Profiling and Prioritizing Climate-Smart Aquaculture Technologies, Innovations, and Management Practices in Kenya

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Research Article

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Climate-smart agriculture (CSA) has been promoted in Kenya as a panacea for climate change impacts on agricultural productivity. Consequently, various climate-smart aquaculture technologies, innovations, and management practices (CSA-TIMPs) have been developed, validated, and adopted through the Kenya Climate-Smart Agriculture Project (KCSAP). Nevertheless, there has been no evaluation of the climate-smartness of the CSA-TIMPs for priority setting. In this study, we evaluated and ranked the CSA-TIMPs using a modified Climate-smart Agriculture Prioritization Framework (CSA-PF). The prioritization process included multistakeholder validation workshops involving researchers, fisheries officers, farmers, traders, and policy makers. The climate-smartness scores of the CSA-TIMPs were given based on the CSA pillars (i.e., adaptation, mitigation, and productivity) under various climate-smartness indicators, with a score ranging from −10 (for a negative impact) to +10 (for a positive impact). This resulted in the identification and documentation of forty (40) CSA-TIMPs. Climate-smartness scores varied from 3.8 to 6.1, with higher values indicating strong synergies between the CSA pillars, with productivity having the highest average score of 6.4. The top 5 list of CSA-TIMPs with the best synergies among the CSA pillars was then developed for prioritization. Adoption of these CSA-TIMPs would be instrumental in achieving the CSA triple wins, especially in improving aquaculture productivity. Therefore, sustained efforts in stakeholder engagement, capacity building, and policy support are essential to ensure the successful adoption of CSA-TIMPs in Kenya. A dynamic approach that includes continuous validation, comprehensive monitoring and evaluation, and an enabling environment for adoption will be key to achieving sustainable and scalable impacts.

Keywords: aquaculture; climate-smart agriculture; CSA pillars; Kenya; prioritization

1. Introduction

Aquaculture presents a significant opportunity for reducing rural poverty, addressing malnutrition, and bolstering climate resilience among impoverished households. However, the aquaculture sector in Kenya experiences detrimental effects of climate change since it is predominated by small-scale farmers who are less resilient to climate shocks. On the other hand, aquaculture in the country contributes to climate change through greenhouse gas (GHG) emissions [1]. Most aquaculture production systems in Kenya are ponds [2, 3], which can act as GHG emission hotspots because they generally have high availability of organic matter as a result of constant feeding or manure addition to improve primary production [4]. Maximizing the contribution of aquaculture to food and nutrition security in Kenya in the face of climate change calls for the adoption of new technologies, innovations, and practices that improve resilience to climate change and reduce GHG emissions [1, 5, 6].

The climate-smart agriculture (CSA) concept was first brought to light by the Food and Agriculture Organization (FAO) of the United Nations [7] in 2009 to improve agricultural production in the face of climate change. CSA is based on three pillars, productivity, adaptation, and mitigation, and requires practices that address synergies and trade-offs among the three pillars to achieve the "triple wins" [8, 9]. To fulfill its commitment as a signatory to the United Nations Framework Convention on Climate Change, the Government of Kenya [10] has mainstreamed CSA practices as a priority area in its national agricultural development programs. With funding from the World Bank, the government established the Kenya Climate-Smart Agriculture Project (KCSAP), under the framework of the Agriculture Sector Development Strategy (2010–2020) and National Climate Change Response Strategy. The project aimed to improve agricultural productivity, increase climate change resilience in targeted smallholder farming and pastoral communities in Kenya, and prepare for an immediate and efficient response to any climate crisis or emergency [11].

As part of the project, and building on previous works by various national agricultural research systems and development partners in the country, several climate-smart aquaculture technologies, innovations, and management practices (CSA-TIMPs) were identified, targeting the freshwater fish value chain across six thematic areas: (1) culture systems and best management practices; (2) culture species, breeding techniques, and genetics; (3) fish nutrition and feed management practices; (4) fish health management and biosecurity; (5) fish post-harvest loss reduction, value addition, and nutrition; and (6) fish marketing, trade, and supply channels. These research efforts aim to improve food and nutrition security, enhancing livelihood options for both smallholder and commercial fish farmers and promoting overall societal development [12]. However, these practices have not been empirically evaluated for their climate-smartness to inform their prioritization and implementation. Additionally, they have been mainly promoted separately without exploiting possible synergies between them, thus slowing down their adoption [13].

