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Bridging knowledge gaps in fish health management through education, research, and biosecurity

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Education, research, and biosecurity have global recognition as strong pillars of sustainable aquaculture development. In many developing countries, insufficient knowledge and awareness among stakeholders regarding the relevance of education, research, and biosecurity have influenced aquaculture sustainability negatively. To uncover the gaps in education, research, and biosecurity practices in aquatic animal health management, we conducted a questionnaire-based study in various East and West African countries. By adopting the methodology of self-reporting data, we invited a significant number of individuals to participate in the study. In the end, 88 respondents contributed, with the majority from Ghana (47) and Kenya (20), and 21 respondents from five other East and West African nations. The results revealed substantial educational gaps, including the need for practical training in aquatic animal health management, nutrition, and genetics. Respondents also emphasized the importance of creating additional national aquaculture research institutions and augmented funding to enable them to address industry needs. Governments of the represented nations should actively intervene by providing the essential logistics and capacity to support aquaculture research and development. Informed government involvement is paramount for bridging the disconnection among all stakeholders, as revealed in the results. Furthermore, the lack of biosecurity measures and the understanding of the importance of biosecurity measures in the industry addressed through awareness creation. Creating awareness on biosecurity underpinned with national aquaculture biosecurity policies can prevent disease incidences in the industry. The outcomes of this study can serve as a vital working document to enhance aquatic animal health management in East and West Africa, thereby fostering sustainable and resilient aquaculture.

KEYWORDS
African aquaculture, fish health management, education, research, biosecurity

1. Introduction

Severe exploitation of wild fish stocks in several geographical areas against the growing global human population, is expected to reach 9 billion by 2050 (United Nations, 2007; Oidtmann et al., 2011). This has increased pressure and demand on aquaculture to supplement capture fisheries to meeting the deficit in fish production. The aquaculture industry is already playing a key role in providing animal protein to support global food security. Egypt in North

Africa is the leading producer of farmed fish on the Africa continent, followed by East and West Africa, at second and third position, respectively (Hinrichsen et al., 2022). The adoption and implementation of better management practices for routine control, disease prevention and surveillance has not matched the intensification of aquaculture production (Kyule-Muendo et al., 2022). As a result, aquaculture in Africa and other regions have been subjected to many disease incidents of bacterial, viral, mycotic, and parasitic in nature.

Proper aquatic animal health management must accompany aquaculture practices to sustain the industry (Chinabut, 2001; Opiyo et al., 2018; Peeler and Ernst, 2019). Health services in aquatic animals are relatively undeveloped as compared to health services in terrestrial animals (Peeler and Taylor, 2011; Scarfe and Palić, 2020). In many of the developing countries, inadequate or lack of fish health services stems from the perception that fish do not get sick. However, this perception is changing particularly in Africa when the economic impacts of fish disease outbreaks have been devastating. Stakeholders are consequently gaining interest in fish health management through a myriad of national and regional projects (Kyule-Muendo et al., 2022) in the wake of these outbreaks. It is worthy to note that several related NORAD (Norwegian Agency for Development Cooperation)-financed projects aimed at boasting sustainable aquaculture production in East and West Africa have been initiated. For example, the ongoing Aquatic Animal Health in Africa project (AHA). AHA aims at increasing sustainability and resilience in the aquaculture sector by improving aquatic animal health management in East and West Africa (WorldFish, 2021). The beneficiary countries of the project are principally Ghana and Kenya but includes some neighbouring countries, due to recent economic losses caused by disease-causing vectors in their aquaculture sectors (Abarike, 2018; Opiyo et al., 2018). Among these other East and West African countries were Madagascar, Mozambique, Malawi, Zambia, Nigeria, and Mali as beneficiaries through training programs aimed at building a network of competent practitioners in aquatic animal health management across the continent. Central in the AHA project is the enhancement of education and the capacity-building in research and biosecurity to improve aquatic animal health management.

Education and training are essential for developing the right set of skills for aquatic animal health management. It is therefore paramount to identify the appropriate level of knowledge and technical skills needed in the curricular of educational institutions to effectively manage aquatic animal health (Weber et al., 2009; Scarfe et al., 2021). This will ensure that education focusses on providing not only degrees but the competencies and skills needed by aquatic animal health professionals. Educational institutions must provide competencies and skills that match the needs of the growing aquaculture industry in developing countries (Subasinghe et al., 2001). For this to happen, there should be effective partnership between public and private sectors, where expectations of all parties are clearly defined (Scutt and Ernst, 2019). Similarly, research institutions need public-private sector partnerships to undertake studies that inure to the benefit of the industry. The need to set up research institutions, co-funded through public-private sector collaborations to conduct targeted research in fish health management is essential (Anon, 2001; Bondad-Reantaso et al., 2005; Scutt and Ernst, 2019). Some of the essential research areas for fish health management include among others, hazards identification, transmission patterns, host susceptibility, and interventions (Peeler et al., 2007).

Identifying indispensable research areas is essential not only for conducting targeted research in fish health management but can inform specific biosecurity measures. Biosecurity is a fundamental component in fish health management practice to reduce the risk of introduction, establishment, and spread of diseases [World Organization for Animal Health (WOAH), 2019]. However, many developing countries have been lacking, inadequately implementing, or poorly applying biosecurity measures (Adah et al., 2023; Georges et al., 2023). These countries are increasingly recognizing the importance of aquaculture biosecurity and conducting sensitization programs. Yet, additional efforts are required to maintain this awareness through education and research (Osborn and Henry, 2019). In essence, education and research can form the foundation of fish health management by generating the necessary knowledge for creating robust biosecurity plans, which are critical for the success of aquaculture. The AHA project argues that by leveraging the power of education, research, and biosecurity in East and West Africa, we can promote aquatic animal health management for resilient aquaculture. This study therefore aims at identifying the gaps in education, research, and biosecurity practices to underpin capacity building initiatives in fish health management in East and West Africa.

2. Materials and methods

2.1. Study design and data collection

This is a cross-sectional study that collected data relevant to identifying the knowledge gaps in education, research, and biosecurity practices in East (Kenya) and West (Ghana) Africa. The data was collected using an online survey consisting of unstructured and structured questions (Table 1). The majority of the structured questions require nominal responses (e.g., Yes/No/Do not Know), including other responses based on predetermined categories (e.g., Likert scale, educational levels, etc.). There was an unstructured question conceived to investigate the major challenges affecting research quality and suggestions for improvement. The online survey was disseminated widely to aquaculture stakeholders in Ghana and Kenya, through emails and follow-up telephone calls to aquaculture associations and public sector institutions. These stakeholders working along the aquaculture value chain in academia, including private and public sector institutions are the target population of the study. The responses to the online survey were based on self-reporting leading to diverse respondents from the target countries, and other respondents in East and West Africa with aquaculture interest. Apart from collating diverse respondents, self-report studies are less expensive, not always time consuming, and representative of the target population for findings to be used in drawing general inferences (Short et al., 2009). The self-reporting of data through the online survey started in August 2021 and closed in May 2022 for data analysis.

