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REVIEWS IN Aquaculture

REVIEW

From the AKAP to AKAIE model to assess the uptake of technological innovations in the aquaculture sector

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Abstract

The purpose of this study is to explore the adoption of innovation in the aquaculture sector through the Awareness Knowledge Adoption Implementation Effectiveness (AKAIE) sequence. The AKAIE is an extension of the Awareness Knowledge Adoption Product (AKAP) model in order to better investigate the post-adoption phases. Using the '*Implementation*' and '*Effectiveness*' phases, this study aims to further the understanding of both the different levels of adoption and the impact of innovation in terms of environmental, economic and social benefits produced. The proposed sequence is contextualised in light of the multidimensional scenario of on-farm and off-farm factors acting alongside the adoption of new technologies in the aquaculture sector. In this paper, the perspective of aquaculturists is represented with the concept of perceived complexity as the central node of the adoption process. The proposed tool could support policy makers in understanding and disseminating innovation in aquaculture.

KEYWORDS
adoption process, AKAIE model, AKAP model, aquaculture, innovation, technology

1 | INTRODUCTION

The growing pressure for food and nutrition security and for more efficient use of natural resources imposes increasingly sustainable trajectories for agri-food systems. Aquaculture has experienced the fastest expansion among worldwide food producing sectors over the past 30 years[1] and is estimated to provide 106 million tonnes of the 202 million tonnes of aquatic animals produced globally in 2030.[2] Over the past two decades, institutions and scientists have supported actions for sustainable intensification to combat negative externalities associated with aquaculture,[3–5] which are related to combat the overexploitation of natural stocks to produce fish meal and oils, the emergence of new diseases in wildlife species, chemical and nutrient pollution, and effects on marine and coastal habitat or inland uses of land and water.[6]

New technological innovations (TIs) have been proposed in aquaculture to address the reduction in negative externalities and global sustainability challenges. In February 2021, the Food and Agriculture Organisation's (FAO) Thirty-Fourth Session on the Committee on Fisheries released a report[7] on the fish industry's contribution to sustainable development goals, emphasising how the diffusion of innovation in fisheries and aquaculture could accelerate the transition of systems towards the 2030 targets. The role of innovation is emphasised as central to the achievement of SDG 14 "*Life Below Water*" to both guarantee food and nutritional security and to support the transition towards sustainable and circular models of the aquaculture sector. For example, the role TIs can play in reducing poverty (SDG1 "*No poverty*"), food insecurity (SDG2 "*Zero hunger*"), inequalities (SDG 5 "*Gender Equality*"; SDG 10 "*Reduced Inequalities*") and in ensuring decent working conditions (SDG 8 "*Decent Work and Economic*

Growth") allowing these activities to provide economic resilience is discussed. As a result, the diffusion of innovations could facilitate cooperation between the public and private sectors, companies, research bodies, and policy networks.[8]

The most innovative management of practices is now required at the European level to support the challenges of predicted climate change, especially for fisheries, and for monitoring environmental conditions and the performance of aquaculture activities; supporting the policy network in implementing actions for more sustainable production and consumption (SDG 12 "*Responsible consumption and production*"; SDG 13 '*Climate Action*').

The European Green Deal strategy also supports the essential role of research and innovation in driving the technical and ecological transition of agri-food systems. In particular, the Farm to Fork (FTF) strategy has set ambitious goals for the sustainability, competitiveness and resilience of European aquaculture, which is considered fundamental to achieving the transition of the entire primary sector.

European countries are reviewing their actions (i.e., legislative frameworks, funding) in light of the FTF strategy. In particular, the objectives of the European strategies have conditioned the new Common Fisheries Policy (CFP), translating this new trajectory into new measures of the European Maritime, Fisheries and Aquaculture Fund (EMFAF), focused foremost on the development of the aquaculture sector. Both new funding flows supported by the EMFAF (2021–2027) with a budget of 6.108 million Euros and ecological schemes plan to promote more sustainable practices through the CFP and accelerate the transition to respect the roadmap of European Strategies on climate and environment. Finally, research and innovation on sustainable aquaculture is a priority for Horizon Europe, the European framework program for research and innovation.

The reasons why innovation is entrusted with driving this transformation can be found in the definition provided by Mbabu and Hall[9]: "*innovation is the new use of existing or new ideas or the combination of ideas that have social or economic significance*" to respond to ecological, social and institutional changes which are implied as agri-food systems. Numerous technological and non-technological innovations have been recognised as driving forces able to combine the growth and social and environmental issues of aquaculture production systems.[10] Technological advances include breeding systems, feeds, information and communication technologies, while non-technological includes improved regulatory frameworks, organisational structures, and market standards.[11,12]

The aim of this paper is to provide a new model for interpreting the transfer of TIs in aquaculture and their implementation based on different levels of analysis, from an extra-farm context to an intra-farm context to consider the characteristics of the technology itself. The combination of TIs and aquaculture practices can offer great opportunities to the sector, when applied to breeding and genetic techniques, disease management, feeding processes and sustainable production systems.[13–15] In this sense, technological innovation could help to monitor processes and resolve production risks.[16]

Previous studies highlighted this potential not only at a production level but also at a broader level. do Amaral et al.[17] (p.184) state that "*a low level of technology adoption reflects on less efficient production systems*"; while Wetengere[18] (p.34) adds that "*the contribution of fish farming to household nutrition and income security depends more on the level of technology adopted*".

Studies have traced the adoption of innovation in aquaculture,[19,20] mainly on a firm level[21] applied to freshwater,[22–25] marine[15,16] and shrimp farming[19,26] primarily conducted in Asia and Africa.

Adoption is defined as a complex framework[22,27] especially when aligned with the socio-economic dynamics of the aquaculture production system.[20,28,29] Complexity stems from numerous factors affecting the propensity to adopt.[19] Kumar et al.[27] conducted an in-depth review for this in aquaculture, indicating it as very recent and underdeveloped.[19,30] In fact, the attitude to innovate has been primarily explored in the agricultural field since Ryan and Gross[31] and Griliches[32] discussed the barriers and drivers of adoption[33,34] by investigating how structural (on-farm factors) and institutional (off-farm factors) aspects can generate a perceived complexity and, therefore, significantly influence potential adoption.[35]

Furthermore, there is a great heterogeneity of studies, some have investigated the determinants of adoption during the entire decision-making process, from awareness to the phases of developing interest and evaluation of TIs, to those of experimentation and adoption according to the Innovation Diffusion Theory (IDT) by Rogers.[36] While, others have focused mainly on concerns related to the final decision to purchase the innovation. At the same time, a deficiency exists in the assessment of the post-adoption phases and the eventual implementation of innovation between studies, which results in difficulty in distinguishing a purchase choice from a partial adoption or more intensive levels of adoption. Furthermore, scholars revealed a plurality of visions when assessing the impacts, or in other words the effectiveness, of technological innovation on the performance of the aquaculture sector, mostly due to the complexity of defining unambiguous parameters to estimate its effects. From this scenario, some concerns need to be mentioned:

i. Current studies in aquaculture on the uptake of new technologies, implementation and effectiveness are still lacking and most have been performed at the farm level in developing countries[19,20,37];
ii. Further investigation is rewired in order to understand the reasons for the low or partial adoption of TIs at the farm level and the influence of context dynamics whereby innovation is applied.[13]

The present study intends to investigate the adoption of TIs in aquaculture and the intensity of uptake at the farm level after the first purchase. On one hand, it is relevant to discern bottlenecks of the adoption of innovation, and on the other hand, it is necessary to highlight drivers preventing a greater inclusion in farms.

To further the post-adoption phases, we intend to analyse the decision-making process through an implemented Awareness Knowledge Adoption Product (AKAP) model, which also incorporates the

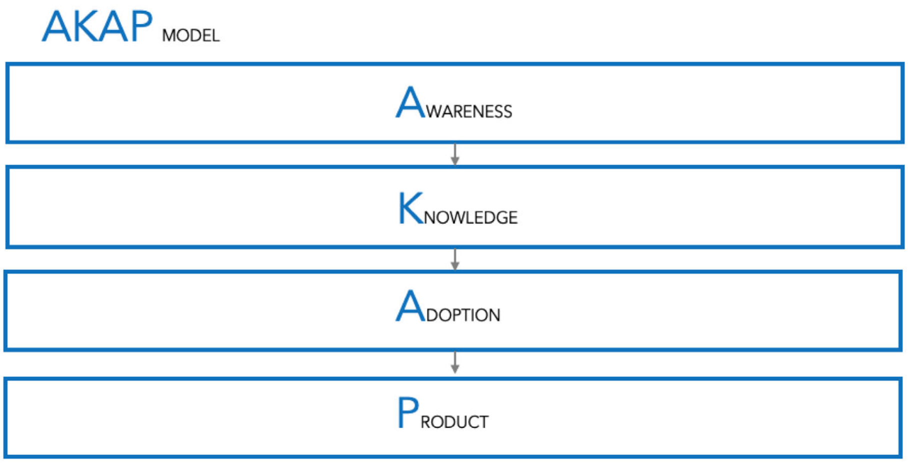

FIGURE 1 The AKAP model, according to Evenson (1997).

