Agricultural Systems 218 (2024) 104006

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Guidance on farmer participation in the design, testing and scaling of agricultural innovations

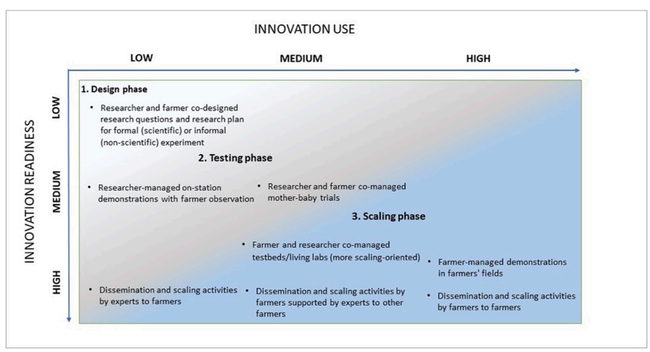
Lukas Pawera [a,*], Ravishankar Manickam [b], Carolyne Wangungu [c], Uon Bonnarith [d], Pepijn Schreinemachers [e], Srinivasan Ramasamy [a]

[a] World Vegetable Center, Shanhua, Tainan, Taiwan
[b] World Vegetable Center, ICRISAT Campus, Patancheru, Hyderabad, India
[c] World Vegetable Center, c/o World Agroforestry (ICRAF), Nairobi, Kenya
[d] World Vegetable Center, Siem Reap, Cambodia
[e] World Vegetable Center, Bangkok, Thailand

HIGHLIGHTS

- Despite rapid developments in agricultural innovations, there has been limited adoption by smallholder farmers.
- There is limited guidance on choosing an appropriate level of farmer participation in the innovation processes.
- A list of participatory approaches for design, testing and scaling of innovations was created.
- A guidance for choosing a suitable level of participation based on ‘innovation readiness and use’ was developed.

GRAPHICAL ABSTRACT



ARTICLE INFO

Editor: A Beaudreault

Keywords:
Participatory approaches
Innovation readiness
Agricultural technology
Research
Co-creation

ABSTRACT

CONTEXT: Despite accelerated developments in agricultural innovations, there has been a limited progress in their adoption by smallholder farmers, especially in the Global South. Innovations are not adequately reaching farmers, and new technologies are often unsuitable for farmers, or the overall innovation landscape is discouraging the deployment of innovations at scale. The methodological approaches to designing, testing and scaling of innovations play an important role. Involving farmers in the innovation process from the start increases the likelihood of them being more relevant and having a higher chance of adoption. Whereas there is much literature on participatory approaches, there is a limited guidance on choosing an appropriate level of farmer participation across the innovation process.

OBJECTIVE: This study aims to develop practical guidance for researchers, development agents and project managers on how to choose an appropriate methodological approach with a suitable level of farmer participation for designing, testing and scaling of agricultural innovations, according to levels of innovation readiness and innovation use.

* Corresponding author.
E-mail address: lukas.pawera@worldveg.org (L. Pawera).

https://doi.org/10.1016/j.agsy.2024.104006
Received 15 October 2023; Received in revised form 27 April 2024; Accepted 15 May 2024
Available online 30 May 2024

METHODS: Relevant scientific literature on participatory design, research and scaling of agricultural innovations was reviewed, followed by compiling lessons learned from selected vegetable innovation projects implemented by the World Vegetable Center (WorldVeg) in Asia and Africa. A list of methodological approaches for participatory design, testing and scaling of innovations was generated, with various levels of farmer participation. A simple guiding framework was then developed for choosing an appropriate approach with a suitable level of farmer participation, according to the readiness and use of the innovations. Examples of selected approaches and application of the proposed guidance are given in project case studies.

RESULTS AND CONCLUSIONS: Based on the literature review and experience at WorldVeg, we believe it is critical to choose the right level of participation based on how ready are the innovations for application in the local setting. This dimension of how ready the innovations are has been largely overlooked in earlier frameworks on farmer participation. The developed guidance generally recommends increasing participation with higher levels of technology readiness and use. In addition, farmer consultation in early research design should also be strengthened, to co-design locally relevant innovations. The overall innovation systems' landscape must be considered when researching and scaling new innovations.

SIGNIFICANCE: The guidance, experiences and lessons provided in this paper will be useful to various scholars, researchers, development agents, funders and project managers who aim to design, test and scale agricultural innovations in a more inclusive and responsible way.

1. Introduction

Rapid progress is being made in developing, promoting and scaling food and agricultural new technologies, practices, products. Such agricultural innovations span the production cycle and the entire value chain, in farming, forestry, fisheries and livestock production, involving the management of inputs and resources to market access (FAO, 2018). The increasing pace of technological advancement in the agri-food sector is contributing to increased efficiency and productivity (Ugochukwu and Phillips, 2018), but there has been limited adoption of innovations by smallholder farmers, especially in the Global South (Curry et al., 2021). They are not adequately reaching farmers, and new technologies are often not suitable for their socio-economic conditions or are not fully ready to be deployed in complex realities (Johnson et al., 2003). FAO (2018) stated, "Innovation is not just about technology, which on its own may simply remain on the shelf". This is also due to the potentially constraining innovation landscape, which includes social networks, markets and supply channels, and that can result in limited progress and inequitable distribution of benefits. This should be of great concern for the governments, funders, development agencies, researchers, markets, and communities.

Innovations can only be impactful and scaled if farmers or other end users adopt them. Scaling is related to 'diffusion', which was defined by Rogers (2003) as the "process by which an innovation is communicated through certain channels over time among the members of the social system". Despite various models of technology adoption or rejection, Rogers' diffusion model has been the most widely used theory for adoption and diffusion of innovations (Ugochukwu and Phillips, 2018), though dissemination and scaling concepts have been increasingly replacing diffusion (Breaugh et al., 2021; Schut et al., 2020). It is increasingly recognised that diffusion, dissemination and adoption of innovation are more dynamic processes that happen in scaling processes (Wigboldus et al., 2016). Furthermore, there has been an evolution of systemic thinking in agricultural innovation studies, culminating in the recognition of the importance of agricultural innovation systems (Klerkx et al., 2012) and systemic perspectives on scaling (Wigboldus et al., 2016). Agricultural innovation system is a web of dynamic interactions among farmers, researchers, input suppliers, extension agents, traders, and processors that may interact in the creation, diffusion, adaptation, and use of agricultural innovations (Hellin and Camacho, 2017).

In practice, it is often seen that innovations that are not ready or suitable for the local conditions are being demonstrated and transferred to farmers and local stakeholders, with limited adoption (Johnson et al., 2003). Adoption is a very complex process that usually starts with seeking information about the innovation, followed by a careful review of the perceived attributes and the potential benefits and costs. Only after examining an innovation's characteristics and assessing the benefits, costs, and trade-offs associated with it, the decision to adopt or reject it is made (Wisdom et al., 2014). In addition, socio-cultural factors play an important role in determining adoption outcomes and innovations that disrupt socio-cultural and moral frameworks are less likely to be adopted (Curry et al., 2021). In the case of local farmer-led innovations, adoption might be a more natural and spontaneous process (Hoffmann et al., 2007). Ultimately, the broader innovation system and its adoption-enabling effect should be considered (Sartas et al., 2020; Klerkx et al., 2012). (Kohl, 2023) recently discussed numerous key factors advancing innovations to scale.

Apart from the characteristics of the innovation itself and the supporting conditions in the innovation system, the methodological approaches of testing and scaling innovations play an important role in adoption (Kirimi et al., 2023). Involving the local community and end users in research and innovation testing through strategic partnerships from the beginning can increase the likelihood of adoption (Sodjinou, 2024; Rijsberman and Atta-Krah, 2016). Moreover, when farmers generate their own knowledge and experiences relevant to local conditions, they are more likely to adopt new practices (MacMillan and Benton, 2014).

There have been longstanding calls to place farmers at the centre of innovation processes, to better align innovations with their needs and aspirations (Lacoste et al., 2022). According to Johnson et al. (2004), participatory research can strengthen communication between researchers and end users, which leads to a better understanding of the problems, more relevant solutions, and faster adoption. The pioneers of participatory approaches championed farmers' involvement in innovation processes since the 1980s with different concepts such as farmer-back-to-farmer (Rhoades and Booth, 1982), putting the last first (Chambers, 1983), participatory rural appraisal, participatory technology development, and participatory action research, among others (Probst et al., 2000; Duraiappah et al., 2005). Despite earlier successes with these approaches, they have not become standard practice, which is likely due to social barriers, differences in knowledge systems, different experimental styles, and other challenges (Bentley, 1994). Others added that impacts like technology adoption, increased knowledge, increased farm income, or improved livelihoods are often not measured in contrast to the number of released varieties or published articles (Van De Gevel et al., 2020). Whereas participatory research still attracts attention, it remains poorly integrated into biophysical or experimental research focused on agricultural innovations, though it is applied more commonly in the development sector (Van De Gevel et al., 2020).

