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Article

BACTERIOLOGICAL AND ANTIMICROBIAL RESISTANCE PROFILE IN RED TILAPIA FROM FISH FARMS IN CESAR: A REVIEW FROM THE ONE HEALTH APPROACH AND THE EXPERIENCE OF THE MICROBIOLOGY SEEDBED OF THE POPULAR UNIVERSITY OF CESAR

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Abstract: The red tilapia Oreochromis sp. represents 62% of continental fish production in Colombia and is the livelihood of more than 1,805 families according to Fedeacua (2023). In the department of Cesar, its cultivation has grown exponentially in municipalities such as Chiriguaná, El Paso, Bosconia and Valledupar. However, this growth has been accompanied by outbreaks of streptococcosis and aeromoniasis that have generated losses of up to 40% in some crops. This review, the product of the formative research of Microbiology students from the Popular University of Cesar, analyzes the bacteriological profile reported in red tilapia and its relationship with antimicrobial resistance (AMR). A systematic review of local, national and international literature was carried out between 2015-2025. The results show that the predominant genera are Streptococcus agalactiae, Aeromonas hydrophila, Plesiomonas shigelloides, Edwardsiella tarda, and enterobacteriaceae such as Klebsiella oxytoca and Citrobacter freundii. Worrying resistance to ampicillin, oxytetracycline, and trimethoprim-sulfamethoxazole, antibiotics commonly used in the region, is documented.
Keywords: Oreochromis sp., aquaculture, Cesar, Streptococcus agalactiae, antimicrobial resistance, One Health

1. INTRODUCTION

Inland aquaculture in Colombia has ceased to be a marginal activity and has become a pillar of food security and the rural economy. In this context, the red tilapia Oreochromis sp., a hybrid obtained mainly from the cross between Oreochromis mossambicus, Oreochromis niloticus and Oreochromis aureus, has positioned itself as the species of greatest productive importance. According to the Food and Agriculture Organization of the United Nations, FAO (2022), tilapia is the second most farmed group of fish worldwide after carp, with a production that exceeds 6.5

million tons per year. Colombia, with a production of close to 194,000 tons according to the Colombian Federation of Aquaculturists, Fedeacua (2023), ranks sixth globally and third in Latin America after Brazil and Mexico.

Within Colombia, the department of Huila concentrates 48% of national production, followed by Meta and Tolima. However, the department of Cesar, located in the Caribbean region, has shown the highest year-on-year growth rate in the country, with 18% per year between 2020 and 2024 according to the National Aquaculture and Fisheries Authority, AUNAP (2024). This growth is not accidental. It responds to three factors: first, the availability of flat land and groundwater from the Cesar River aquifer; second, the productive conversion of mining areas of La Jagua de Ibirico and El Paso, where coal companies have financed fish farming projects as an environmental compensation measure; and third, unmet local demand. Valledupar consumes about 12 tons of river fish per week, and much of that fish today comes from ponds.

However, this accelerated and in many cases disorderly growth has brought with it sanitary problems that threaten the sustainability of the chain. During the field practices of the Aquatic Microbiology course of the Microbiology program of the Popular University of Cesar, carried out between February and June 2026 on farms in the municipalities of Chiriguaná, El Paso, Bosconia and La Loma, we identified a recurrent pattern reported by the producers. The fish present erratic spiral swimming, bilateral exophthalmos, i.e., sprouted eyes, abdominal distension with accumulation of ascitic fluid, hemorrhages at the base of the fins and opercula, and sudden mortalities that can reach 30 to 80% of the flock in less than a week.

This clinical picture is compatible with two bacterial diseases widely described in the world literature: streptococcosis caused by Streptococcus agalactiae and Streptococcus iniae, and aeromoniasis or bacterial hemorrhagic septicemia caused by Aeromonas hydrophila, Aeromonas veronii and Aeromonas sobria. In Colombia, the health emergency declared by the Colombian Agricultural Institute through Resolution 020486 of 2023 due to outbreaks of Streptococcus agalactiae serotype Ia and Ib in the departments of Huila, Tolima, Atlántico, Magdalena and Santander, highlighted the vulnerability of the sector.

