This is an Accepted Manuscript of an article published by Taylor & Francis Group in *Aquaculture Economics and Management* on 08 Nov 2020, available online: http://www.tandfonline.com/10.1080/13657305.2020.1840661

Title:

What influences the intention to adopt aquaculture innovations? Concepts and empirical assessment of fish farmers' perceptions and beliefs about aquafeed containing non-conventional ingredients.

Authors

Brugere, Cecile (1), Padmakumar, Krishna (2), Leschen, William (3), Tocher, R. Douglas (3)

(1) Soulfish Research & Consultancy, UK
(2) Kerala University Campus, Dept. of Aquatic Biology and Fisheries, India
(3) University of Stirling Institute of Aquaculture, Faculty of Natural Sciences, UK

Accepted in ***Aquaculture Economics and Management***, 2020

Abstract

The Theory of Planned Behaviour (TPB) has so far found few applications in aquaculture research. Using Rogers' innovation adoption characteristics as a complementary framework, we explore its relevance in describing Indian carp farmers' perceptions of the attributes of fish feed containing non-conventional ingredients (seaweeds, freshwater macrophytes, microalgae and microbes), and in understanding the factors influencing their intention to use these feeds. We find that fish farmers familiar with manufactured feed tend to have more positive attitudes to the inclusion of non-conventional ingredients in fish feed than those who are not. Perceived peer pressure, importance and benefits from the novel aquafeed, perceived comparative advantage and uncertainty regarding outcomes from its use are the main determinants of intention to adopt the proposed feed innovation. The combined application of the TPB and Rogers' innovation framework provides valuable insights into fish farmers' attitudes and behavioural intention towards innovation adoption, and we recommend its wider use for designing interventions that promote technological innovations and improved farm management. By exploring the underpinnings of intention to adopt an innovation, our study contributes to the literature on fish farmers' behaviour and attitudes to innovations in aquaculture.

Keywords

Theory of Planned Behaviour
Rogers' innovation framework
Innovation adoption
Attitudes X
Fish feed
Non-conventional ingredients

Introduction

Innovation has been defined as "an idea, practice, or object that is perceived as new" (Rogers, 2003, p. 12, cited in Borges et al., 2015). Innovation in aquaculture takes many forms and is present at all stages of the supply chain regardless of species: from breeding (e.g. artificial spawning, improved fish strains), feeding (e.g. feeding technologies), disease control (e.g. vaccines, monitoring systems), to farm management and farming practices (e.g. Better Management Practices, codes of conducts) and post-harvest handling (e.g. animal welfare) (Kumar & Engle, 2016, Asche, 2019). Greater control over production processes has enabled innovations and efficiency gains which have been fundamental for the growth of the sector (Asche, 2008). However, the development of aquaculture innovations has been mainly "linear and technology-oriented" (Joffre, Klerkx, Dickson, & Verdegem, 2017, p. 144). Inadequate attention to social and human factors has resulted in limited adoption or disappointing impacts (Bailey, Jentoft, & Sinclair, 1996). In aquaculture as in other sectors, the potential adoption of innovations by users is the result of the interplay of the characteristics of the innovation itself, of the psychological, behavioural and economic factors inherent to the adopter, and of factors external to both. One individual's decision to either continue using an innovation after trying it or deciding to try it in the first place essentially depends on the utility of the innovation this person has experienced (ex-post adoption) or perceived (ex-ante adoption), 'utility' being understood here in its economic sense, i.e. in terms of satisfaction and benefits that this user will seek to draw from the use of the innovation (Borges, Foletto & Xavier, 2015).

In this paper, the innovation considered is novel aquaculture feeds containing non-conventional ingredients as a source of long-chain omega-3 precursors. The long-chain polyunsaturated fatty acids, eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), often commonly referred to as omega-3 fatty acids, are essential dietary nutrients for human health. Marine fish remain the predominant source of these nutrients partly through their conversion into fish oil and fishmeal for inclusion in aquafeeds. However, with finite supplies and a growing global population, availability of omega-3 is well below the minimum recommended intake, particularly in low income countries (Stark, Van Elswyk, Higgins, Weatherford, & Salem, 2016). The possibility to increase intake of omega-3 fatty acids is based on two key observations: (i) the metabolic precursor to EPA and DHA, alpha-linolenic acid (ALA), can be abundant in some terrestrial and freshwater plants (Gunstone & Harwood, 2007), (ii) some freshwater fish such as carp and tilapia can metabolically convert dietary ALA into EPA and DHA (Tocher, 2015). As these are two of the main cultured and consumed species in India and sub-Saharan Africa, there is therefore potential to exploit this endogenous pathway by supplementing ALA to aquafeeds and enhance the amounts of EPA and DHA available for human populations (Tocher, Francis, & Coupland, 2011, Torstensen & Tocher, 2011). Such advances could play a key role in making aquaculture more nutrition-sensitive (Gephart et al., 2020). Widely available sources of ALA include terrestrial and freshwater plants such as *Lemna minor* and *Spirodella polyrhiza*, seaweeds, some microalgae, and microbes. These qualify as "non-conventional" feed ingredients. The use of these ingredients is limited in India (Ayyappan & Ahmad, 2007), but *Lemna* sp. is showing promise as a fishmeal replacement (Chakrabarti, Clark, Sharma, Goswami, Shrivastav, & Tocher, 2019). The inclusion of these ingredients as alternative, novel ingredients in aquaculture feeds is therefore a form of innovation. Whilst the nutritional properties of these ingredients for the growth of fish are important, their perceived utility and potential acceptability by fish farmers are just as critical and must be elicited to ensure utilisation and long-term adoption of these new aquafeeds as part of improved feeding practices. A key question is therefore: would farmers intend to adopt fish feed containing non-conventional ingredients?

As the study of the biological properties and effectiveness of the non-conventional feed ingredients listed above is still ongoing, and the development of aquafeeds containing non-conventional ingredients is still at an experimental stage, fish farmers will not know what the properties of aquafeed containing these non-conventional ingredients are, nor how this type of aquafeed can be applied. However, they will be able to form an a-priori opinion based on their prior experience with conventional feeds (commercially formulated or farm-made) and feeding practices, and possibly from prior sight of these ingredients in the wild. Assessing their perceptions of the hypothetical attributes and benefits of these novel aquafeeds and their potential intention to use these feeds calls for theories and concepts from the field of innovation and technology adoption, and from the psychological and behavioural sciences.

The objectives of this paper are therefore twofold: (i) to empirically explore the potential attractiveness of an innovative aquafeed containing non-conventional ingredients for fish farmers (case study in India), and (ii) to discuss, and elaborate on, the relevance of concepts typically used to characterise behavioural motivations for innovation adoption, in the context of aquaculture. The paper begins by reviewing and framing innovation adoption in aquaculture (section 1). It then elicits the perceptions and beliefs underlying Indian carp farmers' intention to choose aquafeeds containing non-conventional ingredients (Section 2). Section 3 discusses these fish farmers' attitudes towards innovative feeds and the relevance of an extended analytical framework in capturing farmers' motivations for adopting innovations in aquaculture more generally. Section 4 concludes.

Unpacking innovation adoption

The study of innovation adoption has been largely framed by two perspectives, which have tended to be considered in exclusion: a technological one, focused on the characteristics of the innovation itself, and a human one, focused on the behavioural characteristics of its (potential) user. They are reviewed below.

1.1 Technology perspective on innovation adoption: Rogers' innovation adoption and diffusion framework

Almost all innovation adoption studies are framed by Rogers' seminal work on the diffusion of innovations (1962, 1983 and subsequent years) and his description of characteristics of innovations that matter for their successful adoption and diffusion: relative advantage, compatibility, complexity, divisibility (or "triability"), and communicability. Nature of communication channels and factors pertaining to local and wider contexts, whether they are of an environmental, economic, geopolitical, socio-economic or institutional nature (e.g. land tenure, policies, regulations), or relate to personal circumstances (e.g. education, sex, experience, availability of capital, inputs etc.) have also been acknowledged as complementary influences (Feder, Just, & Zilberman, 1985, Rogers, 1985), along with risk associated with innovation uptake (Bauer, 1960). While the latter has since been included in many innovation adoption studies (e.g. Feder et al., 1985, Holak & Lehmann 1990), the description of farmers' attitudes to risk (averseness or risk-taking) remains surprisingly scant in aquaculture (Joffre, Poortvliet, & Klerkx, 2018).

Table 1 summarises the hypothesised attributes of an innovation such as aquafeed containing non-conventional ingredients, according to Rogers' innovation adoption and diffusion framework (Rogers 1962, 1995, 1983, 2001).

Table 1 here.

Although comparatively fewer than in agricultural studies, Roger's innovation characteristics framework has found applications in the context of aquaculture development to assess the attributes and adoption advantages and disadvantages of innovations as diverse as: small-scale tilapia farming as a new livelihood activity in the Solomon Islands (Blythe, Sulu, Harohau, Weeks, Schwarz, Mills, & Phillips, 2017), the creation of a new cooperative to improve the mud crab value chain in Bangladesh, a specially-formulated feed for enhancing out-of-season spawning of Indian Major Carp broodstock (Sahoo, Ananth, Sundaray, Barik, & Jayasankar, 2017), integrated multi-trophic aquaculture (Kinney, 2017), open sea cage culture in India (Ramachandran, 2009). Other studies of a more qualitative nature have used Rogers' framework as a starting point and extended its remit to profile the types of adopters and rejecters of organic fish farming as an innovation (Lasner & Hamm 2011), or to analyse the development phases of the salmon farming industry in Norway (Orstavik, 2017). Sahoo et al. (2017) used Rogers' framework to identify and refine the elements of innovations that are likely to become bottlenecks for adoption and diffusion. Similarly, Kinney (2017) identified the complexity of integrated multi-trophic aquaculture (IMTA) as one of the major hurdle for its adoption by farmers at a larger scale in the USA. Some studies have also broadened the scope of technology adoption by bringing into light the behavioural and institutional dimensions that are essential in ensuring that innovation adoption leads to positive outcomes and supports progress towards the greater sustainability of the agri-food systems within which they are embedded (Joffre et al., 2017, El Bilali, 2018).

However, very few studies of innovation adoption in aquaculture focus on feed formulation and feeding practices, despite it being an essential part of the fish farming process and an area where efficiency gains are constantly sought. When innovation in feeding has been studied, it has been approached qualitatively and descriptively: Petersen et al. (2013) compared mud crab farmers' perceptions of the adaptability, cost and growth rates achieved through manufactured feeds in Vietnam, and Petersen et al. (2014) assessed fish farmers' perceptions of feed use in cobia farming in the same country.