Sova et al. [14] noted that different regions have different needs, and CSA practices should be context-specific and tailored to the needs of a particular region. Previous studies have developed context-specific climate-smart aquaculture practices in various countries. For instance, Lundeba et al. [15] highlighted climate-smart aquaculture practices for smallholder fish farmers in Zambia related to integrated agriculture-aquaculture through a training of trainers workshop. Nyamete [16] developed a context-specific climate-smart aquaculture framework for Tanzania by assessing the adequacy of existing aquaculture practices through farmer interviews and designing context-specific climate-smart fish pond and fish feed. However, none of these studies have identified context-specific CSA-TIMPs for prioritization and empirically evaluated their climate-smartness through a multi-stakeholder participatory process. An evidence-based participatory process is needed to identify applicable, context-specific, and relevant CSA practices [17].

Given the preceding, a participatory CSA profiling and prioritization process was undertaken to identify various CSA-TIMPs across all nodes of the aquaculture value chain in Kenya, and evaluate their climate-smartness based on the three CSA pillars. This paper presents the CSA-TIMPs identified and ranked based on their relevance to achieving the CSA triple wins. It highlights the impact of the CSA-TIMPs on productivity, adaptation, and mitigation, providing stakeholders with evidence-based insights for making informed decisions for aquaculture interventions. The study enriches the existing knowledge by providing context-specific and empirically validated climate-smart practices in aquaculture, thereby contributing to more effective and sustainable climate change adaptation strategies in Kenya and beyond.

2. Methodology

2.1. Prioritization Framework. A participatory prioritization framework was used for the profiling and prioritization of the CSA-TIMPs in Kenya (Figure 1). The framework was a modification of the Climate-smart Agriculture Prioritization Framework (CSA-PF), developed by the Consortium of International Agricultural Research Centres (CGIAR), Research Program on Climate Change, Agriculture and Food Security, and the International Center for Tropical Agriculture [17]. CSA-PF is used when prioritizing a CSA practice that is evidence-based and practical, allowing progress despite data and resource limitations [18]. Prioritization is based on inclusive participatory approaches that integrate actors to ensure conformity with stakeholder prioritization criteria and situational considerations. The framework can be modified by users at all levels and across all sectors to meet their planning needs [17].

Participatory approaches for prioritizing CSA options allow for more accurate evaluations [19]. They allow for the inclusion of people's views and opinions in the decision-making process, enhancing inclusivity and representativeness [20]. Additionally, they can be customized in terms of the number and type of variables included and even the number of stakeholders involved [20]. These approaches have been applied in various CSA prioritization works [20–23]. For instance, Mwongera et al. [21] employed the