The recent discussions have shifted to how to blend various forms and levels of farmer participation with modern science, and to co-create new transformative knowledge beyond the "farmer-first" ideology of the 1980s and early 1990s, most existing frameworks of participation in agricultural research still refer to linear typologies with an inherent assumption that “the more participation, the better” (Neef and Neubert, 2011). Identifying a suitable level of participation will be more important in the current and growing interest in on-farm experimentation, living labs and other inclusive approaches. Neef and Neubert (2011) and Jackson-Smith and Veisi (2023) proposed frameworks with multiple dimensions of participation. For example, the typology of farmer participatory research proposed by Jackson-Smith and Veisi (2023) includes different types of goals (non-research-manipulative, functional-instrumental, functional-substantive, normative-empowerment) and methods (decision-making, timing, communication, representation, location). New frameworks are certainly needed to advance future R&D actions, but multidimensional frameworks with many attributes can be challenging for practical use and decision-making.

Currently, in the context of more holistic food system approaches, recognition of the complexity of farming systems’ and the spread of new digital tools, there is a resurgence of interest in on-farm research and participatory experimental approaches as a vehicle for agricultural transformation (Gardezi et al., 2024; Cascone et al., 2024; Snapp et al., 2023; Lacoste et al., 2022; Lawrence et al., 2007). More attention is being given to co-production and co-innovation (Gardeazabal et al., 2023; Ingram et al., 2020; Fielke et al., 2018). Participatory approaches are becoming more creative and inclusive, with examples of successful combinations of local and scientific knowledge (Šūmane et al., 2018; Neef and Neubert, 2011), and using participatory experimentation for precision agriculture (Gardezi et al., 2024). There is a rapidly growing interest in real-life experimentation by multiple stakeholders through ‘living labs’ (Cascone et al., 2024; Gardezi et al., 2024). More intensive use of new digital technologies, that are increasingly applied in ‘citizen science’, brings an innovative approach to a creative reshaping of participatory research (Occelli et al., 2024; Van De Gevel et al., 2020). This aims to produce new knowledge while increasing the public understanding of problems, and science in general. Digital interventions can foster participation and inclusivity (Steinke et al., 2024). New approaches are being developed, such as “tricot” (triadic comparisons of technologies) that apply participatory on-farm testing of new crop varieties supported by digital platforms such as ClimMob (Quirós et al., 2024).

It is also being recognised that participatory approaches can improve power relations and knowledge dynamics. Participatory techniques facilitate the inclusion of local knowledge and needs of vulnerable and marginalised groups (Van der Riet and Boettiger, 2009). Thus, a more inclusive innovation process ultimately empowers vulnerable communities, transforming them from mere beneficiaries to solution makers and innovation co-owners. Shaping innovations according to the needs of the vulnerable ones is also critical for improving the livelihood of those who need it most. It is known that agricultural innovations tend to benefit wealthier farmers, who are less affected by the risk associated with the innovation process and adoption (Gorman, 2018; Valbuena et al., 2015). There are known to be ‘early adopters’ who are the first to try and adopt the innovations (Rogers, 2003). Some studies indicate that only one-third of the population might be willing to test an innovation (Hammond et al., 2017) and that those should be identified and preferentially targeted by R&D programs. The overall adoption rates tried to be increased by targeting particular groups of farmers through farmer typologies but with limited success (Gorman, 2018). It has been suggested that more attention should be given to personal motivations and attitudes of different farmer typologies including the ones in lower wealth categories, however, there is not yet enough empirical evidence on the adoption outcomes (Hammond et al., 2017; Meijer et al., 2014; Gorman, 2018). Recently, new methods such as GenderUp has been developed for responsible and inclusive scaling of innovations (McGuire et al., 2024).

Although there is much literature on participatory research approaches and classifying specific types of participation in research, we identified a knowledge gap in terms of guidance for deciding a suitable level of participation across the agricultural innovation process (from design to testing and scaling). For example, new products or technologies are sometimes tested with or by farmers in their fields without adequate previous validation in a controlled environment and/or the local setting. In some places, especially in Africa, there is also an increasing number of unvalidated products and agricultural inputs with substantially lower quality than advertised (Ashour et al., 2019). All this can easily result in the failure of the technology in the local conditions, leading to the disappointment of farmers, waste of resources, and unlikely adoption in the future. In development-oriented projects, there is also a strong interest in promoting innovations for impact at scale, but project stakeholders and implementing partners are often uncertain about what level of farmer participation is appropriate in the scaling process and what participatory approaches to use. In this paper, we suggest that it is critical to choose an appropriate approach with a suitable level of participation, based on how ready the innovations are for application and scaling in the local setting (e.g., a higher level of farmer participation for more ready innovations, or lower level of farmer participation in case of less ready innovations).

The main objective of this paper is to provide practical guidance for researchers, development agents, and project managers on how to choose the right methodological approach with a suitable level of farmer participation for testing (research experiments) and scaling of agricultural innovations (technology demonstrations, dissemination, etc.) according to the levels of innovation readiness and use. Innovation readiness is the development stage of an innovation and how ready it is for scaling. And innovation use is the extent to which an innovation is already being used in society and by whom (Sartas et al., 2020). The proposed guidance can answer questions such as: What level of farmer participation is suitable for the testing and/or scaling of target agricultural innovation? What are the appropriate methodological approaches for participatory design, research and scaling?

After describing the background and introducing the guiding framework, examples are provided of how the guidance can be used, using case studies from projects on vegetable innovations in Asia and Africa. High-value crops such as vegetables are an opportunity for livelihood improvement, but they also require higher input, more management, and increased technological requirements that drive innovation (Nature Food Editorial, 2022; Wopereis et al., 2019). At the same time, engaging farmers in testing and scaling is important for experimental learning, inclusive testing, and peer-to-peer sharing. Working in this context shows the need to go beyond existing typologies of participatory research, towards a better understanding and integration of the readiness of particular innovations and choosing the right methodological approach with the suitable level of farmer participation. Although it is increasingly recognised that besides farmers, other stakeholders and citizens should be part of the innovation process, the proposed framework in this paper focuses on guiding the level of participation of farmers and researchers/experts based on the readiness of agricultural innovations.

2. Methods

First, we conducted a comprehensive review of pertinent scientific literature focusing on participatory design, research, development, and scaling of agricultural innovations. Literature was collected using Google Scholar and Scopus databases. The keywords to initiate a search query were: ‘participatory agricultural design,’ ‘participatory agricultural research,’ ‘on-farm research,’ ‘on-farm experiment,’ and ‘scaling agricultural innovation,’. Literature not related to agricultural innovations was excluded. The time range was not set considering the rich body of literature on participatory approaches since the 1980s. Excluding this work could result in losing relevant information and lessons learned. Subsequently, we compiled recent experiences and gathered lessons learned from the research and scaling of good agricultural practices and novel production technologies. These experiences were drawn from the selected agricultural projects implemented by the World Vegetable Center across Asia and Africa. Based on the insights gathered from the literature review and the compilation of lessons and experiences gained during the project implementation, we constructed a list of methodological approaches applicable to participatory testing (design and research) and scaling (demonstration and dissemination activities) of agricultural innovations with various levels of farmer participation. Thereafter, we developed a simple guiding framework for choosing an appropriate methodological approach with a suitable level of farmer participation according to the readiness and use of the innovation. To assess innovations' readiness and use, we linked up with the Scaling Readiness framework recently developed by CGIAR (Sartas et al., 2020). Finally, the proposed guidance and experiences with selected approaches are discussed through project case studies from different contexts in Asia and Africa. In this paper, the term 'farmer' includes broadly all kinds and sizes of agricultural producers, and the terms 'researcher' and 'expert' mean more broadly scientists, development experts, extensionists, private sector agents, and other expert stakeholders that can be part of the innovation process.

3. Getting familiar with the readiness and use of innovation to choose a suitable level of farmer participation in designing, testing and scaling of innovations

3.1. Assessment of the innovation according to its readiness and use

For a researcher or project manager to be able to make a good decision about a suitable level of farmer participation in the innovation process, the innovation needs to be first characterised and assessed for its level of readiness and level of use.[1] The characterisation of the innovation is beyond this paper. In brief, it can follow common frameworks such as the one by Rogers (2003), i.e., describing its advantages, complexity, compatibility, triability, and observability. The innovation readiness and use level can be assessed according to the Scaling Readiness framework developed by CGIAR (Sartas et al., 2020).

So what exactly is 'innovation readiness' and how to assess it? It refers to the demonstrated capacity of an innovation to achieve a specific result (Sartas et al., 2020). The readiness moves from basic and working models validated in a highly controlled setting (such as a laboratory or controlled experimental fields) to settings where the concept has fully matured and succeeds in uncontrolled environments. Following Sartas et al. (2020), innovation readiness is measured along 9 levels that range from an idea or hypothesis (Level 1) to innovation with low readiness for scaling (Levels 2–5: innovations have been tested or validated theoretically) to medium readiness for scaling (Levels 6–7: innovations are successfully tested in a controlled environment), to high readiness for scaling (Levels 8–9: innovations are proven to work in an uncontrolled environment) (Table 1).