1.2 Human perspective on innovation adoption: Ajzen's Theory of Planned Behaviour

Ajzen's Theory of Planned Behavior (TPB) seeks to understand the influence of people's attitudes and beliefs on their intention towards a particular behaviour, such as their decision to adopt an innovation or not. The key tenet of the TPB is that intention comes before behaviour: by understanding the factors at play behind one's intentions, one can get insights into their future behavior. Intention is itself determined by attitude, subjective norm and perceived behavioral control (Ajzen, 1991). Attitude is underpinned by one's own beliefs and evaluation – positive or negative - of the behaviour in question (behavioral beliefs). Subjective norm refers to the perceived social pressure to perform or not the behaviour and the normative expectations of others (normative beliefs). Perceived behavioral control (PBC) refers to one's beliefs about the presence of factors that may facilitate or impede performance of the behavior (control beliefs). PBC is slightly different from the other types of beliefs in that it can also have a separate, direct effect on behavior (Ajzen, 1991, Verbeke & Vackier, 2005). As a general rule, the more favourable attitude and subjective norms are, and the greater PBC is, the stronger the prediction to perform a certain behaviour is (Ajzen, 1991). The TPB recognises and can also account for the indirect influence of exogenous variables, called "background factors", such as age, gender, education, race etc. on behavioural, normative and control beliefs (Ajzen, 2015). The strength of the TPB over other analytical frameworks lies in its potential to "reveal the latent (not directly observable) factors influencing the farmers' behaviour" (Sambodo & Nuthall 2010, p.113, Ajzen, 2015). However, whilst most studies confirm the influence of the three constructs of the TPB, they also highlight variations in the prediction power of the constructs depending on sectors and products, situations, locations (Thong & Olsen 2012, Ghifarini et al., 2018, Foguesatto & Machado, 2019), and even generations (Olsen, Heide, Dopico, & Toften, 2008).

The components of the TPB, interpreted in the context of the adoption of aquaculture feeds containing non-conventional ingredients, are presented in Figure 1.

Figure 1 here.

The TPB has been frequently used in agricultural studies as a conceptual framework to understand the determinants of terrestrial farmers' behaviour towards adoption of new or improved farm management practices and technologies (c.f. the systematic reviews of Borges et al., 2015, Borges, Oude Lansink, & Emvalomatis, 2019, Foguesatto & Dessimon Machado, 2019) and to highlight the importance of accounting for socio-psychological factors, including farmers' own inventiveness, in the promotion of agricultural innovations (e.g. Pino et al., 2017, Woldegebrial Zeweld, Van Huylenbroeck, Tesfay, & Speelman, 2017). The TPB has also found numerous applications in seafood consumption studies, in which it is used in an extended version to incorporate consumers' behavioral or psychological traits, in order to capture motives behind particular seafood consumption choices, either quantitatively (e.g. Verbeke & Vackier 2005, Siddique, 2012, Tomić, Matulić, & Margareta, 2015, Higuchi, Dávalos, & Hernani-Merino, 2016, Ghifarini, Sumarwan, & Najib, 2018) or qualitatively (e.g. Brunsø, Verbeke, Osen, & Jeppesen, 2009). All these studies concur on the relevance and suitability of the TPB model to provide an accurate and holistic understanding of the multiple interacting factors and complexity underpinning human intention, behavior and decision-making.

The empirical, quantitative applications of the TPB in aquaculture are however few. Sambodo and Nuthall (2010) used it to characterise the observed and latent factors Indonesian rice-shrimp farmers perceived as important in their decision to adopt improved "pandu" farming systems. Yasmin (2018) used a modified version of the TPB to investigate mud crab farmers' willingness to engage in a new cooperative created to improve the mud crab value chain in Bangladesh. Used as a broader theoretical framework, Brugere, Onuigbo and Morgan (2016) pointed out its relevance for understanding fish farmers' motivations towards reporting aquatic disease incidences to authorities. Ringa and Kyalo (2013) used it to guide the qualitative investigation of young entrepreneurs' perceptions of incentives provided by Kenya's Economic Stimulus Programme in support of the construction of fish ponds, but did not go as far as quantifying the influence of behavioral factors on the youth's intention to adopt pond fish farming. Ndah, Knierim and Ndambi (2011) adopted a related theory – the Theory of Behavior Modification, and combined it to the attributes of innovations described by Rogers (2003) to qualitatively assess the reasons for the low uptake of freshwater pond aquaculture in Cameroon. More recently, Brugere, Msuya, Jiddawi, Nyonje and Maly (2020) used a similar approach in a semi-quantitative manner to describe how gender dynamics and behavioral intention towards the adoption of an improved seaweed farming technology were at play in women's empowerment.

One of the reasons for the limited number of studies using the TPB is that the study of innovation adoption in aquaculture has been chiefly grounded in the Expected Utility Theory, which is sometimes put in opposition to the TPB (Ajzen, 2015, Borges et al., 2015, Foguesatto & Dessimon Machado, 2019). Kumar, Engle and Tucker (2018)'s extensive review of the driving factors behind technology and innovation adoption in aquaculture, and other studies of new technology and innovation uptake (e.g. Feder et al., 1985, Caffey & Kazmierczak, 1994, Ruddle, 1996, Rauniyar, 1998, Sevilleja, 2000, Tain & Diana 2007, Kripa & Mohamed, 2008, Dey, Paraguas, Kambewa, & Pemsl, 2010, Haque, Little, Barman, & Wahab, 2010, Ndah et al., 2011, Weterenge, 2011, Wandji, Pouomogne, Binam, & Nouaga, 2012, Ponnusamy & Pillai, 2014) are typically focused on understanding innovation adoption as an outcome of farmers' decision making, i.e. after farmers have had direct hands-on experience with the innovation (i.e. *ex-post*). These studies work 'backwards', linking adoption (outcome) back to either the attributes of the innovation (using Rogers' innovation attributes framework) and/or to the exogenous socio-economic, institutional and environmental factors that condition this outcome. As a consequence, they provide little foresight into the likelihood of innovation adoption.

Investigating carp farmers' intention to adopt novel aquafeeds containing non-conventional ingredients: a case study in India

2.1 Hypotheses and analytical approach

On the basis of the above review, our first hypothesis is that the TPB, when extended to incorporate Rogers' innovation characteristics, offers a compelling framework to investigate in an *ex-ante* manner the underpinnings of farmers' intentions to adopt (or not) an innovation – here aquafeeds containing non-conventional ingredients. Given that use of commercially-formulated aquafeed is at different stages and largely dependent on the scale and intensity of farming operations (Hasan, Hecht, De Silva & Tacon, 2007), we further hypothesize that farmers' attitude towards the novelty of non-conventional ingredients in aquafeeds is likely to differ depending on their current feeding practices, and that those who are regular users of commercial feeds are more likely to display a positive attitude than those who aren't. Our study is structured to answer three specific questions:

1. Who are the farmers, what is their current feed use?
2. How do they perceive the attributes of aquafeeds containing non-conventional ingredients and what are their revealed a-priori beliefs about these?
3. How do the components of the TPB and Rogers' framework complement one another to comprehensively capture influences on farmers' intention to use aquafeeds containing non-conventional ingredients?

We empirically explore this with survey data collected from carp farmers in three districts of Kerala, India (Ernakulam, Allapuzha, Pathanamthitta) in 2017. Initial key informant interviews were carried out to gain an understanding of the study context, prevalent farming practices and aquafeed use, and types of stakeholders. These interviews also enabled refining the design of a structured questionnaire which combined the innovation characteristics of Rogers' framework with the components of the TPB, as piloted by Borges et al. (2015) and Ansari and Tabassum (2018). The questionnaire comprised several sections: (i) farmers and farms' characteristics (sex, age, experience, aquafeed use and feeding practices, fish production, social capital, knowledge of Omega-3 fatty acids), (ii) a-priori perceptions of the advantages and disadvantages of aquafeeds containing non-conventional ingredients as sources of ALAs, based on Rogers' five innovation characteristics, (iii) a-priori assessment of farmers' behavioural, normative and control beliefs as per the TPB. Likert scales were employed to gauge respondents' agreement with statements in sections (ii) and (iii). Data collection was tablet-based using an offline surveying software (Qualtrics®). Local enumerators were trained to administer the questionnaire in local language when English was insufficiently spoken. Sixty carp farmers were randomly selected from a sample stratified according to pond size ownership (small, medium, large). Data was statistically analysed using Qualtrics® and Jasp (Jasp Team 2019). Descriptive statistics, cross-tabulations and statistical tests of significance (ANOVA and Chi-squared (χ^2) tests) were compiled to answer questions (1) and (2). To address question (3), we drew on Verbeke and Vackier (2005), Siddique (2012), Tomić et al. (2015), Yasmin (2018) and Ghifarini et al. (2018), and used exploratory factor analysis (EFA) to identify latent factors responsible for the variance of measured variables elicited through the questionnaire. Where necessary, measured variables were reverse coded to be in the same direction. Standard data checks were performed before analysis (e.g. outliers, missing values, normality – Watkins, 2018). Only factor loadings over 0.4 were retained (Osborne, 2014), while double loadings and non-loading variables were removed. Both convergent and discriminant validity were examined. Composite reliability (CR) was used as a measure of internal reliability of the elicited factors and tested through Cronsbach's alpha, with values > 0.7 indicating high internal reliability (Hair, Anderson, Tatham, & Black, 1995). EFA was followed by Confirmatory factor analysis (CFA) to quantify the relationship between the measured variables and their underlying constructs. We underscore that given the experimental nature of both the innovation and the study, intention is not measured as such, but inferred from the constructs (latent factors) and measured variables.

2.2 Results

We first describe farmers' profile and aquafeed use. We then describe farmers' perceptions and beliefs regarding aquafeeds containing non-conventional ingredients. Finally, we present the results of EFA and CFA performed on all measured variables.

2.2.1 Fish farmers' profile and aquafeed use

Carp farmers are typically male (83%), around 50 years old, and have on average between 2 and 6 years of fish farming experience. In general, fish farming is not their main source of income. Indian Major Carp is the species of choice for the majority of farmers (65%). Their pond area tends to be relatively small (less than 1 acre) and few hire employees, except at the time of harvest. Their average production is 150kg per growth cycle (equivalent to 0.52 tonne per hectare per year). Fish is sold at a premium during festivals (176INR/kg), and at 159 INR/kg the rest of the time (equivalent to USD2.6/kg and USD2.35/kg respectively). Farmers do not have loans (98%), nor insurance (100%), and do not keep detailed records of their operations (91%). They do not follow closely farm management advice from the Fisheries Department (78%). Only 33% of the farmers interviewed belong to an association or network.