2.2. Data analysis

The responses to the online survey were collated in Microsoft Excel and filtered to remove all blanks caused by unanswered questions. The diverse aquaculture respondents were then grouped into academia, private, and public sector based on a structured question that investigated their sector affiliations. This grouping became relevant in visualizing the distributions of nominal responses (Yes/No/Do not Know) across sectors. The nominal response data was categorized into contingency table, and then the Chi-square statistic ($\alpha = 0.05$) was calculated in SPSS to assess the association between the independent variables (sectors) and the dependent variables of Yes, No, and Do not Know. Chi-square statistic is a non-parametric test that analyzes group differences when the dependent variable is measured at a nominal level (McHugh, 2013). We therefore investigated whether the "Yes, No, and Do not Know" responses were independent or influenced by sector affiliations. Subsequently, the results were visualized in graphs using the number of respondents to the response categories, as a percentage of the total respondents to each question. The responses to some of the structured questions such as those on Likert scale were pooled together to draw general conclusions across sectors. This was necessary because the data becomes much more complex when analyzed in sectors yet did not produce any emergent information. The comments on the open-ended question were summarized including quoting of some selected comments as evidence of originality.

3. Results

3.1. Respondent characteristics

The final respondent sample consisted of 88 participants, comprising twenty (20) Kenyans, forty-seven (47) Ghanaians, and additional respondents from Madagascar (3), Mozambique (4), Nigeria (5), Malawi (4), and Zambia (5). In total, the response rate for all the questions was 97%. The lowest response rate was 36 out of 88 (Table 1; footer note), with an average response rate of 82.7 for the online survey questions. Table 2 shows the number of respondents in academia, private, and public sector, with 24, 16, and 48 individuals, respectively. This included the percentage of respondents per occupation according to their respective sectors.

3.2. Education

More than half of the respondents (55.2%) reported the introduction of aquaculture education at the university level. Twenty-eight percent (28.7%) selected the introduction of aquaculture education at the high school level, while 16.1% selected diploma level (Figure 1A). Aquatic animal health is taught through bachelor courses (64.4%) compared to 19.5%, 9.20%, and 6.9% for Master courses, infrequent courses, and "others" respectively (Figure 1B). At the high school level, 58% of the participants selected 'more than 40 students' as the percentage of students graduating each year. The number of aquaculture graduates with bachelor's degrees is 'more than 40 students' (73%) per year. The highest number of aquaculture graduates with master's degrees is distributed among "less than 20 students" and "20–40 students" as reported by 41% and 38% of correspondents, respectively. The number of graduates with aquaculture PhD degrees is less than 20 students (80%) per year (Figure 1C). In Figure 1D, majority of the respondents in academia (92%) and public (83%) sector confirmed the presence of aquatic animal health in the aquaculture curriculum, while the private sector showed some uncertainty (67%). The three most important gaps to consider in aquaculture curriculum planning for industry needs are aquatic animal health management (95.3%), aquatic animal nutrition (51.2%), and aquatic animal genetics (45.3%) (Figure 1E). The Pearson Chi-square statistics show that the responses were not influenced by sector affiliations (Figure 1D).

According to respondents (Figure 2A), the three most important gaps to consider in aquaculture curriculum planning to support government needs are controlling diseases and improving aquatic animal health management (77.9%), improving the regulatory aspects of aquaculture (38.4%), and increasing education related to aquatic animal genetics (33.7%). Across sectors, there were no responses indicating the exclusive teaching of aquatic animal health through practical courses alone. The private sector primarily views courses as theoretical (53%) but acknowledges that some practical training elements (47%) are included in the theoretical courses. Respondents from academia (58%) and the public (57%) sector confirmed a blend of practical and theoretical lessons (Figure 2B). The private sector takes the lead (67%) in providing entry-level training for newly hired technical staff. For academia and public sector, there is no clear evidence to affirmatively indicate entry-level training for newly hired technical staff, given the prevalence of "No" and "Do not Know" responses, which exceed "Yes" responses in both sectors (Figure 2C). Across all sectors, more than 40% of the respondents confirmed the absence of on-the-job training for technical staff. The private (43%) and public (42%) sectors confirmed presence of on-the-job training, whereas academia (24%) had a relatively lower rate (Figure 2D). Most of the respondents are inclined towards easy employability of graduates in the aquaculture industry. However, in national and provincial institutions, obtaining employment is not easy (Figure 2E). Pearson Chi-square statistics indicate that the responses were not influenced by sector affiliations (Figures 2B–D).

3.3. Research

More than 90% of the respondents confirmed the existence of institutions engaged in aquaculture research (Figure 3A). Over 60% of the respondents stated that the number of aquaculture research institutes is insufficient to support the industry needs (Figure 3B). Of the respondents, 55.2% indicated that aquaculture research questions were generated to meet academic interests, while, 27.6% mentioned that research questions addressed industry needs. About 17.2% of the responses pointed out that research primarily serves authority needs (Figure 3C). Aquaculture research is funded mainly by international organisations (41.9%) and through international collaboration (38.4%). National research funds for aquaculture was attributed to 18.5% of the respondents (Figure 3D). The Pearson Chi-square statistics indicated that the responses were not influenced by sector affiliations (Figures 3A,B).

More than 45% of the respondents from academia and private sectors indicated the absence of functional national laboratories dedicated to fish health diagnostics. Nonetheless, the public sector tend to confirm the presence of functional laboratories (56%), a clear bias to indicate a semblance of their usefulness (Figure 4A). The three main diagnostic laboratories available for confirming field diagnoses include public laboratories (46.5%), national reference laboratory (29.1%), and foreign laboratories (24.4%) (Figure 4B). There is

TABLE 1 Online survey questions to evaluate gaps in education, research, and biosecurity.