'Innovation use' refers to the extent to which an innovation is already being used in a community and by whom (Sartas et al., 2020). Innovation use is also measured along nine levels that range from low use (Levels 1–3: core or complementary innovations are used only by project teams and their direct partners) to medium use (Levels 4–7: innovations are used by other projects and their partners), to high use (Levels 8–9: innovations are used by farmers and other end-users) (Table 2).

Innovation readiness can be assessed through the 9 levels in Table 1 and innovation use level can be diagnosed through the 9 levels in Table 2. For more details, follow Sartas et al. (2020), or use online Scaling Readiness calculators that can be used to diagnose your innovation or innovation package. The calculators use a series of questions to determine innovation readiness and use levels quickly. While Sartas

[1] Note that formulation or co-creation of new ideas and hypothesis for an innovation to meet specific objectives is part of the innovation readiness levels – level number 1 (Sartas et al., 2020)

Table 1
Levels of innovation readiness for its measurement (adopted from Sartas et al., 2020).

LEVEL OF READINESS	LEVEL NUMBER	LEVEL DESCRIPTION
Ready	9	Validated capacity of the innovation to meet specific objectives in an uncontrolled environment without support from an intervention
Incubation	8	Tested capacity of the innovation to meet specific objectives in an uncontrolled environment with support from an intervention
Proof of Application	7	Tested capacity of the innovation to meet specific objectives in an uncontrolled environment with support from an intervention
Working Application	6	Tested capacity of the innovation to meet specific objectives in a controlled environment
Working Model	5	Validated capacity of the innovation to meet specific objectives using applied science evidence
Formulating Working Model	4	Researched capacity of the innovation to meet specific objectives using applied science evidence
Basic Model	3	Validated principles that the innovation can meet specific objectives using basic science evidence
Basic Research	2	Validated hypothesis that the innovation can meet specific objectives using basic science evidence
Idea/Hypothesis	1	Formulated idea or hypothesis for an innovation to meet a specific objective for intended users

Table 2
Levels of innovation use for its measurement (adopted from Sartas et al., 2020).

LEVEL OF USE	LEVEL NUMBER	LEVEL DESCRIPTION
Livelihood system (common)	9	The innovation is commonly used by intended end-users who had nothing to do with the innovation development or the intervention project
Livelihood system (rare)	8	The innovation is used by some intended end-users who had nothing to do with the innovation development or the intervention
Innovation system (common)	7	The innovation is commonly used by organisations or individuals who work on the innovation in similar geographies or sectors but are not directly connected to the intervention partners
Innovation system (rare)	6	The innovation is used by some organisations or individuals who work on the innovation in similar geographies or sectors but are not directly connected to the intervention partners
Innovation network (common)	5	The innovation is commonly used by organisations or individuals who are not formally involved in the project but are connected to intervention partners
Innovation network (rare)	4	The innovation is used by some organisations or individuals who are not formally involved in the intervention but are connected to intervention partners
Project partners	3	The innovation is used by the intervention or project teams and the direct partners that were involved in the development of the project and receive funding from the intervention project
Project team	2	The innovation is used only by the intervention or project team
Project leaders	1	The innovation is not yet used by the intervention or project team but is embraced by project leaders

et al. (2020) has designed the Scaling Readiness framework mainly to inform scaling strategies to achieve impact, in this paper, we adopt and integrate the assessment of innovation readiness and use levels (‘Diagnose’ section starting on page 42 in Sartas et al., 2020) in order to match a suitable level of farmer participation for more inclusive design, testing and scaling of agricultural innovations. In a project, there is typically more than one target innovation (often a package), hence the levels of readiness and use should be assessed for each of the innovations, and the level of farmer participation can vary among the innovations.

According to Sartas et al. (2020), research articles, data, reports, or other evidence must be provided to validate the level of innovation readiness in a specific context. As an example of providing evidence, World Vegetable Center has developed and validated various integrated pest management (IPM) packages, e.g., IPM packages against the major insect pests of yard-long bean and Chinese mustard in Cambodia (Srinivasan et al., 2019; Srinivasan et al., 2020). Through researcher-managed multi-location on-station and on-farm trials during 2015–2018, it was confirmed that the performance of the IPM package was on par with farmers’ practice of calendar-based pesticide application in reducing the damages by target pests, leading to significant yield gains (Srinivasan et al., 2019; Srinivasan et al., 2020). On the readiness scale, this innovation could be considered ‘incubation’ – a highly ready innovation (level 8) with tested capacity to meet specific objectives in an uncontrolled environment with support from an intervention. At the time of the project, this innovation’s use level was rather low as it was used only by the project team (level 2).

It should be noted that besides readiness and use, innovations are embedded in innovation systems, which are interrelated landscapes of stakeholders, social networks, markets, and existing innovations that form the enabling or disabling environment (Sartas et al., 2020; Aerni et al., 2015). Hence, the wider innovation systems should be considered when studying and scaling new innovations.

- RECOMMENDED STEP 1: Assess the readiness and use level of the target innovation.

3.2. *Participatory approaches for designing, testing and scaling of agricultural innovations*

According to Lilja and Ashby (1999), the technology innovation process can be divided into three main stages: 1) the Design stage; 2) the Testing stage; 3) and the Diffusion stage (see Box 1). This represents a simplified overview of the innovation process, although it may not necessarily be a linear process, and there can be more specific sub-steps or more stages.

For practicality, we follow the 3-stage innovation process proposed by Lilja and Ashby (1999), however, to be better aligned with more comprehensive scaling approaches (Breaugh et al., 2021) and the Scaling Readiness framework (Sartas et al., 2020), the last stage of the innovation process is changed from ‘Diffusion stage’ to ‘Scaling stage’. Hence, three stages of the innovation process we follow are: The Design stage; The Testing stage; and the Scaling stage. See Breaugh et al. (2021) for more details on the differences between diffusion and scaling. In brief, scaling is a more proactive approach to spreading of innovations purposively driven by strategic actors.

Below in Table 3, we listed a wide range of methodological approaches that can be used in participatory designing, testing, and scaling of agriculture innovations with different levels of farmer participation. First, participatory approaches are grouped according to the stages of the innovation process as given in Box 1 (i.e., Design stage, Testing stage, and Scaling stage). Second, based on the earlier work (e.g., Selener, 2005; Johnson et al., 2003) combined with our practical project experiences, the approaches were classified according to the following criteria – the level of management/decision-making exercised by researchers and farmers and the location of the intervention, when applicable. Third, we overview the key characteristics and purpose of each approach. Although there can be more criteria, we consider these aspects the most relevant specifications that can be applied in the research and development projects involving farmers in designing, testing, and scaling of agricultural innovations. However, see other possible criteria and dimensions (Jackson-Smith and Veisi, 2023; Neef and Neubert, 2011; Probst et al., 2003). In the earlier frameworks, decision-making between researchers and farmers was the most common criterion. Those frameworks (Johnson et al., 2003; Lilja and Ashby, 1999) distinguished five types of decision-making (conventional, consultative, collaborative, collegial, and farmer independent experimentation). Based on our practical experience from various projects, we first follow a simplified typology which distinguishes approaches into three main types of management (researcher-managed; research and farmer co-managed; and farmer-managed), and two types of locations (on-station; and on-farm). Through this typology, we organise the approaches in the left column of Table 3, which results in a balanced number of approaches. To not hide details on power dynamics between farmers and experts, each approach is characterised by whether it is designed or implemented conventionally, consultatively, collaboratively, collegially or independently (middle column of Table 3).

It is important to note that the participatory approaches in Table 3 are better suited to “core innovations” that can be applied in farming (e.g., new agricultural inputs, farming practices, technologies, etc.) rather than “complementary innovations” (e.g., innovation platforms, stakeholder networks, market outlets, policies and laws, etc.) which relate to the broader innovation landscape and enabling the environment for the core innovations to achieve impact at scale (Sartas et al., 2020; Rijsberman and Atta-Krah, 2016). Various complementary innovations can be participatory due to their social nature, this however goes beyond the scope of approaches for core innovations in this paper.

The approaches in Table 3 are kept at a generic level for more universal guidance on the level of farmer participation. Each approach can take a more specific form and process in different projects depending on

Box 1
The innovation process can be divided into three main stages (adopted and modified from Lilja and Ashby, 1999 while replacing Diffusion stage with Scaling stage):

The **Design stage** is when problems and opportunities for research are identified and prioritised, and potential solutions are proposed. At this stage, decisions are made about which innovations to test, variables or outcomes to monitor, and under which conditions, where and by whom the solutions will be tested.

The **Testing stage** is when potential solutions and innovations are tested. It includes implementing fieldwork, collecting data and monitoring progress, interpreting the data and findings, and recommending solutions to diffuse at scale.

The **Scaling stage** follows when solutions are tested, validated and ready to be scaled. It includes planned activities that enable the uptake and use of innovations to positively impact many people across broader communities and geographies.

Table 3
A list of approaches for participatory design, testing, and scaling of agricultural innovations based on the level of farmer* decision-making, key characteristics and purpose of the approach.