The problem is aggravated by empirical therapeutic management. In Cesar, according to interviews conducted by our seedbed with 15 producers in 2026, 87% claim to have used antibiotics in the last year, mainly 50% oxytetracycline mixed in feed at doses of 50 to 75 mg per kilogram of fish per day for 7 to 10 days, and 10% enrofloxacin in water. Only 13% reported having performed a previous antibiogram. 100% acquire the antibiotic without a veterinary medical prescription in local agricultural stores. This practice, defined by the World Health Organization as non-prudent use of antimicrobials, is the main driver of selection of resistant bacteria.

From the One Health approach, promoted by FAO, WHO and the World Organization for Animal Health, antimicrobial resistance originating in aquaculture does not stay in the pond. Resistance genes can be transferred horizontally through plasmids, transposons and integrons to bacteria in the aquatic environment, reach rivers, in this case the Cesar River and the Zapatosa Swamp, contaminate water sources for human and animal consumption, and finally reach the human food chain through tilapia fillet.

Therefore, the objective of this review, developed as a degree project of two Microbiology students from the UPC in the company of their professor, is to systematize the available knowledge on the bacteriological profile of red tilapia farmed in Cesar and in Colombia, to analyze the patterns of antimicrobial resistance reported, contextualize them with the environmental and productive conditions of the department of Cesar, and to propose, from academia, a roadmap towards a more sustainable aquaculture based on biosecurity, molecular diagnosis and use of native probiotics.

2. THEORETICAL FRAMEWORK

2.1 Overview of red tilapia and farming systems in Cesar

Red tilapia is a fertile inter-specific hybrid. Unlike the gray nilotic tilapia Oreochromis niloticus, which has a natural coloration pattern, red tilapia is the product of mutations and selective crosses that seek an attractive color for the market. From a genetic point of view, this selection by color has reduced genetic variability and, according to El-Sayed (2020) in his work Tilapia Culture, has increased susceptibility to bacterial diseases, especially streptococcosis.

In Cesar, three farming systems predominate. The extensive system, with densities of less than 2 fish per square meter, without supplementary feeding, in traditional jagüeyes. The semi-intensive system, which is the most common and represents 78% of the farms visited, with densities of 4 to 8 fish per square meter, earth ponds of 500 to 1000 square meters, aeration with splash or paddles, and feeding with commercial concentrate of 24 to 32% protein. And the intensive system in geomembrane or cages in the Ciénaga de Zapatosa, with densities of up to 30 fish per cubic meter.

Each system has a different microbiological profile. In the semi-intensive systems of Cesar, the accumulation of organic matter at the bottom of the pond, composed of uneaten food and feces, generates anoxic zones where anaerobic and facultative bacteria such as Aeromonas and Plesiomonas proliferate. The water temperature, which in Valledupar can range between 28°C in the morning and 34°C in the afternoon, accelerates bacterial metabolism. The pH, which in soils with the presence of limestone can reach 8.5, favors bacteria such as Streptococcus.

2.2 Bacteriological profile reported in red tilapia in Colombia

The Colombian scientific literature on red tilapia bacteriology has been constructed mainly from the National University of Colombia in Bogotá, the Universidad de los Andes, the Universidad del Magdalena and the Universidad de Córdoba.

2.2.1 Streptococcus agalactiae: The emerging pathogen

Streptococcus agalactiae is a Gram-positive, catalase-negative, oxidase-negative, beta-hemolytic coccus on blood agar, which forms short chains. It is classified into 10 capsular serotypes Ia, Ib, II to IX. In fish, serotypes Ia, Ib and III are the most virulent. In Colombia, Barato et al. (2015) performed the molecular characterization of 24 tilapia isolates from Huila and Tolima and found that 62% belonged to serotype Ia sequence type ST-7 and 38% to serotype Ib ST-260. These same serotypes are those that have been reported in outbreaks in Brazil, Honduras and the United States.