Theme	Question	Response categories	Response rate (a/b)*
Education	- At which academic level is the aquaculture education introduced?	High school; Diploma; University	87/88
	- At which level is aquatic animal health taught?	Bachelor courses; Master courses; Infrequent courses; others	87/88
	- At the national level, what is the average number of students graduating from these courses/year [High school; Bachelor; Master; PhD][#]	Less than 20; 20–40; More than 40	252/264
	- Is aquatic animal health part of the aquaculture curriculum?	Yes; No; Do not know aquaculture curriculum?	87/88
	- What would you consider the 3 most important gaps to fill in the present aquaculture curriculum to support industry needs?	Aquatic animal nutrition; Aquatic animal genetics; Diseases and aquatic animal health management; to support industry needs? Basic farming knowledge; Technical knowhow; Environmental issues; Marketing and consumer perceptions; Food hygiene and quality; Economy; Others	86/88
	- What would you consider the 3 most important gaps to fill in the present aquaculture curriculum to support governmental needs?	Aquatic animal nutrition; Aquatic animal genetics; Diseases and aquatic animal health management; Basic farming knowledge; Technical knowhow; Environmental issues; Marketing and consumer perceptions; Food hygiene and quality; Economy; Regulatory aspects; Others	86/88
	- Are the aquatic animal health courses practical, theoretical, or both?	Practical; Theoretical; Both	86/88
	- Are newly hired technical staff given entry-level training?	Yes; No; Do not know	86/88
	- Are technical staff regularly called for continuation and on-the-job training?	Yes; No; Do not know	83/88
	- Graduates easily get employment in the following sectors [Aquaculture industry; National institutions; Provincial institutions]¤	Neutral; Agree; Disagree; Strongly agree; Strongly disagree	253/264
Research	- Are there any research Institutions doing aquaculture research as a primary focus?	Yes; No; Do not know	87/88
	- If yes, are they enough to support aquaculture industry in the country?	Yes; No; Do not know	87/88
	- In general, how are research questions generated?	Industry interest; Authority interest;	87/88
	- How is aquaculture research funded?	International organizations; International collaborations; National research funds; Industry funded	86/88
	- Are there dedicated national fish health diagnostic laboratories in service?	Yes; No; Do not know	87/88
	- What type of diagnostic laboratories confirm field diagnoses?	Foreign laboratories; National reference laboratory; Public laboratories; private laboratories; Do not know	86/88
	- Do research institutions meet farmers and industry expectations in terms of providing science-based solutions for aquaculture problems?	Yes; No; Do not know	87/88
	- Results from research are easily available for all stakeholders?	Neutral; Agree; Disagree; Strongly disagree; Strongly agree; Do not know	87/88
	- What are the major challenges affecting research quality? Any suggestions for improvement?	None (open-ended answers)	78/88
Biosecurity	- Are there regulations that guide government and industry's engagement in aquaculture?	Yes; No; Do not know	87/88
	- Are there legislation that mandate biosecurity on farms?	Yes; No; Do not know	86/88
	- Do you think there is high compliance to mandated biosecurity measures?	Yes; No; Do not know	86/88
	- How do competent authorities monitor biosecurity on farms?	Never; Do not know; When necessary; Annually	87/88
	- Is there a national aquatic animal biosecurity policy or plan?	Yes; No; Do not know	87/88
	- Are there biosecurity checklists to which farms must comply? [National biosecurity; Industry biosecurity; Farm biosecurity]¤	Yes; No; Do not know	246/264
	- How do competent authorities monitor biosecurity on farms?	Questionnaires; Farmers self-reporting; Inspector extension service; Do not know; Other	86/88
	- Are farmers given any biosecurity specific training?	Yes; No; Do not know	86/88

*Response rate (a – number of respondents; b – total number of respondents). [#]36/88 – high school; 74/88 – bachelor; national institutions; 84/88 – provincial institutions. ¤85/88 – national biosecurity; 79/88 – industry biosecurity; 82/88 – farm biosecurity.

TABLE 2 Demographic information of sector respondents.

Sector (*N*)	Occupation	Percentage of respondents (n)
Academia (*N* = 24)	- Lecturer	62.5 (*n* = 15)
	- Student	16.7 (*n* = 4)
	- Research scientist	20.8 (*n* = 5)
Private (*n* = 16)	- Fish farmer	50 (*n* = 8)
	- Research scientist	31.1 (*n* = 5)
	- Feed producer	6.3 (*n* = 1)
	- Student	6.3 (*n* = 1)
	- Veterinarian/epidemiologist	6.3 (*n* = 1)
Public (*n* = 48)	- Compliance officer	52 (*n* = 25)
	- Research scientist	12.5 (*n* = 6)
	- Lecturer	14.6 (*n* = 7)
	- Veterinarian/epidemiologist	14.6 (*n* = 7)
	- Fish farmer	2.1 (*n* = 1)
	- Technician	2.1 (*n* = 1)
	- Unspecified	2.1 (*n* = 1)

N = total respondents/sector; *n* = subtotal of respondents/occupation.

insufficient evidence from academia regarding the sharing of science-based solutions, as 38% of responses were recorded for both "Yes" and "No" respectively. Majority (50%) of the private sector answered "Yes" while majority (46%) of the public sector answered "No" (Figure 4C). Regarding the availability of research findings, 20.7% of the respondents stated that research findings are made available to all stakeholders, with some respondents expressing neutrality (32.2%) and disagreement (33.3%). A small percentage of the respondents (9.2%) strongly disagreed on the availability of research findings (Figure 4D). Pearson Chi-square statistics indicated that the responses were not influenced by sector affiliations (Figures 4A,C).

3.3.1. Major challenges affecting research quality and suggestions for improvement

Funding is a major challenge affecting research quality. Respondents expressed concerns about inadequate funding from government and industry for purchasing equipment/tools, and supporting diagnostic and research works. Some responses provided evidence of reliance on international bodies for funding instead of receiving sufficient national funding to address industry needs through research. Here are some examples of comments supporting this concern: "*(1) Poor funding from the government and lack of logistics and (2) Most research funds come from external sources, therefore, research projects are often tailored to meet donors' needs*." Some respondents mentioned problems related to weak infrastructural development and shortage of human resources. This includes antiquated laboratories and a limited number of fish health experts which in turn affect research quality. Comments supporting these limitations include: "*(1) The institutions conducting research are understaffed, which hinders their ability to conduct rigorous research that will result in accurate information and (2) Unavailability of essential equipment for conducting analyses*".

Other responses revealed the inadequacy of research bodies focusing on aquatic animal health. As a result, a recommendation was made for the establishment of Centres of Excellence in various universities dedicated to research and training in aquatic animal health management. Some respondents further suggested that these research centres could act as liaisons between the industry and government. Comments supporting these arguments include: "*(1) The establishment of a Centre of Excellence in a university dedicated to aquatic animal health, with the goal of spearheading research and training while acting as a liaison between industry and government and (2) The provision of infrastructure for aquatic animal health diagnostics and surveillance, including the establishment of a national reference laboratory*".

The respondents have also identified weak cooperation between researchers and the industry, as well as issues with poor research techniques and experimental designs. Some respondents have suggested establishing researcher-farmer partnerships to better understand industry needs. These partnerships are believed to inform the development of appropriate methodologies and experimental designs to generate research-based information necessary for industry use. According to some respondents, research quality has been compromised due to lack of trust between researchers and farmers. The respondents attributed this lack of trust to a failure to communicate research findings to the farmers who cooperated during data collection. Other responses have buttressed the weak linkage between universities, research institutes, and the industry. Supporting comments from the transcripts include: "*(1) Lack of effective coordination between the industry and academia, (2), Poor research techniques that affect the results of research, and (3) Weak linkages between research and the industry*".