APPROACH ACCORDING TO THE INNOVATION STAGE	KEY CHARACTERISTICS OF THE APPROACH	PURPOSE OF THE APPROACH
1. RESEARCH DESIGN (DESIGN STAGE)	**KEY CHARACTERISTICS**	**PURPOSE**
Researcher-designed innovations/research questions and research plan for a formal experiment	Standard research design for an experiment in a controlled environment designed conventionally by researchers.	To generate data and evidence.
Researcher and farmer co-designed research questions and research plan for formal or informal experiment	Standard or simplified research design for an experiment in a controlled or uncontrolled environment co-designed consultatively or collaboratively by researchers and farmers.	To generate data and evidence or to test and adapt innovations.
Farmer-designed research questions and research plan for informal experiment with support from researchers	Simplified and flexible design for an experiment in an uncontrolled environment designed collegially or independently by farmers supported by researchers.	To test or adapt innovations.
2. RESEARCH (TESTING STAGE)	**KEY CHARACTERISTICS**	**PURPOSE**
Researcher-managed on-station experiments	On-station experiments managed conventionally by researchers without farmer participation or only as labour.	The purpose is to generate data and evidence of how innovations work in a controlled environment.
Researcher-managed on-station experiments with inputs/feedback from farmers	On-station experiments managed consultatively by researchers, where farmers are invited to observe, discuss, or qualitatively assess the tested innovations through visits or field days.	The purpose is to generate data and evidence of how innovations work in a controlled environment, with qualitative data and feedback from farmers.
Researcher-managed on-farm experiments in farmers' fields (or project partners' fields)	On-farm experiments managed consultatively by researchers in arranged farmers' or partners' fields in the local context. This typically involves observations from farmers, but the main purpose is to generate data and evidence of how innovations work in a local environment.	The main purpose is to generate data and evidence of how innovations work in a local environment.
Researcher and farmer co-managed mother-baby trials (with larger mother trials managed by researchers on-station/in farmers' fields and smaller baby trials implemented by farmers in their fields)	On-farm mother trial (experimental design with multiple treatments in replicated plots) is managed conventionally or consultatively by researchers in farmers' or partners' fields in the local context. Baby trials with 2–4 treatments chosen from the mother trial by farmers are implemented simultaneously near the mother trial in a collaborative or collegial manner.	While the purpose of the mother trial is to generate scientific data and evidence, the baby trials allow for farmer experimentation and technology adaptation.
Researcher and farmer co-managed on-farm collaborative experiments	On-farm experiments managed jointly and collaboratively by researchers and farmers. There is an organised communication, and preferences and observations of both sides are considered. Decisions are made together.	There tends to be a dual purpose to generate data and evidence while enhancing farmer learning and experiencing innovations.
Researcher and farmer co-managed living labs (more research-oriented)	On-farm experimental space or territory-bound places where farmers, local stakeholders, and researchers test, evaluate, and co-create innovations in a consultative or collaborative manner. It puts stakeholders at the centre of the process, and it generates data according to the needs of stakeholders.	This type of living lab is more research-oriented and focused on testing innovations.
Farmer-managed on-farm experiments with the primary goal of technology adaptation and adoption (a hybrid approach transitioning from testing to scaling)	On-farm fully participatory and flexible experiments implemented collegially or independently by farmers supported by researchers.	The purpose is to enable farmers to experience, adapt, and adopt ready innovations.
3. TECHNOLOGY DEMONSTRATION (SCALING STAGE)	**KEY CHARACTERISTICS**	**PURPOSE**
Researcher-managed on-station demonstrations with farmer observation	On-station demonstrations of innovation managed conventionally by researchers. The scale of reach depends mainly on how many farmers can visit the research station.	The main purpose is to demonstrate how innovations work in the controlled environment of the research station.
Researcher-managed on-farm demonstrations in farmers' fields (or project partners' fields)	On-farm demonstrations of innovation managed conventionally or consultatively by researchers. The scale of reach depends mainly on the location and number of demonstrations and field days.	The purpose is to demonstrate how innovations work when managed by researchers in farmers' fields.
Farmer and researcher co-managed on-farm demonstrations in farmers' fields	On-farm demonstrations of innovation managed collaboratively by farmers and researchers. The scale of reach depends mainly on the location and number of demonstrations and field days.	The purpose is to demonstrate how innovations work when managed by farmers in their fields with support from researchers.
Farmer and researcher co-managed testbeds/living labs (more scaling-oriented)	On-farm or territory-bound demonstrations where farmers, stakeholders, and researchers demonstrate co-created innovations in a collaborative or collegial manner. This type of testbed or living lab is focused on the dissemination of innovations when the environment is enabled. The dissemination is led by farmers with support from various stakeholders. The scale of reach depends mainly on the location and size of the living labs.	The purpose is to demonstrate how innovations work when managed by farmers and stakeholders in their fields or territories.
Farmer-managed demonstrations in farmers' fields	On-farm fully participatory demonstrations managed collegially or independently by farmers in their fields. This type of demonstration is suitable for innovations with high levels of readiness. The scale of reach depends mainly on the location and number of demonstrations and field days.	The purpose is to demonstrate how innovations work when fully managed by farmers in their fields.
4. DISSEMINATION AND SCALING (SCALING STAGE)	**KEY CHARACTERISTICS**	**PURPOSE**
Dissemination and scaling activities by experts to farmers	More vertical, institutiona,l and conventional dissemination of innovations by experts (e.g., extensionists, researchers, private sector) to farmers through communication, advisory, training, courses, digital tools, strengthening supply channels etc. An example is the expansion of the innovation promotion from a farmer organisation to a national extension	The purpose is to disseminate knowledge and scale up innovations to a high number of farmers in a more linear and structured way.

(*continued on next page*)

Table 3 (*continued*)

APPROACH ACCORDING TO THE INNOVATION STAGE	KEY CHARACTERISTICS OF THE APPROACH	PURPOSE OF THE APPROACH
	system (scaling up). Although usually less participatory, the higher the institutional level, the greater the chance for higher reach and horizontal scale out.	
Dissemination and scaling activities by farmers supported by experts to other farmers	More horizontal, guided, and collaborative dissemination of innovations by trained farmers or farmer groups/networks supported by experts to other farmers and communities (scaling out). This can be done by communication, advisory, training, farm visits, farmer field schools, innovation networks, etc. The trained farmers are supported or complemented by experts and/or digital tools. A more participatory approach, with the scale of reach depending mainly on the motivation of trained farmers and the extent of support by experts.	The purpose is to disseminate knowledge and scale out innovations in a more participatory but supported and proactive way.
Dissemination and scaling activities by farmers to farmers	Highly horizontal, spontaneous, and independent dissemination of innovations by innovative farmers to other farmers and communities (scaling out). This is done by more informal communication, farm observations, peer-to-peer learning, etc. A highly participatory and spontaneous approach, with the scale of reach depending mainly on the motivation and openness of the innovative farmers.	The purpose is to disseminate knowledge and scale out innovations in a more participatory and spontaneous way.

* Note: the term 'farmer' includes all types and sizes of producers, and the terms 'researcher' and 'expert' can mean scientists, development experts, private sector innovators, governmental extensionists, etc.

the context and need. For example, co-designing innovations might be a more complex consultative process with several phases (Andrieu et al., 2019). Also designing better on-farm research itself may require specific planning (Lawrence et al., 2007). Participatory action research can serve as step-by-step guidance from co-identifying problems to testing and sharing their solutions (Snapp et al., 2023). Also, the dissemination and scaling activities are kept very generic Table 3, but they can take various forms and methods which is beyond the scope of this paper to cover these in detail (for instance, dissemination and scaling of innovation physically in the field or online extension services through digital tools). The training and knowledge transfer are often linked with demonstrations and field days mentioned in Table 3. It is acknowledged that capacity development and outreach activities are critically important for dissemination and scaling. For capacity building related to innovations, see the Common Framework on Capacity Development for Agricultural Innovation Systems (Tropical Agriculture Platform, 2016), and for participatory outreach to support innovation, refer to Morrone (2017). In addition, an initial assessment of the needs and capacities of farmers should be considered before the start of any innovation process.

It should be mentioned that different levels of farmer participation at different stages of the innovation process will lead to different results (Johnson et al., 2003). Stronger participation at the design stage can influence overall prioritisation and co-design of innovations to be tested. Including farmers at this beginning might be challenging due to typically short project proposal timelines, but it could enhance farmers' ownership of the innovation process. Participatory research at the testing stage can help identify the best innovation from a prioritised set of solutions to a given problem while giving practical experience to the participants and increasing their capacity to identify solutions (Probst et al., 2003). If farmers gain training in the design, implementation, and evaluation of experiments, their capacity for innovation can be substantially increased. At the scaling stage, farmer participation can result in a more authentic, dynamic and successful scaling of innovations (Johnson et al., 2003).

- RECOMMENDED STEP 2: Get acquainted with the range of participatory approaches for designing, testing and scaling agricultural innovations.

3.3. Introduction of the guidance to help choose an appropriate approach with a suitable level of farmer participation for designing, testing and scaling of agricultural innovations

After assessing both the levels of innovation readiness and use in Step 1, you will be more familiar with the development status of your innovation. After Step 2, you should be acquainted with the range of approaches for participatory design, testing and scaling of agricultural innovations. Now, in Step 3, you should be ready to use the developed decision-making guidance below (Fig. 1). Fig. 1 supports deciding on an appropriate approach with a suitable level of farmer participation in designing, testing and scaling agricultural innovations.

