloe vera gel on pH, ionic strength, and total dry matter can positively or negatively affect the surimi gel network. Therefore, studies should be conducted for surimi applications by planning together the whiteness index, gel hardness, folding test, water retention capacity, and sensory acceptance (Rodríguez et al., 2010: 305, Kurek et al., 2024: 1417). In omega-3-rich seafood products, oxidative stability represents an important research target because EPA and DHA are susceptible to lipid oxidation. Aloe vera-based coatings may therefore be investigated as one possible strategy for controlling oxidative deterioration. Such applications should be evaluated using direct oxidation measurements and appropriate controls rather than inferred solely from the nutritional importance of EPA and DHA (Fofandi & Tanna, 2020: 1438, Waris & Pilavtepe-Celik, 2025: 1). While EPA and DHA have high health value, they also have high oxidative sensitivity. Therefore, the antioxidant effect of Aloe vera should be planned together with biopolymer films that provide an oxygen barrier and controlled release systems.

Table 6. Potential and evidence level of aloe vera use in value-added aquaculture products.

Product range	Possible Aloe vera function	Level of evidence	Recommended validation	References
Fish burger	Moisturizing and antioxidant components in the formulation; Shelf life supporter in surface coating.	Indirect evidence is strong, direct fish burger-Aloe studies are limited.	Pilot recipe, sensory panel, TBARS/TVB-N and cooking yield should be measured together.	Maan et al., 2021; Kurek et al., 2024

Product range	Possible Aloe vera function	Level of evidence	Recommended validation	References
Fish patty	Natural binder/coating and oxidation retarder.	Direct evidence is limited.	Since aloe ratio may soften the texture, it should be tested together with gelatin/chitosan.	Feng et al., 2016;
Surimi and jelly products	Gel water retention and antioxidant support.	Hypothesis level; species and process validation is needed.	The effect of aloe on protein gelation and whiteness should be tested separately.	Rodríguez et al., 2010; Kurek et al., 2024
Smoked fish	Coating that reduces surface oxidation and moisture loss.	Potential is high for oily fish.	Interaction with smoke flavor and sensory acceptance must be measured.	Kurek et al., 2024; Waris & Pilavtepe-Celik, 2025
Omega-3 rich products	Delaying EPA-DHA oxidation.	Biochemical rationale is strong, product-based studies are needed.	Microencapsulation and oxygen barrier should be planned together.	Golden et al., 2021; Kong et al., 2022
Nutraceutical/fortified product	Co-positioning of aloe gel and marine bioactives.	Regulatory and safety factors	Aloin/HAD control, dosage, labeling and stability are mandatory.	EFSA, 2018; EFSA, 2024

Source: Compiled from the references listed in the table.

Aloe Vera, Marine Biopolymers, and Circular Bioeconomy

The utilization of fish processing by-products means not only mitigating an environmental problem but also developing new sources of packaging and functional components. Collagen, gelatin, peptides, fish oil, and minerals are the main high-value fractions that can be obtained from these by-products (Coppola et al., 2021: 116, Honrado et al., 2022: 3656).

The combined use of aloe vera and marine biopolymers is noteworthy in terms of transforming plant and marine resources into a hybrid technology. In this approach, aloe vera can form the active phase, while fish gelatin or collagen can form the carrier matrix. The combination of Aloe vera with marine-derived biopolymers represents a potential strategy for integrating plant-based bioactive components with materials recovered from seafood-processing by-products. Fish gelatin and collagen can provide film-forming matrices, while Aloe vera may contribute bioactive functionality. Such systems could contribute to both material valorization and food preservation, but the environmental and technological benefits need to be demonstrated through comparative performance and life-cycle studies (Chin et al., 2017: 128, Sánchez et al., 2020: 1248, Rajabimashhadi et al., 2023: 544, Coppola et al., 2021: 116). The most important question from a sustainability perspective is whether aloe vera-based systems truly have a lower environmental impact. Plant cultivation, gel extraction, drying, transportation, biopolymer production, and coating application all require energy and water consumption. Therefore, an assessment should be made not only based on biodegradability but also across the entire life cycle (FAO, 2024; Honrado et al., 2022: 36356).