Importantly for the study, 7.4% of farmers are regular users of commercially formulated feed imported from a foreign (non-Indian) company; 22.2% are regular users of commercially formulated feed from an Indian company; 61.1% are regular users of feed made on farm with locally available ingredients and agricultural by-products; and 9.3% feed their fish irregularly, infrequently or not at all. Higher levels of educational attainment, number of years in fish farming, or number of training sessions attended are not significantly associated with any type of fish feed used, suggesting that "experience" in fish farming is not linked to the use of more sophisticated, commercially-formulated, fish feed. However, when fish farming is main source of income, it is significantly associated with the regular use of commercially-formulated fish feed ($\chi^2(3, n=54)= 10.26, p<0.05$).

The difference in fish production between categories of feed users is statistically significant ($F=3.267$, $p<0.05$): farmers using commercially-formulated feed produce twice more than those using farm-made feed (121kg/cycle or 0.42t/ha/year), and up to six times more than those irregularly feeding their fish (37kg/cycle or 0.13t/ha/year). Fifty percent of farmers report that their feed costs represent between 50% and 80% of their operational costs, which is within the norm. Farmers' awareness of Omega-3 fatty acids and their health benefits is significantly uneven: while nearly than 75% of irregular and on-farm made feed users report having never heard of Omega-3s or their precursors, 40% of those who feel they know "a bit" about them, and 100% of those who feel they know "a lot" are regular users of commercial feed (imported or Indian) ($\chi^2(6, n=54)= 13.66, p<0.05$).

2.2.2 Farmers' perceptions and beliefs about aquafeeds containing non-conventional ingredients

What are farmers' perceptions of the attributes of aquafeeds containing non-conventional ingredients?

When carp farmers are presented with the four non-conventional ingredients for potential inclusion in the new aquafeed formulation, their a-priori preference goes overwhelmingly towards seaweed (52% of respondents ranked it as their number 1 preferred ingredient, followed by freshwater macrophytes as number 2, microalgae as number 3, and finally microbes as the least favourite choice for 51% of the respondents). Their perceptions of the characteristics of aquafeed containing these non-conventional ingredients, founded on their knowledge of ALA sources, are presented in Figure 2, according to the components of Rogers' innovation adoption framework (cf. Table 1), to which is added their perception of risk associated with the use of the new feed compared to the one they are currently using.

Figure 2 here.

The characteristic of triability of the new aquafeed is the one standing out most compared to the other characteristics. It is followed by compatibility of the new feed with existing feeding practices, routines and values, and in third position, simplicity. We speculate that the lower percentages for the other characteristics are due to the difficulty for respondents to a-priori evaluate the new feed's relative advantage and associated risk over the one currently in use, as large proportions of farmers not able to tell (47.1% on average). Perceptions of relative advantage, compatibility, triability and riskiness were not statistically significant across the different types of feed users. However, they were significant for complexity ($\chi^2(9, n=53)= 24.89, p<0.01$) with 53% of regular users of commercial feed perceiving the complexity of using the new feed as lower (i.e. they would have sufficient knowledge to use the new feed), compared to 45.2% of on-farm feed users perceiving it as higher. They were also significant for communicability ($\chi^2(6, n=53)= 13.61, p<0.05$), with 52.6% of irregular and on-farm feed users perceived it as slower, compared to 33% for regular users of commercial feed (imported or made in India).

What are farmers' beliefs towards aquafeed containing non-conventional ingredients?

Figure 3 (A, B, C, D) presents how the survey respondents perceived the variables underlying the three constructs of the TPB.

Figure 3 here.

Figure 3 suggests that, overall, farmers are uncertain about the new feed and believe that it will not change things much apart from improving fish growth (behavioural beliefs). Regardless of their type of feed use, farmers appear rather unsure of the implications of using the new feed: only 9.6% think that it will make feeding easier (Fig. 3A), 39.6% that it will increase their production costs (Fig. 3B), and 17% that they may be ill-equipped to apply it (Fig. 3B), echoing the fear of complexity evoked in Figure 2. Differences across types of feed users were however significant regarding beliefs that the new feed would:

- make feeding fish easier (χ^2 (9, n = 52) = 22.59, p=0.007), with 9.1% of those using Indian manufactured feed agreeing, and 25% of those not regularly feeding disagreeing.
- increase one's popularity as an innovator (χ^2 (9, n = 52) = 18.07, p=0.034), with 27.3% of those using Indian manufactured feed and 36.4% of those using on-farm feed agreeing, against 25% of those not feeding who disagreed.
- increase one's dependence on feed suppliers (χ^2 (9, n = 52) = 17.12, p=0.047), with 80% of those not feeding thinking it would stay the same compared to between 20% and 25% for the other feed users, and 25% of those importing feed disagreeing.
- be more difficult to source (χ^2 (9, n = 53) = 17.01, p=0.048), with 25% of those using imported feed disagreeing, 80% of those who don't feed thinking it would not change, and 27.3% and 24.3% of those using Indian manufactured feed and on-farm feed respectively agreeing.

Farmers also felt that positive peer-pressure (normative beliefs) for adoption would come mainly from family and immediate neighbors, and less so from other farmers and the feed supplier who were perceived to be more disapproving of innovative behaviour (Fig. 3C). However, the importance of approval by other farmers varied significantly across types of feed users (χ^2 (9, n = 53) = 40.59, p<0.001), with those not feeding (60%) and using on-farm feed (51.5%) perceiving pressure from other farmers the most, compared to 45.5% of users of Indian manufactured feed, and none of users of imported feed. This is revealing of the perceived obligation to comply with farming codes that are implicitly imposed, not by the Fisheries Department, but by the farming and feed business community itself.

With regards to control beliefs, all types of incentives were believed to alleviate barriers to adoption, although proximity and ease of supply (with a feed distributor coming to the farms or a feed shop nearby) surprisingly less so than other incentives (Fig. 3D). Opinions about the incentives of having a feed shop nearby and being eligible for training on ALA-enriched feed were the only two control beliefs varying significantly across feed user groups (respectively: χ^2 (9, n = 53) = 16.92, p=0.050 and χ^2 (6, n = 53) = 16.42, p = 0.012). 80% of those not feeding and 72.7% of those using on-farm feed considered shop proximity as an incentive to adopt it, while 50% of those using imported feed, and 9% of those using Indian feed, considered it would not make any difference. Similarly, 45.5% of those using Indian feed did not think additional training on the new feed would make a difference in their intention to adopt it, compared to 80% of those not feeding and 75.8% of those using on-farm feed thinking that it would.

2.2.3 Combining the components of the TPB and Rogers' innovation framework to capture all influences behind farmers' intention to use aquafeeds containing non-conventional ingredients

Exploratory factor analysis (EFA) loaded four factors (parallel analysis, promax oblique rotation), with a total of 26 items loading over 0.4 (Table 2). Eight variables were excluded for no or double loading. As the values of the Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy for "make feeding easier" and "I may not know how to apply it (reversed)" were below the cut-off value of 0.5 (Kaiser, 1974, Watkins, 2018), these two variables were also excluded from the EFA. Tests of Bartlett's for sphericity on the remaining variables were significant (p<0.001) and all KMO measures well above 0.5, indicating appropriateness of the data for EFA and sampling adequacy respectively (Hair et al., 1995). Together the four latent factors accounted for 54.4% of the common variance in all the measured variables.

Factor 1 clearly encompasses all the normative belief measured variables, which have the largest factor loadings (compared to the capped or subsidized price of feed). This factor explains 17.8% of the variance of the items under it. Cronsbach's alpha is >0.7, indicating high composite reliability. This factor is therefore named **perceived peer pressure** in line with the TPB construct. Factor 2 groups a larger number of variables. Despite displaying high composite reliability (CR>0.8), it explains only 15.4% of the variance in the items. Items under this factor relate mainly to the perceived advantages of the novel feed, notably in terms of economic benefits (whose variance is more largely explained by this factor than other items) and compatibility characteristics which we had presumed as both falling under behavioural beliefs. Consequently, we name this factor **perceived importance and benefits**. Factor 3 distinctively groups all measured variables related to the relative advantage of Rogers' innovation characteristics, and accounts for 12% of the items' variance, though with high reliability (CR>0.8). We name this factor **perceived innovation comparative advantage**. Factor 4 explains only 9.3% of its items' variance. Items under this factor also hang together well (CR>0.8). These items relate to the perceived disadvantages (reversed) of the new feed, mainly due to uncertainty about the outcomes of its use. For this reason, we name this factor **perceived outcome uncertainty**. Although we had anticipated that these items would fall under the behavioural beliefs of the TPB, this suggests that they are more closely associated with control beliefs instead.

Whilst CR scores enable convergent validity to be established within each factor, examination of the four factors for discriminant validity (root square of average variance extracted) shows scores lower than 0.85, confirming that the four factors do not overlap (Campbell & Fiske 1959) (Table 2). Model fit, indicated with a Root Mean Square Error of Approximation (RMSEA) value of 0.0894 is still within the accepted range (Hu & Bentler, 1999). Measured variables related to barriers/incentives (except for capped or subsidized price) and triability did not load. This suggests that control beliefs may play a lesser role as a separate construct in behavioral intention, although a number of items explained by factor 'Perceived importance and benefits' are related to perceived barriers or incentives towards potential adoption (e.g. having sufficient knowledge to handle the new feed). Complexity, assessed in terms of having sufficient knowledge, loaded under comparative advantage rather than perceived barrier.

Table 2 here.

Figure 4 shows the results of the confirmatory factor analysis (CFA). The standardized factor loadings express the direct effects of the latent variables (factors) on the indicators (Brown & Moore, 2012), and as such correspond to effect size estimates (Suhr, 2006). The second order factor, established as behavioural intention to adopt aquafeed with non-conventional ingredients, has a significant direct effect on variance in perceived peer pressure and outcome uncertainty from the use of the innovation, but not on its perceived importance and benefits, nor comparative advantages.

Figure 4 here.

When a second order factor is not established, the factors covariates are shown in Table 3. Logically, perceived importance and benefits and outcome uncertainty have the largest co-variances, followed by perceptions of peer pressure and comparative advantages of the new feed. In contrast, perception of the comparative advantage of the new feed is the factor with the least influence over the others.

Table 3 here.

Discussion

Gaps to fill in relation to carp farmers' aquafeed knowledge and management
Farming practices and patterns of feed use in our sample of farmers correspond to the practices and typology of carp farming systems described by Ayyappan and Ahmad (2007). Limited use of commercially-formulated feed is symptomatic of the suspicion of carp farmers towards manufactured aquafeed as they doubt its cost-effectiveness (Suresh, 2007). This underscores the large gaps that remain to be filled in terms of: 1. Persistence of sub-optimal on-farm feed management practices and effectiveness, and 2. Farmers' insufficient knowledge about fish feeding despite the fundamental importance of this step in the rearing of fish, and despite calls for reducing feeding inefficiencies through greater use of commercially-formulated feeds in India (Suresh 2007). The potential complication for farmers that using non-conventional ingredients either as integral or supplementary feeds represents should therefore not be under-estimated. Any technological advances in this field should be complemented by capacity building. However, as the rest of our analysis shows, many other factors are also at play.