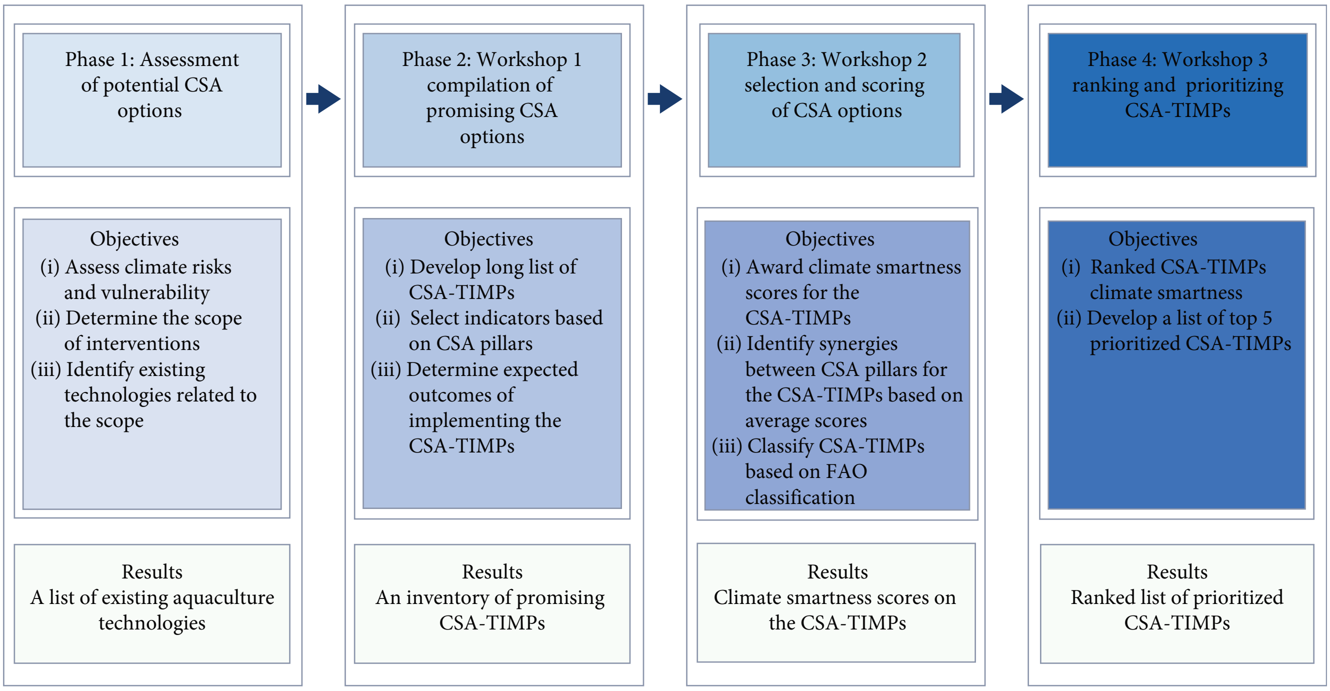

Figure 1: The CSA prioritization framework for profiling and prioritizing CSA-TIMPs. Modified from Andrieu et al. [17].

Climate-Smart Agriculture Rapid Appraisal (CSA-RA) method to involve key agriculture stakeholders in assessing vulnerability, prioritizing CSA investments, and assessing barriers to such investments in their study of two farming systems in Uganda and Tanzania. Kumar et al. [22] used a participatory ranking method through multistakeholder workshops to assess and prioritize suitable CSA interventions in Telangana State of India. Wassmann et al. [23] used a multicriteria ranking technique for CSA technologies in rice farming in Laos by involving different stakeholder groups. These approaches allow for a sufficient assessment of the climate-smartness of CSA practices and are often restricted to the regional, political, and socioeconomic environment due to the heterogeneity of the actors engaged, and are therefore best suited for country-level assessments [24, 19]. Additionally, such approaches must effectively handle any potential problems of representativeness [20]. However, there are still gaps in the application of the prioritization framework in the aquaculture sector.

2.2. The CSA-PF Process for Aquaculture in Kenya

2.2.1. Phase 1: Assessment of Potential Options. An extensive desktop study was done to collect relevant literature on the state of aquaculture in Kenya, challenges related to climate change, and the climate change adaptation measures applicable to the country [25]. This entailed reviewing journal articles, books, policy briefs, research results, websites, and reports of various national and international agricultural research organizations. Besides, a field study was conducted from October to December 2019 to assess various agroclimatic and agroecological zones, socioeconomic dynamics, climate risks and vulnerability, production systems, and technologies in the country's aquaculture sector. This was done by a team of researchers from the Kenya Marine and Fisheries Research Institute (KMFRI), Kenya Agricultural and Livestock Research Organization (KALRO), University of Eldoret, Egerton University, and Maseno University, who were key implementing partners of the KCSAP project.

Additionally, the researchers conducted 12 focus group discussions (FGDs) with farmers from various farmer groups, to gather information on their production practices. This gave the farmers a chance to suggest any changes or interventions needed to their aquaculture practices. Each of the focus groups consisted of 10 farmers (four group officials and six farmers who had more than 10 years of experience in aquaculture), comprising both males and females. The FGD participants were purposively selected since the FGDs relied on their ability and capacity to provide relevant information [26]. The purpose of the literature review, field study, and FGDs was to determine the scope of aquaculture TIMPs needed for interventions regarding six aquaculture thematic areas, namely, (1) culture systems; (2) culture species, breeding, and genetics; (3) fish nutrition and feed management practices; (4) fish health management and biosecurity; (5) fish post-harvest loss reduction, value addition, and nutrition; and (6) fish marketing, trade, and supply channels.

2.2.2. Phase 2: Preliminary Selection and Compilation of Promising CSA Options. Following the literature review, field study, and FGDs, a 5-day expert-level participatory workshop involving 20 researchers and 10 fisheries officers was conducted in February 2020 to compile an inventory of aquaculture practices that are relevant to the Kenyan context and related to the thematic areas. The participants were from KMFRI; KALRO; State Department for Fisheries, Aquaculture, and the Blue Economy; Kenya Fisheries Service (KeFS); University of Eldoret; Egerton University; Maseno University; and Consultative Group for International Agricultural Research (CGIAR) experts. They were selected based on their direct involvement in the KCSAP project either as implementing partners, project investigators, or co-project investigators. Through experts' knowledge, farmers' feedback, literature review, and multiple deliberations, an initial "long list" of CSA practices was developed and distributed across the six thematic areas [12]. The practices were then categorized into technologies, innovations, and management practices (TIMPs). The experts then selected CSA indicators to evaluate the climate-smartness of the selected TIMPs. The CSA indicators used in our prioritization process were adopted from an array of existing indicators that have been developed for measuring the effectiveness of CSA [27] and classified under various biophysical, social, and economic climate-smartness categories of the CSA pillars of productivity, adaptation, and mitigation [28, 29].