In the aquaculture processing industry, by-products such as skin, scales, bones, heads, and offal contain significant biological resources. Treating these materials directly as waste leads to both a loss of economic value and an environmental burden. Current literature shows that collagen, gelatin, peptides, oils, and mineral

fractions can be obtained from fish by-products, and this approach offers a strong foundation for a circular bioeconomy (Coppola et al., 2021: 116, Honrado et al., 2022: 36356, Ghalamara et al., 2024). Combining aloe vera with marine biopolymers creates a dual value in this respect: on the one hand, it imparts a natural antioxidant/antimicrobial function to seafood packaging, and on the other hand, it transforms fish processing by-products into biodegradable packaging raw materials. Fish gelatin-aloe vera films are direct examples of this approach in the literature (Chin et al., 2017: 128, Sánchez et al., 2020: 1248).

However, the sustainability claim should not be limited to the words 'biodegradable' or 'natural'. Life cycle analysis, energy consumption, water use, packaging waste, product loss, cold chain performance, and cost should be evaluated together when transitioning to industrial application. The environmental performance of Aloe vera-based packaging cannot be evaluated solely on the basis of biodegradability or the use of natural materials. Cultivation and processing of Aloe vera, production of the biopolymer matrix, water and energy consumption, transportation, packaging disposal and any reduction in food loss should be considered together. Comparative life-cycle assessment is therefore required to determine whether an Aloe vera-based system provides an environmental advantage over conventional packaging under defined conditions (FAO, 2024; Honrado et al., 2022: 3656).

Table 7. Evaluation of aloe vera applications in terms of sustainability and circular bioeconomy.

Approach	Application logic	Expected Contribution	References
Gelatin/collagen from fish by-products	Use of skin, scales, fish bones and bones as biopolymer sources.	Waste burden is reduced, packaging raw materials are produced.	Coppola et al., 2021; Rajabimashhadi et al., 2023

Approach	Application logic	Expected Contribution	References
Aloe-biopolymer composites	Plant-based bioactive + marine polymer.	Both shelf life and biodegradable packaging goals are combined.	Chin et al., 2017; Kaur et al., 2024
Reducing food loss	Expanding sales and consumption window by extending shelf life.	The potential for waste and economic loss reduction arises.	FAO, 2024; Kurek et al., 2024
Blue foods	The role of aquaculture in nutrition and sustainability.	It supports the waste-free utilization of high nutrient-dense products.	Golden et al., 2021; FAO, 2024
LCA and carbon footprint	Coating/packaging together the raw material, energy, waste and shelf life impacts.	It transforms laboratory success into industrial sustainability data.	Honrado et al., 2022; FAO, 2024
AI-powered quality monitoring	Image processing, electronic nose/tongue and modeling	Freshness classification and shelf life estimation can be accelerated.	Kurek et al., 2024

Source: Compiled from the references listed in the table.

Safety, Toxicity and Legal Regulations

The European Union's regulations regarding hydroxyanthracene derivatives clearly indicate that Food applications of Aloe vera require careful control of the plant fraction and processing procedure because hydroxyanthracene derivatives, including aloin, are associated particularly with latex and whole-leaf fractions. European regulatory and scientific assessments have addressed the safety of hydroxyanthracene derivatives in food, highlighting the need for appropriate control of these compounds in relevant Aloe preparations (EFSA, 2018; Commission Regulation

(EU) 2021/468; EFSA, 2024). The key distinction here is between safe preparations derived from the inner gel and latex/whole leaf fractions or extracts with high aloin content. Materials to be used in seafood coatings must be supported by quality certificates and analyses documenting this distinction (Commission Regulation (EU) 2021/468; EFSA, 2024).

