RESEARCH PAPER

Development Of Novel Plant-Derived Antiparasitic Formulations for Sustainable Aquaculture

S. Sudhakar*

Assistant Professor, Department of Zoology, H.H. The Rajah's College, Pudukkottai – 622 001, Pudukkottai District, Tamil Nadu, India. (Deputed From) Assistant Professor in Marine Biology, Centre of Advanced Study in Marine Biology (CASMB), Faculty of Marine Sciences, Annamalai University, Parangipettai – 608 502, Cuddalore District, Tamil Nadu, India.

*Corresponding Author Email ID: sudhakarcasmb@gmail.com

Abstract

Parasitic infections remain a major constraint to the productivity, welfare and economic sustainability of intensive aquaculture. Repeated use of conventional antiparasitic chemicals can create concerns relating to operator exposure, non-target toxicity, residues, environmental release and reduced treatment effectiveness. Plant-derived products contain chemically diverse secondary metabolites, including limonoids, organosulfur compounds, phenolics, flavonoids, terpenoids and tannins, that may interfere with parasite attachment, motility, tegument integrity, energy metabolism or reproduction. However, botanical activity alone does not establish therapeutic suitability: extract composition, formulation stability, host tolerance, water chemistry and environmental fate must be evaluated together. This article proposes the development and assessment of a standardized, water-dispersible botanical formulation based on Azadirachta indica (neem) and Allium sativum (garlic) extracts as candidate antiparasitic agents for freshwater aquaculture. The proposed workflow includes botanical authentication, controlled extraction, preliminary phytochemical screening, chromatographic fingerprinting, formulation optimization, physicochemical stability assessment, in-vitro parasite bioassays, acute fish-tolerance testing and a controlled in-vivo bath-treatment trial. A confirmed monogenean infection in Nile tilapia or another locally relevant host is used as the model system. Treatment performance is to be assessed through parasite abundance, prevalence, host survival, clinical condition, haematological and biochemical indices, gill histopathology and post-treatment recurrence. A randomized design with untreated infected, vehicle, positive-reference and multiple botanical-dose groups is recommended. Concentrations should be selected only after range-finding and host-safety studies; no universal safe dose is assumed. The principal outcome will be the therapeutic margin between parasite inhibition and adverse effects on the fish. Secondary outcomes will include formulation stability, changes in host stress and immune indicators, and potential effects on non-target aquatic organisms. The study is expected to provide a reproducible framework for translating medicinal-plant extracts into standardized aquaculture therapeutics. Its contribution will depend on demonstrating parasite-specific efficacy, acceptable host tolerance, batch-to-batch chemical consistency and environmental compatibility rather than relying on the assumption that natural products are inherently safe.

Keywords: aquaculture; antiparasitic; medicinal plants; Azadirachta indica; Allium sativum; monogeneans; botanical formulation; fish health; ecotoxicological safety; sustainable disease management.

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1. Introduction

Aquaculture is an increasingly important source of aquatic food, employment and livelihood. Intensification can improve production per unit area, but high stocking densities, handling, variable water quality and repeated movement of fish can increase opportunities for pathogen transmission. Parasitic infections are particularly important because ectoparasites can damage skin and gill epithelia, disturb osmoregulation, impair respiration, reduce feeding and growth, and create entry points for secondary infections. The consequences range from subclinical production losses to severe morbidity and mortality, depending on parasite identity, infection intensity, host condition and environmental conditions. Fish parasites include protozoans, monogenean flatworms, crustacean ectoparasites and internal helminths. Monogeneans are of particular practical concern in freshwater and marine farms because many species have direct life cycles and can multiply rapidly under favourable conditions. Their attachment organs and feeding activity may produce epithelial erosion, excess mucus, inflammation and respiratory compromise. Accurate identification is essential because treatment susceptibility differs among parasite groups and life stages. A product effective against a crustacean such as Argulus cannot automatically be assumed to control ciliates or monogeneans. Chemical bath treatments and other chemotherapeutic interventions remain part of fish-health management. Nevertheless, their selection and use must comply with local veterinary, food-safety and environmental regulations. Concerns about chemical residues, worker safety, non-target organisms and treatment failure have encouraged investigation of alternatives. Recent reviews identify phytotherapeutics, probiotics, immunoprophylaxis and other bio-based strategies as promising components of integrated disease management, while emphasizing the need for rigorous efficacy and safety evidence (Elgendy et al., 2024). Plant extracts are attractive because they contain multiple bioactive constituents and may be sourced from renewable biomass. Neem contains limonoid-related