3.4. Biosecurity

More than 80% of respondents across all sectors confirmed the presence of aquaculture regulations guiding government and industry engagements. However, about 10% of public sector respondents expressed a lack of knowledge ("Do not Know") regarding regulatory instruments, probably because they may not feel the effects of their

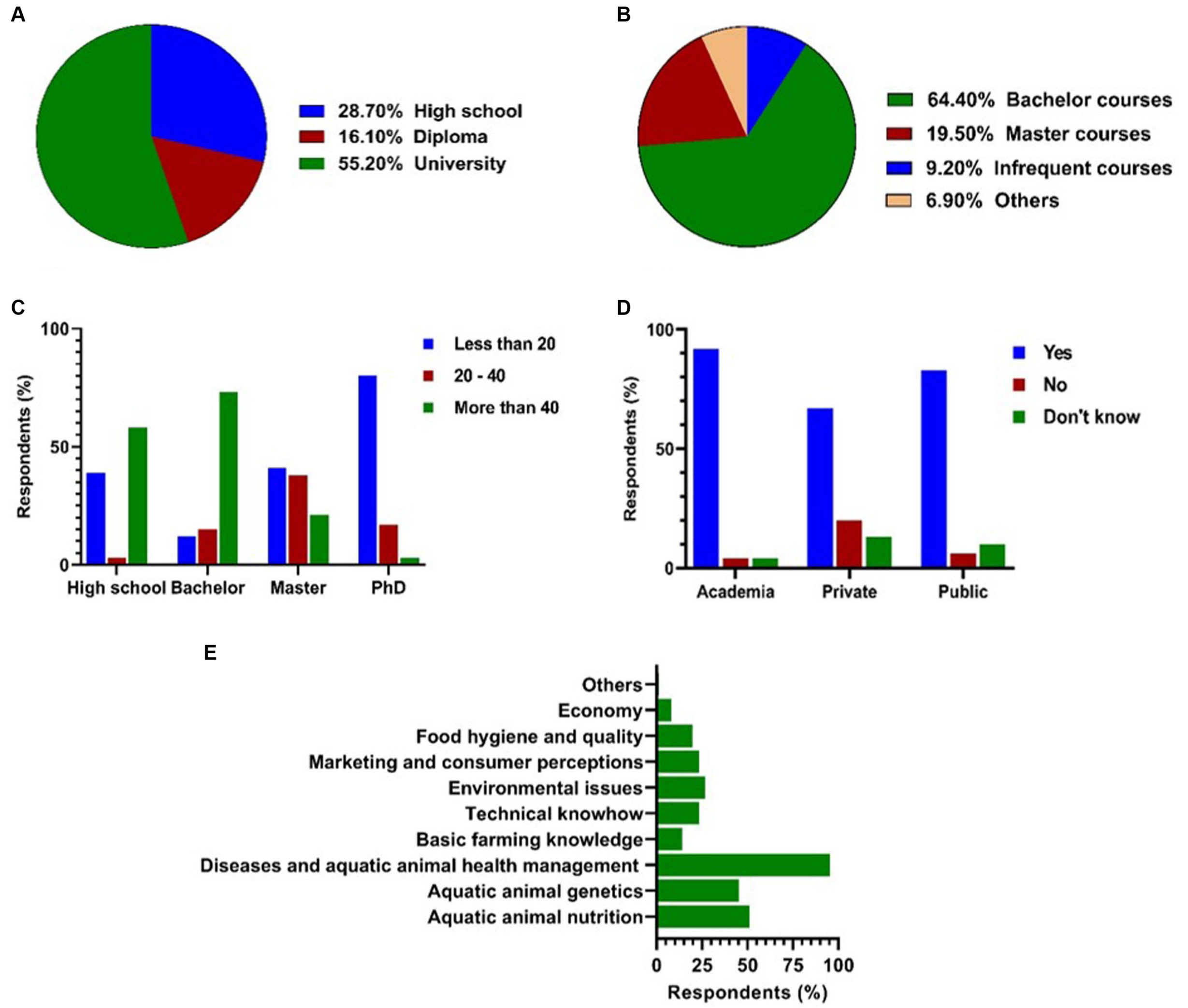

FIGURE 1
Overview of aquaculture and aquatic animal health education, aquaculture graduates, and aquaculture curriculum for industry needs. **(A)** Introduction of aquaculture education at different academic levels. **(B)** Level at which aquatic health education is acquired. **(C)** Number of aquaculture graduates per year. **(D)** Inclusion of aquatic animal health within the aquaculture curriculum. **(E)** Important gaps to fill in aquaculture curriculum to support industry needs [Pearson Chi-square test = **(D)**: 1.000, $p > 0.05$].

enforcement (Figure 5A). Over 50% of respondents from all sectors confirmed the existence of legislation mandating biosecurity on farms. Nonetheless, some respondents in public (30%) and private (27%) sectors disagreed about the presence of legislation mandating biosecurity on the farms exists (Figure 5B). From Figure 5C, the responses across all sectors are more than 65% to confirm non-compliance to biosecurity, while the academic respondents (17%) expressed lack of knowledge ("Do not Know") that is significantly higher compared to the responses from the other sectors. The respondents (52.9%) confirmed the monitoring of farm biosecurity when necessary, while 26.4% responded 'Do not Know' regarding the frequency of such monitoring (Figure 5D). Pearson Chi-square statistics indicated that the responses were not influenced by sector affiliations (Figures 5A–C).

More than 40% of the respondents from all sectors confirmed the presence of a national biosecurity policy. This was disputed by more than 20% of respondents from all sectors who disagreed, with more than 15% expressing "Do not Know" on the matter. It is concerning that academia had a high percentage (58%) of "Do not know" responses and confirmed the absence of national aquatic animal biosecurity policy (Figure 6A). In sum, "No" and "Do not know" responses collectively accounted for 50 and 75% respectively, confirming the absence of national and industry biosecurity checklist. However, "No" and "Do not know" responses combined were relatively low (49%) as compared to "Yes" (51%), confirming the presence of farm biosecurity checklist (Figure 6B). The majority of the respondents (65.1%) claimed that biosecurity is monitored during extension service delivery by inspectors. In contrast, only 14% of the respondents suggested farmers' self-reporting as a confirmation of farm biosecurity monitoring in practice (Figure 6C). There is high certainty among academic and private sector as more than 35% confirmed biosecurity specific training for farmers. Nonetheless, the public sector remained uncertain since 38% of the respondents agreed, but was disputed by 44% of the respondents