The microbiological safety of Aloe vera should also not be overlooked. Since fresh gel has a high water content, it can be a source of contamination if stored under unsuitable conditions. Therefore, Aloe preparations to be applied to an already sensitive food such as seafood need to be checked for pathogens and total microbial load (Ahlawat & Khatkar, 2011: 525).

Another regulatory issue is the assessment of the active packaging as food contact material. The amount of active components that may migrate from the packaging to the product, consumer exposure, and potential chemical changes on the product must be measured. Direct application on an industrial scale is not appropriate without conducting these analyses (EFSA, 2024; Kurek et al., 2024: 1417). Properly processed and standardized aloe vera inner gel preparations may be potentially usable; however, their application in food should not be recommended without controlling for aloin and other hydroxyanthracene derivatives, ensuring microbiological safety, and demonstrating regulatory compliance. The natural origin of Aloe vera does not by itself establish food safety. For seafood applications, the Aloe vera preparation should be characterized with respect to plant fraction, processing method, hydroxyanthracene derivatives, microbiological quality and relevant compositional parameters. Particular attention should be given to separation of the inner gel from latex or whole-leaf material and to the control of aloin and related compounds (EFSA, 2018; Malysheva et al., 2024: 505, Ramachandra & Srinivasa Rao, 2008: 502).

Therefore, for Aloe vera preparations to be used in aquaculture, the description 'inner gel-derived, latex-free, microbiologically safe, and aloin/HAD level controlled' is necessary. The reproducibility of results decreases when the plant age, leaf section, extraction method, stabilization process, dry matter content, and aloin level of the Aloe vera material used in studies are not specified. As an academic approach, while highlighting the potential of Aloe vera, standardization and regulatory requirements should be clearly stated (Ramachandra & Srinivasa Rao, 2008: 502, Ahlawat & Khatkar, 2011: 525, Malysheva et al., 2024: 505).

Another important issue in active packaging and edible film applications is migration. Aloe vera components, essential oils, or other active substances may migrate to the product surface during storage. In active packaging systems, migration or controlled release of Aloe vera-derived compounds and other active ingredients into the food-contact environment may occur during storage. The extent and significance of such transfer should be evaluated with respect to concentration, exposure, toxicological considerations, sensory effects and applicable food-contact requirements. Consequently, migration assessment should be included alongside shelf-life, microbiological and sensory evaluations during product development (EFSA, 2024; Kurek et al., 2024: 1417).

Table 8. Safety risks and control measures in aloe vera applications.

Risk area	Possible source	Control measures	References
Aloin and hydroxyanthracene derivatives	Latex/whole leaf-derived aloin A-B, aloe-emodin, emodin.	Internal gel separation, decolorization/filtration, aloin analysis.	EFSA, 2018; Commission Regulation (EU) 2021/468; EFSA, 2024
Microbiological contamination	High water content of aloe gel and	GMP, hygienic filleting, pasteurization or	Ahlawat & Khatkar, 2011; Ramachandra &

Risk area	Possible source	Control measures	References
	improper processing.	appropriate stabilization.	Srinivasa Rao, 2008
Dose and sensory dominance	Use with aloe concentrate or essential oil.	Sensory panel, threshold tests, consumer acceptance studies.	Oğuzhan Yıldız, 2026; Jamali et al., 2023
Migration	Migration of active ingredients to the product surface.	Migration test, food simulants, monitoring throughout shelf life.	EFSA, 2024; Kurek et al., 2024
Raw material variability	Plant age, climate, leaf type and processing method.	Standardized extract, lot-based chemical characterization.	Hamman, 2008; Maan et al., 2021
Allergen/irritation risk	Rare individual sensitivities.	Labeling and target consumer group assessment.	Rodríguez et al., 2010; Ahlawat & Khatkar, 2011

Source: Compiled from the references listed in the table.