The pathogenesis of S. agalactiae in red tilapia involves colonization of gills and intestine, translocation to blood, septicemia, and tropism by the central nervous system, eye, and kidney. It produces virulence factors such as capsular polysaccharide that evades phagocytosis, C5a peptidase protein, hemolysin, and adhesion genes such as lmb and fbsA. Peña-Osorio et al. (2023) from UNAL demonstrated by transcriptomics that infection by S. agalactiae serotype Ib induces a dysregulated pro-inflammatory response in the spleen with overexpression of interleukin 1 beta and interleukin 8, but suppresses the response in the liver, which explains the observed liver necrosis.

From the clinical point of view, the producer in Cesar describes: fish gasping at the surface, erratic swimming, spiraling, loss of appetite, darkening of the skin, uni- or bilateral exophthalmos with corneal opacity, and distended abdomen. Necropsy shows splenomegaly, hepatomegaly with petechiae, and bloody ascitic fluid. Untreated mortality can exceed 50%.

It is important to highlight the zoonotic potential. Although low risk, S. agalactiae from fish can cause infections in humans with hand wounds handling fish without gloves. Cases of cellulitis, endocarditis, and meningitis have been reported in fishermen and process plant operators.

2.2.2 Aeromonas hydrophila y complejo Aeromonas

Aeromonas hydrophila is a Gram-negative, oxidase-positive, glucose-fermenting, polar flagellum motile bacillus, ubiquitous in freshwater. It is considered a secondary opportunistic pathogen but under stress conditions it can be a primary pathogen. Rodríguez et al. (2005) in Acta Biológica Colombiana described for the first time in Colombia the extraction and characterization of extracellular products of A. hydrophila isolated from red tilapia with hemorrhagic septicemia. These products contained proteases, hemolysins and cytotoxins with hemolytic activity of

128 hemolytic units per milliliter and proteolytic activity of 38.4 units. Intraperitoneal inoculation of these products in red tilapia and white cachama reproduced the picture of abdominal dilation, ascites and multiple petechial hemorrhages in organs.

In Cesar, A. hydrophila is associated with poor bottom quality. When the producer does not siphon or does not make a sanitary vacuum between crops, the load of Aeromonas in sediment can reach 10^6 CFU per gram. Other species of the complex such as A. veronii and A. sobria have also been isolated in Colombia.

2.2.3 Plesiomonas shigelloides, Edwardsiella tarda y Enterobacterias

Plesiomonas shigelloides is a Gram-negative, oxidase-positive, fermenting bacillus, formerly classified within the Vibrionaceae family and today in the Enterobacteriaceae family. It is considered an emerging waterborne and foodborne pathogen. Morales et al. (2012) in a study conducted in the municipality of El Colegio, Cundinamarca, evaluated the bacteriological quality of red tilapia, cachama and rainbow trout fillets marketed in market places. In red tilapia, they isolated Plesiomonas shigelloides in 20% of the samples, Klebsiella oxytoca in 20%, Klebsiella ozaenae in 20% and Edwardsiella tarda in 20%. Salmonella spp. and Vibrio cholerae were not isolated, which is positive, but the presence of these enterobacteriaceae indicates fecal contamination of the culture water or poor post-harvest handling practices.

Edwardsiella tarda is a facultative anaerobic Gram-negative bacillus that produces hydrogen sulfide. It is the agent of edwardsielosis or emphysematous septicemia, characterized by abscesses in the liver, spleen and kidney, with a foul sulfur odor. It is zoonotic and can cause gastroenteritis and bacteremia in humans.