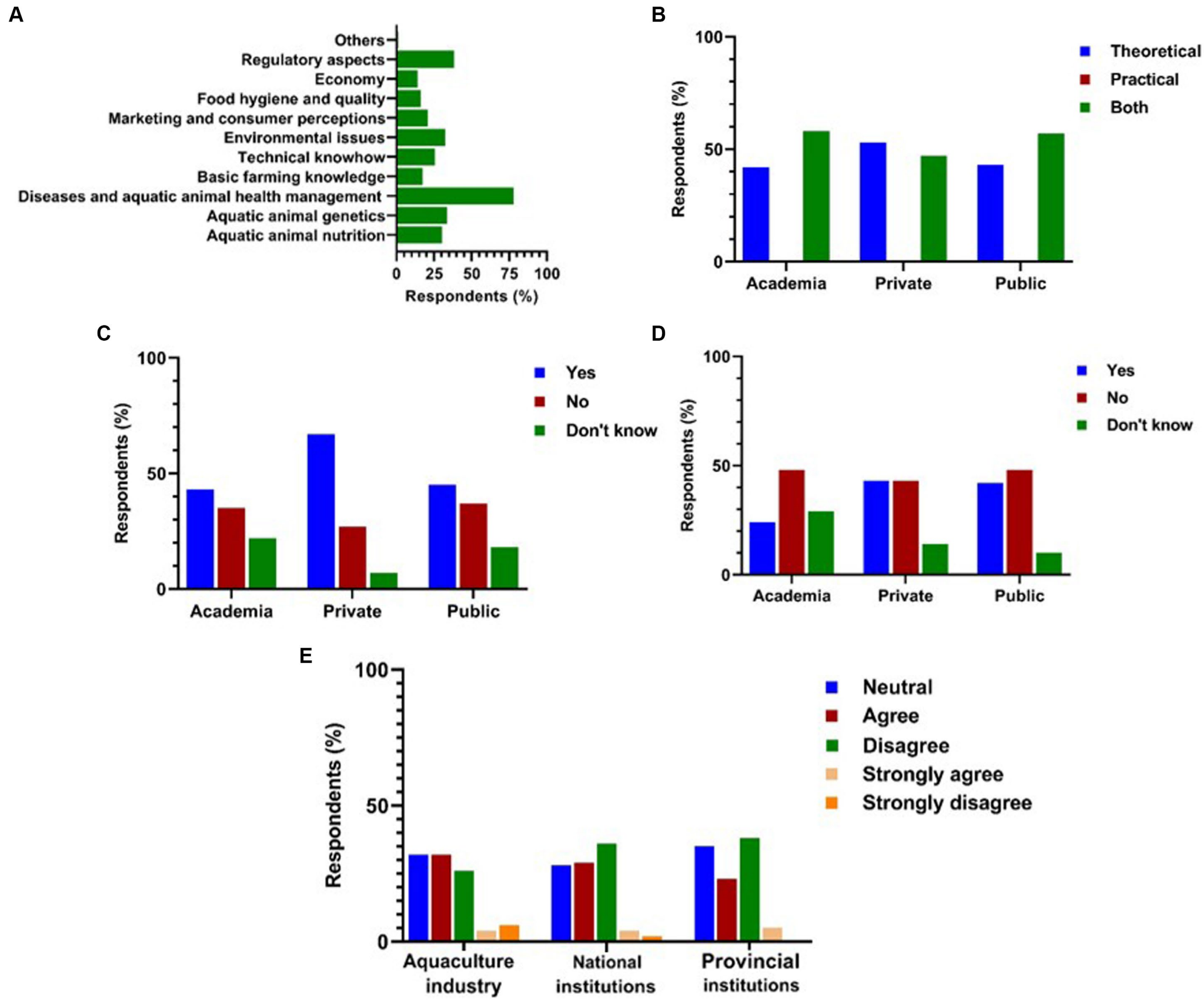

FIGURE 2
Enhancing aquaculture and aquatic animal health education, and workforce development to meet government and sector needs. **(A)** Important gaps to fill in aquaculture curriculum to support governmental needs. **(B)** The nature of aquatic animal health courses. **(C)** Entry-level training for newly hired technical staff. **(D)** On-the-job training for technical staff. **(E)** Graduates employability in the sector [Pearson Chi-square test = **(B)**: 0.871; **(C)**: 0.595; **(D)**: 0.352, $p > 0.05$].

(Figure 6D). The Pearson Chi-square statistics show that the responses were not influenced by sector affiliations (Figures 6A,D).

4. Discussion

Aquaculture is increasingly practiced in African countries to address food security needs and to generate personal incomes. The enterprise is however fraught with risks of major losses due to diseases. The sustainability of the industry has been negatively impacted by insufficient knowledge and awareness among stakeholders regarding the relevance of education, research and biosecurity practices. In this study, we aimed to bridge the knowledge gaps in research, education, and biosecurity, specifically in East and West Africa, with a focus on Ghana and Kenya. We conducted a questionnaire-based study, some of which were analyzed using tests of independence to investigate whether the responses were influenced by sector affiliations. The tests showed that the responses were independent of sector affiliations (for instance, Figures 3A, 4A, etc.).

4.1. Education

The health challenges in the growing field of aquaculture require educational reforms and training programs to improve the skills and services of health personnel in the industry (Dehaven and Scarfe, 2011). Based on the results and recommendations from the respondents, veterinary medicine education should include aquatic animal health rather than focusing solely on terrestrial animal health. This approach encourages education in aquatic animal health management, addressing the imbalance in veterinary medicine education, which often emphasizes competence in terrestrial animals (Hartman et al., 2006; Scarfe and Palić, 2020). Training in aquaculture and fish health management typically occurs at the tertiary level through Bachelor's and Master's Programs. This is

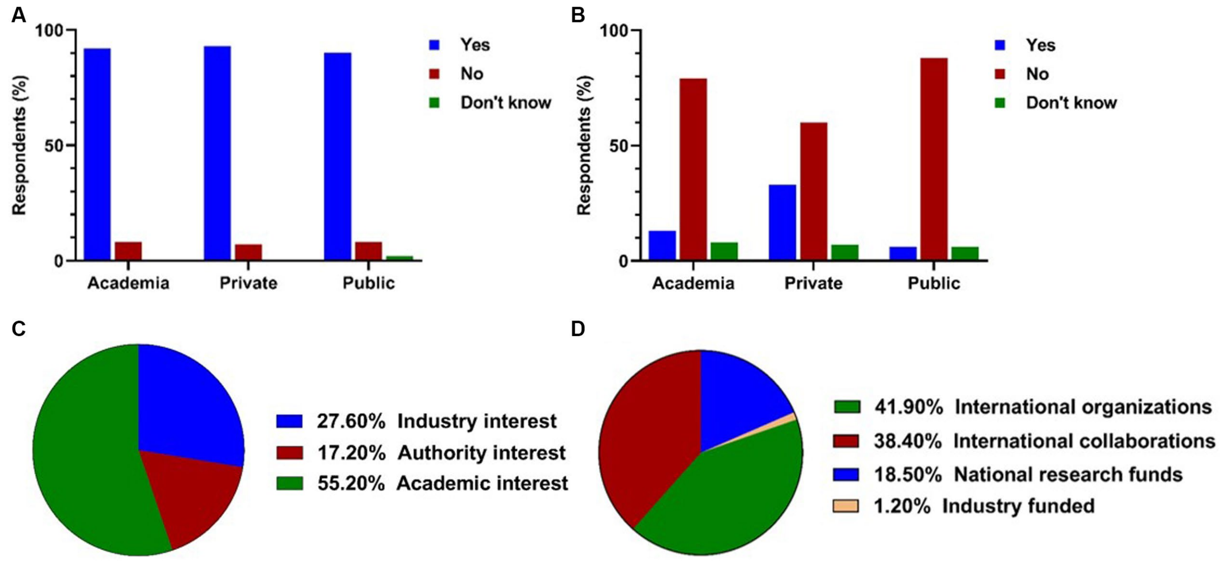

FIGURE 3
Mapping aquaculture research institutions: research questions and funding. **(A)** Presence of institutions pursuing aquaculture research. **(B)** Satisfactory presence of institutions supporting aquaculture research. **(C)** Means of formulating research questions. **(D)** Means of funding aquaculture research [Pearson Chi-square test = **(A)**: 1.000; **(B)**: 0.093, $p > 0.05$].