compounds, while garlic contains organosulfur compounds such as alliin-derived products. Depending on extraction and processing, these constituents may exhibit antiparasitic, antimicrobial, antioxidant or immunomodulatory activity. Yet the chemical profile of a crude extract varies with plant genotype, growing conditions, harvest season, plant part, storage, solvent and extraction method. This variability can undermine reproducibility unless raw materials and extracts are standardized.

A further barrier is delivery. Many plant-derived constituents have low water solubility, are volatile or degrade under light, oxygen and heat. Direct addition of crude extract to culture water can result in uneven dispersion, uncertain exposure and rapid loss of active material. A suitable formulation should therefore improve dispersion and handling without introducing a carrier that is harmful to fish or aquatic organisms. The present work is designed around a formulation-development pathway rather than a simple screening of crude plant extracts. Neem and garlic are proposed as candidate botanicals, but their combination is not presumed to be synergistic. The study will determine whether standardized single extracts or a defined combination provides the best balance of parasite control, fish tolerance and environmental acceptability.

2. Literature Review

2.1 Parasitic disease pressure in aquaculture

Disease outbreaks are influenced by interactions among host, pathogen and environment. Crowding, organic loading, poor dissolved oxygen, abrupt temperature shifts and handling stress may weaken host barriers and facilitate parasite transmission. In monogenean infections, direct transmission can allow rapid amplification within a production unit. The parasite species, attachment site and developmental stage determine clinical presentation and response to treatment. Consequently, routine microscopy, parasite counts and confirmatory identification should precede treatment selection. The broader disease-management literature emphasizes prevention, biosecurity, water-quality management, vaccination where applicable, diagnostics and targeted therapeutics. Elgendy et al. (2024) reviewed alternative therapies for farmed-fish diseases and highlighted phytotherapeutics among approaches receiving increased attention. The authors also identify unresolved questions concerning efficacy, cost, availability, adverse effects and ecological risk. Botanical products should therefore be treated as candidates requiring the same level of scientific scrutiny as other veterinary interventions.

2.2 Plant-derived bioactive compounds

Plants synthesize secondary metabolites that function in defence against herbivores, microbes and environmental stress. Classes relevant to fish-health research include alkaloids, terpenoids, limonoids, flavonoids, phenolic acids, tannins, saponins, glycosides and organosulfur compounds. Their biological effects can involve membrane perturbation, enzyme inhibition, disruption of energy metabolism, altered neuromuscular activity or interference with parasite development. The actual mechanism depends on the compound, target parasite and exposure conditions; it should not be inferred solely from the presence of a phytochemical class. Neem (Azadirachta indica) is widely investigated because its tissues contain structurally diverse limonoids and related compounds. Azadirachtin is one recognized neem-derived bioactive molecule, but its abundance is not constant across plant parts or extraction conditions. A 2025 study evaluated azadirachtin in vitro against several ectoparasites affecting goldfish, including Ichthyophthirius multifiliis, Dactylogyrus and Argulus, illustrating the need to test different parasite taxa and life stages separately (Biopesticidal Efficacy and Safety of Azadirachtin, 2025). Garlic (Allium sativum) contains sulfur-containing precursors and enzymatically generated organosulfur compounds. Crushing and extraction conditions influence the composition of the final preparation. Garlic-derived preparations have been explored in aquatic animal health, but an antiparasitic claim must be linked to a defined extract, measured chemical profile and validated parasite endpoint. A crude garlic extract should not be treated as chemically equivalent to purified allicin or a standardized garlic oil.

2.3 Evidence for botanical antiparasitic approaches

Recent literature has expanded from isolated plant screening toward broader evaluation of herbal therapeutics in fish. Gadallah et al. (2024) reviewed herbal agents investigated against protozoan parasites in aquaculture and discussed the need for alternatives to conventional chemicals. Woo (2025) reviewed medicinal herbs and plants used against ciliate infections in finfish, including important pathogens such as Ichthyophthirius multifiliis and Cryptocaryon irritans. These reviews show that activity is parasite-specific and that evidence for one organism cannot be generalized to all fish parasites.