'*Implementation*' and '*Effectiveness*' phases, theorising the *Awareness Knowledge Adoption Implementation Effectiveness* (AKAIE) model.

The study will be structured as follows: section 2 will discuss the AKAIE model. The on-farm, off-farm factors and perception spheres influencing uptake will be illustrated to contextualise the proposing sequence. Finally, section 3 provides a discussion of topics, conclusions and policy implications.

2 | A HOLISTIC APPROACH FROM AKAP TO AKAIE MODEL

The AKAP model was theorised by Evenson in 1997.[38] Over time, the AKAP model has been used to study the impacts of alternative extension approaches in agriculture.[39] Today, this sequence has been approached to analyse the adoption process to help policy makers in developing lines of action to support innovation in agriculture.[40,41] Vecchio et al.[41] reported that this sequence aligned perfectly with the multidimensional nature of the adoption process and with the systemic character which the concept of the innovation process is increasingly assuming.

This model consists of four phases[38] (Figure 1). The first phase is the '*farmers' awareness*', in which the individual becomes aware of the existence of innovation. It is only later that, after developing interest and experience, the individual decides to acquire more information and gain knowledge, which is represented by the second step, namely "*farmers' knowledge, through testing and experimenting*". In the third phase, called "*farmers' adoption of technology practices*", the individual decides to adopt after having made assessments and possibly, having experienced the innovative practice.

Finally, the last phase considers "*changes in farmers' productivity*" by the following adoption, as conceptualised by Evenson[38] as the "*added value of goods produced from a given set of inputs*".

The present paper aims to study TIs' adoption in aquaculture by proposing an extended AKAP model which is built to further post-adoption phases, where adoption is expressed as the decision to first use/first purchase new technology and consider the 'Implementation' and '*Effectiveness*' as post-adoption phases (Figure 2). This paper introduces into the sequence '*Implementation*', understood as the phase in which the farmers engage in a higher level of adoption than the initial purchase, and '*Effectiveness*', understood as the phase in which concrete benefits from the adoption of ITs can be experienced. The AKAIE sequence suggests the importance of considering the post-adoption phases. In the case of a technological tool, the adoption process requires the evaluation of both the post-adoption phases of implementation of the technology in business practices over time (i.e., involvement, capacity of use) and, consequently, the impact of these actions. During the adoption of innovation, it is necessary to verify whether the initial adoption (i.e., the purchase) is likely to result in a partial adoption if the purchase is not followed by an '*Implementation*' phase or if the results are not very effective ('*Effectiveness*').

First, the model proposes to interpret the phase of the '*Product*' as the '*Effectiveness*' of the innovation. There are few empirical studies that have investigated the post-adoption phase and specifically the impacts of innovation on the food value chain. From the existing studies, most have proposed to explore the impact of innovation in agriculture through productivity measurement. Fewer studies have emphasised improved input/output ratios resulting from precision management of temporal–spatial soil variability.[42] Today, there is an increasing need for additional studies demonstrating the benefits and performance, not just economic, of the food supply chain. The need to extend the scope of the investigation has long been identified in the literature on Small and Medium-sized Enterprise (SME) performance[43,44] questioning the concept of innovation effectiveness. Empirical evidence has supported this view, focusing on non-financial indicators when assessing innovation effectiveness in SMEs.[45] For these reasons, we believe that interpreting the 'Product' phase as '*Effectiveness*' could be functional to fully consider the result of the application of innovation in terms of economic, social and environmental benefits produced.

Second, the model includes the '*Implementation*' phase. In most studies, adoption was considered only as use/non-use or purchase/

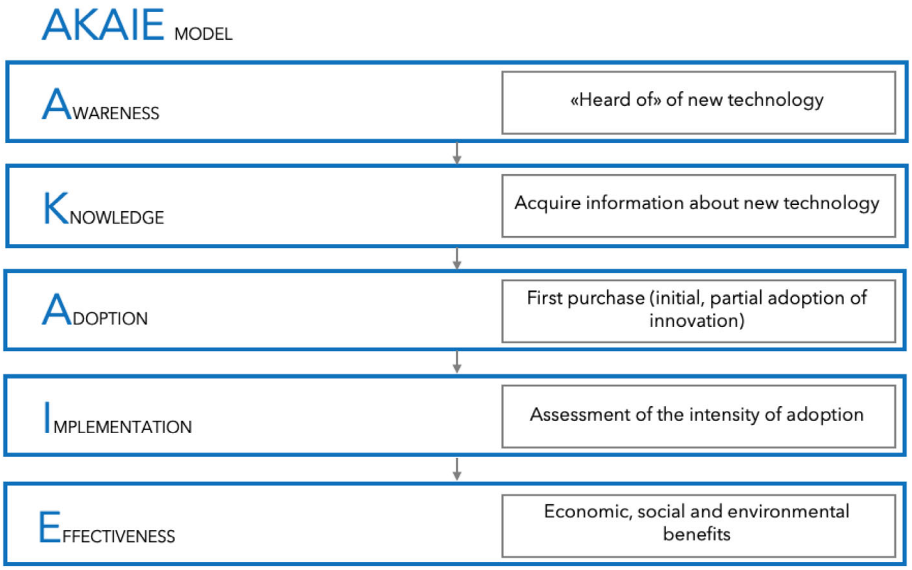

FIGURE 2 The Awareness Knowledge Adoption Implementation Effectiveness (AKAIE) model (own elaboration).

non-purchase. However, criticisms have been made for many years at the definition of adoption. According to Black[46] (p.356–361) "*Proper measurement extends beyond the initial decision and requires the addition of the time or use dimension of the innovation*", also adding that "*Dichotomous operationalization can be significant when examining discontinuous innovations, but even in these cases, the evaluative processes or confirmation phase and their potentially important effects on subsequent actions are overlooked*". In our opinion, more studies on post-adoption phases are needed to evaluate different levels of adoption of TIs.[47]

2.1 | Phase 1– AWARENESS

The first stage is '*Awareness*', or in other words "*having heard about*" a technology for the first time.[48] This is a prerequisite for adoption[49] and corresponds to the moment in which the individual becomes aware that a technology exists.[50] Among innovations, some researchers[13,14,15,51] have attempted to discern the available technologies in aquaculture farming into several areas: breeding and genetic technics, biosecurity and disease management, nutrition and feeding technologies and sustainable production systems. In the genetics field, the use of improved stocks is proposed to increase farm productivity, ensuring farm efficiency by controlling cost items mainly related to feeding or to the control of diseases. In the feed sector, alternative diets to fishmeal are proposed, based on plants and with low environmental impact. For the control of diseases, selective reproduction, improved management of feeding or hygiene techniques and new diagnostic tools or monitoring systems are employed. In contrast, more sustainable farming systems include recirculation aquaculture systems, biofloc technologies, and integrated systems.[52]

Antonucci and Costa[53] (p.1) reviewed some TIs that can be used in the field of precision aquaculture (PA), including the "*computer vision for animal monitoring, environmental monitoring tools and sensor networks, robotics and finally data interpretation and decision tools (e.g., Internet of Things and decision support systems)*".

In a study by Føre et al.[54] on intensive salmon farming, a clearer definition of PA was provided by imagining the application of these tools to the farming cycle. Cage farming can be seen as a series of cyclic operations that produce bio-responses in different phases. The first phase is where the bio-responses of the fish are observed inside the cages ('Observation'), thus, making use of tools such as smart sensors and online monitoring instruments (e.g., GPS, echo sounder, remote sensing). The second phase occurs when the responses are interpreted ('Interpretation') through predictive models or simulation systems, which provide the answers to make decisions ('Decision') through the use of artificial intelligence and decision support systems on specific actions ('Action'). It is in the latter phase that specific actions are implemented to integrate automated operations and innovative tools to achieve certain objectives and, more generally, to generalise the expected biological response of the salmon.