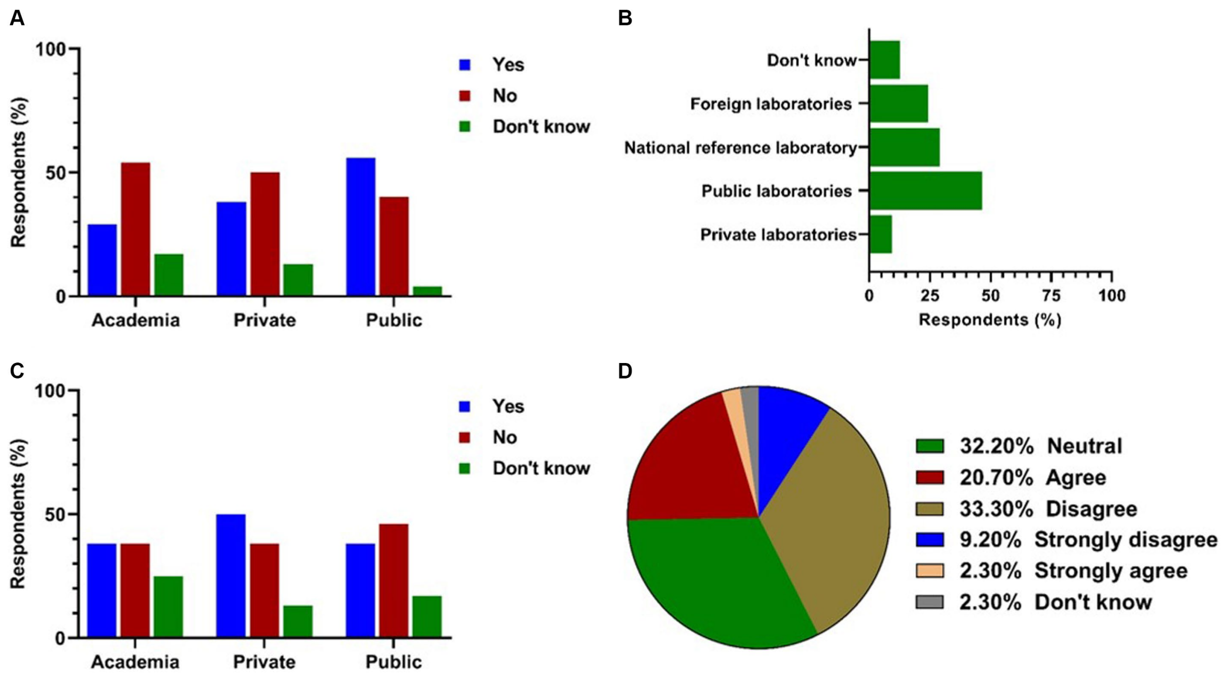

FIGURE 4
Comprehensive overview of fish health labs and knowledge exchange. **(A)** The presence of national fish health diagnostic laboratories. **(B)** Types of fish diagnostic laboratories. **(C)** Disseminating science-based solutions by research institutions to meet farmers and industry expectations. **(D)** Sharing of research findings among stakeholders [Pearson Chi-square test = **(A)**: 0.144; **(C)**: 0.784, $p > 0.05$].

evident from the strong representation of graduates from Bachelor's and Master's Programs. This presupposes that High School and Diploma graduates may not be adequately prepared for Bachelor's or Master's Programs in aquaculture and fish health management. The results also provide strong evidence for the inclusion of aquatic animal health in the aquaculture curriculum (Figure 1D). This inclusion is primarily at the Bachelor's level, with fewer representations at the Master's level (Figure 1B). It is clear from the foregoing that Bachelor's degree holders should be encouraged to pursue postgraduate programs in aquatic animal health to enhance their competence in managing emerging diseases that challenge the industry. Postgraduate programs require a diverse curriculum of

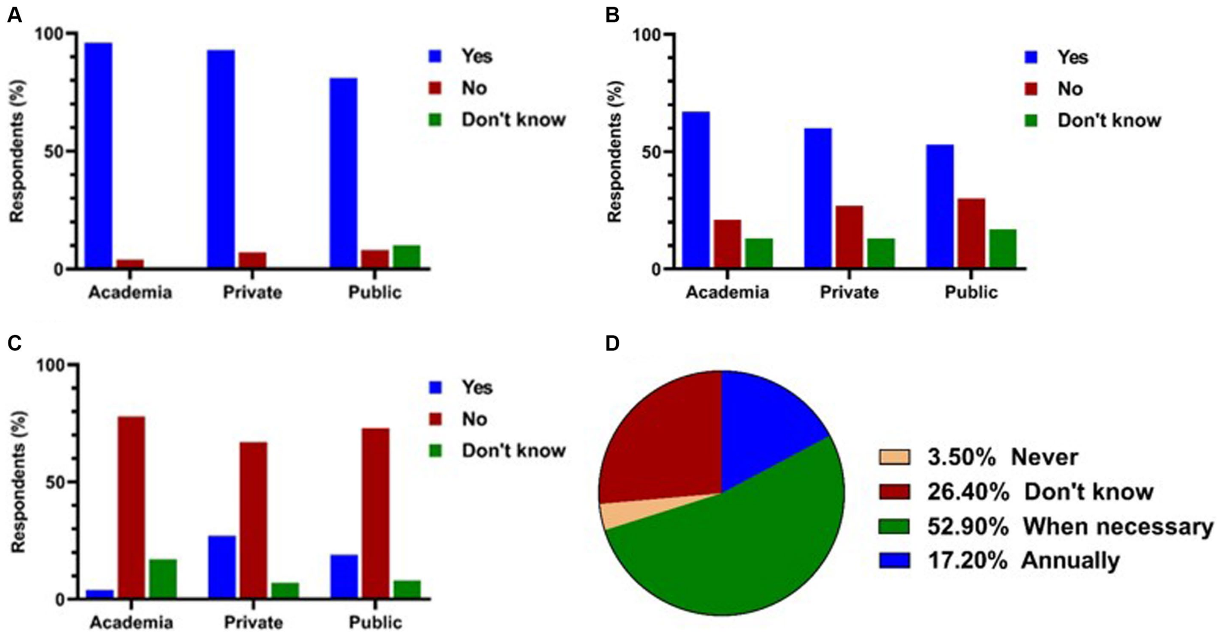

FIGURE 5
Examining monitoring and compliance to aquaculture regulations and biosecurity. **(A)** The existence of aquaculture regulations. **(B)** The presence of legislation mandating farm biosecurity. **(C)** Level of compliance to biosecurity measures. **(D)** How often competent authorities monitor biosecurity [Pearson Chi-square test = **(A)**: 0.298; **(B)**: 0.931; **(C)**: 0.316, $p > 0.05$].