2.4 Formulation challenges

A botanical extract may be chemically active but unsuitable for direct application because of poor solubility, volatility, oxidation, photodegradation, precipitation or adsorption to tank surfaces. Formulation approaches include emulsions, nanoemulsions, liposomes, polymeric carriers and encapsulation in biodegradable materials. The choice must be proportionate to the intended application and supported by toxicological evidence. A simple water-dispersible emulsion may be preferable to a complex nanocarrier if it provides adequate stability and exposure consistency. The carrier is not biologically inert by default. Surfactants, solvents, preservatives and stabilizers can irritate gills or affect aquatic invertebrates. Every formulation therefore requires a vehicle control containing the same carrier concentration as the treatment. The carrier concentration should be minimized and screened independently. Formulation quality should be reported through droplet-size distribution where applicable, polydispersity, pH, visual separation, active-marker content and stability over the intended storage period.

3. Materials and Methods

3.1 Study design and ethical approval

The investigation should be conducted in four sequential phases: (I) botanical authentication and extract preparation; (II) formulation development and characterization; (III) in-vitro antiparasitic screening and host-tolerance range finding; and (IV) controlled in-vivo efficacy and safety evaluation. Before fish collection or experimental exposure, obtain approval from the relevant Institutional Animal Ethics Committee or competent national authority. Follow applicable national legislation and institutional standard operating procedures for animal care, anesthesia, humane endpoints and euthanasia.

3.2 Experimental organisms and parasite identification

Nile tilapia (Oreochromis niloticus) is proposed as a model because it is widely cultured; however, the final host must be selected according to local parasite prevalence and facility capacity. Collect naturally infected fish only under approved procedures. Examine skin, fins and gill mucus using wet mounts under light microscopy. Record parasite morphology, attachment structures, body dimensions and infection site. Preserve representative specimens for taxonomic confirmation. Where feasible, confirm parasite identity by DNA barcoding using an appropriate marker region selected for the taxon, such as 18S rRNA or a mitochondrial marker. Report primers, PCR conditions, sequence quality, database used and accession number. If molecular confirmation is not possible, use the most defensible morphological identification and state the limitation. Do not label an isolate as Dactylogyrus or Gyrodactylus without diagnostic evidence.

3.3 Plant material collection and authentication

Collect healthy leaves of Azadirachta indica and bulbs of Allium sativum from documented locations or authenticated suppliers. Record collection date, geographic origin, plant part, maturity, supplier and voucher specimen numbers. A qualified botanist or herbarium should authenticate each species. Deposit voucher specimens in an accessible institutional herbarium and report accession codes. Remove soil and foreign matter; wash with clean water, blot dry and dry under shade with adequate ventilation at a controlled temperature that limits degradation.

Grind dried material separately using a cleaned mill and store powders in airtight, light-resistant containers at a controlled temperature. Determine moisture content and retain representative samples for quality control. Do not combine plant materials before extraction because separate extraction allows the contribution of each botanical to be assessed.

3.4 Extraction and phytochemical characterization

Prepare extracts using a defined solvent system selected after a small-scale extraction comparison. A hydroethanolic solvent (for example, ethanol–water) may be considered for a broad range of polar and moderately polar constituents. The solvent ratio, plant-to-solvent ratio, extraction temperature, duration, agitation method and number of extraction cycles must be optimized and reported. Avoid assuming that one extraction protocol is optimal for both neem leaves and garlic bulbs. Filter the extracts and remove solvent under reduced pressure at a temperature appropriate to the stability of the constituents. Record extraction yield as dry extract mass divided by initial dry plant mass multiplied by 100. Store extracts in amber containers under validated storage conditions. Prepare a fresh working stock for each experiment and document the interval between preparation and use. Conduct preliminary qualitative tests for major phytochemical classes, followed by quantitative assays where appropriate. Total phenolic content may be estimated using the Folin–Ciocalteu method and expressed as gallic acid equivalents; total flavonoid content may be reported as quercetin equivalents. These are broad indices and should not be presented as identification of individual active compounds. Use HPLC-DAD, LC-MS or GC-MS according to the chemical properties of the candidate markers. For neem, quantify azadirachtin only if the analytical method and reference standard are validated for the matrix. For garlic, select and validate a suitable sulfur-containing marker; sample handling must account for the instability and transformation of reactive organosulfur compounds. Report calibration range, linearity, precision, recovery, limit of detection and limit of quantification where quantitative claims are made.