Finally, multi-actor technologies such as innovative platforms and business incubators have also been applied to aquaculture.[10,55] More systemic approaches to innovation are increasingly required to better climb different levels of complexity (technological, socio-cultural, institutional, environmental aspects of the sector) and to stimulate innovation for sustainable aquaculture by promoting learning processes among actors and improving the ability to anticipate changes for the sector.[51]

More generally, in the agricultural field the concept of the innovation process has been the subject of a major evolution in thinking that has increasingly characterised its complexity and systemic nature, as opposed to linear processes, in which innovation was channelled from science to end users.[56] As a result of this evolution, the structure of knowledge services created for the agricultural sector now supports systems such as the Agricultural Knowledge Innovation System

(AKIS), which encourages systemic visions of innovation processes as well as an interactive approach in which social learning is an important lever for the diffusion of innovation. This vision, which has been widely supported by common agricultural policies since the 1990s, has barely been explored for the aquaculture sector over the last decades and, only recently, experiences such as innovation platforms and business incubators* have invested in knowledge to provide innovative solutions for the sustainable transition of aquaculture farms.[10,51]

2.2 | Phase 2– KNOWLEDGE

The second phase is 'Knowledge', which according to Evenson[38] (p.46) "*requires awareness, experience, observation, and the critical ability to evaluate data and evidence*". Once the individual is aware about innovation, they seek to determine "*how and why it works*".[57] Two types of knowledge have been distinguished:

i. '*How-to-knowledge*' or in other words, the individual learns how the technology technically works to ensure that it will be used at the expected level;
ii. '*Principles-knowledge*' to understand why an innovation should be applied and how it could be integrated into everyday practices.

According to Rogers[57] '*how-to-knowledge*' is a prerequisite for adoption. However, having a proper '*how-to-knowledge*' does not indicate that farmers will adopt that technology; their attitude also greatly influences this choice. It is also relevant to note that adopting without the '*principles-knowledge*' can lead to discontinuous forms of adoption or even interruption.

2.3 | Phase 3- ADOPTION

The adoption processes have primarily been described as subprocesses of the diffusion of innovation.[58] Otherwise, 'Adoption' has been approached at a theoretical level from different perspectives in sociological, economic and even, marketing fields.[59]

The *economic approach* focused on the individual's rational choice that depends on factors that normally act on the purchase decision. Through this approach, it is argued that the potential adopter is a rational individual who weighs the benefits and costs before buying a new technology. The first study that supported this approach was Griliches[32] with the first empirical work on the spread of hybrid corn in the United States, which demonstrated how economic factors such as expected benefits and economy of scale were positively related to adoption.

A more *sociological approach* has emphasised the influence of the institutional context in the adoption process. The first study that supported this approach was Rogers' IDT,[36] which described the role of communication channels, change agents and the nature of the social systems in which potential adopters had fallen as the determinants. Adoption is not a dichotomous choice, it involves a multi-step process, as theorised by some sociologists since the 1950s[48] which runs from the individual learning about the existence of the innovation ('awareness'), passing through the phase of developing an interest ('interest'), mentally applying it to the specific farm context ('evaluation'), trying it on a smaller scale ('trial') to adoption. In aquaculture, one of the most used approaches to study the adoption path is the IDT; in agriculture, many other models and theories are widespread such as the Theory of Planned Behaviour (TPB), the Theory of Reasoned Action (TRA), the Unified Theory of Acceptance and Use of Technology (UTAUT) and Technology Acceptance Model (TAM).[16]

Finally, the *marketing approach* is described as the multiple factors that form the perspective of the supplier leading the consumer to purchase the TIs. Dissemination is based on learning about the existence and benefits of innovation, hence, information channels and the characteristics of the product itself are underlined as influential in this approach. It focuses on determinants that can predict market success and, those leading to the '*take off*', the point at which the S-curve of the diffusion denotes the moment of the best success of the product.[60]

In all of these approaches, there is a sensible search for the determinants of adoption. However, even though studies have exhibited great efforts to represent adoption as a long and complex process rather than a discrete event, these approaches often result in looking for the factors that influence the choice of product purchase. Hence, the projections of studies on the number of adopters often needs additional interpretations. Identifying those who have bought the technology does not mean having envied those who are truly convinced of adopting innovation and maybe have implemented or who interrupts use by trespassing in cases of partial adoption.

2.4 | Phase 4 - IMPLEMENTATION

The fourth stage is '*Implementation*', conceptualised in this study as a post-adoption phase. Uncertainty associated with TI implementation has been reported by Eastwood et al.[61] who describe how it arises primarily from doubts surrounding outcomes. Several studies have investigated the implementation of innovation at the company level in the agricultural field by measuring the intensity of adoption over time in terms of the number of TIs adopted,[62–65] however, few studies have attempted to focus on the propensity to innovate by the already adopting farmer. Loganandhan et al.[47] reported that "*once adopted, there is every chance that the particular technology is being continued with the same specifications or with some technological gaps or discontinued completely*".

In the aquaculture field, Obiero et al.[14] followed this vision by describing high adopters as those who "*had fully adopted*" TI's components. To discern different levels of uptake, Ulhaq et al.[26] framed the initial stages of adoption, referring to that period in which fish farmers have not yet experimented or seen pilot experiences with Information and Communication Technology (ICT) and have not been able to appreciate the effectiveness of innovation. In addition, a study by

Kumar et al.[66] attempted to identify factors influencing early adoption decisions, recognising the existence of different stages of use according to Rogers' IDT.[57]

Going beyond the purchase of TIs might be relevant to understand whether farmers will continue to innovate, pause at initial adoption, or even return to traditional practices. It is through the implementation phase that early adopters could be distinguished from adopters with a greater intensity to use new TIs.

2.5 | Phase 5 EFFECTIVENESS

In this study, the ‘*Product*’ was analysed as a phase of evaluating the effectiveness of the adoption in terms of expected benefits at a firm level. For this reason, it is called ‘*Effectiveness*’.

As “*empirical studies of the welfare impact of an aquaculture-specific technology on households are scanty, but there are potential direct and indirect benefits of improved aquaculture technologies on households*”,[30] (p.1) we intend to explore the positive externalities that can result in innovation in terms of social, environmental and economic benefits.

At the company level, the introduction of TIs permits monitoring processes and improving sustainability performance.[26] In particular, PA tools offer the possibility of performing ‘precision’, such as the continuous and autonomous monitoring of fish biomass. This not only provides decision support to the farmer but also reduces manual labour fatigue and improves safety in the workplace. Combining manual operations with precision tools allows the combination of economic performance and social and environmental sustainability. Indeed, the feeding processes, behaviour and welfare of animals, and control of environmental and water parameters could be performed. The continuous monitoring makes it possible to improve the use of inputs, reducing production costs and operation time to gain high productivity.[54,67,68] This could lead to environmental benefits and to an improvement in water quality and animal welfare.[69]

ICT systems are not applied only at the production level, but innovation engineering can be extended to the entire value chain, for example, for traceability and monitoring the quality of the final fish product.[26] In addition, they can result in indirect benefits to all fish value chain actors as their introduction can reduce fish prices and incentivise the creation of jobs and higher wages even outside the industry.[30] Their dissemination might also increase competitivity within the aquaculture sector through an increase in supply for the internal market.[70,71]

In addition to the positive aspects, it is important to ensure that the technology does not pose a negative impact on future farming reality. In this sense, innovation is given a responsible role in ensuring not only economic, but also socio-ethical benefits. The field of responsible research innovation (RRI) is enhancing evaluation tools that can measure innovation's ‘effectiveness’. This strand emphasises the importance of analysing the possible impacts of innovation on individual beneficiaries, society and the ecological environment in order to modify innovation objectives and strategies in the face of changing scenarios.[72,73]

2.6 | Contextualising the AKAIE in the aquaculture sector

The AKAIE model could offer a key understanding of the adoption process at each stage, thus, the next step is to interpret the sequence in the light of the context in which the innovation processes occurred. The stages of this sequence should be contextualised on the basis of two aspects (Figure 3):

i. The company level, represented by intrinsic structural factors which in this paper are defined as ‘on-farm’;
ii. The institutional level, represented by extrinsic factors of the context which are defined as ‘off-farm’.