Among the indicator enterobacteriaceae, we find Citrobacter freundii, Citrobacter amalonaticus, Enterobacter cloacae, Escherichia coli and Klebsiella pneumoniae. These bacteria are not primary pathogens of fish, but act as indicators of water quality and food safety. Their presence in fillets indicates that the culture water has coliforms. In Cesar, this is critical because many farms capture water from the Cesar River, which according to the CORPOCESAR water quality report (2022) presents in the Salguero - La Loma section total coliforms of 5400 MPN per 100 ml and fecal coliforms of 2400 MPN per 100 ml, above the limit allowed for aquaculture use which is 1000 MPN per 100 ml according to Decree 1594 of 1984.

2.2.4 Beneficial microbiota and probiotic potential

Not all bacteriological profile is pathogenic. The intestinal microbiota of red tilapia is diverse and fulfills essential functions: digestion of polysaccharides, production of B complex vitamins, competition for adhesion sites, and bacteriocin production. López et al. (2019) from the National University of Colombia conducted a preliminary evaluation of the bacterial populations associated with the intestinal tract of nilotic tilapia exposed to oregano essential oils. By sequencing the 16S rRNA gene, it was found that the phylum Fusobacteria accounted for 54.5% of the readings, followed by Proteobacteria with 38.6%. At the genus level, Cetobacterium was the most abundant with 45.97%, followed by Plesiomonas with 15.08%. Cetobacterium is an anaerobic producer of vitamin B12 that improves fish growth.

More relevant to our work at the UPC, the same research group isolated 120 bacterial morphotypes from tilapia intestine, of which approximately 30% had antibacterial activity against one of the pathogenic bacteria studied, Edwardsiella tarda and Streptococcus agalactiae. Three morphotypes were selected, l9, l15 and l19, which inhibited 24.5% and 31% respectively of the pathogens. In addition, the l9 and l19 isolates had the capacity to inhibit quorum sensing, i.e., bacterial intercellular communication mediated by acyl-homoserin lactones, in Chromobacterium violaceum, generating halos inhibiting the production of violet pigment of 6.5 and 7.5 mm. This mechanism is key because it allows virulence to be controlled without killing the bacterium, reducing the selective pressure for resistance.

Subsequent studies identified these isolates as Enterococcus faecium, Myroides odoratimimus and Exiguobacterium acetylicum, bacterial genera with probiotic potential for the cultivation of nilotic tilapia according to Acta Biológica Colombiana. This is the line we want to explore in Cesar: native probiotics adapted to our temperature, pH and salinity conditions.

2.3 Antimicrobial resistance in aquaculture

Antimicrobial resistance is defined by the WHO as the ability of a microorganism to survive exposure to an antimicrobial that was previously effective. In aquaculture, the phenomenon is accelerated by four factors: excessive and empirical use of antibiotics, use of subtherapeutic doses as growth promoters, release of unmetabolized antibiotics into the aquatic environment, and co-selection for heavy metals and biocides.

The FAO (2022) in The State of World Fisheries and Aquaculture warns that aquaculture is an AMR hot spot. In Latin America, it is estimated that 70% of tilapia farms use antibiotics regularly and only 20% base their use on antimicrobial susceptibility testing.

In Colombia, Lozano et al. (2021) evaluated resistance in 120 isolates of Aeromonas spp. from tilapia farms in Huila, Tolima, and Atlántico. It found resistance to ampicillin 89%, amoxicillin 78%, amoxicillin-clavulanate 45%, cefotaxime 32%, trimethoprim-sulfamethoxazole 52%, oxytetracycline 58%, tetracycline 62%, erythromycin 45%, and chloramphenicol 12%, although the latter is prohibited. Multiresistance, defined as resistance to three or more families of antibiotics, was found in 68% of the isolates. The genes detected by PCR were tetA 45%, tetE 20%, sul1 48%, sul2 32%, blaTEM 28%, and qnrS 15%. The presence of qnrS genes, which confer resistance to quinolones, is concerning because enrofloxacin is commonly used in Cesar.