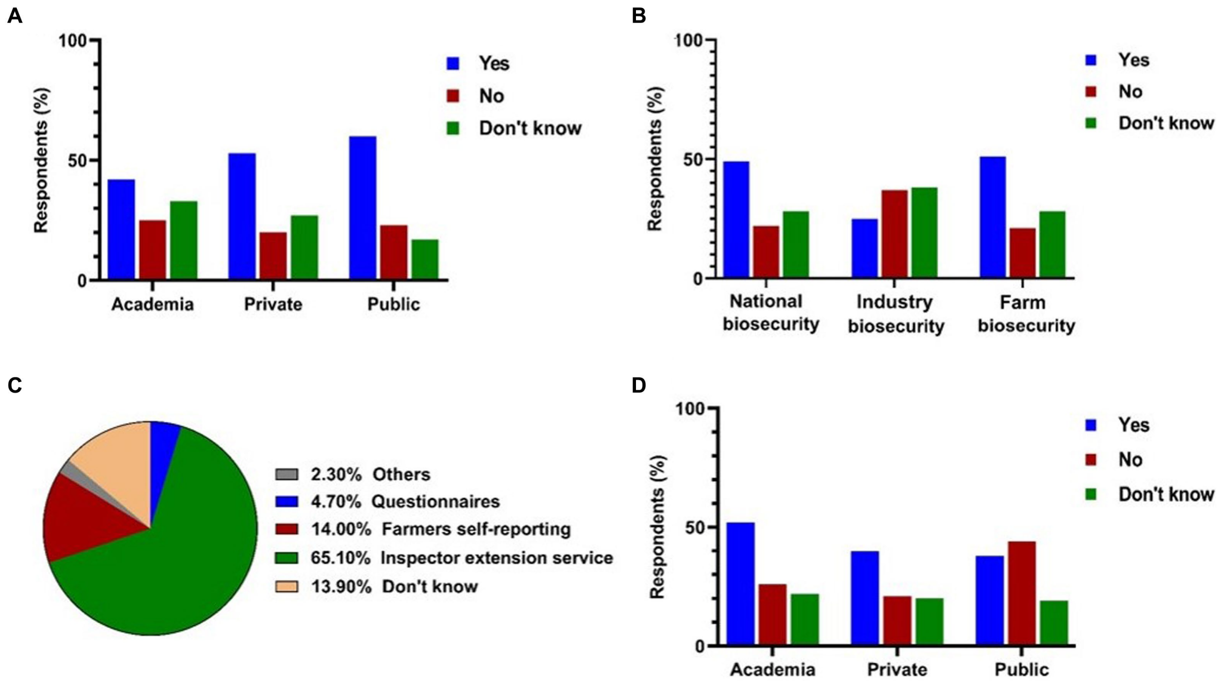

FIGURE 6
Examining presence of policy and checklists on biosecurity, its compliance, and level of biosecurity training. **(A)** Presence of a national policy on biosecurity for aquatic animals. **(B)** Presence of aquaculture biosecurity checklists. **(C)** Ways of monitoring farm biosecurity. **(D)** Biosecurity specific training offered to fish farmers [Pearson Chi-square test = **(A)**: 0.533, **(D)**: 0.587].

courses on aquatic animal health to produce a continuum of health professionals for the industry (Weber et al., 2009). In this study, the most relevant educational gaps to address in the current aquaculture curriculum include the training of more personnel in health management, nutrition and genetics. This approach will not only address the deficiencies in expertise related to health, nutrition, and genetics but facilitate the development of competencies in quality feed and seeds. Additionally, graduates with expertise in both health and nutrition will play a crucial role in developing balanced diets necessary for the optimal growth and health of fish (Oliva-Teles, 2012; Prabu et al., 2017).

The responses from the private sector suggest that there is an overemphasis on theoretical lessons (53%) compared to the preference for practical lessons in aquaculture education (Figure 2B). This may imply that graduates working with private sector institutions may have exhibited limited practical skills at the industry level. As a result, the private sector appears to recognize the importance of entry-level training and on-the-job training (Figures 2C,D), which they have incorporated into their employment practices. Through internal in-house training programs, employees can accumulate invaluable skills and knowledge that will mature over time as they gain long-term working experiences (Scarfe et al., 2021). It is therefore necessary to provide entry level and in-service training for technical persons across sectors to keep them abreast on emerging industry issues and strategies to overcome them. For example, farmers and extensions officers should be offered trainings that can enhance their knowledge of biosecurity and competence in controlling viral, bacterial, and parasitic diseases in aquatic animals (Lusiastuti et al., 2020). Additionally, academic institutions in represented countries are encouraged to pursue practical oriented aquaculture education. Educational strategies tailored to the needs of a country should be formulated through joint efforts involving all stakeholders. Government efforts should be focused on giving strategic policy direction based on a deep understanding of industry's needs, rather than relying on *ad hoc* measures. When educational institutions are tasked with meeting real industry needs while aligning with government strategic goals, a balanced triad is developed, providing the predictability and sustainability that the industry desperately needs. In summary, we recommend the inclusion of basic aquaculture education at the high school level. This can serve as preparation and motivation for students to pursue advanced aquaculture or related programs at the tertiary level. At the tertiary level, adequate infrastructural logistics are required to ensure that aquatic animal health education is practical oriented. The government can also offer scholarships as incentives to stimulate interest in pursuing education in aquatic animal health. Lastly, enhancing the skills of fish farmers and professionals in the field of aquaculture and fish health management can be achieved through robust educational curricular and routine training workshops.

4.2. Research

Research informs science-based decisions in any life science enterprise. While aquaculture research institutions exist in respondent countries, there is evidence to suggest that they are not meeting the country's research needs. This underscores the need for increased aquaculture research that addresses a wide range of topics to meet industry demands. Consequently, building interdisciplinary research competencies will enable collaboration and networking within and across participating countries. The results also show that aquaculture research questions are often formulated to align with academic interests rather than providing direct benefits to the industry (Figure 3C). The lack of direct government involvement in providing strategic national direction and funding is a major bottleneck to research development. In many African countries, government funding for aquaculture development has generally been low (Olapade, 2020; Ragasa et al., 2022). To address industry needs effectively, it is crucial to have national research funding accompanied by comprehensive research questions. This will enable academia and other research institutions to align with industry expectations and provide science-based solutions. International organizations collaborating with country-specific institutions are the primary sponsors of aquaculture research (Figure 3D). However, relying solely on international funding for research, without substantial government involvement can lead to skewed priorities that primarily serve foreign donors' demands to the disadvantage of recipient countries. This has been reported by Natsios (2005), suggesting that aid programs often prioritise the objectives of donor countries rather than addressing specific needs of recipient countries.

The availability of best aquaculture research infrastructures are paramount for conducting research and gaining new knowledge and technological advancements in aquaculture [Brugere et al., 2021; Ministry of Marine Affairs and Fisheries (MMAF), 2022; Further Africa, 2023]. In this study, research quality is impacted by weak infrastructure and human resource base, and it is limited in scope because research questions are not holistic and multidisciplinary. This is evident in Figure 3B concerning the unsatisfactory presence of institutions supporting aquaculture research. This also includes the uncertainty regarding the existence of national fish health diagnostic laboratories (Figure 4A). More than 45% of respondents from academia and private sector indicated the absence of functional national fish health diagnostic laboratories. In contrast, the public sector tends to confirm the presence of functional laboratories (56%), which indicates a bias towards acknowledging their potential usefulness (Figure 4A). These conflicting responses highlight a disconnection between industry, academia, and government. Furthermore, the existing laboratories are publicly owned (Figure 4B) with obsolete equipment, insufficient number of technicians and researchers. The government of represented countries need to intervene by providing the necessary logistics and human resources to support diagnostics, education, and research services. As highlighted by Hansen (2023), biological and technological developments in aquaculture require modern infrastructure to improve education and research services for the industry. Additionally, the results from this survey suggested that the establishment of national reference laboratories is essential to confirm results and establish protocols that guide diagnostic and research works. The recommendations for the establishing research centres in universities to serve as liaisons between industry and government should be implemented. These centres can guide the development of specific training courses for students and industry personnel, equipping them with the skills necessary for the growth of the industry.