2.7 | On-farm factors

Aquaculture studies are controversial in terms of the correlation between age and adoption, both positive[20] and negative.[25] Wetengere[18] provided insight on this by proposing a study where the influence of many variables on the intensification of technology in aquaculture was evaluated on three levels, from the least to most intensive use. According to the majority of adoption studies on agriculture[74] results of Wetengere[18] indicated that younger individuals had a greater propensity to innovate; however, they registered the lowest level of adoption. Whereas the elderly were positively correlated with a greater intensity level. Although these results need to be interpreted in the context of innovation, these findings have occurred because adults tend to carry on family business, while younger people are more likely to take other opportunities.[18] For the same reasons, Wetengere[18] reported that women were more motivated to intensify fish farming activity.

Furthermore, producers with a higher level of education, who undergo continuous training[14,23] and in general were well informed[18,24] tended to be classified as more inclined to adopt. It is important to highlight that a farmer's knowledge of TIs depends on their level of education and personal experiences and also on the influence of information sources (e.g., family and friends; their involvement in clusters; the role of farm advisors).[14,29]

Some studies highlight how uptake was also well combined with diversified[14] and large farms with greater financial possibilities[23,66] and higher household income levels.[25,26] Other studies indicated that small-scale farmers were more willing to adopt these technologies when fish farming was their dominant activity; the converse result occurred for larger farms.[17,24] Small-scale producers often interface with very low local demand, which does not encourage them to implement the business or invest, unlike those who can take advantage of

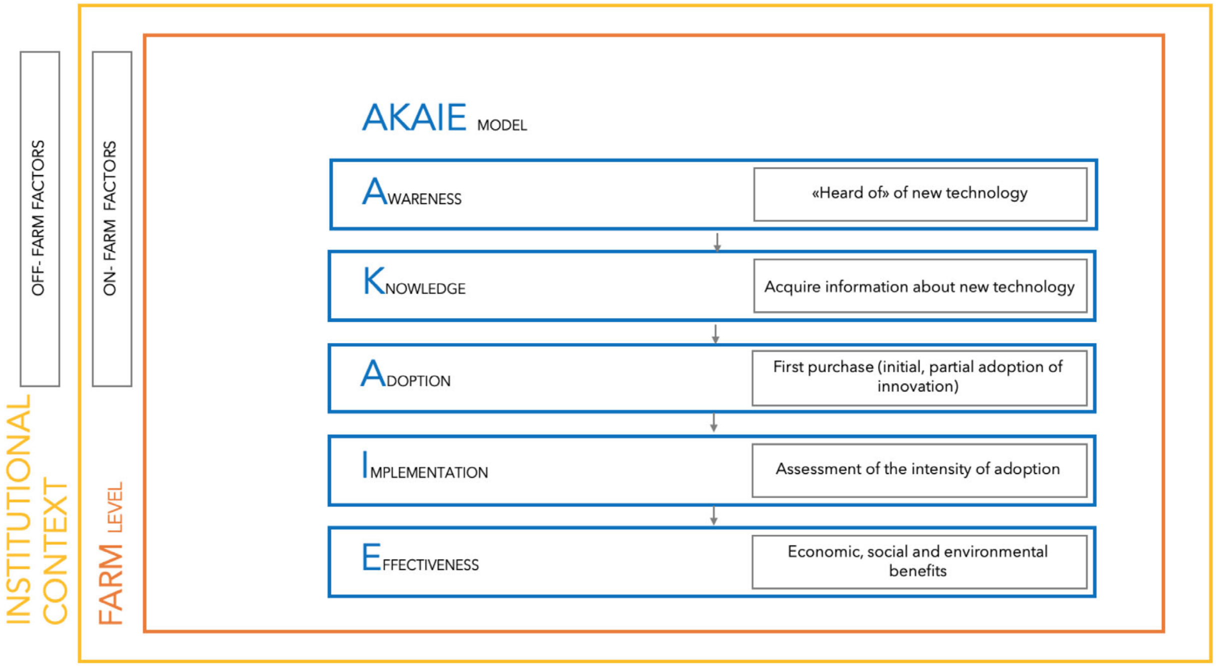

FIGURE 3 On-farm and off-farm factors as key elements to interpret the Awareness Knowledge Adoption Implementation Effectiveness (AKAIE) model (own elaboration).

demand from nearby cities or wholesalers.[75] Furthermore, large farms could have a stronger beneficial influence on other farmers to adopt these new practices.[26]

Caffey and Kazmierczak[76] determined that an external income could represent a method to tolerate the initial costs of purchasing technology in grab production. The initial cost of investment has a high perceived risk associated with these technologies and is described in existing literature as a major reason for non-adoption.[66]

2.8 | Off-farm factors

The institutional context in which innovation operates is often referred to as the ecological environment, policy, markets and socio-cultural dynamics.[10,22,23,77] Studies by Loeber[78] and Elzen et al.[79] explored the concept of "*anchoring innovation to a context*" to assess potential scaling by defining the micro-, meso- and macro-levels. This multilevel perspective helps to define the dynamics that occur within innovation processes moving from the level of technological niche, passing through networks, to the systemic dimension defined by the institutional context in which they are dropped.[80] Studies addressing the contextual dynamics conducive to innovation adoption in aquaculture are scarce, and most still propose to explore fish farming adoption.[28,81] The reason why they still analyse the factors leading to start-up aquaculture activities is because most studies have been conducted in developing countries where issues of access and availability of material and financial resources are primary. The certainty of receiving material (equipment, training, etc.) and financial support from the public and non-governmental institutions, as well as efficient local administrative structures, are driving forces for adoption. Further, the difficulty to source feed or fries and the impossibility of having fast transport to deliver the production in controlled conditions prevent them from leaving the market logic marked by local demand and therefore from exploring more innovative trajectories.[75] Thus, fish seed networks are growing, especially in Asia, boosting aquaculture activities in inland areas.[82] The adoption of innovative selective breeding can provide great results, although it is not highly widespread due to economic and training difficulties and low level of public support.[83]

Socio-cultural factors, such as religion and ethnicity also direct, for example, the consumption of fish on certain days. Cluster membership itself enhances social relationships and drives shared cultural habits but also uncertainties and responsibilities.[29,75] In particular, Joffre et al.[29] demonstrates how group membership is positively correlated with a higher likelihood of adoption. Indeed, the power of collective action leads to knowledge sharing, which goes beyond the farmer to farmer knowledge emphasised in many studies for example,[13,84] Similarly, the frequency of interactions and the relationships of trust that are established, especially with relevant actors in the aquaculture sector, strongly influences decision-making processes.[29] The clustering of multiple segments of the value chain in a local area has been demonstrated to boost innovation adoption among aquaculture farmers.[85]

Information sources exert different influences based on user type and when they intervene in the adoption process.[20] Brugere et al.[22] demonstrated that in the adoption of aquafeed containing non-conventional ingredients different types of feed users were affected by different social pressures: farmers using commercial feeds were increasingly influenced by the approval of neighbours and family, while those using farm feeds were perceived the opinion of other farmers or feed suppliers as more relevant. In addition, extension and advisory services, offered by graduate students, ministry experts or territorial extension agents, play an important role in promoting new practices in aquaculture.[3,27,75] For example, extension support and involvement in research programs were found to be positively associated with alternative catfish production technologies adoption in the early stages.[66]

2.9 | Which is the role of aquaculture farmers' perception in the adoption process?

To correctly interpret the adoption sequence, it is necessary to analyse the context in which the innovation is dropped, as was discussed in the preceding section. For these reasons, the influence of structural and institutional components on the decision-making process have been discerned. In this scenario, there is a need to deepen the behavioural component,[49] thus understanding which role is involved in the perception of this theoretical framework. Perception plays a relevant role in the decision-making process leading to the adoption of innovation and it has been explored in different ways.[18,22,35,86–88]

A much broader strand encompasses studies[20,88] sustaining most conventional approaches by proposing perception as highly driven by the characteristics of innovation, according to Rogers' IDT. Specifically, some studies have demonstrated that the perception of increased yield[66,89] and ease of understanding were positively associated with a higher likelihood of uptake of innovation in aquaculture.[14] In contrast, others highlighted how aspects of compatibility with current practices and trialability of innovative practice were more critical than economic aspects.[22]

In addition to Rogers' framework, many studies[18,19,22,66] include perceived production and financial risk as attributes, the minimization of which is positively associated with adoption. In general, the perception of risk as an element is emphasised as being influential in the aquatic environment.[90]

Wetengere[18] noted a good chance of intensifying uptake if the new tools proved to be profitable and if fish products were easier to raise and more marketable and desirable.

