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Acceptance of innovations for sustainable food production: A consumer and farmer perspective on the use of soil-microbes

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Kurzfassung

Um den zahlreichen Herausforderungen im Zusammenhang mit den endlichen Ressourcen der Erde zu begegnen, wurde der Ruf nach einer nachhaltigen Entwicklung immer lauter. Für die Erreichung der Ziele einer nachhaltigen Entwicklung der Vereinten Nationen ist vor allem der Agrarsektor von Bedeutung. In der Regel setzt die konventionelle Landwirtschaft auf eine Vielzahl von Dünge- und Pflanzenschutzmitteln, um produktive Felder zu ermöglichen, jedoch verursachen diese Produkte auch externe Kosten für die Umwelt und die biologische Vielfalt. Im Hinblick auf einen Wandel zu einer nachhaltigen Landwirtschaft sind Alternativen zu diesen schädlichen Mitteln erforderlich. Im Bereich des Pflanzenbaus ist der Zustand der Böden eine der wichtigsten Grundlagen für die Nahrungsmittelproduktion. Forscher*innen aus dem Bereich des Pflanzenbaues haben die Rolle hervorgehoben, die nützliche Bodenmikroben für eine nachhaltigere Landwirtschaft leisten können. Sie kommen in natürlichen, unbehandelten Böden selbstständig vor, und die Pflanze und ihre Umgebung können auf verschiedene Weise von diesen Mikroben profitieren. Durch ihren Einsatz auf landwirtschaftlichen Flächen können sie diese Vorteile auch für die Lebensmittelproduktion erbringen. Um die nützlichen Bodenmikroben als Schlüsselinstrument für eine nachhaltige Landwirtschaft zu nutzen, muss die Perspektive zweier wichtiger Interessengruppen berücksichtigt werden: die Perspektive des*der Landwirts*Landwirtin – als diejenigen, die die Mikroben anwenden müssen – und die Perspektive der Verbrauchenden – als diejenigen, die ein Endprodukt konsumieren müssen. Ziel dieser Arbeit ist ein besseres Verständnis der Mechanismen, die sich auf die Akzeptanz dieser innovativen Pflanzenproduktionsmethoden von Landwirten*Landwirtinnen und Verbrauchende auswirken, sowie der Mechanismen, die bei der entsprechenden Kommunikation relevant sind. Zur Bewertung und Identifizierung von Faktoren, die die Akzeptanz beeinflussen können, wurde ein multimethodischer Ansatz verwendet: qualitative, quantitative und experimentelle Studien wurden mit Landwirten*Landwirtinnen und Verbrauchenden im Rahmen dieser Dissertation durchgeführt.

Zuerst wurde eine qualitative Studie mit 36 Landwirten*Landwirtinnen in Deutschland und im Vereinigten Königreich durchgeführt. Durch diesen explorativen, offenen Ansatz war es möglich, die Wahrnehmungen der Landwirte*Landwirtinnen eingehend zu verstehen. Ziel war es, die Merkmale zu ermitteln, die die Landwirtinnen*Landwirte mit nützlichen Bodenmikroben in Verbindung bringen, sowie die wichtigsten Kommunikationskanäle, die diese nutzen, um sich über derartige Innovationen zu informieren. Die Befragung von Adopter, Dis-Adopter und Non-Adopter Gruppen ergab, dass die Innovation im Allgemeinen als schwierig empfunden wird, und das unabhängig von den Erfahrungen, die die Landwirte*Landwirtinnen mit ähnlichen Innovationen bereits gemacht haben. Die Teilnehmerinnen*Teilnehmer finden es schwierig, die Effekte der Innovation zu beobachten und empfinden die Innovation als kompliziert zu begreifen und/oder umzusetzen. Insgesamt hatten die Gruppen der Adopter und Non-Adopter eine positivere Wahrnehmung zur Innovation und diskutierten die relativen Vorteile in größerem Umfang als die Dis-Adopter. Für die Landwirte*Landwirtinnen in

allen Adopter-Gruppen wurden die folgenden Quellen als besonders relevante Informationskanäle identifiziert: andere Landwirtinnen*Landwirte, Beratungsdienste, Handel und Hersteller.