2.2.3. Phase 3: Evaluation, Selection, and Scoring of Selected CSA-TIMPs. A 5-day participatory workshop involving 35 participants (the 20 researchers involved in Phase 2, five fisheries officers from KeFS, five fish farmers, two traders, and three policy makers from the State Department of Fisheries and the Blue Economy) was conducted in July 2020 to evaluate the practices according to the selected CSA indicators. The participants were selected based on their leadership positions and more than 10 years of experience in the Kenyan aquaculture sector. This effort resulted in practices from the initial "long list" being either confirmed as relevant, modified, eliminated, or having some new practices introduced.

Following the evaluation and selection process, the average climate-smartness scores of the CSA-TIMPs were calculated for each practice based on the selected indicators. A practice can have a negative, positive, or zero impact on a selected CSA indicator, with +10 or −10 indicating a 100% change (positive/negative) and 0 indicating no change [17, 30]. For each practice, a score between −10 (for a negative impact) and +10 (for a positive impact) was attributed to each indicator. A score of 0 (zero) was given for a practice that did not have an impact on a specific indicator. The score for each pillar was then calculated from the average score of all the indicators under that pillar [17].

2.2.4. Phase 4: Participatory Ranking and Prioritization of CSA-TIMPs. The results of Phase 3 were presented during a 2-day workshop conducted in August 2020 to rank and prioritize the CSA-TIMPs. The participatory workshop involved the 35 participants (researchers, fisheries officers, farmers, traders, and policy makers) that were involved in Phase 3. The workshop entailed ranking the CSA-TIMPs based on their average scores on all the CSA pillars and developing a list of the top-5 CSA-TIMPs for prioritization.

3. Results

3.1. Selection and Compilation of Potential CSA Options. Through the survey of various agroclimatic and agroecological zones in the country, climate risks and vulnerability, production systems and technologies, literature review, and several deliberations, the researchers established an initial "long list" of 51 relevant TIMPs (Table 1). An inventory of the TIMPs was developed, including 12 technologies, 34 innovations, and 5 management practices, distributed among the 6 thematic areas.

A total of 17 CSA indicators under various climate-smartness categories were selected by the experts based on relevance to the CSA pillars and aquaculture practices listed, and their viability given the data that were available (Table 2). The CSA indicators were categorized under various climate-smartness aspects to align with the three pillars of productivity, adaptation, and mitigation. For the productivity pillar, the categories were yield smartness, income smartness, and health smartness. The selected indicators included yield, income, post-harvest losses, and fish nutritional quality. For the adaptation pillar, the categories were soil smartness, water smartness, risk smartness, and gender smartness. The selected indicators were soil disturbance, water availability, water use efficiency, water quality, climate risk management, diversification of income sources, and gender considerations. Under the mitigation pillar, the categories were energy smartness, carbon smartness, and nutrient smartness. The selected indicators included energy use, methane emissions, aboveground biomass, belowground biomass, soil carbon stock, and nutrient use efficiency.

3.2. Evaluation and Scoring of CSA-TIMPs. Following the assessment of the practices as per the CSA indicators, some of the TIMPs were found to be valid, while others were modified, eliminated, or added, resulting in a list of 40 TIMPs (Table 3). For instance, under fish culture systems, "crop–livestock–fish system" and "HDPE fish cage technology," were validated as relevant, "land-based production system" was modified to "pond-based culture system," "in-pond raceway system (IPRS)" and "integrated multitrophic aquaculture (IMTA)" were removed, and "biofloc-based live food dispenser" was added.

The scores attributed to each practice and the average score per pillar for each are also presented in Table 3. "Value-added fish products" had the highest productivity potential since it had the highest score on the productivity pillar (8.6), and "aggregated aqua-parks" had the highest adaptation potential (highest score of 6.7 on the adaptation pillar), while "aquaponics" had the highest mitigation potential (highest score of 7.3 on the mitigation pillar). TIMPs such as selective breeding, crop–livestock–fish system, novel insect-based feeds, improved fish smoking kiln, and biofloc-based live food dispenser had the highest average scores, while TIMPs such as pond-based culture system, fingerponds, prophylactic treatments, nutrition and social behavior change communication, and floating pellets had the lowest average scores.

The overall average score for each CSA pillar was computed to measure the climate-smartness of all the TIMPs that were selected for interventions (Figure 2). The productivity pillar had the highest average score (6.4) among the CSA pillars.

3.3. Ranking and Prioritization of CSA-TIMPs. The top 5 list of prioritized TIMPs which showed the best synergies among

Table 1: Inventory of relevant aquaculture CSA-TIMPs and their categories.