Perception has also been proposed to be shaped by normative, control, and behavioural beliefs, according to Ajzen's Theory of Planned Behaviour.[91] Brugere et al.[22] emphasised the importance of behavioural beliefs such as "*the perceived importance and effectiveness of innovation*"; normative beliefs such as "*social pressure and approval from other actors*" in the fish supply chain; and control beliefs such as "*perceived barriers or incentives*". Among them, perceived peer pressure and outcome uncertainty were determined as the most significant. Social norms exert a relevant influence on this decision because farmers exhibit a greater intention to adopt if they witness their peers' trialling innovation and demonstrating expected outcomes.[26]

Fewer studies (e.g., Diedrich et al.[28]) have been influenced by psychological[92] and behavioural economic[35,93] fields, in which perception was clearly analysed as key to understanding the external context and thus as a central node of the adoption process. The same psychological studies emphasised how behaviour was the result of interconnections between individuals and the environment. The individuals developed a positive or negative attitude towards adoption as it expresses the environment subjectively perceived.[94] Obiero et al.[14] and Ndah et al.[75] described how perception was directly related to adoption propensity in aquaculture highlighting both the contribution of the first strand mentioned above and sociological approaches, conceptualising perception as driven by on-farm and off-farm characteristics. In the agricultural field, Vecchio et al.[35,41] managed to incorporate the influences of the context by proposing to investigate the process of innovation adoption through the indicator "*perception of complexity*", in which the most relevant technical-economic, financial and organisational aspects were encapsulated. In these studies, the perception of complexity, defined as a subjective mental process shaped by the structural profile of the farm and by the environment in which innovation occurs, decreased from non-adopter to adopter.

The present study follows the latter conceptualisation (Figure 4) where our model proposed to consider perception as a central node of the adoption process.

3 | DISCUSSION AND CONCLUSIONS

Aquaculture boasts greater diversity in terms of feed, production processes, disease, products and farm buildings. Several TIs have considerably contributed to the sustainable development of aquaculture, and these have been made possible by scientific and technological advancements. However, still, many barriers are reported in the literature that according to Yue and Shen[95] mark a slow pace of adoption of innovation compared to the current development of aquaculture. A more in-depth study of the adoption process and its contextualisation could also be very useful to analyse the reasons why certain TIs register greater acceptance in different contexts and for different productions within the sector.

This study aimed to assess the process of TIs uptake in aquaculture, both in the pre- and post-adoption phases by proposing the theoretical sequence of AKAIE.

The model attempts to identify a number of dimensions from awareness to effectiveness as perceived complexity, institutional and farm contexts may have different weights in the technology adoption process, depending on the nature of the technology itself.[96] This model, however, allows for scalability of the adoption process because it is possible to change the indicators within different stages, allowing for possible standardisation when comparing the adoption processes of different technologies. The model has a limitation which was due to the assumptions as it is not possible to compare the results of the process for different TIs.

To conduct this theoretical analysis, a literature review was performed on the available studies. Unlike the agricultural field, this topic requires further exploration. Most existing studies tended to analyse the drivers and barriers with respect to the initial adoption of

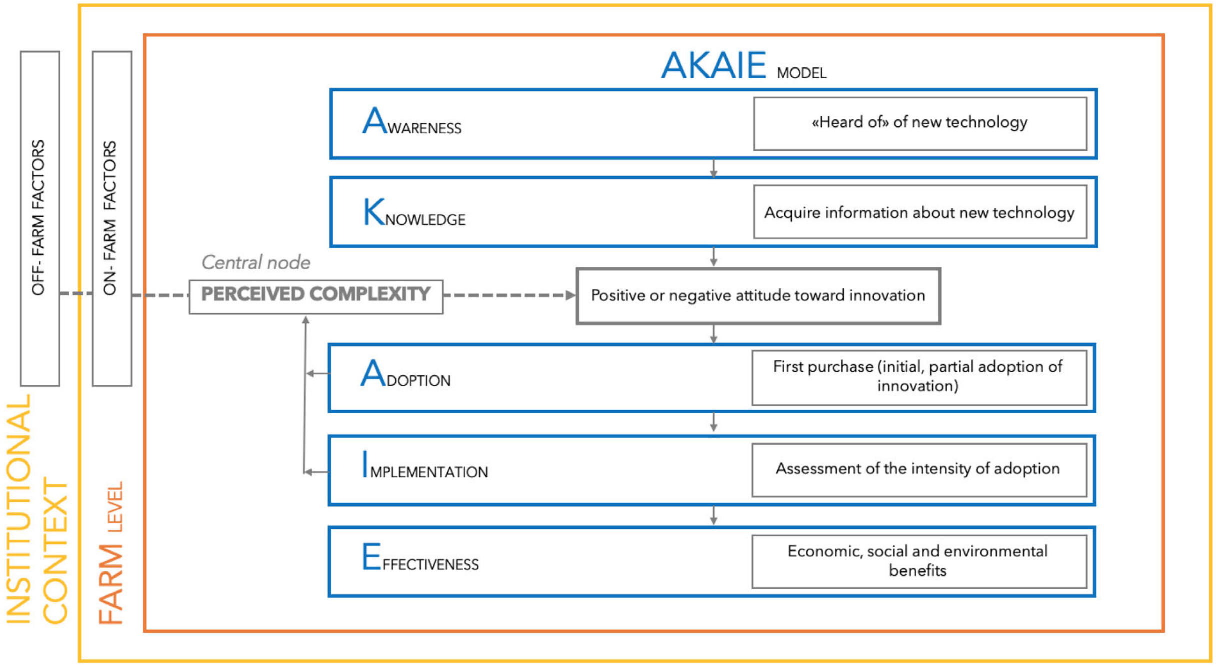

FIGURE 4 Perception as the cornerstone of the adoption process in aquaculture (own elaboration).

technology, which coincides with the first use/purchase of the innovation. A model that could provide a key understanding of the TIs adoption process for the aquaculture sector has been proposed. From the model, three main concepts emerged:

i. Adoption of innovation is a multistage process and perception plays a key role;
ii. Perception should be considered as a central node of the adoption process and should be studied by including the influence of on-farm and off-farm variables;
iii. The AKAIE model could represent a tool for assessing the post-adoption phases, including '*Implementation*' and '*Effectiveness*' of innovation in aquaculture farms.

The proposed sequence allows the identification of bottlenecks in the pre-adoption, purchase and post-adoption phases. The pre-adoption phase begins from the moment the individual learns about a technology for the first time and continues with the phase of developing interest and knowledge. At this point, based on the knowledge gathered and the context in which the technology acts, the individual forms a more or less complex perception of adoption. This indicator should be assessed differently for a non-adopter and an early adopter and a user who desires to implement TIs. The non-adopter should exhibit a greater perception of complexity compared to an individual willing to innovate or an adopter. In the same way, an individual who has already adopted and intends to implement has an even lower perception than an adopter who has just purchased the technology. The initial stages of adoption mainly concern the purchase of the technology, and to reach a more advanced level of adoption the individual needs to acquire technical aspects regarding innovation ('*How-to-knowledge*') and also principles and benefits it can ensue ('*Principles-knowledge*'). In general, the post-adoption phase includes the possible implementation of TIs and the concrete evaluation of the benefits received. Reaching the stage where the benefits are visible not only demonstrates the '*Effectiveness*' of adoption, but also that the individual has fully understood the innovation and reasons for uptake. A good effectiveness result can demonstrate the effectiveness of political action in supporting innovation. Indeed, this model could represent a tool for understanding the effectiveness of innovation in a given context and therefore an additional tool for policy makers to understand the state of the art of innovation's uptake in a specific context and to formulate new measures of intervention for the diffusion of TIs in aquaculture.