The particular approaches in Fig. 1 are allocated according to the innovation's level of readiness from low to high (direction from up to down) and level of use from low to high (direction from left to right). Regarding the stages of the innovation process (design, testing, and scaling), we can see a pattern in the recommendations of approaches linked to innovation readiness and use. When both readiness and use are low, it is time for a design of research (in grey). When the innovation readiness and use progress to around medium, recommendations move to various experiments (in orange). When readiness and use reach medium-high levels, demonstrations are recommended (in green), followed by further dissemination and scaling activities (in blue) in case of highly ready innovations.

In terms of farmer participation, generally, there is a trend of increasing participation with higher levels of technology readiness and use. Based on our experience, it there is a lower risk of failure when

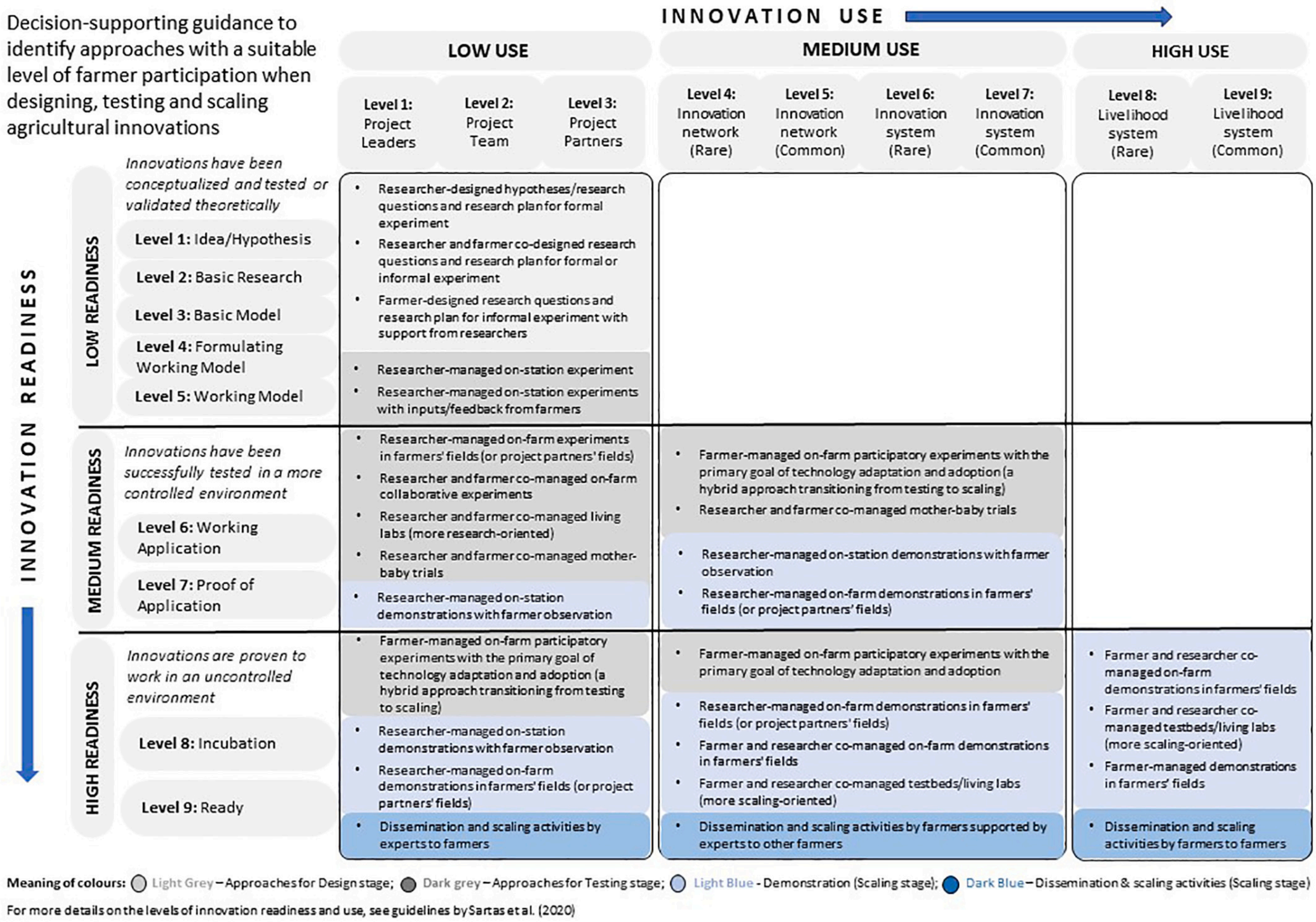


Fig. 1. Decision-supporting guidance to identify approaches with a suitable level of farmer participation when designing, testing and scaling innovations.

applying a less participatory approach recommended for innovations with lower readiness levels and use to innovations with higher readiness and use. On the contrary, there is a higher risk of failure when a more participatory approach recommended for innovations with higher readiness and use is applied to innovations with lower readiness and use. For example, while *researcher-managed demonstrations on-station with farmer observation* are recommended mainly for the technologies with medium levels of readiness and use, the same approach can also be applied to innovations with high levels of readiness and use. For instance, if a new biodegradable mulch is proven to work in an uncontrolled environment of local field conditions and some pioneer farmers are already using it, it is recommended to opt for *farmer-managed demonstrations in farmers' fields.* Nevertheless, using *researcher-managed on-station demonstrations with farmer observation* or other approaches is possible; it would just result in a lower extent of participation in the scaling of that innovation.

On the other hand, application of an approach which is recommended only for innovations with high levels of readiness and use such as *farmer-managed demonstrations in farmers' fields* could result in a high chance of failure/problems if deployed on new innovations with low levels of readiness and use. For instance, if a new crop variety is not proven to work in an uncontrolled environment in local conditions, it is risky to collaborate with farmers and ask them to demonstrate and promote new varieties in their fields. There might be a high chance of challenges and disappointment for the farmers, who will likely lose trust and interest in testing and adopting a similar innovation.

It should be noted that in projects targeting communities, there are commonly more innovations. Thus, different approaches can be applied to different innovations according to their readiness. In longer projects, there can be dynamic changes and switches between approaches as the innovation readiness progresses (for example, from Proof of Application - Level 7 to Ready Innovation - Level 9).

- RECOMMENDED STEP 3: Follow the guiding Fig. 1 to assist with choosing the appropriate approach with a suitable level of participation in designing, testing and/or scaling of innovations.

Overview of three steps to support the choice of suitable approach and participation level:

Step 1: Assess the level of innovation readiness and use.

Step 2: Get familiar with the methodological approaches for participatory design, testing, and scaling of agricultural technologies.

Step 3: Choose the appropriate methodological approach with a suitable level of participation in the design, testing, and scaling of innovations according to the innovation's readiness and use.

4. Examples of application of selected approaches and guiding framework on project case studies

4.1. Case study 1: Greener Greens project in Kenya where agroecological approaches to vegetable production were tested through participatory on-farm trials and scaled out through training, business networks and supply channel linkages

The Biovision Foundation-funded Greener Greens project was implemented from 2021 to 2024 in Murang'a County in Kenya by

WorldVeg and SNV. At the beginning of the project, several agroecological practices and inputs were found of generally high readiness but low to medium level of use (such as biopesticides and organic fertilisers) through Step 1. Therefore, after considering different approaches through Step 2 and matching them with the innovation readiness and use levels through Step 3, *Researcher and farmer co-managed on-farm collaborative experiments*, where individual farmers in their fields compare agroecological and conventional treatments to test selected biopesticides and organic fertilisers were implemented. These experiments had a dual purpose: to generate evidence and to drive farmer learning, experiencing, and adopting agroecological approaches to reduce the use of chemical inputs. Parallel to the experiments (where core innovations were studied), the project established complementary innovations – vegetable business networks (VBNs), groups of producers, service providers, traders and other value chain stakeholders to strengthen their capacity and scale out agroecological practices. Each VBN has a local business coach, and training on agroecological and regenerative production practices was delivered to VBN members (*Dissemination and scaling activities by experts to farmers*). The innovations and approaches applied in the Greener Greens project can be seen projected in the developed guiding framework (Fig. 2). The linkages with markets and supply channels have also been established, although with limited success due to the small scale nature of the vegetable producers. As the agroecological approaches performed well in most cases in terms of productivity and profitability (manuscript in development), the participating farmers have been expanding the land area under agroecological approaches, including application on other crops. Some of the learnings are that researcher and farmer co-managed experiments with dual purposes can be challenging, as the scientific principles often do not adhere to the need for more flexible testing and adaptation by the farmer. For example, it was challenging to maintain conventional control plots in some cases, as farmers wanted to scale proven agroecological practices to the control plots in their fields. Also, repeating the trials with the same crops (repetition to get robust data) was less preferred by some farmers who wanted to try the solution on other crops. The final lesson from testing and scaling of agroecological inputs was that it is better to focus on fewer practices and start from 'more known to less known' for better adoption.