Thematic area	CSA-TIMPs	Category
Culture systems	Land-based production system; in-pond raceway system (IPRS); fish aquarium; aquaculture park (aqua-park); aquaponics/hydroponics systems; integrated multitrophic aquaculture (IMTA); rice–fish culture systems; crop–livestock–fish system; fingerponds; pond–cage integration	Innovation
	High-density polyethylene (HDPE) fish cage technology; recirculating aquaculture systems (RAS)	Technology
Culture species and breeding	Improved Nile tilapia; improved African catfish strain	Technology
	Victoria tilapia (*Oreochromis variabilis*); Singida tilapia (*Oreochromis esculentus*); Jipe tilapia (*Oreochromis jipe*); Ningu (*Labeo victorianus*); hormonal sex reversal; artificial propagation; selective breeding; temperature shock treatment	Innovation
Fish nutrition and feed management practices	Biofloc technology; periphyton technology; carbonized pond technology; bioencapsulation technology; live food dispenser	Technology
	Conventional plant-based protein feeds; conventional fishmeal-based protein feeds; novel plant-based feeds; novel insect-based feeds, specifically black soldier fly (BSF); fish feed pelletizer	Innovation
	Feed management practices	Management practice
Fish health management and biosecurity	Prophylactic treatments; therapeutic treatments	Innovation
	Biosecurity practices; best management and hygiene practices	Management practice
Fish postharvest loss reduction, value addition and nutrition	Improved fish smoking kiln; improved fish display unit, "*mama karanga*" box; value-added fish products	Technology
	Fish solar drier; solar-powered freezers; solar tent driers; novel nutrient-rich fish products	Innovation
	Traceability and certification, e.g., fish seed standards	Management practice
Fish marketing, trade, and supply channels	Web-based systems, e.g., aquaculture management information systems (AquaMIS); mobile-based applications; Internet of things (IoT)–based applications, e.g., AquaRech; aquaculture business starter kit, e.g., cage investor's kit; fish branding and ecolabeling	Innovation
	Aquaculture service and input providers directory	Management practice

Table 2: Selected CSA smartness categories and indicators per CSA pillar.

CSA pillar	Smartness category	CSA indicator
Productivity	Yield smart	Yield
	Income smart	Income
		Postharvest losses
	Health smart	Fish nutritional quality
Adaptation	Soil smart	Soil disturbance
	Water smart	Water availability
		Water use efficiency
		Water quality
	Risk smart	Climate risk management
		Diversification of income sources
	Gender smart	Gender
Mitigation	Energy smart	Energy use
	Carbon smart	Methane emissions
		Aboveground biomass
		Belowground biomass
		Soil carbon stock
	Nutrient smart	Nutrient use efficiency

Table 3: Selected CSA-TIMPs and their scores on productivity, adaptation, and mitigation.

CSA-TIMPs	Productivity	Adaptation	Mitigation	Avg. score	Rank
Selective breeding	7.5	6.1	4.6	6.1	1
Crop–livestock–fish integrated system	7.0	6.4	4.3	5.9	2
Novel insect-based feeds, i.e., BSF	6.8	5.0	6.1	5.9	3
Improved fish smoking kiln	7.0	4.1	6.6	5.9	4
Biofloc-based live food dispenser	6.8	5.0	5.7	5.8	5
HDPE fish cage technology	6.6	5.0	5.4	5.7	6
Improved Nile tilapia strain (F8)	7.5	6.2	3.4	5.7	7
Aquaponics	6.3	3.5	7.3	5.7	8
Insect-based complete fish diet	7.5	5.5	4.2	5.7	9
Value-added fish products	8.6	4.9	3.3	5.6	10
Aggregated aqua-parks	5.5	6.7	4.7	5.6	11
Hormonal sex reversal	7.0	5.8	4.0	5.6	12
Nile tilapia YY offspring	7.4	5.3	3.6	5.4	13
Biosecurity practices	6.3	6.0	3.7	5.3	14
BSF rearing and multiplication protocol	8.0	3.8	4.2	5.3	15
Conventional plant-based protein feeds	6.5	5.0	4.1	5.2	16
Artificial propagation	7.2	4.8	3.8	5.2	17
Improved African catfish strain (F3)	6.6	5.8	3.3	5.2	18
AquaRech (IoT Systems)	6.5	5.3	3.8	5.2	19
Improved fish display units (*mama karanga*)	5.5	5.3	4.7	5.2	20
Conventional fishmeal-based protein feeds	6.9	4.8	3.5	5.1	21
Protocol for mass production of macrophytes	6.0	5.8	3.4	5.1	22
BSFL production and packaging	5.8	4.0	5.7	5.1	23
Recirculating aquaculture system (RAS)	7.0	4.4	3.8	5.1	24
Insect-based fish feed recipe	5.0	4.6	5.7	5.1	25
Domestication of indigenous tilapiine species	4.3	6.5	4.2	5.0	26
Best management practices (BMPs)	7.3	4.4	3.3	5.0	27
Fish solar drier	5.0	5.5	4.3	4.9	28
Feed management practices	7.0	4.3	3.3	4.8	29
Novel nutrient-rich fish-based products	7.3	4.0	2.8	4.7	30
Duckweed-based diets	5.6	4.8	3.8	4.7	31
Therapeutic treatments	6.2	3.7	4.0	4.6	32
Production of indigenous tilapia	4.9	5.2	3.8	4.6	33
AquaMIS	6.0	3.0	4.6	4.5	34
ASIP directory	6.3	4.0	3.3	4.5	35
Floating pellets	5.6	4.8	2.8	4.4	36
NSBC communication	5.7	3.3	3.7	4.2	37
Prophylactic treatments	4.8	2.4	5.0	4.1	38
Fingerponds	5.0	4.7	2.5	4.1	39
Pond-based culture system	4.8	3.4	3.3	3.8	40