Future Perspectives and Research Needs

Although different studies may refer to their material simply as "Aloe vera gel," the chemical and technological properties of the preparation may vary according to plant source, leaf fraction, processing, stabilization and storage. Future studies should therefore report relevant characterization parameters, including dry matter, pH, hydroxyanthracene derivatives, polysaccharide characteristics and microbiological quality. Such standardization would improve comparability and reproducibility among seafood preservation studies (Hamman, 2008: 1599, Maan et al., 2021: 329).

Another need is to transfer laboratory-scale successes to pilot and industrial scales. Although dip coatings give good results in the laboratory environment, application speed, solution stability, product variety, and cost differ in the industrial line. Therefore, semi-industrial trials should be conducted in the future, and the reuse of

the coating solution, hygiene management, and process integration should be tested (Kurek et al., 2024: 1417).

Consumer acceptance should be considered alongside chemical and microbiological shelf-life indicators. Aloe vera and other active ingredients may influence product appearance, odor, surface characteristics or post-cooking properties, while essential oils may introduce additional aroma effects. Future studies should therefore combine trained sensory evaluation with consumer acceptance testing when appropriate (Jamali et al., 2023:93, Oğuzhan Yıldız, 2026: 118).

Finally, the sustainability claim of aloe vera-based packaging should be verified with LCA. Extending shelf life can reduce product loss; however, if the energy and water consumption of the packaging production process is high, the net environmental gain may decrease. Therefore, shelf life, packaging waste, and carbon footprint should be modeled together (FAO, 2024; Honrado et al., 2022: 3656).

The use of aloe vera in aquaculture products may develop in three directions in the future: active packaging with controlled release, biodegradable films reinforced with marine biopolymers, and digital quality monitoring systems. Nanoemulsion and nanoencapsulation can enable more homogeneous distribution of aloe vera or co-used essential oils, longer-lasting effects at lower doses, and reduced sensory dominance. However, particle size, release kinetics, toxicological safety, and scale-up must also be validated in these systems (Kong et al., 2022: 555, Jamali et al., 2023: 93).

In smart packaging systems, aloe vera-based films can be combined with pH indicators, anthocyanins, TVB-N sensitive sensors, or color-changing biosensors. As pH and volatile basic compounds increase as fish spoil, the color change on the packaging surface can provide consumers with visual information about

freshness. This approach is important for quality management and consumer confidence in high-value fillet products; However, the effects of temperature fluctuations, light, humidity, and product matrix should be tested on real products (Bekhit et al., 2021: 280, Kurek et al., 2024: 1417).

Digital quality-control approaches represent a potential future direction for Aloe vera-treated seafood. Image analysis, hyperspectral imaging, electronic-nose systems and machine-learning models could potentially be used to classify freshness or predict quality changes. However, reliable predictive models require calibration and validation against reference chemical, microbiological and sensory measurements. Therefore, future studies should integrate digital measurements with conventional quality-control parameters rather than replacing reference analyses (Kurek et al., 2024: 1417).

- Direct validation of aloe vera applications in different fish species and shellfish should be performed.
- The aloin/HAD level, dry matter content, and polysaccharide profile of the aloe vera preparation used should be reported.
- Sensory acceptance should be considered as an important success criterion as shelf-life extension.
- LCA and economic feasibility studies should be conducted for aloe vera-fish gelatin/collagen films.
- Migration and long-term safety assessments in active packaging should be added to the standard analysis set.

Conclusion and Recommendations

In practice, the most realistic way is to use aloe vera together with biopolymers such as chitosan, fish gelatin, collagen or alginate

as a standardized gel preparation. Thus, both the active protective effect and the biodegradable packaging potential are strengthened. However, for the commercialization of these systems, legislation, migration, aloin/HAD control, sensory acceptance and cost analyzes must be completed together (Kaur et al., 2024: 242; EFSA, 2024). Aloe vera is a strong candidate for natural ingredients in terms of shelf life extension in aquatic products, edible coating development and active packaging design. Current studies show that aloe vera gel or composite coatings containing Aloe vera can slow the loss of TVB-N, TBARS/MDA, microbial load, pH increase and sensory quality loss. However, this effect depends on the species, product form, storage temperature, coating matrix, Aloe vera concentration and the active ingredients used together (Kurek et al., 2024: 1417, Waris & Pilavtepe-Celik, 2025: 1, Oğuzhan Yıldız, 2026: 118).