4.2. *Case study 2: Resilient cities CGIAR initiative, where new urban gardening technologies are tested and promoted through mother-baby trials on rooftops in Dhaka, Bangladesh*

Within the Resilient Cities CGIAR Initiative, WorldVeg and Bangladesh Agricultural University are since 2022 identifying affordable, innovative urban gardening technologies in Dhaka. In this experiment, simplified urban gardening technologies (aquaponics, NFT hydroponics, Kratky system hydroponics, geo bags, sack bags, and traditional pots) that have already been studied in the on-station conditions are currently being tested on the rooftop of a building in Dhaka. Through Step 1, most of the technologies were assessed to be of medium readiness and low use. Thus, in the first crop cycle, these technologies were initially tested through *Researcher-managed on-farm experiments in project partners' fields* an approach identified by Step 2 (Table 3) and matched through Step 3 (Fig. 1). After the testing and learnings from the first crop cycle and advancing the level of technologies readiness, the experiment has expanded into *Researcher and farmer co-managed mother-baby trials*, where the main mother trial continued to be managed by researchers to generate scientific evidence, and the smaller baby trials started to be implemented by individual farmers in their rooftops to test,

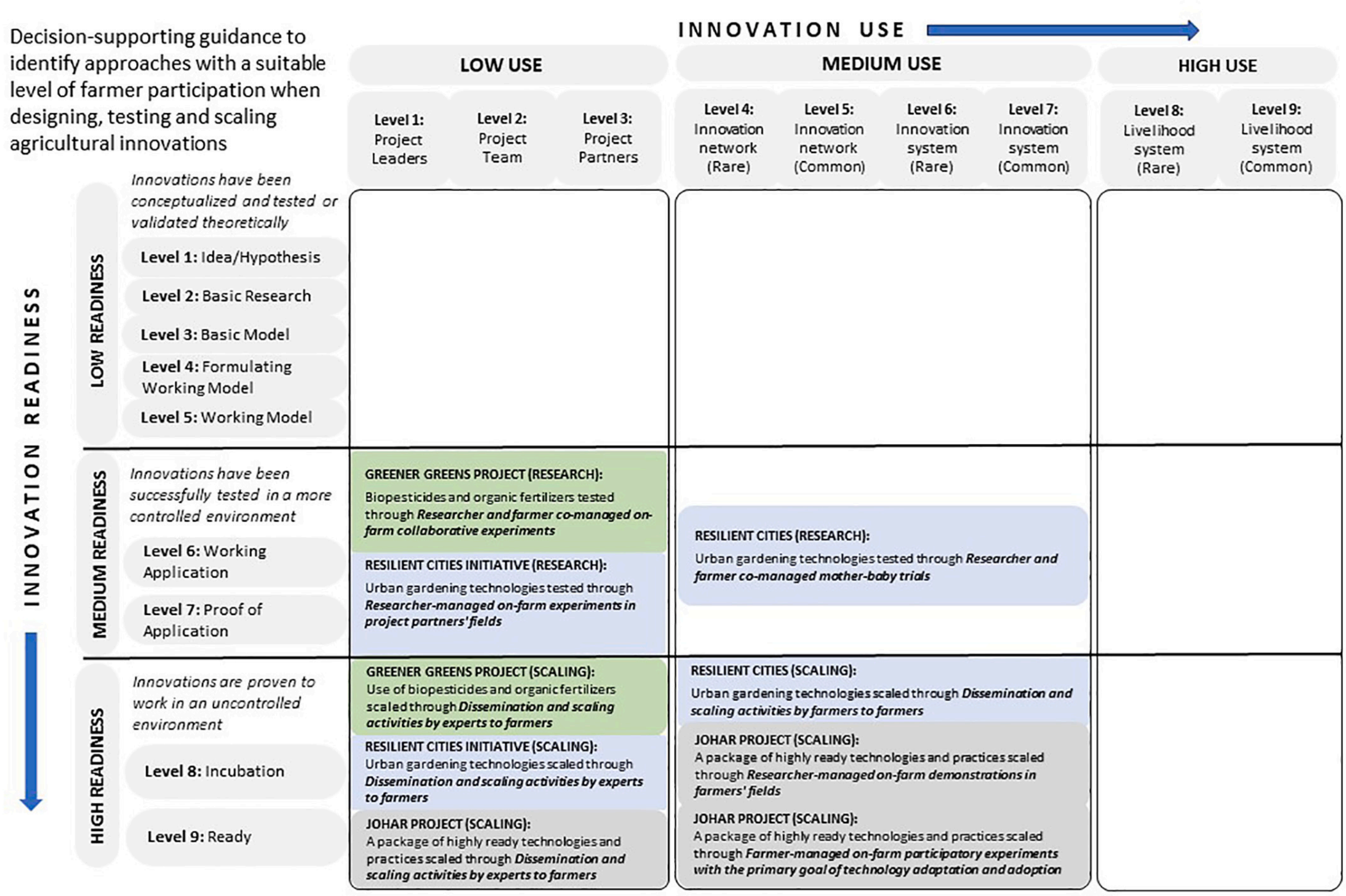


Fig. 2. Visualisation of approaches applied in three project case studies for testing and scaling of selected agricultural innovations.

adapt and disseminate the best-performing technologies in a participatory way. The technologies were promoted through *Dissemination and scaling activities by experts to farmers,* as expert-led training on technologies was organised. It was then expected that the farmers involved in baby trials would promote the best-performing technologies more spontaneously through *Dissemination and scaling activities by farmers to farmers.* This was confirmed by field observations and discussions with the participating households which invited their family members, neighbours, and classmates to visit their trial. The mother-baby trial proved to be a useful approach for balancing the need for robust data and enabling farmers to test and adapt the technologies according to their needs. However, the expansion of the technologies from the main (mother) trial to farmer (baby) trials had significant cost implications while not necessarily generating comparable and secured data. This indicates the importance of considering purpose when choosing the right approach (Table 3). The application of mother-baby trials and projecting this approach on the proposed framework (Fig. 2) demonstrated that the proposed approaches may not be necessarily applied in a linear way with increasing readiness and use of innovations as visualised in the framework (Fig. 1). There can be for instance a more spontaneous scaling of innovations from farmers to farmers even when the innovations are not fully ready or used.

4.3. Case study 3: Jharkhand opportunities for harnessing rural growth (JOHAR) project in India where ready technologies were scaled through field demonstrations, adoption experiments, and training

WorldVeg and the National Extension System, implemented a Jharkhand Opportunities for Harnessing Rural Growth Project (JOHAR) in Jharkhand state, India, from 2018 to 2022, which was funded by a loan from the World Bank. In this more development-oriented project, a package of highly ready technologies and practices (such as good crop management practices, validated IPM packages, water-saving techniques, nursery management, and good postharvest practices) were selected after confirming their high readiness and use through Step 1; hence no testing through research experiments was conducted. Three approaches for dissemination and scaling of technologies were selected through Step 2 (Table 3) and Step 3 (Fig. 1) as follows: 1) *Researcher-managed on-farm demonstrations in farmers' fields*; 2) *Farmer-managed on-farm experiments with the primary goal of technology adaptation and adoption*; and 3) *Dissemination activities by experts to farmers*. The innovations and approaches applied in the JOHAR project can be seen projected in the developed guiding framework (Fig. 2). First, the researcher-managed demonstrations in farmers' fields efficiently reached many farmers and local stakeholders. Second, farmers implemented and managed participatory experiments in their fields, and they were regularly monitored by experts from the WorldVeg. This approach proved highly useful for experiencing new technologies through on-farm experiments. Any changes needed to adapt the technologies to suit local conditions were quickly made due to the full participation of farmers. Third, training materials and wider digital reach out through WhatsApp groups supported the training, communication and dissemination activities. While all the approaches worked well, the main shortcomings were the innovation system, namely in the limited availability and capacity of the national extension system to promote new technologies, and the limited availability of affordable, quality inputs such as sticky and pheromone traps, as input suppliers were not well-connected to farmers, and the national extension system could not address this issue. This lesson reflects the importance of building conducive environment for scaling innovation and the need to move from transfer of technologies to more comprehensive innovation packages (Sartas et al., 2020) and systemic approaches to scaling (Wigboldus et al., 2016; Klerkx et al., 2012).