Abbreviations: AquaMIS, aquaculture management information system; ASIP, aquaculture service and input providers; BSF, black soldier fly; BSFL, black soldier fly larvae; HDPE, high-density polyethylene; NSBC, nutrition and social behavior change.

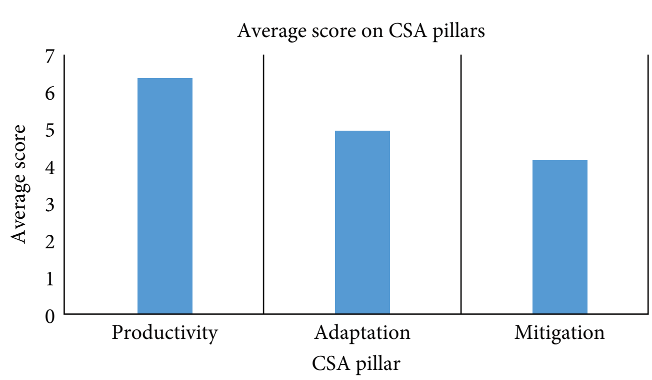

Figure 2: Aquaculture TIMPs' average score on CSA pillars.

Table 4: Top 5 prioritized CSA-TIMPs and their impact on productivity, adaptation, and mitigation.

CSA-TIMPs	Climate smartness score	Impact on CSA pillars		
		Productivity	Adaptation	Mitigation
Selective breeding	6.1	Better feed conversion ratio (FCR) Improved fish quality and condition factors lead to higher income per production cycle	Reduced culture period by about 3 months, hence reducing the risk of exposure to climate hazards	Reduced GHG emission due to efficient use of feeds The culture period is also reduced hence less fuel is used
Crop–livestock–fish system	5.9	Increased yield and income due to more food production lines compared to nonintegrated systems	There is nutrient cycling and carbon sinks	Manure management and nutrient cycling limit methane production
Novel insect-based feeds, i.e., BSF	5.9	Increased fish yield and income due to improved growth performance and FCR	Reduced water use compared to the production of conventional protein sources (e.g., soya meal) Diversified income streams (feed protein, oil, and biofertilizer) and savings through reduced buying of feeds Increased youth and gender inclusivity compared to baseline protein sources (commercial feed)	Increased fossil fuel Improved soil carbon stock through the use of biofertilizer by-product Reduced GHGs in BSFL production relative to conventional ingredients (fish meal and soya bean) Improved nutrient use efficiency
Improved fish smoking kiln	5.9	Reduced postharvest losses Increased income due to the production of superior products (fillets, whole fish, smoked chunks, etc.)	Increased diversification of income sources and reduced labor in operating the kiln	Uses less firewood hence comparatively carbon smart
Biofloc-based live food dispenser	5.8	Increased yield and income due to high fish survival rates	Reduced labor for fry feeding	High carbon arrest and increased nutrient recycling

the CSA pillars (productivity, adaptation, and mitigation) and their impact on the pillars is presented in Table 4.

4. Discussion

4.1. The Choice of CSA Profiling and Prioritization Approach. This prioritization process of aquaculture CSA-TIMPs using a modification of CSA-PF adds to the growing knowledge on agricultural participatory processes that promote the formulation and implementation of climate change policy [21, 31, 32]. When informing farmers' decision-making processes about their choice of various aquaculture practices, it is necessary to assess the opportunities and anticipated productivity and compatibility with future climatic circumstances. Farmers, however, typically have little interest in the opportunities for upscaling and the implications at higher levels and primarily care about the implications at the local level [33]. It is therefore important to involve different stakeholders from different regions of the country when assessing the out-scaling potential of practices and doing ex-ante assessments at the national level.