Figure 1. Experimental Workflow for the Development of Plant-Derived Antiparasitic Formulations in Sustainable Aquaculture

3.5 Formulation development

Develop three candidate preparations: neem extract alone, garlic extract alone and a defined neem–garlic combination. A preliminary screening matrix may examine botanical ratios such as 1:1, 1:2 and 2:1 by dry-extract mass. These ratios are experimental starting points, not recommended treatment proportions. Use a low concentration of an aquaculture-compatible emulsifier or dispersant and a water-based carrier. The carrier identity and concentration must be disclosed and independently evaluated for fish and non-target toxicity. Prepare formulations using controlled mixing and, if required, homogenization. Record mixing speed, duration, temperature and order of addition. Avoid claiming nanoemulsion formation unless droplet size and distribution are measured using a validated method. Characterize pH, appearance, phase separation, droplet-size distribution, polydispersity index, viscosity and marker-compound retention. Assess short-term physical stability under the intended storage conditions and after dilution into representative culture water. Select the lead

formulation using pre-defined criteria: reproducible marker content, acceptable dispersion, absence of visible precipitation during the intended exposure, compatibility with water quality, and no unacceptable vehicle toxicity. The lead formulation should proceed to biological testing only after these criteria are met.

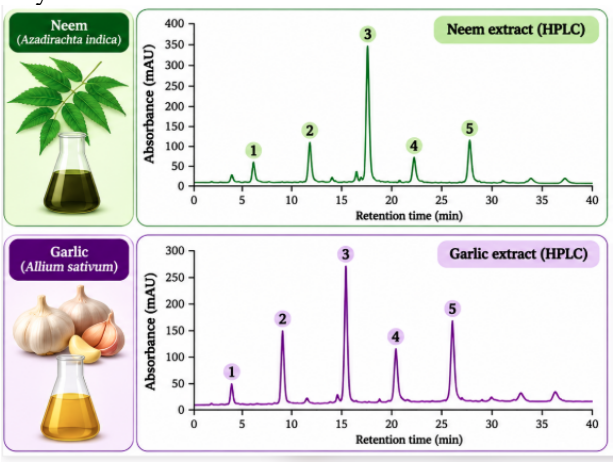

Figure 2. Chromatographic fingerprints of standardized neem and garlic extracts.

3.6 In-vitro antiparasitic assay

Obtain viable parasites from confirmed infected donor fish using approved handling procedures. Maintain parasites in suitable assay medium and minimize the time between collection and exposure. Randomly allocate parasites to treatment wells or chambers. Include untreated control, vehicle control, reference treatment where legally and ethically appropriate, neem extract, garlic extract and combination formulation. Use at least three independent biological replicates, with the final sample size determined by pilot variability and a power calculation. Conduct a range-finding assay to establish concentrations that span no observable effect to substantial parasite impairment. A pilot concentration series may be prepared using logarithmic or geometric spacing; the final concentrations must be selected from solubility, formulation and preliminary toxicity data. Do not transfer concentrations from unrelated parasite species without justification. Record exposure temperature, pH, dissolved oxygen where relevant, water hardness, illumination and exposure duration. Define parasite viability before starting the experiment. A parasite should be classified as non-viable only when it shows no movement after standardized gentle stimulation and the endpoint is confirmed using a pre-defined observation period. Record motility impairment separately from mortality. Examine parasites at fixed time points, for example 5, 15, 30, 60 and 120 minutes, if these intervals are appropriate for the parasite and pilot assay. Report the number examined and the number non-viable in each replicate. Calculate corrected mortality where control mortality is present using Abbott's correction only when its assumptions are met. If control mortality is high or unstable, invalidate and repeat the assay rather than mathematically correcting an unreliable experiment. Estimate concentration–response relationships using an appropriate binomial or dose-response model and report LC50/EC50 with 95% confidence intervals only when the data support such estimation.