From an academic and industrial perspective, it may be wrong to see aloe vera as a perfect preservative on its own. Therefore, it is necessary to consider aloe vera as part of a multi-component active packaging strategy supported by chitosan, fish gelatin, collagen, alginate or controlled release systems. This approach strengthens both shelf-life performance and circular bioeconomy potential (Chin et al., 2017: 128, Kaur et al., 2024: 242, Rajabimashhadi et al., 2023: 544).

Future studies should include standardized Aloe vera preparations, aloin/HAD control, migration analyses, sensory acceptance, cost and life cycle analyses. When these conditions are met, Aloe vera based systems; It will continue to be an important research and application area in the development of quality, safe, sustainable and consumer-acceptable aquatic products (EFSA, 2024; FAO, 2024; Maan et al., 2021: 329).

For aloe vera to be successfully used in aquaculture, it is not sufficient to define it only as a "natural preservative"; the standardization of the gel or extract used, the oil content of the target

product, storage temperature, packaging type, and sensory acceptance criteria must be evaluated together. Current studies show that aloe vera can delay indicators of oxidation and microbial spoil, especially in cold-stored fish; however, the effect varies depending on the formulation, dose, and product matrix (Kurek et al., 2024: 1417; Waris & Pilavtepe-Celik, 2025: 1, Oğuzhan Yıldız, 2026: 118).

Before moving to industrial application, it is recommended to conduct TVB-N, TMA-N, TBARS, total viable count, psychrotrophic bacteria count, pH, color, texture, and sensory acceptance analyses together in small-scale trials. Decisions to extend shelf life based solely on chemical or solely on microbiological results can be misleading; Because consumer acceptance is often determined by sensory indicators such as odor, surface gloss, and texture (Gram & Dalgaard, 2002: 262, Kurek et al., 2024: 1417).

Migration, aloin/hydroxyanthracene derivatives, microbiological safety, and labeling issues should also be addressed in edible films or coatings containing aloe vera. In particular, the removal of the latex fraction and the control of anthraquinone levels are considered essential for the safe and regulatory-compliant commercialization of these technologies (Commission Regulation (EU) 2021/468; EFSA, 2018; EFSA, 2024).

Table 9. Short checklist for industrial use of aloe vera applications.

Control heading	Points to consider in practice	Expected contribution	References
Raw material standardizatio n	Gel/extract ratio, dry matter, pH, and aloin level should be defined.	Reproducible quality and safety.	Hamman, 2008; Ramachandra & Srinivasa Rao, 2008; EFSA, 2024
Product-matrix compatibility	Oily fish, white-fleshed fish, and	Correct dosage and application method.	Gram & Dalgaard, 2002; Waris &

Control heading	Points to consider in practice	Expected contribution	References
	shellfish should be tested separately.		Pilavtepe-Celik, 2025; Oğuzhan Yıldız, 2026.
Coating/film formulation	Aloe vera should be optimized with carriers such as chitosan, gelatin, collagen, or alginate.	Better mechanical and barrier performance.	Kaur et al., 2024; Kurek et al., 2024; Maan et al., 2021
Shelf life validation	TVB-N, TMA-N, TBARS, microbiology, and sensory analysis should be monitored together.	Scientifically defensible shelf life claim.	Kurek et al., 2024; Oğuzhan Yıldız, 2026.
Regulations and safety	Migration, anthraquinones, allergen/labeling, and microbiological safety should be checked.	Commercializatio n and consumer safety	Commission Regulation (EU) 2021/468; EFSA, 2018; EFSA, 2024.

Source: Compiled from the references listed in the table.

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