The CSA-PF process was modified to assess aquaculture CSA-TIMPs in Kenya in an easy and fast manner. An important insight in CSA profiling and prioritization using CSA-PF is that the integration of physical, biological, and socioeconomic CSA indicators is essential for enabling stakeholders to evaluate practices in relation to the diverse objectives of the end-users [17]. The process is entirely stakeholder-driven, which distinguishes CSA-PF from other research methods which can also be used to gather available data on the effectiveness of practices in relation to the objectives of CSA [34]. Involving experts and stakeholders is crucial since they are required to fill the gap in data on CSA practices in various agroclimatic and agroecological zones, which is currently insufficient [20, 21, 34]. Stakeholders also steer the prioritization process by defining the factors that are most crucial for making context-specific decisions. Without this, prioritizing CSA activities for expansion or funding might turn out to either be a quick process with minimal data input or a lengthy research seeking to analyze practices on a variety of parameters and utilizing tedious data collection techniques [17].

4.2. Profiling CSA Options. The choice of aquaculture CSA practices for out-scaling depends on, among others, the climatic and socioeconomic conditions of the targeted region [20, 35]. Accordingly, the profiling and prioritization process of aquaculture CSA-TIMPs in Kenya began with an extensive study of various agroclimatic and agroecological zones, socioeconomic and climate risks and vulnerability, and existing production systems and technologies used in the country. This informed the development of the initial "long list" of practices which were deemed as critical under various thematic areas in the aquaculture value chain. The thematic areas were selected to cover the full range of activities from the input node (production) to the output node (consumption) of the value chain [36], and they included culture systems, culture species and breeding, feeds and feed management practices, fish health management and biosecurity, fish post-harvest loss reduction, value addition and nutrition, and fish marketing, trade, and supply channels [12]. The list of 60 TIMPs compiled included new TIMPs and others that were already in existence in the country, most of which were already being implemented in the aquaculture value chain.

To measure the climate-smartness of a practice, Challinor, Arenas-Calles, and Whitfield [19] propose the use of either metrics that explicitly quantify an element of climate-smartness or indices, which are integrated metrics that aggregate and quantify data from various pillars or within a single pillar. The use of the CSA indicators in the evaluation of the TIMPs against CSA outcomes was important in yielding a shorter list of TIMPs relevant to the Kenyan context. The validation, modification, elimination, and addition of TIMPs in the process ensured context-specific options for interventions. For example, the modification of "land-based production system" to "pond-based culture system" was intended to ensure specificity since land-based production systems could even include raceways and RAS. Despite having been promoted globally as a climate-smart aquaculture production system, IMTA was removed since it is restricted to certain species and is still practiced on a trial basis only in the marine aquaculture sector in the country [37], which was not a target area for KCSAP.

4.3. Ranking and Prioritizing CSA Investment Options. Assessment of the impact of TIMPs on the CSA pillars and the synergies and trade-offs between productivity, adaptation, and mitigation goals acts as a basis for priority setting in response to climate change [21]. Different countries and social groups have different priorities regarding climate change policy interventions. For example, in the global south where small-scale farming is dominant, priority is more likely to be given to practices that improve productivity and adaptation than practices that enhance carbon sequestration and minimize emissions [8, 38]. The TIMPs were assessed for their impact on productivity, adaptation, and mitigation, and the synergies and trade-offs between the CSA pillars were assessed from the scoring of the TIMPs based on the CSA indicators. The best synergies between the pillars were shown in TIMPs with the highest average scores, hence recommended for prioritization.

The prioritized TIMPs were found to be more beneficial in terms of their productivity potential. This is viable in the Kenyan context since the country's immediate goal, being a developing country where small-holder farming predominates, is to enhance agricultural productivity. However, being more beneficial in terms of productivity is not a barrier to achieving the triple wins because adaptation and mitigation usually tend to complement each other and are not mutually exclusive options [9, 23]. For example, selective breeding reduces the fish culture period by about 3 months, hence reducing the risk of exposure to climate hazards and reducing GHG emissions since less fuel and feed are used in the shortened culture period [39]. Biofloc technology demonstrates its alignment with CSA principles by promoting productivity through efficient resource use, mitigating environmental impacts by reducing nutrient discharge and greenhouse gas emissions, and enhancing adaptation by improving resilience to environmental stressors [40]. The use of insect-based fish feeds improves fish yield and income due to improved growth performance and food conversion ratio (FCR) [41, 42] and improves soil carbon stock through the use of biofertilizer by-products [43, 44].