The private aquaculture sector is at the forefront and is directly impacted by industry sustainability challenges such as disease outbreaks. However, the results suggest that research institutions are not effectively disseminating science-based solutions among fish farmers to solve industry problems (Figure 4C). Meanwhile, fish farmers appreciate the culture of sharing information and discussing solutions with relevant stakeholders to adopt coping strategies for the ongoing uncertainties in the industry (Tonje et al., 2017). Research bodies and academia are knowledge-based institutions that should play a crucial role in transferring science-based information to address sustainability issues. Collaborative research is essential in represented countries, where close partnerships between researchers, research institutions, universities, and farmers are needed. Such collaborations will keep researchers in the loop of industry problems and make their findings useful for sustainable growth. Presently, there is a lack of trust, which may have stemmed from insufficient communication between researchers and industry personnel for sharing research findings (Figure 4D). This aligns with earlier findings suggesting that lack of communication in sharing information can lead to mistrust among fish farmers and stakeholders in the industry (Agyei, 2022; Falconer et al., 2023). Researchers should prioritise effective communication of research findings to stakeholders throughout the aquaculture value chain in a user-friendly manner.

4.3. Biosecurity

Practical biosecurity which prevent disease-causing agents into aquaculture premises and control their spread is the bedrock of a successful industry. Aquaculture practitioners must understand this important pillar of sustainable aquaculture development. This must be reinforced by government agencies mandated to enforce regulations designed to protect the industry from disease causing agents.

The majority of sector respondents provided evidence of aquaculture and biosecurity regulations in the represented countries. However, compliance is notably low (Figure 5C). This can be attributed to policy implementing agencies not being adequately resourced to discharge their duties. Consequently, activities such as biosecurity monitoring are only conducted reactively when the need arises, compared to routine monitoring (Figure 5D). This pattern may be linked to the prevailing approach to health management in African aquaculture, which tends to be reactive than proactive in protecting the industry against disease-causing agents (FAO, 2018). This survey further revealed a high level of certainty among academic and private sector respondents, with more than 35% confirming biosecurity specific training for farmers. Nonetheless, the public sector remained uncertain, with 38% of respondents in agreement but disputed by 44% of respondents (Figure 6D). However, academia's claim of providing biosecurity training to farmers contradicts their earlier responses regarding the existence of biosecurity policies or plans and their enforcement (Figures 5A,B). In responses from academia, it emerged majority of 58% have insufficient biosecurity knowledge and confirmed the absence of a national biosecurity policy or plan. This observation is concerning and could potentially impact students' training in biosecurity if educational institutions give less preference to aquatic animal health courses. Knowledge-based institutions are expected to make education more responsive to meet industry needs (Nda and Fard, 2013; Kuna et al., 2022). Additionally, academia confirmed a lack of compliance with mandated biosecurity measures, a situation that could further complicate the essence of biosecurity measures in the education to students. Meanwhile, a bulk of the graduates are easily employed in the aquaculture industry where biosecurity measures are most needed (Figure 2E). Biosecurity training especially for students and fish farmers should be a continual process to facilitate the adoption and compliance to biosecurity measures. This must include national biosecurity policies for aquatic animals in represented countries that underpin the implementation of aquaculture biosecurity measures.

In addition, biosecurity checklists are generally lacking at the industry level compared to checklist imposed by competent authorities and based on farmer initiatives. This is not new, as most countries lack regulations to enforce disease prevention in aquaculture (Leaño, 2022; Adah et al., 2023). As a result, fish farmers' practices generally do not align with biosecurity principles. Consequently, the aquaculture industry may remain unregulated in terms of biosecurity compliance. For instance, inputs such as feed and seed delivered to fish farmers may already be compromised in terms of contamination and quality. This can have significant negative impacts on fish health at the farm level. Therefore, we propose implementing biosecurity checklists alongside biosecurity trainings. It is imperative to adopt collaborative approaches that allow regulatory authorities and private sector institutions to complement each other's expertise for shared biosecurity monitoring. Involving the private sector enables them to support and contribute to government efforts in addressing biosecurity risks in various aspects, including policy, knowledge-base, capacity building, and investments (FAO, 2015). This collaborative approach will pave way for holistic strategies in monitoring fish health and aquaculture activities in general to ensure sustainability across the participating countries.

While this study contributed to identifying the gaps in educations, research, and biosecurity, one of its limitations is the reliance on self-reported data from respondents. Although the online survey forms were distributed to many individuals, not all chose to respond, resulting in the limited number of study participants (or sample size). Self-report studies are less expensive and not time consuming, but having researchers conduct one-on-one interactions with participants can potentially increase the response rate and sample size. Nevertheless, the study provided a snapshot of the research, education, and biosecurity gaps in the represented countries.

5. Conclusion

To enhance aquatic animal health management in East and West African nations, this study identified the gaps in education, research, and biosecurity. The results suggest that aquatic animal health education should adopt practical approaches rather than focusing solely on theory. It is therefore critical to address the need for additional personnel trained in aquatic animal health management, nutrition, and genetics through practical oriented education. The disconnection among academia, private, and public sectors requires close partnerships to establish developmental goals for the aquaculture industry. These partnerships can shape educational curriculums and training programs to develop the necessary competence to meet industry goals. Moreover, the government must be intentional about providing adequate resources to support national aquaculture research institutions in their collaborative efforts with stakeholders to generate requisite knowledge for industry decision making. The respondents also recognized the need to establish a national reference laboratory for research, confirming field observations, and validating diagnostic results. Furthermore, the lack of biosecurity measures and understanding of the importance of biosecurity measures in the industry addressed through awareness creation. Creating awareness on biosecurity underpinned with national aquaculture biosecurity policies can prevent disease incidences in the industry. The outcomes of the study can guide aquaculture stakeholders in East and West Africa to foster sustainable and resilient aquaculture as they address the gaps in education, research, and biosecurity practices.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

JZ: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. ST: Conceptualization, Investigation, Methodology, Writing – review & editing. AS: Conceptualization, Investigation, Methodology, Writing – review & editing. SA: Conceptualization, Investigation, Methodology, Writing – review & editing. PN: Conceptualization, Investigation, Methodology, Writing – review & editing. MD: Conceptualization, Investigation, Methodology, Writing – review & editing. KN: Conceptualization, Investigation, Methodology, Writing – review & editing. EB: Conceptualization, Investigation, Methodology, Writing – review & editing. KC: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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