Farmers' perceptions of innovation attributes and beliefs about the new aquafeed
While potential for economic benefits undoubtedly counts (Sahoo et al., 2017), the importance given to triability and compatibility with existing feeding practices and routines suggests that hands-on experimentation and convenience may override cost-effectiveness concerns. This reinforces that going beyond utility maximisation and accounting for behavioural factors matters for adoption outcomes (Dessart, Barreiro-Hurlé, & van Bavel, 2019). Risk minimisation also matters, in line with more conservative farm management strategies that farmers tend to opt for to minimise risk (Joffre et al. 2018, in the case of shrimp farmers). This underlines the usefulness of risk mininization as an additional characteristic of innovations to those described by Rogers.

Comparing farmers' perceptions of innovation characteristics according to their feed use showed that those who are familiar with the regular use of commercially-formulated feed feel better equipped to handle their potentially higher complexity, and are better able to assess, ex-ante, ease of application as one of their potential benefits. These farmers also appeared in a better position for assessing the communicability attribute of the new feed, compared to the farmers who irregularly feed their fish or use on-farm made feeds. These farmers also tend to display a more casual, less cautious attitude to the idea of new feed ingredients, with their existing hands-on experience and confidence showing through their indifference to potential supply bottlenecks and to peer pressure. They appear more aware of additional requirements that may arise from using the new feed, such as commitment to a specific feed supplier (control beliefs), which could nonetheless act as a barrier to adoption for all farmers. More than other farmers, existing commercial feed users perceive the potential to improve their image as innovative farmers as an additional, intangible, benefit of using the new feed (normative belief). For these farmers, whose livelihoods are also more depend on fish farming income and whose awareness about Omega-3s and ALAs is higher than other farmers', the idea of inclusion of non-conventional ingredients in fish feed is therefore likely to be more readily acceptable. This echoes Gachango, Ekmann, Frørup and Pedersen (2017) who documented general acceptability and willingness to use fish feed containing unfamiliar pig by-products among Danish fish farmers'.

However, differences between the categories of feed users were not always significant for all perceptions and beliefs, and our results suggest that carp farmers' attitude towards feed novelty needs to be nuanced. Overall, the majority of farmers were uncertain about the advantages of using the new feed compared to their current method of feeding, and rather wary about the new feed's potential benefits. General preconceptions about the nature of the non-conventional ingredients themselves may be responsible for this, as hinted at by the strong preference for seaweed inclusion, even as a feed for freshwater fish. As advances are being made for the alternative sourcing of fish meal, fish oils and other critical components of fish feed, the inclusion of insect meal in terrestrial and aquatic animal feed is getting increasing attention (Sánchez-Muros, Barroso, & Manzano-Agugliaro, 2014, Barragan-Fonseca, Dicke, & van Loon, 2017, Belghit et al., 2018, Nogales-Mérida et al., 2019). If the general perception of the benefits of 'unusual' ingredients in animal feed – and by extension, of their presence in the final products – is generally positive, their acceptance by all stakeholders along the value chain is paramount (Verbeke et al., 2015, Seepuuya et al., 2019). As fishmeal replacement with plant-based ingredients such as macrophytes and almond oil-cake for Indian Major Carps is progressing (Goswami, Shrivastav, Sharma, Tocher, & Chakrabarti, 2020), and could potentially hold the key to higher EPA and DHA contents in freshwater fish flesh, overcoming farmers' initial resistance will be essential in this regard.

Relevance of combining the TPB and Rogers' framework to understand fish farmers' innovation adoption intentions

The factor analysis revealed that four latent factors –not three as per the TPB – best explained farmers' intention to adopt the new feed, namely: perceived peer pressure, importance and benefits, comparative advantage and outcome uncertainty about using the feed with non-conventional ingredients. In particular, peer pressure and outcome uncertainty had a stronger influence on farmers' intention to use the new feed than the other factors. The fact that the interactions between perceptions of the comparative advantage of the new feed with the other factors was the least strong is indicative of the relatively weaker influence of innovation's technological characteristics on intention. Despite accounting for only just over half of the variance in measured variables, the four identified factors (and the variables they encompass) suggest the necessity to account for innovation characteristics alongside individual attitudes. They also underscore the complementarity that exists between the TPB and Rogers' framework to comprehensively explain farmers' behaviour towards innovation adoption. This confirms that thus combined, the TPB and Rogers' framework offer a compelling entry point for the study of innovation adoption from a multi-disciplinary perspective (Ansari & Tabassum, 2018). If on one hand, the extension of the TPB model to account for other variables is a sign of its inner limitation in explaining behavioural phenomena (Sniehotta, Presseau, & Araújo-Soares, 2014), the insufficient consideration of psychological factors in Roger's framework is a similar shortcoming. The emergence of normative beliefs (peer pressure) as a separate factor is a case in point.

Future research avenues

Despite its relatively small sample size and the challenge of its ex-ante, hypothetical nature, our study opens new avenues for research. Firstly, the approach we have piloted needs to be replicated to affirm our insights into fish farmers' behaviour in relation to innovation adoption and improved feed management on one hand, and further validate the extended TPB-Rogers framework on the other. This could be achieved through a closer examination of interactions between the constructs of the TPB and characteristics of early-adopter farmers, i.e. those who are dissatisfied with their present levels of production, who believe that increases in productivity are possible, who are willing to experiment, who are confident in the support they are receiving, who have a sense of personal responsibility and who are ready to make decisions independently about the future (Mosher, 1960, Rogers, 1995). In an ex-ante context, while the innovation is still under development, psychological and behavioural traits such as extrinsic motivation, open-mindedness, imagination, professional competency, ambiguity, tolerance and interdisciplinary know-how (Sumberg, Heirman, Raboanarielina, & Kaboré, 2013) would be likely important underlayers of the TPB constructs to test and account for. Closer attention could also be paid to the influence of “background factors” (Ajzen, 2015) on intention through regression analysis. Secondly, this approach could be applied to a wider range of stakeholders, for example feed manufacturers and fish consumers, who are also directly concerned with innovation and the inclusion of non-conventional ingredients in fish feed formulae. Innovation hubs are located among aquaculture suppliers, upstream farm production (Bergesen & Tveterås, 2019), which would imply that feed manufacturers have a prime role to play in developing innovations. However, if for them the high price of fish oil is an incentive to seek alternative sources of EPA and DHA (Misund, Oglend & Mezzalira Pincinato, 2017), supply costs and their own perceptions and beliefs about non-conventional feed ingredients will also influence their adoption of novel ingredients and the overall innovation process they undertake to improve aquafeeds. For fish consumers, perceived attributes of fish are the strongest predictor of intention to consume, which is itself a significant predictor of actual consumption (Siddique, 2012). Consumers therefore need to be convinced early of the potential health benefits of farmed fish (carps and tilapia) fed a diet containing seaweeds, freshwater macrophytes, microalgae or microbes. Understanding fish consumer behavior and preferences will be all the more important that demand for seafood and its associated health benefits will play a key role in stimulating aquaculture’s contribution to nutrition security, regardless of the future development trajectories the sector may take (Gephart et al., 2020).

More widespread use of the combined TPB and Rogers’ framework in aquaculture would also improve our understanding of behavioral phenomena in relation to fish farmers’ attitudes to innovative feed and other aquaculture innovations. This would help address bottlenecks and help those who design and deliver interventions (Sniehotta et al., 2014). It could also help with the targeting of awareness raising campaigns on specific topics, or promotion of innovative and more effective farming practices. Fish farm clustering, for example, which is known to incentivize the adoption of more sustainable farm management practices (Joffre et al., 2019), would benefit from a greater understanding of the influence of peer-pressure and other beliefs on the utility and role of clusters. Co-designing innovations with farmers minimises the risk of ill-fitting to local contexts and idiosyncrasies (Joffre et al., 2017), and where there are influential farmers ready to embrace innovation, these could become champions of change.

Conclusion

Fish farmers’ intention to adopt aquaculture innovation is complex and driven by their perception of the attributes of the innovation itself, and by their behavioural, normative and control beliefs about the innovation. We have highlighted that Indian carp farmers are not a homogenous group of potential adopters of innovative aquafeeds, and that those who regularly use of commercially-formulated feeds in their farming operations tend to display a more positive attitude to non-conventional feed ingredients. If feeds improved with these ingredients are to be successfully diffused and widely up-taken, the full range of behavioral influences leading to their adoption needs to be adequately accounted for, so that latent constraints to adoption, in particular among farmers irregularly feeding or using on-farm made feeds, are identified early and addressed. To this end, valuable insights can be gained from the application of the TPB and the description of Rogers' innovation characteristics which, once combined, provide a comprehensive and compelling framework for analysing farmers' intentions towards innovation adoption. We recommend that this approach be more widely applied in studies of farmer's attitudes to the implementation of technological improvements and for promotion of new or better practices at farm and local level in order to anticipate their potential success or bottlenecks. As well as growing the body of literature on fish farmers' feed use and preferences and on aquaculture innovation adoption more generally, it would also shine a stronger light on the influence of human factors at play in the continued growth of the aquaculture sector. With constant technological advances in fish feed composition and progressive substitution of fishmeal with less familiar ingredients, targeted communication and capacity building will be required to alleviate the barriers to adoption that more complex feeds may create. Engaging with farmers from initial design stages will be crucial, not only to improve feed and feeding knowledge, but also overcome preconceived ideas and initial reluctance.

Acknowledgements

The authors acknowledge the Biotechnology and Biological Science Research Council (BBSRC) Newton Fund Global Research Partnership Project (BB/N005031/1) for financial support to carry out this study. They are also thankful to three students from Kerala University for Ocean Science (KUFOS) who helped gather the data, to the fish farmers who willingly took part in the survey, and to the reviewers and editor of the journal who helped us improve the manuscript with their comments.

Declaration of interest statement

The authors declare no conflict of interest.

References

Ahsan, D.A. (2011). Farmers' motivations, risk perceptions and risk management strategies in a developing economy: Bangladesh experience. *Journal of Risk Research*, 14(3), 325-349.

Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes*, 50, 179–211.

Ajzen, I. (2015). Consumer attitudes and behaviour: the Theory of Planned Behavior applied to food consumption decisions. *Rivista di Economia Agraria*, Anno LXX, 2, 121-138.