3.7 Fish acute-tolerance and range-finding test

Before in-vivo efficacy testing, conduct a stepwise host-tolerance study using healthy, parasite-screened fish. Begin with a conservative range-finding phase and observe fish continuously during initial exposure and at scheduled intervals thereafter. Record abnormal swimming, loss of equilibrium, rapid opercular movement, excess mucus, surface gasping, feeding response and mortality. Measure dissolved oxygen, temperature, pH and other relevant water-quality variables. Use a recognized aquatic toxicity framework adapted to fish welfare and the intended short bath exposure. The test should identify a no-observed-adverse-effect concentration or other defensible tolerance threshold. A conventional 96-hour LC50 is not automatically an appropriate therapeutic endpoint for a short-duration bath product; select the test duration based on the intended exposure and ethical review. Stop exposure and provide rescue care when humane endpoints are reached.

3.8 In-vivo experimental setup

Use a randomized controlled design with replicate tanks as the experimental units. Fish should be similar in size and condition and randomly allocated after acclimation and baseline parasite assessment. Avoid treating individual fish within a shared tank as statistically independent replicates. Tank replication, rather than the number of fish alone, is critical to valid inference.

Group	Treatment	Purpose	Dose selection
G1	Infected, untreated	Disease progression control	No botanical
G2	Infected, vehicle only	Carrier effect control	Same carrier level
G3	Infected, reference treatment	Benchmark, if approved	Label/regulatory dose
G4	Neem formulation	Single-plant efficacy	Low safe dose
G5	Garlic formulation	Single-plant efficacy	Low safe dose

G6	Neem–garlic formulation	Combination efficacy	Optimized safe dose
G7	Uninfected, vehicle	Baseline host response	Vehicle only
G8	Uninfected, lead formulation	Direct host tolerance	Selected safe dose

The table is a proposed design and may be reduced or expanded according to the confirmed parasite, facility capacity and ethical approval. A minimum of three independent tanks per group is a common starting point, but the final number must be justified by power analysis and expected tank-level variation. The number of fish per tank should be determined from stocking density, fish size, water volume and welfare requirements.

3.9 Treatment procedure and monitoring

Use a short bath exposure only if preliminary tests demonstrate that the selected formulation can be safely delivered by this route. Record the exact formulation concentration, exposure time, water volume, aeration, temperature, pH and dissolved oxygen. After exposure, transfer fish to clean recovery water where the protocol requires it. Ensure that all groups experience comparable handling and water exchange. Do not discharge treatment water directly to natural water bodies; collect and manage it according to institutional and local environmental requirements. Assess parasite burden at baseline and at pre-specified post-treatment intervals. Use a standardized sampling procedure and, where possible, a blinded observer. Record prevalence (infected fish/total examined × 100), mean intensity (parasites per infected fish) and abundance (parasites per fish examined). Monitor fish survival, feeding, behaviour and external lesions. A follow-up period should be long enough to detect recurrence or reinfection, while recognizing that environmental exposure and parasite life-cycle stage may affect interpretation.

3.10 Host health, histology and environmental assessment

Collect blood at baseline and at the terminal sampling point using an approved anaesthesia and sampling protocol. Potential endpoints include haemoglobin, haematocrit, red and white blood cell counts, glucose, total protein, albumin, globulin, alanine aminotransferase, aspartate aminotransferase and selected oxidative-stress markers. The choice should be hypothesis-driven and feasible for the laboratory. Report assay kits or analytical methods, instrument model, calibration and quality-control procedures. Fix gill, liver and kidney tissues in an appropriate fixative and process using standard histological procedures. Score lesions using a pre-defined semi-quantitative scale and blinded assessment. Representative micrographs should include scale bars and magnification. Avoid interpreting minor histological variation as treatment injury without a control comparison and suitable statistical analysis. Environmental screening should consider the potential effect of the active formulation and its carrier on representative non-target organisms. Depending on the local ecosystem and available facilities, a validated test organism such as a freshwater microcrustacean or algal species may be selected. The test must use an accepted protocol and include a solvent/vehicle control. Measure degradation or marker loss in water where analytical capability exists. A plant-derived formulation should not be described as biodegradable or environmentally safe unless those properties have been experimentally demonstrated.