Researchers and institutions at a global and European level are striving to support change towards more competitive and sustainable aquaculture models that include the adoption of innovations. Past experiences have demonstrated how the possible technological developments within a key sector, such as aquaculture, can become a driver to achieve the UN 2030 goals, as well as contributing to the realisation of several SDGs and regional strategies such as the European Green Deal. For this reason, measures bridged by regional policies, such as the EMFAF in Europe, focus on the dissemination of TIs in the aquaculture sector. However, the need for monitoring tools to assess the effect of the policy measures implemented is increasingly important. Ex-post evaluations of the effects of policy measures are common in existing scientific literature,[97] however, our study forms part of the possibility to offer a new model to evaluate the current state of the dissemination process of a given technology, offering the policy maker the possibility to be able to act promptly in order to improve the effectiveness of the measure deployed. As a result, following the strand of RRI could highlight the vision of making innovation policies responsible. The development of tools for evaluating the effectiveness of innovation is more necessary than ever, especially to orient strategies and interventions in the face of major scenarios of change. In recent years, challenges have become increasingly complex, from the climate crisis to the COVID-19 pandemic and the recent Russia-Ukraine war. Major crises often represent moments of great change, opening a window on unforeseen and sometimes unprecedented scenarios that alter perspectives to consider the future of society. These times often result in the strongest reflection of mechanisms for developing innovations in response to crises, following Mill's theory.[98]

Future research foresees the application of the AKAIE model to empirical cases to evaluate the propensity to innovate some aquaculture producers and to investigate how this model is perceived by aquaculture policy networks. Further studies should focus on understanding the influence of the on-farm and off-farm factors explored in this paper at different stages of the adoption process in aquaculture.

AUTHOR CONTRIBUTIONS

Yari Vecchio: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; resources; software; supervision; validation; visualization; writing – original draft; writing – review and editing. **Margherita Masi:** Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; resources; software; supervision; validation; visualization; writing – original draft; writing – review and editing. **Felice Adinolfi:** Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; resources; software; supervision; validation; visualization; writing – original draft; writing – review and editing.

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DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analysed during the current study

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ENDNOTE

* European Aquaculture Technology and Innovation Platform (https://eatip.eu); Hatch blue (https://www.hatch.blue); Maine aquaculture innovation centre (https://umaine.edu/ cooperative-aquaculture/business-incubation/); WorldFish Incubator http://www. worldfishcenter.org/content/worldfish-incubator; New Jersey aquaculture innovation centre (http://aic.rutgers.edu/);

REFERENCES

1. FAO. *The State of World Fisheries and Aquaculture 2020*. FAO; 2020. doi:10.4060/ca9229en
2. FAO. *The State of World Fisheries and Aquaculture 2022*. FAO; 2022. doi:10.4060/cc0461en
3. Engle CR, McNevin A, Racine P, et al. Economics of sustainable intensification of aquaculture: evidence from shrimp farms in Vietnam and Thailand. *J World Aquac Soc*. 2017;48(2):227-239. doi:10.1111/jwas.12423
4. Little DC, Young JA, Zhang W, Newton RW, Al Mamun A, Murray FJ. Sustainable intensification of aquaculture value chains between Asia and Europe: a framework for understanding impacts and challenges. *Aquaculture*. 2018;493:338-354. doi:10.1016/j.aquaculture.2017.12.033
5. Henriksson PJG, Belton B, Murshed-e-Jahan K, Rico A. Measuring the potential for sustainable intensification of aquaculture in Bangladesh using life cycle assessment. *Proc Natl Acad Sci*. 2018;115(12):2958-2963. doi:10.1073/pnas.1716530115
6. Klinger D, Naylor R. Searching for solutions in aquaculture: charting a sustainable course. *Annu Rev Env Resour*. 2012;37(1):247-276. doi:10.1146/annurev-environ-021111-161531
7. FAO. COFI34 Documents | Committee on Fisheries | Food and Agriculture Organization of the United Nations, Report of the Thirty-Fourth Session- Rome, February 1–5, 2021. Published 2021. Accessed July 21, 2022. https://www.fao.org/about/meetings/cofi/documents-cofi34/en/
8. Zanello G, Fu X, Mohnen P, Ventresca M. The creation and diffusion of innovation IN developing countries: a systematic literature review. *J. Econ. Surv*. 2015;30(5):884-912. doi:10.1111/joes.12126
9. Mbabu AN, Hall A. *Capacity Building for Agricultural Research for Development: LESSONS from PRACTICE in Papua New Guinea*. United Nations University Unu-Merit; 2012.
10. Joffre OM, Klerkx L, Dickson M, Verdegem M. How is innovation in aquaculture conceptualized and managed? A systematic literature review and reflection framework to inform analysis and action. *Aquaculture*. 2017;470:129-148. doi:10.1016/j.aquaculture.2016.12.020
11. Lebel L, Mungkung R, Gheewala SH, Lebel P. Innovation cycles, niches and sustainability in the shrimp aquaculture industry in Thailand. *Environ Sci Policy*. 2010;13(4):291-302. doi:10.1016/j.envsci.2010.03.005
12. Bush S, Marschke M. Insight, part of a special feature on exploring social-ecological resilience through the lens of the social sciences: contributions, critical reflections, and constructive debate making social sense of aquaculture transitions. *Ecol Soc*. 2014;19(3):1-12. doi:10.5751/ES-06677-190350
13. Waite R, Beveridge M, Brummett R, et al. Improving productivity and environmental performance of aquaculture. 2014. https://digitalarchive.worldfishcenter.org/handle/20.500.12348/38
14. Obiero KO, Waidbacher H, Nyawanda BO, Munguti JM, Manyala JO, Kaunda-Arara B. Predicting uptake of aquaculture technologies among smallholder fish farmers in Kenya. *Aquac Int*. 2019;27(6):1689-1707. doi:10.1007/s10499-019-00423-0
15. Kumar G, Engle CR. Technological advances that led to growth of shrimp, Salmon, and tilapia farming. *Rev. Fish. Sci. Aquac*. 2016;24(2):136-152. doi:10.1080/23308249.2015.1112357
16. Cascante MQ, García NA, Fold N. The role of external forces in the adoption of aquaculture innovations: an ex-ante case study of fish farming in Colombia's southern Amazonian region. *Technol. Forecast. Soc. Change*. 2022;174:121185. doi:10.1016/j.techfore.2021.121185