Ansah, Y.B. & Frimpong, E.A. (2015). Impact of the adoption of BMPs on social welfare: A case study of commercial floating feeds for pond culture of tilapia in Ghana. *Cogent Food & Agriculture*, 1, 1048579.

Ansari, S.A. & Tabassum, S. (2018). A new perspective on the adoption of sustainable agricultural practices: A review. *Current Agriculture Research Journal*, 6(2), 157-165.

Asche, F. (2019). Innovations throughout the supply chain. *Aquaculture Economics and Management*, 23(3), 234-236.

Asche, F. (2008). Farming the sea. *Marine Resource Economics*, 23, 527–547.

Ayyappan, S. & Ahmad Ali, S. (2007). Analysis of feeds and fertilizers for sustainable aquaculture development in India. In M.R. Hasan, T. Hecht, S.S. De Silva & A.G.J. Tacon (Eds.), Study and analysis of feeds and fertilizers for sustainable aquaculture development (pp. 191–219), FAO Fisheries Technical Paper. No. 497. Rome: FAO.

Bailey, C., Jentoft, S. & Sinclair, P. (1996). Social science contributions to aquacultural development. In C. Bailey, S. Jentoft and P. Sinclair (Eds.), *Aquacultural Development – Social Dimensions of an Emerging Industry* (Chapter 1). Boulder: Westview Press, Inc.

Barragan-Fonseca, K.B., Dicke, M. & van Loon, J.J.A. (2017). Nutritional value of the black soldier fly (*Hermetia illucens* L.) and its suitability as animal feed – a review. *Journal of Insects as Food and Feed*, 3(2), 105–120.

Bauer, R.A. (1960). Consumer behavior as risk taking. In R.S. Hadcock (Ed.), *Dynamic Marketing for a Changing World* (pp. 389-398). Chicago: American Marketing Association,.

Bergesen, O. & Tveterås, R. (2019). Innovation in seafood value chains: the case of Norway. *Aquaculture Economics and Management*, 23(3), 292-320.

Belghit, I., Liland, N. S., Waagbø, R., Biancarosa, I., Pelusio, N., Li, Y., ... & Lock, E. J. (2018). Potential of insect-based diets for Atlantic salmon (Salmo salar). *Aquaculture*, 491, 72-81.

Blythe, J., Sulu, R., Harohau, D., Weeks, R., Schwarz, A.-M., Mills, D. & Phillips, M. (2017). Social dynamics shaping the diffusion of sustainable aquaculture innovations in the Solomon Islands. *Sustainability*, 9(1), 126.

Borges, J.A.R., Foletto, L. & Xavier, V.T. (2015). An interdisciplinary framework to study farmers' decisions on adoption of innovation: Insights from Expected Utility Theory and Theory of Planned Behavior. *African Journal of Agricultural Research*, 10(29), 2814-2825.

Borges, J.A.R., Oude Lansink Al.G.J.M. & Emvalomatis, G. (2019). Adoption of innovation in agriculture: a critical review of economic and psychological models. *International Journal of Innovation and Sustainable Development*, 13(1), 36-56.

Brown, T. A., & Moore, M. T. (2012). Confirmatory factor analysis. *Handbook of structural equation modelling* (pp. 361-379). New York: The Guildford Press.

Brugere, C., Msuya, F., Jiddawi, N., Nyonje, B. & Maly, R. (2020) Can innovation empower? Reflections on introducing tubular nets to women seaweed farmers in Zanzibar. *Gender, Technology and Development*, DOI: 10.1080/09718524.2019.1695307

Brunsø, K., Verbeke, W., Osen, S.O. & Jeppesen, L.F. (2009). Motives, barriers and quality evaluation in fish consumtion situations. Exploring and comparing heavy and light users in Spain and Belgium. *British Food Journal*, 111(7), 699-716.

Caffey, R.H. & Kazmierczak, R.F. (1994). Factors influencing technology adoption in a Louisiana aquaculture system. *Journal of Agricultural and Applied Economics*, 26(1), 264-274.

Chakrabarti, R., Clark, W. D., Sharma, J. G., Goswami, R. K., Shrivastav, A. K., & Tocher, D. R. (2018). Mass production of Lemna minor and its amino acid and fatty acid profiles. *Frontiers in chemistry*, 6, 479.

Dessart, F.J., Barreiro-Hurlé, J. & van Bavel, R. (2019). Behavioural factors affecting the adoption of sustainable farming practices: a policy-oriented review. *European Review of Agricultural Economics*, 46(3), 417–471.

Dey, M. M., Paraguas, F. J., Kambewa, P., & Pemsl, D. E. (2010). The impact of integrated aquaculture–agriculture on small-scale farms in Southern Malawi. *Agricultural Economics*, *41*(1), 67-79.

El Bilali, H. (2018). Innovation in the agro-food sector: From technical innovation-centred approaches to sustainability transition processes. *International Journal of Agricultural Management and Development*, *8*(2), 201-218.

Feder, G., Just, R. & Zilberman, O. (1985). Adoption of agricultural innovations in developing countries: a survey. *Economic Development of Cultural Change*, 33(2), 255-298.

Foguesatto, C.R. & Dessimon Machado, J.A. (2019). Is there any universal factor that explains the adoption of sustainable agricultural practices? A review and update. Available at SSRN: https://ssrn.com/abstract=3333468 or http://dx.doi.org/10.2139/ssrn.3333468

Gachango, F. G., Ekmann, K. S., Frørup, J. & Pedersen, S. M. (2017). Use of pig by-products (bristles and hooves) as alternative protein raw material in fish feed: A feasibility study. *Aquaculture*, 479, 265-272.

Gephart, J. A., Golden, C. D., Asche, F., Belton, B., Brugere, C., Froehlich, H.E., Fry, J. P., Halpern, B. S., Hicks, C. C., Jones, R. C., Klinger, D. H., Little, D. C., McCauley, D. J., Thilsted, S. H., Troell, M. & Allison, E. H. (2020). Scenarios for global aquaculture and its role in human nutrition. *Reviews in Fisheries Science & Aquaculture*, DOI: 10.1080/23308249.2020.1782342

Ghifarini, A.F., Sumarwan, U. & Najib, M. (2018). Application of the Theory of Planned Behavior in shrimp consumer behaviour analysis. *Independent Journal of Management and Production*, 9(3), 984-1001.

Goswami, R.K, Shrivastav, A.K., Sharma, J.G., Tocher, D.R. & Chakrabarti, R. (2020) Growth and digestive enzyme activities of rohu labeo rohita fed diets containing macrophytes and almond oil-cakes. *Animal Feed Science and Technology*, 263, 114456.

Gunstone, F.D. & Harwood, J.L. (2007). Occurrence and characteristics of oils and fats. In F.D. Gunstone, J.L. Harwood and A.J. Dijkstra (Eds.), *The Lipid Handbook*, 3rd ed., (pp. 37–142). Boca Raton: Taylor & Francis, CRC Press.

Hair, J.F., Anderson, R.E., Tatham, R. & Black, W. (1995). *Multivariate data analysis: With readings*. Per Up Saddle River, N.J.: Prentice Hall.

Haque, M.M., Little, D.C., Barman, B.K. & Wahab, M.A. (2010). The adoption process of ricefield-based fish seed production in Northwest Bangladesh: An understanding through quantitative and qualitative investigation. *The Journal of Agricultural Education and Extension*, 16(2), 161-177.

Hasan, M.R., T. Hecht, S.S. De Silva and A.G.J. Tacon (Eds.) (2007). Study and analysis of feeds and fertilizers for sustainable aquaculture development (pp. 191–219.) FAO Fisheries Technical Paper. No. 497, Rome: FAO.

Higuchi, A., Dávalos, J. & Hernani-Merino, M. (2016). Theory of Planned Behavior applied to fish consumption in modern Metropolitan Lima. *Food Science and Technology*, 37(2), 202-208.

Holak, S. L., & Lehmann, D. R. (1990). Purchase intentions and the dimensions of innovation: An exploratory model. *Journal of Product Innovation Management*, 7(1), 59-73.

Honkanen, P., Olsen, S.O., & Verplanken, B. (2005). Intention to consume seafood – the importance of habit. *Appetite*, 45, 161-168.

Hu, L. & Bentler, P.M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling*, 6, 1-55.

JASP Team (2019). JASP (Version 0.11.1) [Computer software]. https://jasp-stats.org/

Joffre, O. M., Klerkx, L., Dickson, M., & Verdegem, M. (2017). How is innovation in aquaculture conceptualized and managed? A systematic literature review and reflection framework to inform analysis and action. *Aquaculture*, 470, 129-148.

Joffre, O. M., Poortvliet, P. M., & Klerkx, L. (2018). Are shrimp farmers actual gamblers? An analysis of risk perception and risk management behaviors among shrimp farmers in the Mekong Delta. *Aquaculture*, 495, 528-537.

Kaiser, H. F. (1974). An index of factorial simplicity. *Psychometrika*, 39, 31-36.

King, A.S., Elliott, N.G., James, M.A., MacLeod, C.K. & Bjorndal, T. (2018). Technology selection—the impact of economic risk on decision making. *Aquaculture Economics & Management*, 22(4), 383-409.

Kinney, H. (2017). Aquaculturists' perceptions of integrated multi-trophic aquaculture (IMTA). Open Access Master's Theses. Paper 1024. University of Rhodes Island. http://digitalcommons.uri.edu/theses/1024

Kripa, V., & Mohamed, K. S. (2008). Green mussel, Perna viridis, farming in Kerala, India–technology diffusion process and socioeconomic impacts. *Journal of the World Aquaculture Society*, *39*(5), 612-624.

Kumar, G. & C. R. Engle. (2016). Technological advances that led to the growth of shrimp, salmon, and tilapia industries. *Reviews in Fisheries Science,* 24(2), 136–152.

Kumar, G., Engle, C. & Tucker, C. (2018) Factors driving aquaculture technology adoption. *Journal of the World Aquaculture Society*, 49(3), 447-476.

Lasner, T., & Hamm, U. (2011). Ecopreneurship in aquaculture—The adoption of organic fish farming methods. In D. Neuhoff, S. Mok Sohn, C. Ssekyewa, N. Halberg, I.A. Rasmussen & J. Hermansen (Eds.) Organic is Life - Knowledge for Tomorrow. Volume 1 - Organic Crop Production (pp.72-75). Proceedings of the Third Scientific Conference of the International Society of Organic Agriculture Research (ISOFAR). https://s3.amazonaws.com/academia.edu.documents/30953623/isofar_vol2.pdf?AWSAccessKeyId=AKIAIWOWYYGZ2Y53UL3A&Expires=1554740304&Signature=iapiJGZVpoK%2FDnzRFh6ZjgLjyes%3D&response-content-disposition=inline%3B%20filename%3Denvironmental_and_socioeconomic_impact_o.pdf#page=89

Leeuwis, C., & van den Ban, A. (2004). *Communication for Rural Innovation: Rethinking Agricultural Extension*. Oxford: Blackwell Science.