The findings of the current study provide the aquaculture practices for investment priorities in Kenya in the face of climate change. Although research and development partners in the country have established and backed these aquaculture practices [13, 45, 46], they have been mainly promoted separately without exploiting possible synergies between them and have thus often ended up not being largely adopted [13, 47]. Previous studies have reported the awareness and willingness of aquaculture practitioners in the country to adopt some of these technologies [48–50]. Therefore, empirical evidence of how these practices can contribute to sustainable and climate-resilient practices in the sector will significantly improve their adoption.

5. Conclusions

In this article, we assessed CSA-TIMPs and their impact on the CSA pillars of productivity, adaptation, and mitigation in Kenya using a modified CSA-PF. The government, private sector, and development actors are making significant investment decisions regarding the reformation of the aquaculture value chain in Kenya. The participatory prioritization process provided some CSA-TIMPs as investment priorities in the aquaculture value chain to achieve the CSA triple wins, a concept that would otherwise have been utterly neglected.

Through the KCSAP project, the process has attracted interest and implementation of the prioritized CSA-TIMPs. There have been achievements on improving productivity, adaptation, and mitigation on the ground including, among others, (1) establishment of biofloc technology systems in farmers' ponds and hatcheries leading to increased fish larval survival and productivity, improved water-use efficiency, and reduced production cost; (2) design and installation of integrated crop–livestock–fish production systems for increased productivity, increased nutrient cycling, and reduced GHG emissions; (3) procurement and supply of fish value addition and postharvest equipment such as improved fish smoking kilns and fish display boxes to women and youth groups for increased income and improved livelihoods; (4) production and distribution of improved Nile tilapia and African catfish broodstock through adoption of selective breeding and good aquaculture management practices for increased fish productivity and income; (5) establishment of black soldierf fly (BSF) production units to upscale production of insect-based protein-rich feeds for enhanced fish health and nutrition; (6) provision of research and funding support for the establishment of aggregated aqua-parks for improved resilience to climate change impact (e.g., flooding) and increased productivity and income; and (7) development of biosecurity practices for improved fish health and productivity.

To enhance the adoption of CSA-TIMPs for improved aquaculture in the face of climate change, several key areas require ongoing focus and strategic effort. The validation of CSA practices in aquaculture should be an ongoing effort that continuously evaluates new and existing CSA-TIMPs across diverse agroclimatic and socioeconomic conditions in Kenya. Stakeholders can ensure that these practices are sustainable, resilient, and well-suited to the local context. It is essential to involve a wide range of stakeholders, including local communities, research organizations, and government agencies, given the diversity of Kenya's agroclimatic zones. This inclusive approach ensures that the practices prioritized are technically sound, socially acceptable, and economically viable, facilitating broader adoption and alignment of national and local priorities. In addition, a comprehensive monitoring and evaluation (M&E) framework is necessary to assess the long-term impact of CSA-TIMPs and make necessary adjustments. This M&E framework should track the performance of practices against the CSA pillars—productivity, adaptation, and mitigation. Regular data collection and analysis will help identify synergies and trade-offs, providing the evidence needed to guide future interventions and policy adjustments.

Sustainable adoption of CSA-TIMPs requires significant investment in capacity building. Training for farmers, extension officers, and local organizations on the application and maintenance of these practices is essential. Developing local expertise will ensure that the necessary knowledge and skills are retained within the communities, while partnerships with research institutions can support a continuous pipeline of innovation and technical support. Finally, the validation and adoption of CSA-TIMPs must be supported by an enabling environment that includes favorable policies, access to finance, and infrastructure. National and county governments should work together to remove any barriers to adoption, such as limited access to markets and inputs. Creating incentives, such as subsidies or credit schemes, and integrating CSA priorities into national and county action plans will further support the recognition and adoption of these practices at the highest policy levels.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author, Jimmy Mboya, upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

Author Contributions

Kevin Obiero, Erick Ogello, Jonathan Munguti, and Domitila Kyule, conceptualization, funding acquisition, project administration, and writing, original draft. Jimmy Mboya, Mary Opiyo, Cecilia Githukia, and Kevin Ouko, investigation, data curation, and writing, original draft. Elijah Kembenya, Jacob Abwao, Geraldine Matolla, and Josiah Ani, investigation, data curation, and writing, review and editing. Saitoti Sambu, Maureen Cheserek, Kiplangat Ngeno, and Joel Khobondo, investigation and data curation. Menaga Meenakshisundaram, Chrysantus Tanga, and Rodrigue Yossa, writing, review and editing.

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