5. Conclusions and recommendations

The guidance in this paper aims to promote more inclusive and efficient design, testing, and scaling of agricultural innovations by supporting decision-making on a suitable level of farmer participation. It does not encourage a linear approach of 'the more participation, the better', instead, it recommends choosing the right level of participation based on innovation readiness and use levels. For example, new innovations should first be properly tested and validated in a controlled environment. Strengthening farmer participation is generally more suitable when innovations work well in controlled conditions and thus reach a higher level of readiness. However, farmer consultation in the early design stage should be strengthened, as co-designing of new ideas and innovations is often limited and still not common. This paper does not propose a new typology of participatory approaches but provides a complementary overview of easily classifiable and diverse options of approaches for farmer participation according to innovation readiness which has been overlooked in earlier frameworks. Future frameworks should expand the scope of recommending participation levels from farmers and experts to other stakeholders, though it is expected that the participation level of other stakeholders would generally also increase with the increasing level of innovation readiness and use. Efforts should also be made to recommend participation approaches for particular groups/types of farmers based on matching innovation readiness and use with the different typologies of farmers. Furthermore, making participation in innovation processes more gender responsive could better address gender and social inequalities. Apart from the focus on design, testing and scaling of core (more technical) innovations, it will be important to better understand and navigate the dynamics of participation in complementary (more social) innovations while considering complex interactions in the innovation systems. To enable the deployment of more inclusive innovations through advancing participation, donors should recognise the need for longer proposal and project timeframes that allow for more meaningful collaboration with local communities through consultations and co-production processes starting early at the innovation design stage. Agronomists and technical researchers also need to be better trained in social and participatory approaches and in understanding innovation systems. It is essential to recognise that farmers are innovators on their own, and that they support local and spontaneous innovation processes. Future research should develop an understanding and frameworks that better suit and leverage local agricultural innovations. Lessons and guidance in this paper will be useful to various scholars, researchers, development agents, and project managers when designing, testing and scaling agricultural innovations in a more participatory and inclusive way.

CRediT authorship contribution statement

Lukas Pawera: Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Ravishankar Manickam:** Conceptualization, Writing – original draft. **Carolyne Wangungu:** Conceptualization, Writing – original draft. **Uon Bonnarith:** Writing – original draft. **Pepijn Schreinemachers:** Conceptualization, Writing – review & editing. **Srinivasan Ramasamy:** Conceptualization, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Acknowledgement

We thank the long-term strategic donors to the World Vegetable Center for their support: the governments of Taiwan, the UK Foreign, Commonwealth and Development Office (FCDO), the United States Agency for International Development (USAID), the Australian Centre for International Agricultural Research (ACIAR), and the governments of Germany, Thailand, Philippines, Korea, and Japan. We also acknowledge funding for the projects used as case studies: the Biovision Foundation, the World Bank and donors of the CGIAR Research Initiative on Resilient Cities Through Sustainable Urban and Peri-urban Agri-food Systems funded by contributors to the CGIAR Trust Fund (https://www.cgiar.org/funders). We thank Nick Pasiecznik for editing the manuscript. CGIAR Independent Science for Development Council is greatly acknowledged for supporting open access of this article.

References

Aerni, P., Nichterlein, K., Rudgard, S., Sonnino, A., 2015. Making agricultural innovation systems (AIS) work for development in tropical countries. Sustainability 7, 831–850. https://doi.org/10.3390/su7010831.

Andrieu, N., Howland, F., Acosta-Alba, I., Le Coq, J.F., Osorio-Garcia, A.M., Martinez-Baron, D., et al., 2019. Co-designing climate-smart farming systems with local stakeholders: a methodological framework for achieving large-scale change. Front. Sustain. Food Syst. 3, 37. https://doi.org/10.3389/fsufs.2019.00037.

Ashour, M., Gilligan, D.O., Hoel, J.B., Karachiwalla, N.I., 2019. Do beliefs about herbicide quality correspond with actual quality in local markets? Evidence from Uganda. J. Dev. Stud. 55 (6), 1285–1306. https://doi.org/10.1080/00220388.2018.1464143.

Bentley, J.W., 1994. Facts, fantasies, and failures of farmer participatory research. Agric. Hum. Values 11, 140–150. https://doi.org/10.1007/BF01530454.

Breaugh, J., McBride, K., Kleinaltenkamp, M., Hammerschmid, G., 2021. Beyond diffusion: a systematic literature review of innovation scaling. Sustainability 13 (24), 13528. https://doi.org/10.3390/su132413528.

Cascone, G., Scuderi, A., Guarnaccia, P., Timpanaro, G., 2024. Promoting innovations in agriculture: living labs in the development of rural areas. J. Clean. Prod. 141247 https://doi.org/10.1016/j.jclepro.2024.141247.

Chambers, R., 1983. Rural Development: Putting the Last First (Volume 198). Longman, London.

Curry, G.N., Nake, S., Koczberski, G., Oswald, M., Rafflegeau, S., Lummani, J., Nailina, R., 2021. Disruptive innovation in agriculture: socio-cultural factors in technology adoption in the developing world. J. Rural. Stud. 88, 422–431. https://doi.org/10.1016/j.jrurstud.2021.07.022.

Duraiappah, A.K., Roddy, P., Parry, J.E., 2005. Have Participatory Approaches Increased Capabilities? International Institute for Sustainable Development, Winnipeg.

FAO, 2018. The International Symposium on Agricultural Innovation for Family Farmers. Food and Agriculture Organization of the United Nations, Rome. http://www.fao.org/about/meetings/agricultural-innovation-family-farmers-symposium/about/en (accessed 15 October 2023).

Fielke, S.J., Botha, N., Reid, J., Gray, D., Blackett, P., Park, N., Williams, T., 2018. Lessons for co-innovation in agricultural innovation systems: a multiple case study analysis and a conceptual model. J. Agric. Educ. Ext. 24 (1), 9–27. https://doi.org/10.1080/1389224X.2017.1394885.

Gardeazabal, A., Lunt, T., Jahn, M.M., Verhulst, N., Hellin, J., Govaerts, B., 2023. Knowledge management for innovation in Agri-food systems: a conceptual framework. Knowl. Manag. Res. Pract. 21 (2), 303–315. https://doi.org/10.1080/14778238.2021.1884010.

Gardezi, M., Abuayyash, H., Adler, P.R., Alvez, J.P., Anjum, R., Badireddy, A.R., Zia, A., 2024. The role of living labs in cultivating inclusive and responsible innovation in precision agriculture. Agric. Syst. 216, 103908. https://doi.org/10.1016/j.agsy.2024.103908.

Gorman, L., 2018. Improving the Efficiency of Agricultural Development: Can Farmer Typologies Be Used to Predict the Adoption of Agricultural Innovations for the Poorest Farmers, and Therefore, Increase the Impact of Rural Development Programs on the Rural Poor? MSc in International Development in the Faculty of Social Sciences and law. University of Bristol, Bristol, UK.

Hammond, J., van Wijk, M.T., Smajgl, A., Ward, J., Pagella, T., Xu, J., Harrison, R.D., 2017. Farm types and farmer motivations to adapt: implications for design of sustainable agricultural interventions in the rubber plantations of south West China. Agric. Syst. 154, 1–12. https://doi.org/10.1016/j.agsy.2017.02.009.

Hellin, J., Camacho, C., 2017. Agricultural research organisations' role in the emergence of agricultural innovation systems. Dev. Pract. 27 (1), 111–115. https://doi.org/10.1080/09614524.2017.1256373.

Hoffmann, V., Probst, K., Christinck, A., 2007. Farmers and researchers: How can collaborative advantages be created in participatory research and technology development? Agric. Human Values 24, 355–368. https://doi.org/10.1007/s10460-007-9072-2.

Ingram, J., Gaskell, P., Mills, J., Dwyer, J., 2020. How do we enact co-innovation with stakeholders in agricultural research projects? Managing the complex interplay between contextual and facilitation processes. J. Rural. Stud. 78, 65–77. https://doi.org/10.1016/j.jrurstud.2020.06.003.

Jackson-Smith, D., Veisi, H., 2023. A typology to guide design and assessment of participatory farming research projects. Socio Ecol. Pract. Res. 1–16. https://doi.org/10.1007/s42532-023-00149-7.

Johnson, N., Lilja, N., Ashby, J., 2003. Measuring the impact of user participation in agricultural and natural resource management research. Agric. Syst. 78, 287–306. https://doi.org/10.1016/S0308-521X(03)00130-6.

Johnson, N., Lilja, N., Ashby, J.A., Garcia, J.A., 2004. The Practice of Participatory Research and Gender Analysis in Natural Resource Management. In: Natural Resources Forum (Vol. 28, No. 3, Pp. 189–200). Blackwell Publishing Ltd, Oxford, UK. https://doi.org/10.1111/j.1477-8947.2004.00088.x.

Kirimi, F.K., Onyari, C.N., Njeru, L.K., Mogaka, H.R., 2023. Effect of on-farm testing on adoption of banana production technologies among smallholder farmers in Meru region, Kenya. J. Agribus. Dev. Emerg. Econ. 13 (1), 90–105. https://doi.org/10.1108/JADEE-04-2021-0100.

Klerkx, L., van Mierlo, B., Leeuwis, C., 2012. Evolution of systems approaches to agricultural innovation: Concepts, analysis and interventions. In: Darnhofer, I., Gibbon, D., Dedieu, B. (Eds.), Farming Systems Research into the 21st Century: The New Dynamic. Springer, Dordrecht, pp. 457–483. https://doi.org/10.1007/978-94-007-4503-2_20.

Kohl, R.D., 2023. Key factors for advancing innovations to scale: evidence from multiple country case studies of agricultural innovations. Front. Sustain. Food Syst. 7, 1053152. https://doi.org/10.3389/fsufs.2023.1053152.