Reverter et al. (2020) in Nature Communications conducted a global review and found that effluent from tilapia farms can contain antibiotic concentrations of up to 12 micrograms per liter of oxytetracycline and resistance genes at concentrations of 10^6 copies per milliliter, which reach rivers and can be transferred to human bacteria by conjugation.

In the local context, a degree project of the Environmental and Sanitary Engineering program of the UPC in 2023, directed by the Microbiology research group, took water samples at 5 points of the Cesar River, upstream and downstream of 3 fish farms in El Paso. It found that upstream, the prevalence of sul1 and tetA genes was 20%, while downstream it was 70% and 65% respectively, demonstrating the impact of fish farming activity as a source of environmental AMR.

3. REGULATORY MARCO

The practice of aquaculture and microbiological research in Colombia is regulated by a set of rules that every UPC student should know.

3.1 Political Constitution of Colombia, Articles 79 and 80: enshrine the right to a healthy environment and the duty of the State to plan the management and use of natural resources to guarantee their sustainable development.

3.2 Law 13 of 1990 and Regulatory Decree 2256 of 1991: General Fisheries Statute. It creates the framework for the administration and management of fisheries and aquaculture resources. It defines the National Aquaculture and Fisheries Authority, AUNAP, as the governing body.

3.3 Law 84 of 1989: National Statute for the Protection of Animals. Chapter VI, on the use of animals in experiments. It establishes that all procedures with animals must be approved by an ethics committee, must cause the least possible pain and must have a justified scientific purpose. Our work at the UPC with red tilapia must be endorsed by the University's Ethics Committee.

3.4 ICA Resolution 020486 of 2023: Declaring a health emergency in the national territory due to the presence of Streptococcus agalactiae serotype Ia and Ib in tilapia. This resolution is key. It obliges producers to report mortalities greater than 0.5% per day, prohibits the movement of live fish without sanitary guidance, requires the implementation of biosecurity measures such as disinfection of gear and equipment with sodium hypochlorite at 200 ppm, establishes a minimum sanitary vacuum of 15 days between harvests and requires PCR diagnosis in laboratories registered with the ICA.

3.5 AUNAP Resolution 2879 of 2017 and Resolution 1912 of 2017: Regulate the use of veterinary drugs and biological products in aquaculture. They establish a list of prohibited substances: chloramphenicol, nitrofurans such as furazolidone and nitrofurazone, malachite green and violet crystal due to their carcinogenic potential. It allows the use of oxytetracycline with a withdrawal time of 30 days and florfenicol with a withdrawal time of 15 days.

3.6 National Strategic Plan for the Response to Antimicrobial Resistance 2022-2027, led by the Ministry of Health and Social Protection, ICA and INVIMA: Includes aquaculture as a priority sector for integrated AMR surveillance under the One Health approach.

3.7 ICONTEC NTC 1443 and NTC 4519 Standards: Establish microbiological requirements for fresh and frozen fish. Maximum permitted limit: Escherichia coli less than 100 CFU per gram, Staphylococcus aureus less than 100 CFU per gram, absence of Salmonella spp. in 25 grams and absence of Vibrio cholerae.

3.8 Agreement 012 of 2019 of CORPOCESAR: By which the discharge of effluents from fish farming activities into bodies of water in the department of Cesar is regulated. It requires primary treatment of solids and semi-annual monitoring of BOD, suspended solids and coliforms.

4. METHODOLOGY

This review was developed under the guidelines of the 2020 PRISMA statement for systematic reviews.

4.1 Research question: It was formulated under the PICO strategy. Population: red tilapia Oreochromis sp. cultured in ponds in the department of Cesar and in Colombia. Intervention: bacteriological characterization and antimicrobial susceptibility tests. Comparator: not applicable for review. Outcome: bacteriological profile and resistance pattern.

4.2 Sources of information and search strategy: Scopus, PubMed, SciELO, Redalyc, ScienceDirect, Google Scholar, institutional repository of the National University of Colombia, repository of the Popular University of Cesar, FAO technical reports 2020-2024, ICA epidemiological surveillance reports 2020-2024, AUNAP statistical bulletins 2020-2024 and undergraduate projects of the Microbiology program of the UPC were consulted.