Mitterer-Daltoé, M.L., Carrillo, E., Queiroz, M.I., Fiszman, S. & Varela, P. (2013). Structural equation modelling and word association as tools for a better understanding of low fish consumption. *Food Research International,* 52, 56-63.

Mosher, A. (1960). Interrelationships between agricultural development, social organization, and personal attitudes and values. Comparative Extension Publication Number 12 Ithaca, NY: New York State College of Agriculture at Cornell University.

Ndah, H.T., Knierim, A. & Ndambi, O.A. (2011). Fish pond aquaculture in Cameroon: A field survey of determinants for farmers' adoption behavior. *Journal of Agricultural Education and Extension*, 17(4), 309-323.

Nogales-Mérida, S., Gobbi, P., Józefiak, D., Mazurkiewicz, J., Dudek, K., Rawski, M., Kieroczyk, B. & Józefiak, A. (2019). Insect meals in fish nutrition. *Reviews in Aquaculture*, 11, 1080-1103.

Olsen, S.O., Heide, M., Dopico, D.C. & Toften, K. (2008). Explaining intention to consume a new fish product: A cross-generational and cross-cultural comparison. *Food Quality and Preference*, 19, 618-627.

Oparinde, L. O., Fatuase, A. I., & Daramola, A. G. (2016). Risk attitudes and poverty status nexus: A study of fish farmers in Ondo State, Nigeria. *Asian Journal of Agricultural Extension, Economics & Sociology,* 1-12.

Orstavik, F. (2017). Contests of institutional framing: sectorial governance and the innovation of mass-produced Atlantic salmon. *Innovation and Development,7*(1), 63-82.

Osborne, J. W. (2014). *Best Practices in Exploratory Factor Analysis*. Scotts Valley, CA: CreateSpace Independent Publishing.

Petersen, E.H., My Chinh, D.T., Thi Diu, N., Van Phuoc, V., Phuong, T.H., Van Dung, N., Khac Dat, N., Truong Giang, P. & Glencross, B.D. (2013). Bioeconomics of Grouper, *Serranidae: Epinephelinae*, culture in Vietnam. *Reviews in Fisheries Science*, 21(1), 49-57.

Petersen, E.H., Dinh Luan, T., My Chinh, D.T., Anh Tuan, V., Quoc Binh, T., Van Truc, L. & Glencross, B.D. (2014). Bio-economics of Cobia, *Rachycentron canadum*, culture in Vietnam. *Aquaculture Economics & Management*, 18(1), 28-44.

Pino, G., Toma, P., Rizzo, C., Miglietta, P.P., Peluso, A.M. & Guido, G. (2017). Determinants of farmers' intention to adopt water saving measures: Evidence from Italy. *Sustainability*, 9(1), 77.

Ponnusamy, K. & Pillai, S.M. (2014). Evaluation of factors contributing to adoption of management practices productivity and net income in shrimp farming in Gujarat, India. *Indian Journal of Fisheries*, 61(4), 70-83.

Ramachandran, C. (2009). Open sea cage culture in India- A sociological perspective. In: Course manual: National training on cage culture of seabass (pp. 94-98) Kochi: CMFRI & NFDB http://eprints.cmfri.org.in/6089/

Rauniyar, G.P. (1998). Adoption of management and technological practices by fishpond operators in Nepal. *Aquaculture Economics & Management*, 2(3), 89-99.

Ringa, S & Kyalo, T. (2013). Assessment of the relationship between economic stimulus programme and youth entrepreneurship in Kenya. *International Journal of Social Sciences and Entrepreneurship*, 1(3), 398-405.

Rogers, E.M. 1962, 1983, 1995, 2003. Diffusion of Innovations. New York/London: The Free Press.

Ruddle, K. (1996). Household and community factors affecting development of small-scale fish farming in Africa. In C. Bailey, S. Jentoft and P. Sinclair (Eds.), *Aquacultural Development – Social Dimensions of an Emerging Industry* (pp. 211-231). Boulder: Westview Press, Inc.

Sahoo, P.R., Ananth, P.N., Sundaray, J.K., Barik, N.K. & Jayasankar, P. (2017) Early breeding and seed production of Indian major carps: Attributes of the innovation from an adaptive Trial. *Current Agriculture Research Journal*, 5(1), 58-65.

Sambodo, L.A.A.T & Nuthall, P.L. (2010). A behavioural approach to understanding semi-subsistence farmers' technology adoption decisions: The case of improved paddy-prawn system in Indonesia. *The Journal of Agricultural Education and Extension*, 16(2), 111-129.

Sánchez-Muros, M. J., Barroso, F. G., & Manzano-Agugliaro, F. (2014). Insect meal as renewable source of food for animal feeding: a review. *Journal of Cleaner Production*, *65*, 16-27.

Seepuuya, G., Sebatta, C., Sikahwa, E., Fuuna, P., Sengendo, M., Mugisha, J., Fiaboe, K.K.M. & Nakimbugwe, D. (2019). Perception and awareness of insects as an alternative protein source among fish farmers and fish feed traders. *Journal of Insects as Food and Feed*, 5(2), 107-116.

Sevilleja, R.C. (2000). Adoption and economics of tilapia farming technology in the Philippines. IIFET 2000 Proceedings. http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/30433/012.pdf?sequence=1

Siddique, M.A.M. (2012). Explaining the role of perceived risk, knowledge, price, and cost in dry fish consumption within the Theory of Planned Behavior. *Journal of Global Marketing*, 25(4), 181-201.

Sniehotta F. F., Presseau, J. & Araújo-Soares, V. (2014). Time to retire the theory of planned behaviour. *Health Psychology Review*, 8(1), 1-7.

Stark, K.D., Van Elswyk, M.E., Higgins, M.R., Weatherford, C.A., Salem, N. Jr. (2016). Global survey of the omega-3 fatty acids, docosahexaenoic acid and eicosapentaenoic acid in the blood stream of healthy adults. *Progress in Lipid Research* 63, 132–152.

Suhr, D. (2006). Exploratory or Confirmatory Factor Analysis? University of Northern Colorado. Statistics and Data Analysis. https://support.sas.com/resources/papers/proceedings/proceedings/sugi31/200-31.pdf

Sumberg, J., Heirman, J., Raboanarielina, C. & Kaboré, A. (2013). From agricultural research to 'product development': What role for user feedback and feedback loops? *Outlook on Agriculture*, 42(4), 233–242.

Suresh, A.V. (2007). Development of the aquafeed industry in India. In M.R. Hasan, T. Hecht, S.S. De Silva and A.G.J. Tacon (Eds.) Study and analysis of feeds and fertilizers for sustainable aquaculture development (pp. 221–243) FAO Fisheries Technical Paper. No. 497. Rome: FAO.

Tain, F.H. & Diana, J.S. (2007). Impacts of extension practice: Lessons from small farm-based aquaculture of Nile Tilapia in Northeastern Thailand. *Society and Natural Resources*, 20(7), 583-595.

Thong, N.T. & Olsen, S.O. (2012). Attitude toward and consumption of fish in Vietnam. *Journal of Food Products Marketing*, 18, 79-85.

Tocher, D.R. (2015). Omega-3 long-chain polyunsaturated fatty acids and aquaculture in perspective. *Aquaculture*, 449, 94-107.

Tocher, D.R., Francis, D.S. & Coupland, K. (2011). n-3 Polyunsaturated fatty acid-rich vegetable oils and blends. In G.M. Turchini, W.-K. Ng and D.R. Tocher (Eds.), *Fish Oil Replacement and Alternative Lipid Sources in Aquaculture Feeds*. Ch.7 (pp. 209-244). Boca Raton: Taylor & Francis, CRC Press, Boca Raton.

Torstensen, B.E. & Tocher, D.R. (2011). The Effects of fish oil replacement on lipid metabolism of fish. In G.M. Turchini, W.-K. Ng and D.R. Tocher (Eds.), *Fish Oil Replacement and Alternative Lipid Sources in Aquaculture Feeds*. Ch. 13 (pp.405-437). Boca Raton: Taylor & Francis, CRC Press.

Tomić, M., Matulić, D. & Margareta, J. (2015). What determines fresh fish consumption in Croatia? Paper prepared for presentation at the EAAE-AAEA Joint Seminar 'Consumer

Behavior in a Changing World: Food, Culture, Society", March 25 to 27, 2015, Naples, Italy. https://ageconsearch.umn.edu/record/202695/files/76.pdf

Verbeke, W., Spranghers, T., De Clercq, P., De Smet, S., Sasd, B. & Eeckhou, M., (2015). Insects in animal feed: Acceptance and its determinants among farmers, agriculture sector stakeholders and citizens. *Animal Feed Science and Technology*, 204, 72–87.

Verbeke, W. & Vackier, I. (2005). Individual determinants of fish consumption: application of the Theory of Planned Behaviour. *Appetite*, 44, 67-82.

Wandji, D.N., Pouomogne, V., Binam, J.N. & Nouaga, R.Y. (2012). Farmers' perception and adoption of new aquaculture technologies in the Western Highlands of Cameroon. *Tropicultura*, 30(3), 180-184.

Woldegebrial Zeweld, W., Van Huylenbroeck, G., Tesfay, G. and Speelman, S. (2017). Smallholder farmers' behavioural intentions towards sustainable agricultural practices. *Journal of Environmental Management*, 187, 71-81.

Yasmin, S. (2018). Enhancing the sustainable livelihood of crab fishers: a study of the mud crab value chain of coastal Bangladesh using the Social Business Model. PhD Thesis, Curtin University. https://espace.curtin.edu.au/bitstream/handle/20.500.11937/70493/Yasmin%20S%202018.pdf?sequence=1&isAllowed=y

Tables

Table 1: Hypothesised attributes of the aquafeed containing non-conventional ingredients innovation.