17. do Amaral MCF, Medeiros NBC, Rodrigues M, et al. Management and technological practices in Amazonian fish farms: a case study in the southeast of Pará. *Aquaculture*. 2019;507:183-189. doi:10.1016/j.aquaculture.2019.03.076
18. Wetengere K. Socio-economic factors critical for intensification of fish farming technology. A case of selected villages in Morogoro and Dar es Salaam regions, Tanzania. *Aquac Int*. 2011;19(1):33-49. doi:10.1007/s10499-010-9339-2
19. Joffre OM, Klerkx L, Khoa TND. Aquaculture innovation system analysis of transition to sustainable intensification in shrimp farming. *Agron Sustain Dev*. 2018;38(3):1-11. doi:10.1007/s13593-018-0511-9
20. Blythe J, Sulu R, Harohau D, et al. Social dynamics shaping the diffusion of sustainable aquaculture innovations in the Solomon Islands. *Sustainability*. 2017;9(1):126. doi:10.3390/su9010126
21. Townsley P. Small-scale aquaculture and its contextual relationships with the concepts of poverty, food security, rural livelihoods and development. *Enhancing the Contribution of Small-Scale Aquaculture to Food Security, Poverty Alleviation and Socio-Economic Development, Proceedings of the FAO Fisheries and Aquaculture*. FAO; 2013:63-79.
22. Brugere C, Padmakumar KP, Leschen W, Tocher DR. What influences the intention to adopt aquaculture innovations? Concepts and empirical assessment of fish farmers' perceptions and beliefs about aquafeed containing non-conventional ingredients. *Aquac. Econ. Manag*. 2020;25(3):339-366. doi:10.1080/13657305.2020.1840661
23. Bosma RH, Nhan DK, Udo HMJ, Kaymak U. Factors affecting farmers' adoption of integrated rice-fish farming systems in the Mekong delta, Vietnam. *Rev Aquac*. 2012;4(3):178-190. doi:10.1111/j.1753-5131.2012.01069.x
24. Ahmed M, Rab MA, Bimbao MAP. *Aquaculture Technology Adoption in Kapasia Thana, Bangladesh: some Preliminary Results from Farm Record-Keeping Data*. ICLARM Tech. International Center For Living Aquatic Resources Management; 1995.
25. Ngoc PTA, Meuwissen MPM, Le TC, Bosma RH, Verreth J, Lansink AO. Adoption of recirculating aquaculture systems in large pangasius farms: a choice experiment. *Aquaculture*. 2016;460:90-97. doi:10.1016/j.aquaculture.2016.03.055
26. Ulhaq I, Pham NTA, Le V, Pham HC, Le TC. Factors influencing intention to adopt ICT among intensive shrimp farmers. *Aquaculture*. 2022;547:737407. doi:10.1016/j.aquaculture.2021.737407
27. Kumar G, Engle C, Tucker C. Factors driving aquaculture technology adoption. *J World Aquac Soc*. 2018;49(3):447-476. doi:10.1111/jwas.12514
28. Diedrich A, Blythe J, Petersen E, et al. Socio-economic drivers of adoption of small-scale aquaculture in Indonesia. *Sustainability*. 2019;11(6):1543. doi:10.3390/su11061543
29. Joffre OM, De Vries JR, Klerkx L, Poortvliet PM. Why are cluster farmers adopting more aquaculture technologies and practices? The role of trust and interaction within shrimp farmers' networks in the Mekong Delta, Vietnam. *Aquaculture*. 2020;523:735181. doi:10.1016/j.aquaculture.2020.735181
30. Amankwah A, Quagrainie KK, Preckel PV. Impact of aquaculture feed technology on fish income and poverty in Kenya. *Aquac. Econ. Manag*. 2018;22(4):410-430. doi:10.1080/13657305.2017.1413689
31. Ryan B, Gross NC. *Acceptance and Diffusion of Hybrid Corn Seed in Two Iowa Communities*. Agricultural Experiment Station, Iowa State College Of Agriculture And Mechanic Arts; 1950.
32. Griliches Z. Hybrid corn: an exploration in the economics of technological change. *Econometrica*. 1957;25(4):501. doi:10.2307/1905380
33. Pierpaoli E, Carli G, Pignatti E, Canavari M. Drivers of precision agriculture technologies adoption: a literature review. *Proc. Technol*. 2013;8:61-69. doi:10.1016/j.protcy.2013.11.010
34. Barnes AP, Soto I, Eory V, et al. Exploring the adoption of precision agricultural technologies: a cross regional study of EU farmers. *Land Use Policy*. 2019;80:163-174. doi:10.1016/j.landusepol.2018.10.004
35. Vecchio Y, De Rosa M, Pauselli G, Masi M, Adinolfi F. The leading role of perception: the FACOPA model to comprehend innovation adoption. *Agric. Food Econ*. 2022;10(1):1-19. doi:10.1186/s40100-022-00211-0
36. Rogers EM. *Diffusion of Innovations*. The Free Press; 1962.
37. Rossignoli C, Phillips MJ, Beveridge M, Marwaha N. Measuring impact of innovations on aquaculture system performance. *WorldFish*. 2021. Accessed July 21, 2022. https://hdl.handle.net/20.500.12348/5061
38. Evenson R. The economic contributions of agricultural extension to agricultural and rural development. 1997. Accessed March 1, 2021. https://agris.fao.org/agris-search/search.do?recordID=XF1998079209
39. De Rosa M, Bartoli L, La Rocca G. Testing extension services through AKAP models. *J. Agric. Educ. Ex*. 2014;20(5):513-535. doi:10.1080/1389224x.2013.872044
40. Kassem H. An Assessment of Perceived Farm Financial Health of Small Scale Farmers in Egypt: Implications for Extension. 2013. http://www.lifesciencesite.com/lsj/life1003/362_20864life1003_2497_2505.pdf
41. Vecchio Y, De Rosa M, Adinolfi F, Bartoli L, Masi M. Adoption of precision farming tools: a context-related analysis. *Land Use Policy*. 2020;94:104481. doi:10.1016/j.landusepol.2020.104481
42. Godwin RJ, Miller PCH. A review of the technologies for mapping within-field variability. *Biosyst. Eng*. 2003;84(4):393-407. doi:10.1016/s1537-5110(02)00283-0
43. Chiesa V, Coughlan P, Voss CA. Development of a technical innovation audit. *J. Prod. Innov. Manag*. 1996;13(2):105-136. doi:10.1111/1540-5885.1320105
44. Norton RS, Kaplan DP. *Using the Balanced Scorecard as a Strategic Management System. Harvard Business Review*. Harvard Business Review; 1996:75-85.
45. Ittner CD, Larcker DF. Are nonfinancial measures leading indicators of financial performance? An analysis of customer satisfaction. *J. Account. Res*. 1998;36:1. doi:10.2307/2491304
46. Black W. *Discontinuance and Diffusion: Examination of the Post Adoption Decision Process*", in NA - Advances in Consumer Research Volume 10, eds. Richard P. Bagozzi and Alice M. Tybout, Association for Consumer Research, Pages: 356-361 Accessed July 21, 2022. https://www.acrwebsite.org/volumes/6140
47. Loganandhan N, Patil SL, Srivatsava SK, Ramesha MN. Post adoption behavior of farmers towards soil and water conservation Technologies in a Semi-Arid Watershed. *Indian J. Ext. Educ*. 2015;15(1):40-45.
48. Coleman AL, Dimit RM, Lionberger HF, Miller PA, Wilkening EA, Bohlen JM. *How farm people accept new ideas*. Iowa State University. 1955; Special Report(10). Accessed July 21, 2022. https://dr.lib.iastate.edu/handle/20.500.12876/90155
49. Goswami B, Ziauddin G, Datta S. Adoption behaviour of fish farmers in relation to scientific fish culture practices in West Bengal. *Indian J. Ext. Educ*. 2010;10(1):24-28. doi:10.13140/RG.2.2.12152.34567
50. Hoffmann V. Book Review: Five editions (1962-2003) of Everett ROGERS: Diffusion of Innovations. 2007. https://www.researchgate.net/profile/Anja_Christinck/publication/225616414_Farmers_and_researchers_How_can_collaborative_advantages_be_created_in_participatory_research_and_technology_development/links/00b4953a92931a6fae000000.pdf#page=64
51. Bush SR, Pauwelussen A, Badia P, et al. Implementing aquaculture technology and innovation platforms in Asia. *Aquaculture*. 2021;530:735822. doi:10.1016/j.aquaculture.2020.735822
52. Haque MM, Little DC, Barman BK, Wahab MA. The adoption process of Ricefield-based fish seed production in Northwest Bangladesh: an understanding through quantitative and qualitative investigation. *J. Agric. Educ. Ext*. 2010;16(2):161-177. doi:10.1080/13892241003651415
53. Antonucci F, Costa C. Precision aquaculture: a short review on engineering innovations. *Aquac Int*. 2019;28(1):41-57. doi:10.1007/s10499-019-00443-w