3.11 Statistical analysis

Present continuous variables as mean ± standard deviation or median and interquartile range, depending on distribution. Check residual normality and variance assumptions. Use a mixed-effects model where tank is the experimental unit and repeated observations are collected over time. For parasite prevalence, use a binomial generalized linear mixed model; for parasite counts, consider Poisson or negative-binomial models after checking overdispersion. For concentration–response data, fit an appropriate nonlinear model and report effect estimates with confidence intervals. Correct for multiple comparisons where appropriate and report exact p-values, effect sizes and confidence intervals. Statistical significance should not replace biological interpretation. Pre-register primary outcomes and analysis decisions where feasible.

4. Results and Discussion

4.1 Important note on reporting

No experimental observations were provided for this draft. Accordingly, this section is written as a results-reporting framework with interpretation guidance. It must not be submitted as though the proposed experiments have already been performed. Replace each bracketed field with the measured value, sample size, statistical estimate and relevant figure or table number. If the work is intended as a review or protocol paper rather than an experimental article, revise the title and methods accordingly.

4.2 Extraction yield and phytochemical profile

The chromatographic fingerprint should identify major peaks by retention time and, where supported by standards or mass spectra, compound identity. The discussion should relate batch consistency to the selected marker compounds rather than attributing activity to an unconfirmed constituent. If the neem extract contains a measurable azadirachtin marker, report its concentration per gram of dry extract and provide the analytical method validation. If garlic organosulfur markers are unstable or below quantification limits, state this clearly and avoid

using allicin as a quantitative descriptor without direct measurement. Variations between plant batches should be discussed in relation to origin, harvest, storage and extraction conditions.

4.3 Formulation characteristics and stability

Present formulation pH, viscosity, droplet size, polydispersity, visual stability and marker retention at the initial time point and during storage. A suitable table should compare the unformulated extracts and candidate formulations. If phase separation occurs, report the time and conditions. If the formulation remains physically dispersed but marker concentration decreases, distinguish physical stability from chemical stability. A formulation should not be described as stable solely because no visible separation is observed. The most promising formulation should be selected using the pre-defined quality criteria. Explain why the selected botanical ratio and carrier concentration were chosen. If the combination does not outperform the best single extract, the combination should not be described as synergistic. Synergy requires a formal interaction analysis, such as an appropriate combination-index or response-surface method.

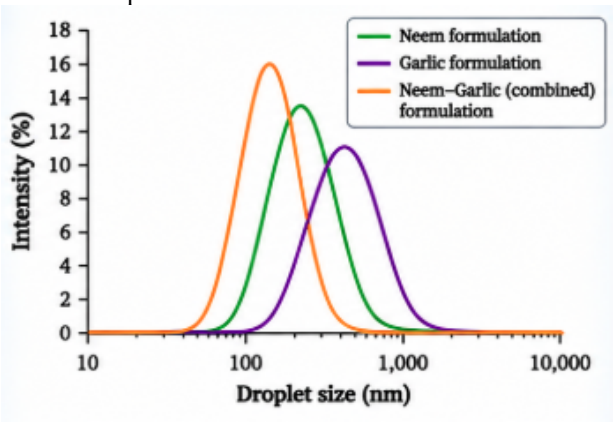

Figure 3. Formulation droplet-size distribution and stability profile

4.4 In-vitro antiparasitic activity

Report the proportion of viable parasites at every concentration and observation time, with the number of parasites and independent replicates. A concentration–response curve should be presented for each extract and the combination. Report EC50/LC50 estimates only where the model fit is adequate. Distinguish reversible motility suppression from confirmed parasite death. Include control mortality and vehicle-control responses to demonstrate assay validity. A treatment-associated reduction in parasite viability would support further evaluation only if the vehicle control is inactive and the response is reproducible across independent biological replicates. Differences among neem, garlic and combination treatments may reflect variation in chemical composition, bioavailability or parasite susceptibility. Mechanistic explanations should be presented as hypotheses unless supported by microscopy, biochemical assays or molecular evidence.