Rogers' innovation attributes (Rogers 1962, 1995, 1983, 2001)	**Hypothesized perceived attributes of aquafeed containing non-conventional ingredients ("new feed")**
Relative advantage Extent to which a new technique or product is preferred to the existing technology. Generally, the superiority of an innovation is measured by its profitability (crucially dependent on assumptions on output prices) or risk-reducing potential.	The new feed is more economically profitable compared to conventional feed containing fish meal and fish oils. The new feed is more effective and reliable (less risky), with comparatively higher FCR. The new feed supports the production of freshwater fish containing higher contents of Omega-3s than conventionally-fed freshwater fish.
Compatibility Extent to which a new innovation is consistent with existing norms, values and prior experience of prospective adopters, and extent to which it is physically and managerially compatible with existing practices.	Application of the new feed is consistent with farmers' existing feeding practices and experience. Use of the new feed is manageable by the farmer. New feed contents are compatible with prevailing norms.
Complexity Extent to which new techniques and their consequences are easy or difficult to understand. In general, less complex ideas are more quickly and widely adopted.	Utilization and purpose of the new feed is reasonably easy to understand and master.
Divisibility (or "triability") Extent to which an innovation can be used on a limited basis. The importance of divisibility stems from the potential risks involved in trying a new innovation. If trials can be done on a limited basis, earlier adopters are able to limit their exposure to losses.	The new feed can be trialed over a discrete period of time to allow farmers form their own opinion. Risk associated with the utilization of this feed is measured. Farmers are not bound to continue using the new feed once trialed.
Communicability/observability Ease with which knowledge of an innovation can be passed along to potential users. This concept includes both the complexity of the innovation, as well as the rapidity and tangibility of benefits.	Fish of higher nutritional quality is produced. Premium market prices reflect this. Other farmers become quickly interested in trying out the new feed.

Table 2: Factor loadings, composite reliability and discriminant validity of the TPB constructs extended with Rogers' innovation model.

Factors and items	Factor loadings	Composite reliability (CR)	Discriminant validity
Perceived peer pressure		0.908	0.778
Feed suppliers' approval	0.883		
Fisheries Dept's approval	0.835		
Fish consumers' approval	0.833		
Other farmers' approval	0.832		
Neighbours' approval	0.786		
Family's approval	0.731		
Capped or subsidized price of enriched feed	0.466		
Perceived importance and benefits		0.834	0.612
Comfortable	0.796		
Create more demand for fish	0.719		
Compatible	0.714		
Obtain a price premium	0.620		
Sufficient knowledge	0.596		
Be inconvenient (reversed)	0.580		
Improve fish growth	0.498		
Increase my popularity as an innovative farmer	0.469		
Speed of experiencing benefits	0.423		
Increase feed costs (reversed)	0.412		
Higher risk (reversed)	0.412		
Comfortable	0.796		
Perceived innovation comparative advantage		0.865	0.803
Comparison: access	0.991		
Comparison: application	0.806		
Comparison: cost	0.710		
Comparison: fish growth	0.665		
Perceived outcome uncertainty		0.773	0.697
Increase dependence from feed suppliers (reversed)	0.771		
Be more difficult to supply (reversed)	0.704		
Fish may not like it (reversed)	0.622		
Consumers may not like it (reversed)	0.599		

Note. 'Minimum residual' extraction method was used in combination with a 'promax' rotation

Table 3: Factor Co-variances

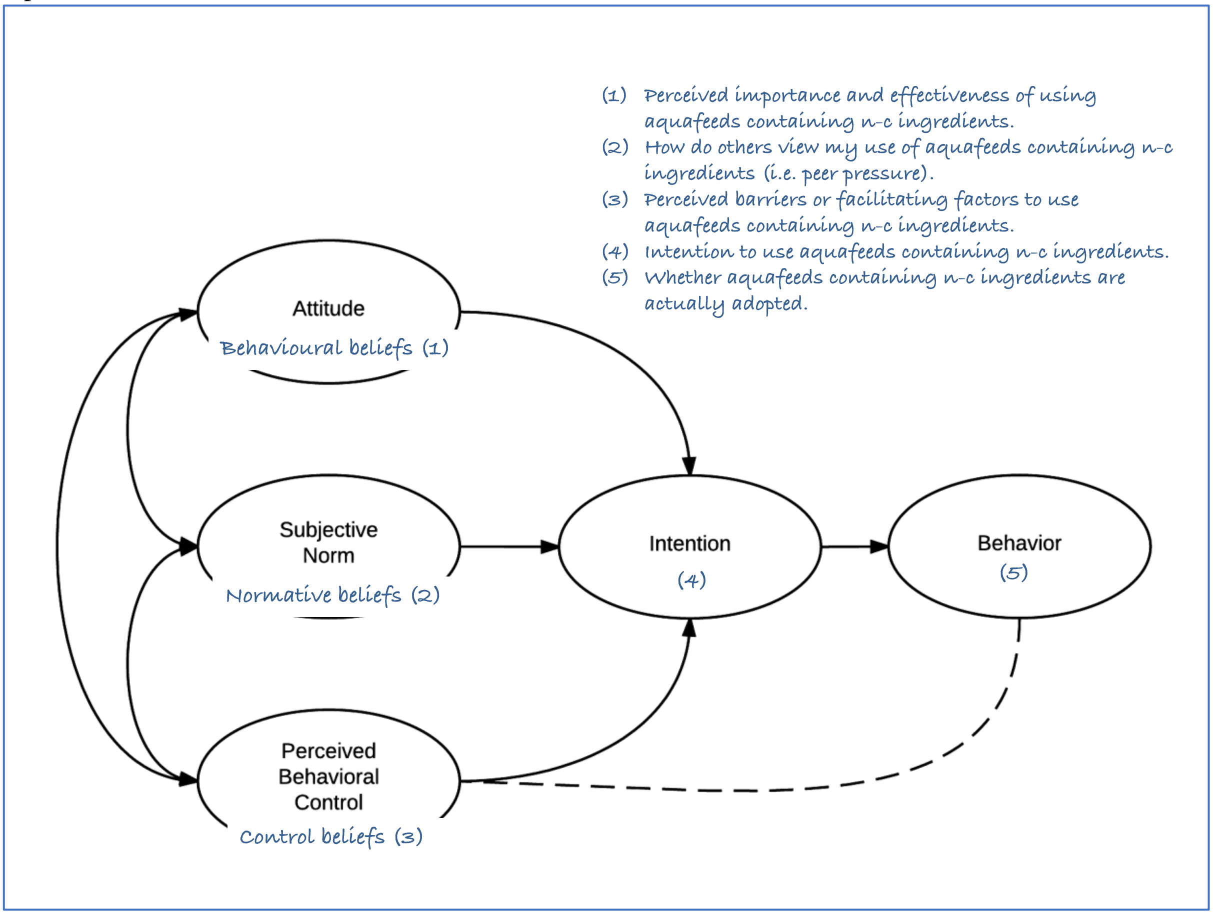
Factors			Standardized estimate	Significance of z-value
Peer pressure	↔	Innovation comparative advantage	0.337	P<0.05
Peer pressure	↔	Outcome uncertainty	0.253	Not significant
Importance and benefits	↔	Innovation comparative advantage	0.284	Not significant
Importance and benefits	↔	Outcome uncertainty	0.563	P<0.001
Innovation comparative advantage	↔	Outcome uncertainty	0.174	Not significant

Note: The ratio of each parameter estimate to its standard error is distributed as a z statistic and is significant at the 0.05 level if its value exceeds 1.96 and at the 0.01 level it its value exceeds 2.56 (Hoyle, 1995, cited in Suhr, 2006).

Figures

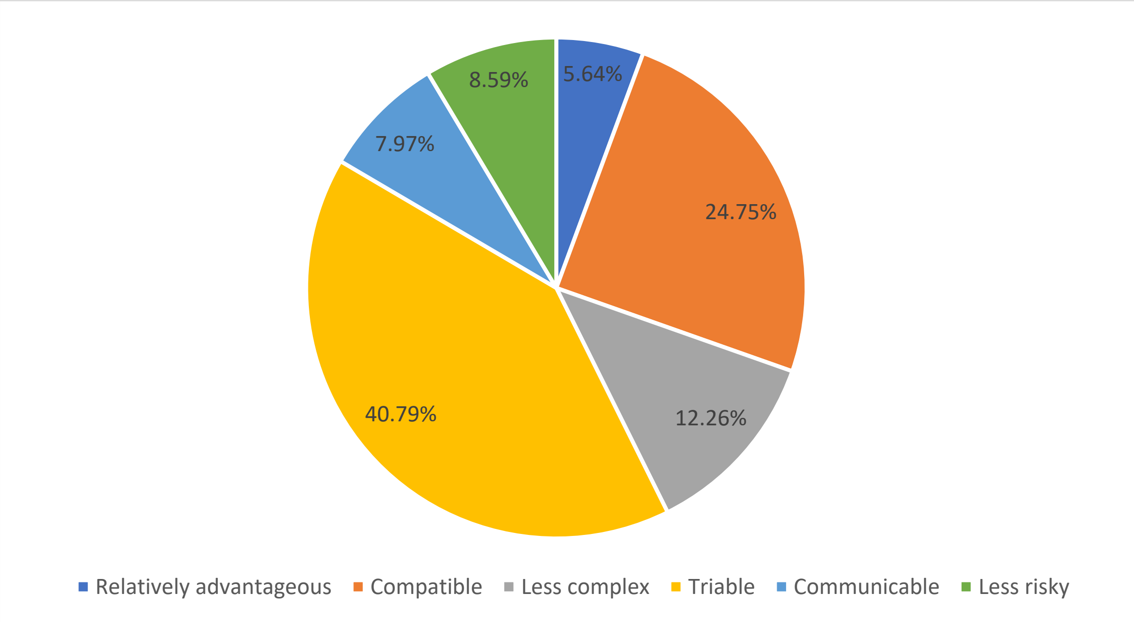
Figure 1: The interpretation of the Ajzen's 1991 Theory of Planned Behavior in relation to fish farmers' decision to adopt or not aquaculture feeds containing non-conventional ingredients.

The dashed line connecting directly perceived behavioral control (PBC) and behavior illustrates the separate direct effect that PCB can have on behaviour.