54. Føre MH, Thorvaldsen T, Osmundsen TC, et al. Technological innovations promoting sustainable salmon (Salmo salar) aquaculture in Norway. *Aquac Rep*. 2022;24:101115. doi:10.1016/j.aqrep.2022.101115
55. Bostock J, Lane A, Hough C, Yamamoto K. An assessment of the economic contribution of EU aquaculture production and the influence of policies for its sustainable development. *Aquac Int*. 2016;24(3):699-733. doi:10.1007/s10499-016-9992-1
56. Klerkx L, Mierlo BV, Leeuwis C. Farming systems research into the 21st century: the new dynamic. *Farming Systems Research into the 21st Century: the New Dynamic*. Springer; 2012:457-483. https://link.springer.com/book/10.1007/978-94-007-4503-2
57. Rogers EM. *Diffusion of Innovations*. 5th ed. Free Press; 2003.
58. Straub ET. Understanding technology adoption: theory and future directions for informal learning. *Rev. Educ. Res*. 2009;79(2):625-649. doi:10.3102/0034654308325896
59. Hall BH. Innovation and diffusion. *Handbook of Innovation*. Oxford University Press; 2004:459-483.
60. Golder PN, Tellis GJ. Will it ever Fly? Modeling the takeoff of really new consumer durables. *Mark Sci*. 1997;16(3):256-270. doi:10.1287/mksc.16.3.256
61. Eastwood C, Klerkx L, Nettle R. Dynamics and distribution of public and private research and extension roles for technological innovation and diffusion: case studies of the implementation and adaptation of precision farming technologies. *J Rural Stud*. 2017;49:1-12. doi:10.1016/j.jrurstud.2016.11.008
62. Isgin T, Bilgic A, Forster DL, Batte MT. Using count data models to determine the factors affecting farmers' quantity decisions of precision farming technology adoption. *Comput. Electron. Agric*. 2008;62(2):231-242. doi:10.1016/j.compag.2008.01.004
63. Paxton KW, Mishra AK, Chintawar S, et al. Intensity of precision agriculture technology adoption by cotton producers. *Agric. Econ. Res. Rev*. 2011;40(1):133-144. doi:10.1017/s1068280500004561
64. Miller NJ, Griffin TW, Ciampitti IA, Sharda A. Farm adoption of embodied knowledge and information intensive precision agriculture technology bundles. *Precis. Agric*. 2018;20(2):348-361. doi:10.1007/s11119-018-9611-4
65. Kolady DE, Van der Sluis E, Uddin MM, Deutz AP. Determinants of adoption and adoption intensity of precision agriculture technologies: evidence from South Dakota. *Precis. Agric*. 2020;22(3):689-710. doi:10.1007/s11119-020-09750-2
66. Kumar G, Engle C, Avery J, et al. Characteristics of early adoption and non-adoption of alternative catfish production technologies in the U.S. *Aquac. Econ. Manag*. 2020;25(1):70-88. doi:10.1080/13657305.2020.1803446
67. Bostock J. 35 - use of information technology in aquaculture. In: Burnell G, Allan G, eds. *New Technologies in Aquaculture*. Vol 35. Elsevier; 2009:1064-1118. doi:10.1533/9781845696474.6.1064
68. Abu Hassan M, Shaffril HAM, D'Silva JL, Omar SZ, Bolong J. Fishermen and ICT: towards creating knowledgeable fishermen in Malaysia. *Aust. J. Basic Appl. Sci*. 2011;5:457-469.
69. Parra L, Sendra S, García L, Lloret J. Design and deployment of low-cost sensors for monitoring the water quality and fish behavior in aquaculture tanks during the feeding process. *Sensors*. 2018;18(3):750. doi:10.3390/s18030750
70. Asche F. Farming the sea. *Mar. Resour. Econ*. 2008;23(4):527-547. https://www.jstor.org/stable/42629678
71. Dey MM, Kamaruddin R, Paraguas F, Bhatta R. The economics of shrimp farming in selected Asian countries. In: Leung P, Engle C, eds. *Shrimp Culture: Economics, Market, and Trade*. Wiley; 2006:239-260. https://onlinelibrary.wiley.com/doi/book/10.1002/9780470277850
72. Blok V, Lemmens P. The emerging concept of responsible innovation. Three reasons why it is questionable and calls for a radical transformation of the concept of innovation. In: Koops BJ, Oosterlaken I, Romijn H, Swierstra T, van den Hoven J, eds. *Responsible Innovation 2*. Springer; 2015:19–35. https://link.springer.com/book/10.1007/978-3-319-17308-5.
73. Charatsari C, Lioutas ED, De Rosa M, Vecchio Y. Technological innovation and Agrifood systems resilience: the potential and perils of three different strategies. *Front. Sustain. Food Syst*. 2022;6(Special Issue):1-15. doi:10.3389/fsufs.2022.872706
74. Tey YS, Brindal M. Factors influencing the adoption of precision agricultural technologies: a review for policy implications. *Precis. Agric*. 2012;13(6):713-730. doi:10.1007/s11119-012-9273-6
75. Ndah HT, Knierim A, Ndambi OA. Fish pond aquaculture in Cameroon: a field survey of determinants for Farmers' adoption behaviour. *J. Agric. Educ. Ext*. 2011;17(4):309-323. doi:10.1080/1389224x.2011.576578
76. Caffey RH, Kazmierczak RF. Factors influencing technology adoption in a Louisiana aquaculture system. *J. Agric. Appl. Econ*. 1994;26(1):264-274. doi:10.1017/s1074070800019350
77. Joao ARB, Luzardo F, Vanderson TX. An interdisciplinary framework to study farmers decisions on adoption of innovation: insights from expected utility theory and theory of planned behavior. *Afr. J. Agric. Res*. 2015;10(29):2814-2825. doi:10.5897/ajar2015.9650
78. Loeber A. Inbreken in Het Gangbare. *Transitiemanagement in de Praktijk: De NIDO-Benadering*. NIDO; 2003. https://www.researchgate.net/publication/303234826_%27Inbreken_in_het_gangbare%27_the_NIDO_approach_in_Dutch
79. Elzen B, van Mierlo B, Leeuwis C. Anchoring of innovations: assessing Dutch efforts to harvest energy from glasshouses. *Environ Innov Soc Trans*. 2012;5:1-18. doi:10.1016/j.eist.2012.10.006
80. Seifu M, van Paassen A, Klerkx L, Leeuwis C. Anchoring innovation methodologies to “go-to-scale”; a framework to guide agricultural research for development. *Agr Syst*. 2020;182:102810. doi:10.1016/j.agsy.2020.102810
81. Miyata S, Manatunge J. Knowledge sharing and other decision factors influencing adoption of aquaculture in Indonesia. *Int. J. Water Resour. Dev*. 2004;20(4):523-536. doi:10.1080/07900620412331329162
82. Little DC, Nietes-Satapornvanit A. In: Barman BK, ed. *Seed Networks and Entrepreneurship*. FAO; 2007. https://agris.fao.org/agris-search/search.do?recordID=XF2016034190
83. Olesen I, Bentsen H, Phillips M, Ponzoni R. Can the global adoption of genetically improved farmed fish increase beyond 10%, and how? *J. Mar. Sci. Eng*. 2015;3(2):240-266. doi:10.3390/jmse3020240
84. Brummett RE, Jamu DM. From researcher to farmer: partnerships in integrated aquaculture—agriculture systems in Malawi and Cameroon. *Int J Agric Sustain*. 2011;9(1):282-289. doi:10.3763/ijas.2010.0570
85. Hu C, Zhang X, Reardon T, Hernandez R. Value-chain clusters and aquaculture innovation in Bangladesh. *Food Policy*. 2019;83:310-326. doi:10.1016/j.foodpol.2017.07.009
86. Khuman ON, Singh YJ. Fish Farmers' perceived constraints and suggestions towards the adoption of scientific fish farming of Pengba (Osteobrama belangeri) in the valleys of Manipur, India. *Int J Curr Microbiol App Sci*. 2019;8(2):2489-2494. doi:10.20546/ijcmas.2019.802.289
87. Unekwu O, Mojisola AO, Tina E, Ogala D. Perception and uptake of aquaculture technologies in Kogi state, Central Nigeria: imperative for improved management practices for sustainable aquaculture development. *Afr. J. Agric. Res*. 2020;16(6):819-828. doi:10.5897/ajar2019.14558
88. Sahoo PR, Ananth PN, Nandi S, Sundaray JK, Barik NK, Jayasankar P. Early breeding and seed production of Indian major carps: attributes of the innovation from an adaptive trial. *Curr. Agric. Res. J*. 2017;5(1):59-65. doi:10.12944/carj.5.1.07
89. Whitmarsh D. Technological change and marine fisheries development. *Mar Policy*. 1990;14(1):15-22. doi:10.1016/0308-597x(90)90034-o

90. Vecchio Y, Di Pasquale J, Pauselli G, Masi M, Adinolfi F. Public health risk management during the Covid-19 pandemic, new amendments in the European maritime and fisheries fund to meet fishers' needs. *Mar Policy*. 2022;135:104873. doi:10.1016/j.marpol.2021.104873
91. Ajzen I. The theory of planned behavior. *Organ Behav Hum Decis Process*. 1991;50(2):179-211. doi:10.1016/0749-5978(91)90020-t
92. Markus HR, Kitayama S. Cultures and selves: a cycle of mutual constitution. *Perspect. Psychol. Sci*. 2010;5(4):420-430. doi:10.1177/1745691610375557
93. Hoff K, Stiglitz JE. Striving for balance in economics: towards a theory of the social determination of behavior. *J. Econ. Behav. Organ*. 2016;126:25-57. doi:10.1016/j.jebo.2016.01.005
94. Lewin K. Defining the "field at a given time.". *Psychol Rev*. 1943;50(3):292-310. doi:10.1037/h0062738
95. Yue K, Shen Y. An overview of disruptive technologies for aquaculture. *Aquac. Fish*. 2021;7(2):111-120.
96. Lowenberg-DeBoer J, Erickson B. Setting the record straight on precision agriculture adoption. *Agron J*. 2019;111(4):1552-1569. doi:10.2134/agronj2018.12.0779
97. Pascucci S, De-Magistris T, Dries L, Adinolfi F, Capitanio F. Participation of Italian farmers in rural development policy. *Eur. Rev. Agric. Econ*. 2013;40(4):605-631. doi:10.1093/erae/jbt005
98. Asche F, Smith MD. Viewpoint: induced innovation in fisheries and aquaculture. *Food Policy*. 2018;76:1-7. doi:10.1016/j.foodpol.2018.02.002

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