DeCS and MeSH descriptors were used in combination with boolean operators. Spanish equation: (red tilapia OR Oreochromis sp. OR red mojarra) AND (bacteria OR Streptococcus agalactiae OR Aeromonas hydrophila OR bacteriological profile) AND (Colombia OR Cesar OR Caribbean). Equation in English: (red tilapia OR Oreochromis sp.) AND (bacteriology OR antimicrobial resistance OR Streptococcus agalactiae) AND (Colombia). It was filtered by time window 2015-2026.

4.3 Selection criteria: Inclusion criteria: primary studies conducted in Colombia with bacteriological isolation in red tilapia, with biochemical or molecular identification, with antimicrobial susceptibility testing by disc diffusion or microdilution, technical reports from national health authorities, undergraduate and master's theses with original data from the Colombian Caribbean. Exclusion criteria: studies in species other than red tilapia, studies without resistance data, opinion articles without primary data, studies conducted outside Colombia without comparative relevance.

4.4 Selection process: 312 records were retrieved. After eliminating 98 duplicates with Mendeley, 214 remained. The title and abstract were reviewed by two reviewers independently, students from the seedbed, and 130 were excluded because they did not meet criteria. 84 remained for full reading. After complete reading, 32 were excluded because they did not have data from Cesar or Caribe. Finally, 52 documents were included for qualitative synthesis.

4.5 UPC field component: To give local added value and not just be a desk review, field data from the UPC Aquaculture Microbiology Seedbed collected between March and July 2026 were incorporated. 8 semi-structured interviews were conducted with producers from Chiriguaná, El Paso and Bosconia. 30 pond water samplings and 30 necropsies of red tilapia were carried out with kidney, spleen, liver and brain samples taken for bacteriological culture in Trypticase Soy Agar, Blood Agar and Rimler-Shotts Agar. The isolates were identified by biochemical tests and Gram staining at the UPC Microbiology Laboratory.

5. RESULTS AND DISCUSSION

5.1 Consolidated bacteriological profile for Cesar

The integration of literature and field data allows us to propose a bacteriological profile for the department of Cesar. In acute mortality events, Streptococcus agalactiae is responsible for 50 to 60% of cases diagnosed by PCR. Second, Aeromonas hydrophila and Aeromonas veronii are responsible for 25 to 35%. Third, Flavobacterium columnare and Francisella orientalis, emerging pathogens, represent 5 to 10% and are usually underdiagnosed due to lack of molecular techniques.

In apparently healthy fish sampled on the farm, the profile changes. Bacteria of the genus Cetobacterium, which is a beneficial commensal, predominate with 30%, Aeromonas 40%, Plesiomonas 20% and Streptococcus as an asymptomatic carrier with 10%. This indicates that the fish can be a carrier without getting sick until it is stressed.

In fillets marketed in Valledupar, according to extrapolation from the study by Morales et al. (2012) and data from INVIMA 2023, the profile is dominated by indicator enterobacteriaceae: Klebsiella oxytoca 25%, Citrobacter freundii 20%, Enterobacter cloacae 15%, Escherichia coli 15% and Plesiomonas 10%. The presence of E. coli in fillet indicates post-harvest fecal contamination, probably due to handling without gloves or washing with contaminated river water.

6. DISCUSSION FROM ONE HEALTH AND CONCLUSIONS

The discussion cannot only be microbiological. It must be social. When a producer in Cesar loses a crop due to streptococcosis, he does not lose only fish. He loses the loan he took out at the Agrarian Bank, he loses his son's semester tuition, he loses confidence. And in that despair, the antibiotic seems the only quick solution. But it is a trap solution.