Lacoste, M., Cook, S., McNee, M., Gale, D., Ingram, J., Bellon-Maurel, V., Hall, A., 2022. On-farm experimentation to transform global agriculture. Nature Food 3 (1), 11–18. https://doi.org/10.1038/s43016-021-00424-4.

Lawrence, D., Christodoulou, N., Whish, J., 2007. Designing better on-farm research in Australia using a participatory workshop process. Field Crop Res. 104 (1–3), 157–164. https://doi.org/10.1016/j.fcr.2007.03.018.

Lilja, N., Ashby, J.A., 1999. Types of participatory research based on locus of decision making. Participatory research and gender analysis (PRGA), working document no. 6. PRGA-Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia.

MacMillan, T., Benton, T., 2014. Agriculture: engage farmers in research. Nature 509, 25–27. https://doi.org/10.1038/509025a.

McGuire, E., Leeuwis, C., Rietveld, A.M., Teeken, B., 2024. Anticipating social differentiation and unintended consequences in scaling initiatives using GenderUp, a method to support responsible scaling. Agric. Syst. 215, 103866. https://doi.org/10.1016/j.agsy.2024.103866.

Meijer, S.S., Catacutan, D., Ajayi, O.C., Sileshi, G.W., Nieuwenhuis, M., 2014. The role of knowledge, attitudes and perceptions in the uptake of agricultural and agroforestry innovations among smallholder farmers in sub-Saharan Africa. Int. J. Agric. Sustain. 13 (1), 40–54. https://doi.org/10.1080/14735903.2014.912493.

Morrone, V., 2017. Outreach to support rural innovation. In: Snapp, S., Pound, B. (Eds.), Agricultural Systems (Second Edition). Agroecology and Rural Innovation for Development. Academic press, pp. 407–439.

Nature Food Editorial, 2022. Innovation in fruit and vegetable supply chains. Nature Food 3, 387–388. https://doi.org/10.1038/s43016-022-00548-1.

Neef, A., Neubert, D., 2011. Stakeholder participation in agricultural research projects: a conceptual framework for reflection and decision-making. Agric. Hum. Values 28, 179–194. https://doi.org/10.1007/s10460-010-9272-z.

Occelli, M., Sellare, J., Sousa, K.D., Dell'Acqua, M., Mercado, L., Paredes, S., van Etten, J., 2024. Group-based and citizen science on-farm variety selection approaches for bean growers in Central America. Agric. Econ. https://doi.org/10.1111/agec.12819.

Probst, K., Hagmann, J., Becker, T., Fernandez, M., 2000. Developing a Framework for Participatory Research Approaches in Risk-Prone Diverse Environments. In: Universität Hohenheim, Tropenzentrum (Eds.), International Agricultural Research – A Contribution to Crisis Prevention, Book of Abstracts and Proceedings on CD-Rom. Hohenheim, Germany.

Probst, K., Hagmann, J., Fernandez, M., Ashby, J.A., 2003. Understanding Participatory Research in the Context of Natural Resource Management: Paradigms, Approaches, and Typologies. In: AgREN. Network Paper No. 130. Overseas Development Institute, London.

Quirós, C., De Sousa, K., Steinke, J., Madriz, B., Laporte, M.A., Arnaud, E., Van Etten, J., 2024. ClimMob: software to support experimental citizen science in agriculture. Comput. Electron. Agric. 217, 108539.

Rhoades, R.E., Booth, R.H., 1982. Farmer-back-to-farmer: a model for generating acceptable agricultural technology. Agric. Adm. 11 (2), 127–137. https://doi.org/10.1016/0309-586X(82)90056-5.

Rijsberman, F., Atta-Krah, K., 2016. Foreword. In: Dror, I., Cadilhon, J.J., Schut, M., Misiko, M., Maheshwari, S. (Eds.), Innovation Platforms for Agricultural Development: Evaluating the Mature Innovation Platforms Landscape. Routledge, New York.

Rogers, E.M., 2003. Diffusion of Innovations, 5th ed. Free Press, New York.

Sartas, M., Schut, M., van Schagen, B., Velasco, C., Thiele, G., Proietti, C., Leeuwis, 2020. Scaling Readiness: Concepts, Practices, and Implementation. CGIAR Research Program on Roots, Tubers and Bananas (RTB), p. 217.

Schut, M., Leeuwis, C., Thiele, G., 2020. Science of scaling: understanding and guiding the scaling of innovation for societal outcomes. Agric. Syst. 184, 102908. https://doi.org/10.1016/j.agsy.2020.102908.

Selener, D., 2005. Definitions, assumptions, characteristics and types of farmer participatory research. In: Gonsalves, J., et al. (Eds.), Participatory research and development for sustainable agriculture and natural resource management: a sourcebook (vol. 1: Understanding participatory research and development). International Potato Center-Users' perspectives with agricultural research and development, Laguna, Philippines, and International Development Research Centre, Ottawa, Canada, pp. 5–15.

Snapp, S.S., Bezner Kerr, R., Bybee-Finley, A., Chikowo, R., Dakishoni, L., Grabowski, P., Kanyama-Phiri, G., 2023. Participatory action research generates knowledge for sustainable development goals. Front. Ecol. Environ. https://doi.org/10.1002/fee.2591.

Sodjinou, E., 2024. Community-based management as a driver of adoption of village poultry improvement technologies: empirical evidence from Benin. Cogent Food Agricult. 10 (1) https://doi.org/10.1080/23311932.2024.2314835.

Srinivasan, R., Sotelo, P., Lin, M.Y., Hy, H.C., Sareth, K., Sor, S., 2019. Development and validation of an integrated pest management strategy for the control of major insect pests on yard-long bean in Cambodia. Crop Prot. 116, 82–91. https://doi.org/10.1016/j.cropro.2018.10.015.

Srinivasan, R., Sotelo, P., Lin, M.Y., Heng, C.H., Kang, S., Sarika, S., 2020. Validation of a bio-based integrated pest management package for the control of major insect pests on Chinese mustard in Cambodia. Crop Prot. 135, 104728. https://doi.org/10.1016/j.cropro.2019.02.004.

Steinke, J., Schumann, C., Langan, S., Müller, A., Opola, F.O., Ortiz-Crespo, B., van Etten, J., 2024. Fostering social inclusion in development-oriented digital food system interventions. Agric. Syst. 215, 103882. https://doi.org/10.1016/j.agsy.2024.103882.

Šūmane, S., Kunda, I., Knickel, K., Strauss, A., Tisenkopfs, T., Ios Rios, I., et al., 2018. Local and farmers' knowledge matters! How integrating informal and formal knowledge enhances sustainable and resilient agriculture. J. Rural. Stud. 59, 232–241. https://doi.org/10.1016/j.jrurstud.2017.01.020.

Tropical Agriculture Platform, 2016. Common Framework on Capacity Development for Agricultural Innovation Systems: Synthesis Document. CABI, Wallingford, UK.

Ugochukwu, A.I., Phillips, P.W., 2018. Technology adoption by agricultural producers: a review of the literature. In: Kalaitzandonakes, N., Carayannis, E.G., Grigoroudis, E., Rozakis, S. (Eds.), From agriscience to agribusiness: theories, policies, and practices in technology transfer and commercialisation. Springer, pp. 361–377. https://doi.org/10.1007/978-3-319-67958-7.

Valbuena, D., Groot, J.C., Mukalama, J., Gérard, B., Tittonell, P., 2015. Improving rural livelihoods as a "moving target": trajectories of change in smallholder farming systems of Western Kenya. Reg. Environ. Chang. 15, 1395–1407. https://doi.org/10.1007/s10113-014-0702-0.

Van De Gevel, J., van Etten, J., Deterding, S., 2020. Citizen science breathes new life into participatory agricultural research. A review. Agron. Sustain. Dev. 40, 35. https://doi.org/10.1007/s13593-020-00636-1.

Van der Riet, M., Boettiger, M., 2009. Shifting research dynamics: addressing power and maximising participation through participatory research techniques in participatory research. S. Afr. J. Psychol. 39 (1), 1–18. https://doi.org/10.1177/008124630903900101.

Wigboldus, S., Klerkx, L., Leeuwis, C., Schut, M., Muilerman, S., Jochemsen, H., 2016. Systemic perspectives on scaling agricultural innovations. A review. Agron. Sustain. Dev. 36, 1–20. https://doi.org/10.1007/s13593-016-0380-z.

Wisdom, J.P., Chor, K.H.B., Hoagwood, K.E., Horwitz, S.M., 2014. Innovation adoption: a review of theories and constructs. Adm. Policy Ment. Health Ment. Health Serv. Res. 41, 480–502. https://doi.org/10.1007/s10488-013-0486-4.

Wopereis, C.S.M., Kuo, G.C., Larrousse, D., Schreinemachers, P., 2019. Vegetable food system innovations for healthier diets in Southeast Asia. In: Proceedings, Southeast Asia Vegetable Symposium (SEAVEG) 2019 on Advancing Vegetable Technology for Higher Productivity and Better Human Health, 9–11 July 2019, Melaka, Malaysia, pp. 29–44.