4.5 In-vivo parasite reduction and host response

Report baseline comparability among groups before treatment. The principal efficacy endpoint should be the change in parasite burden relative to the infected untreated and vehicle controls. Provide prevalence, mean intensity and abundance with confidence intervals. Include fish survival and clinical observations. If parasite burden decreases but fish show respiratory distress or abnormal behaviour, the formulation cannot be considered therapeutically acceptable. A successful treatment would demonstrate a meaningful reduction in parasite burden while maintaining survival, feeding behaviour and physiological indices within acceptable ranges. Histological evidence should be interpreted alongside blood and clinical findings. Improvement in gill architecture may be consistent with reduced parasite-associated injury, but causality should not be claimed unless the study design controls for natural recovery and other confounders.

4.6 Environmental implications and limitations

Environmental compatibility requires more than plant origin. Active compounds may affect non-target invertebrates, algae or microbial communities, and the carrier may alter water quality. The environmental discussion should therefore be based on measured non-target endpoints, water stability and disposal procedures. The absence of observed acute toxicity in one test organism does not establish ecosystem-wide safety. Likely limitations include variability in botanical composition, instability of selected phytochemicals, parasite identification challenges, short observation periods, and limited extrapolation from laboratory tanks to commercial ponds. A field trial should follow only after replicated laboratory efficacy, host tolerance, product standardization and regulatory review. The study should also consider cost per treated volume, supply-chain consistency and farmer handling requirements.

5. Conclusion

This manuscript presents a research framework for developing a standardized plant-derived antiparasitic formulation for sustainable freshwater aquaculture. Neem (Azadirachta indica) and garlic (Allium sativum) are proposed as candidate botanical sources, with the final formulation to be selected through chemical characterization, formulation screening and parasite-specific bioassays. The design integrates in-vitro efficacy, host-tolerance testing, controlled bath treatment, parasite-burden assessment, fish-health monitoring and preliminary environmental evaluation. The central scientific requirement is to establish a therapeutic window: a concentration and exposure schedule that reduces the target parasite without causing unacceptable harm to the fish or surrounding aquatic environment. Chemical fingerprinting and batch-control procedures are necessary to ensure reproducibility. A combination formulation should be claimed to be synergistic only after formal interaction analysis. Likewise, biodegradability, environmental safety and commercial suitability must be supported by direct evidence. The proposed work may contribute to integrated parasite management by providing a reproducible pathway for evaluating botanical therapeutics. It should be regarded as a candidate

development programme rather than evidence that neem–garlic products are already validated treatments. Further studies should investigate chronic exposure, parasite life-cycle effects, residue or tissue depletion where relevant, non-target organisms, formulation shelf life, farm-scale performance and compliance with applicable veterinary and food-safety regulations.

References

Daniel, E. (2024). Use of medicinal plants in the control of fish parasites and problems related to their use in ethnoveterinary treatment—A review. Journal of Istanbul Veterinary Sciences, 8(3). https://dergipark.org.tr/en/pub/http-www-jivs-net/article/1572627

Elgendy, M. Y., Ali, S. E., Dayem, A. A., Khalil, R. H., Moustafa, M. M., and co-authors. (2024). Alternative therapies recently applied in controlling farmed fish diseases: mechanisms, challenges, and prospects. Aquaculture International, 32, 9017–9078. https://doi.org/10.1007/s10499-024-01603-3

Gadallah, A. O., Kaya, D., Gürler, A., & Genç, E. (2024). Effective herbal therapeutics against the protozoan parasites in aquaculture. Ege Journal of Fisheries and Aquatic Sciences, 41(2), 158–165. https://doi.org/10.12714/egejfas.41.2.10

Morales-Serna, F. N., and co-authors. (2026). Plant-derived treatments for monogenean parasites in farmed fish: A systematic review and meta-analysis. Reviews in Aquaculture. https://doi.org/10.1111/raq.70152

Tan, X., Yang, C., Zhou, Q., and co-authors. (2026). The application of herbal medicines for parasites control in aquaculture: A review. Reviews in Aquaculture, 18(3), e70151. https://doi.org/10.1111/raq.70151

Woo, S. J. (2025). Application of medicinal herbs and plants to control ciliate infection in finfish for sustainable aquaculture: A review. Reviews in Aquaculture, 17(4), e70063. https://doi.org/10.1111/raq.70063

Phytotherapeutics for parasite control in global fish aquaculture: A review of anti-monogenean agents and their mechanisms. (2026). Aquatic Living Resources, 39. https://doi.org/10.1051/alr/2025021