The One Health approach teaches us that the resistance we select for in the pond does not stay in the pond. The tetA gene that makes Aeromonas hydrophila resistant in El Paso can travel in a plasmid to Escherichia coli in the human intestine in Valledupar. And that resistant E. coli can cause a urinary tract infection that does not respond to treatment. That is already happening. The Rosario Pumarejo Hospital in Valledupar reported a 22% increase in infections with extended-spectrum beta-lactamase-producing E. coli in 2023.

For this reason, the proposal for the UPC seedbed is clear and has three pillars.

Pillar one: Real and applicable biosecurity. No expensive technology is needed. Bottom liming with quicklime at 2000 kilograms per hectare between harvests, sanitary vacuum of 15 days with drying in the sun, disinfection of nets and knives with hypochlorite at 200 ppm, control of piscivorous birds that are vectors of Streptococcus, and daily recording of mortality, oxygen and temperature. With that alone, mortality can drop from 30% to 5% according to FAO.

Pillar two: Fast and accessible diagnosis. The UPC should become a reference laboratory for molecular diagnosis of Streptococcus agalactiae by PCR in Cesar. Today, a producer must send samples to Bogotá and wait 15 days. In 15 days the harvest has already been lost. With a thermal cycler at the UPC and specific primers for the cfb gene and the 16S gene, we can give results in 24 hours.

Pillar three: Native probiotics. This is the line of research that we as students want to leave as a legacy. Instead of importing probiotics from the United States or Norway at 300 thousand pesos per liter, we can isolate bacteria from the intestine of healthy tilapia in Cesar, such as Enterococcus faecium, Bacillus subtilis, Myroides sp. and Exiguobacterium sp., which have already been shown at UNAL to inhibit Streptococcus agalactiae and Aeromonas hydrophila, and produce them in the UPC laboratory with Cesar sugarcane molasses as a substrate. It is circular economy, it is local science, it is technological sovereignty.

7. FINAL CONCLUSIONS

First: The bacteriological profile of red tilapia in Cesar is dominated by Streptococcus agalactiae serotype Ia and Ib and Aeromonas hydrophila, with a high load of enterobacteriaceae indicative of fecal contamination that reflect problems of water quality and post-harvest management. It is not a problem of the fish, it is a problem of the semi-intensive culture system with low turnover and high density.

Second: There is a documented, growing and worrying antimicrobial resistance to first-line antibiotics used in the region, especially ampicillin, oxytetracycline, tetracycline and trimethoprim-sulfamethoxazole, with the presence of resistance genes tetA, sul1, sul2, blaTEM and qnrS in fish bacteria and in effluents that reach the Cesar River.

Third: The particular conditions of Cesar, high temperatures, alkaline pH, low exchange rate due to energy costs and empirical use of antibiotics without diagnosis, favor the emergence and persistence of these pathogens.

Fourth: The Colombian regulatory framework is robust and up-to-date, especially ICA Resolution 020486 of 2023, but its application in the field in Cesar is low due to lack of institutional presence, lack of local diagnostic laboratories and lack of training for producers.

Fifth: The Popular University of Cesar, from its Microbiology program, has the technical capacity, human talent and social responsibility to lead the transition towards an antibiotic-free aquaculture based on molecular diagnosis, biosecurity and native probiotics. This review work is the first step of a research agenda that as students we want to continue in our undergraduate work.

8. RECOMMENDATIONS

For producers in Chiriguaná, El Paso and Bosconia: implement a daily logbook, do not self-medicate, respect a 30-day withdrawal time for oxytetracycline, make a sanitary vacuum and liming, install water inlet filters.

For the UPC: create the Collection of Aquaculture Strains of Cesar with registration with the Humboldt Institute, offer a diploma in Aquaculture Health and Biosecurity to technicians and producers, formulate a project with CORPOCESAR and AUNAP for AMR monitoring in the Cesar River and Ciénaga de Zapatosa.

For authorities: implement active surveillance of AMR in red tilapia in Cesar with quarterly sampling, incentives such as the seal of Good Aquaculture Practices for farms that do not use antibiotics, and financing of regional laboratories.

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