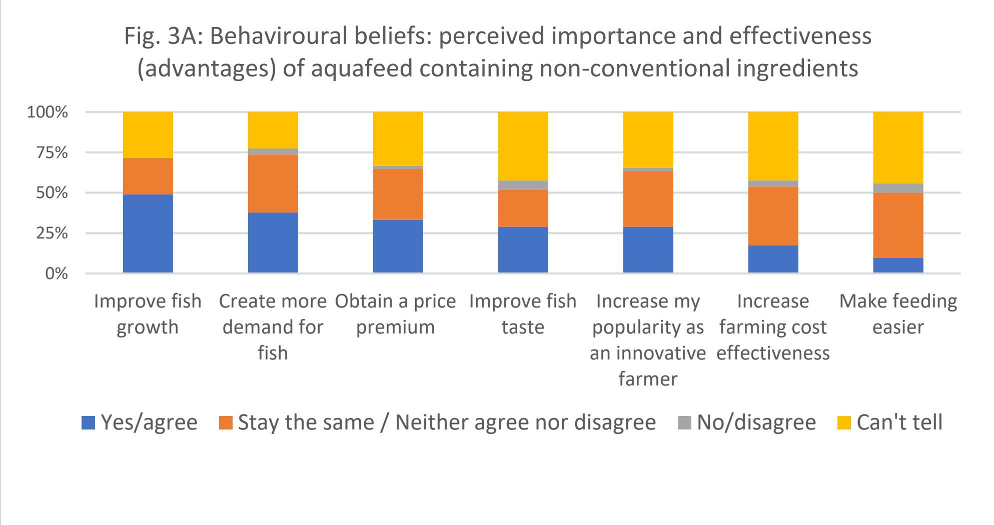
n-c: non-conventional

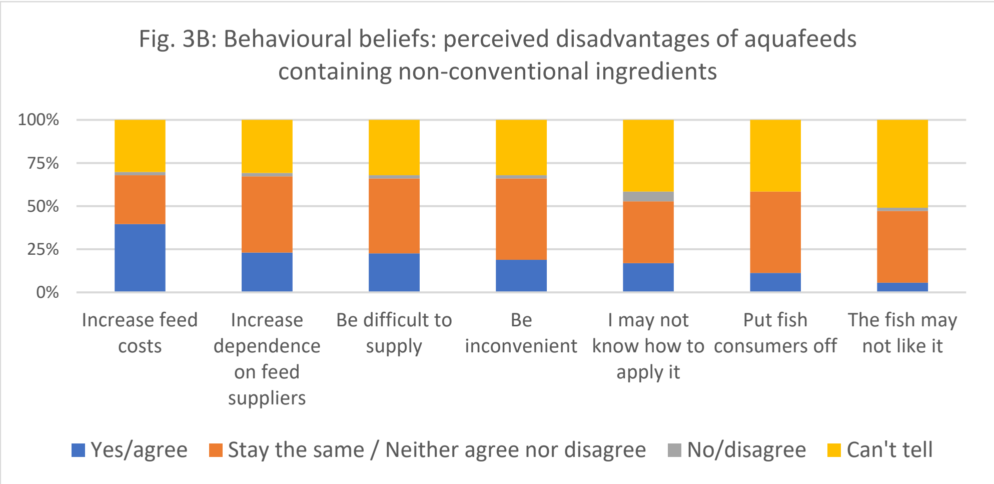
Figure 2: Indian carp farmers' perceptions of aquafeed improved with non-conventional ingredients according to Rogers' innovation characteristics, and risk (percentage of responses, n = 53).

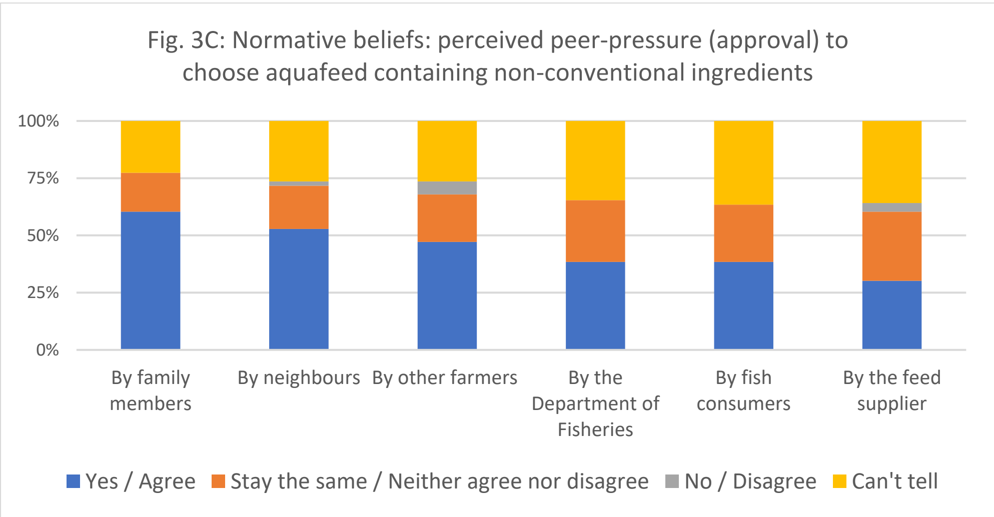


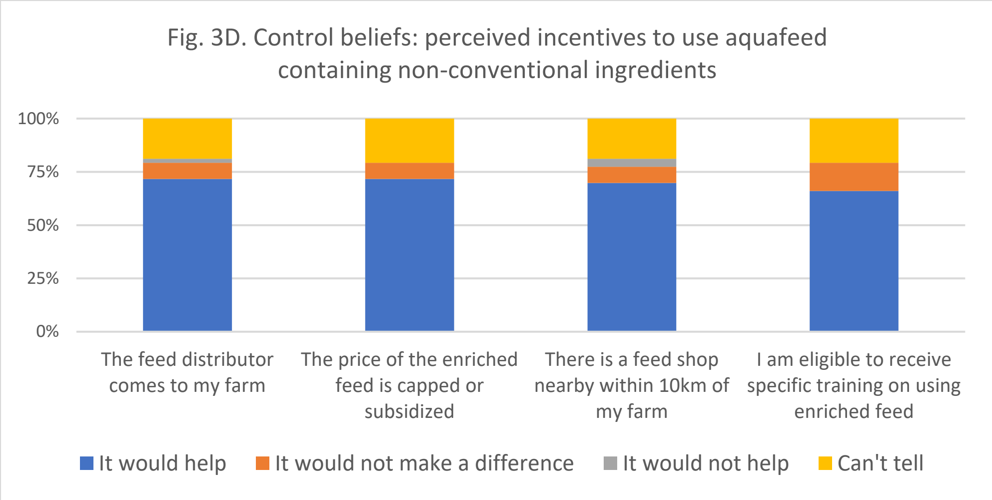
Notes: (1) Relative advantage was broken down according to cost, fish growth, ease of access and purchase and ease of application. (2) The notion of complexity was enquired through "current knowledge". When farmers deemed it to be insufficient, this was equated to (high) complexity. (3) Communicability was broken down according to the ease with which it would be possible for farmers to find out more about the new feed, and the speed at which farmers would be able to learn how to use it. (4) Compatibility refers to both compatibility with current feeding practices and compliance with personal norms and values. When more than one sub-indicators were use, answers were averaged.

Figure 3: Indian carp farmers' behavioural, normative and control beliefs regarding the use of aquafeed containing non-conventional ingredients (percentage of responses, n = 53).



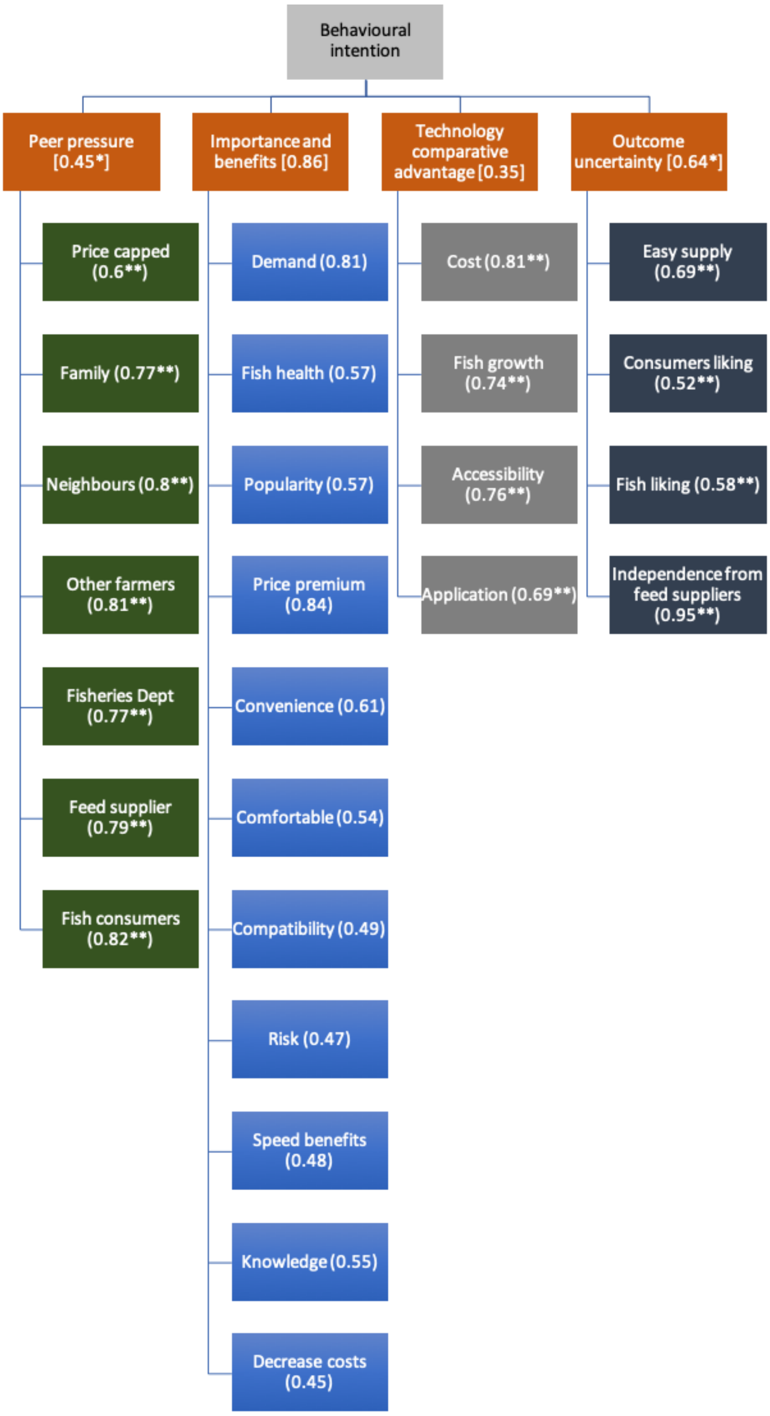






Note: in the above figures, results were significantly different across feed user categories for "make feeding easier" and "increase my popularity as an innovative farmer" (3A), "increase dependence on feed suppliers" and "be more difficult to obtain" (3B), "by other farmers" (3C), "there is a feed shop nearby within 10km of my farm" and "I am eligible to receive specific training on using enriched feed" (3D).

Figure 4: Extended TPB-Rogers' model.



Notes: All factor loading values are standardised. Factor loadings of the first order constructs (latent factors) are indicated in brackets, factor loadings of the second order construct (behavioural intention) are indicated in square brackets. * denotes significance at 0.05. ** denotes p-values <0.001. For the sake of clarity, the item and factor variances are not represented.