Zweitens wurde eine quantitative Studie mit Ausbildungsbetrieben in Deutschland durchgeführt, welche darauf abzielte, Determinanten der Intention der Landwirte*Landwirtinnen zu identifizieren, Produkte auf Basis von Bodenmikroben zu verwenden. Zu diesem Zweck wurden Konstrukte aus Verhaltenstheorien, aus dem Technologieakzeptanzmodel (TAM), sowie aus anderen relevanten, empirischen Adoptionsstudien abgeleitet. Auf der Grundlage von 102 gesammelten Beobachtungen wurden verschiedene Modelle zur Erklärung der Intention geschätzt. Das Modell, welches Konstrukte aus der Theorie des überlegten Handelns mit Konstrukten aus dem TAM erweiterte, erwies sich als das beste Modell. Darüber hinaus zeigten die Ergebnisse dieser Studie, dass die wahrgenommene Nützlichkeit ein Schlüsselfaktor für die Intention ist. Auch injunktive Norme und Einstellungen gegenüber diesen Bodenmikroben wurden als einflussreiche Determinanten identifiziert. Insgesamt überschneiden sich die Ergebnisse der qualitativen und quantitativen Landwirtschaftsstudien hinsichtlich der Bedeutung der Leistungserwartung (d. h., wahrgenommenen Vorteile und Nutzen) und der identifizierten Interessen-/Bezugspersonengruppen, die die Kommunikation und Diffusion von Innovationen auf der Grundlage nützlicher Bodenmikroben erleichtern können.

Drittens wurde eine experimentelle Online-Studie mit deutschen Verbrauchenden durchgeführt, um die Auswirkungen der Informationsgestaltung auf die Akzeptanz der Verbrauchenden von einem Endprodukt welches mit Bodenmikroben produziert wurde zu bewerten. Wenn eine unbekannte Innovation bewertet wird, können Informationen eine entscheidende Grundlage für die Beurteilung bilden. Daher wurde untersucht, wie sich das Goal-Framing (d. h., Verlust- und Gewinn-Framing) auf die Einstellungen und Kaufintentionen der Verbrauchenden in Bezug auf Tomaten auswirken kann, die mit nützlichen Bodenmikroben erzeugt wurden. Die Vermittlung der Informationen wurden mit kurzen Videoclips durchgeführt, die diese Bodenmikroben erklärten. Anhand der Daten von 754 deutschen Verbrauchenden zeigte das Experiment, dass Goal-Framing, also die Kommunikation möglicher Konsequenzen einer Innovationsanwendung (oder des Ausbleibens der Anwendung), zu stärkeren Reaktionen führte als ein Kontrollvideo ohne derartige Informationen. Dieser Effekt wurde bei expliziten Einstellungen beobachtet, die wiederum eine Auswirkung auf die Kaufintentionen hatten. Der Effekt des Framings auf implizite Einstellungen blieb jedoch unklar. Im Gegensatz zu unserer Hypothese erwies sich Verlust-Framing nicht als effektiver als Gewinn-Framing.

Die Ergebnisse dieser Arbeit bieten eine erste Orientierung für Akteure, die sich mit der zukünftigen Entwicklung und Diffusion von Innovationen auf Basis von nützlichen Bodenmikroben und anderen ähnlichen Innovationen beschäftigen. In erster Linie liefert diese Arbeit Hinweise für die Bereitstellung von Informationen und Kommunikationsstrategien, die sich auf Landwirte*Landwirtinnen und Verbrauchende als die wichtigsten Interessengruppen konzentrieren. Im weiteren Sinne bietet diese

Arbeit Erkenntnisse über Aspekte, die die Akzeptanz – und die anschließende Diffusion – von nützlichen Bodenmikroben in Zukunft erleichtern können.

Abstract

There has been an overarching call for sustainable development to counter the many challenges associated with the earth's finite resources. In particular, the agricultural sector is of significance for achieving the United Nations Sustainable Development Goals. Generally, conventional agriculture has relied on fertilizers and plant protection products in order to enable productive fields, however, these products also incur external costs for the environment and biodiversity. In alignment with a transition to sustainable agriculture, alternatives for these harmful inputs are needed. In the field of crop production, the condition of soils provides one of the key foundations for food production. Researchers in the field of plant production have emphasised that beneficial soil-microbes can offer support for more sustainable agriculture. They occur in natural, untreated soils autonomously, and the plant and its surroundings can benefit from these microbes in a number of ways. Through their application in agricultural fields, they can also provide these benefits to food production. To make use of beneficial soil-microbes as a key tool for sustainable agriculture, it is necessary to consider the perspective of two important stakeholders: the farmer's perspective – as the one who needs to administer the microbes – and the consumer's perspective – as the one who needs to consume a final product. This thesis aims to create a better understanding of mechanisms which impact the acceptance of these innovative plant production methods by farmers and by consumers, and of mechanisms important for relevant communications. To assess and identify factors which can influence their acceptance, a multi-methods approach was employed: qualitative, quantitative and experimental studies with farmers and consumers were conducted and are part of this dissertation.

Firstly, a qualitative study was conducted with 36 farmers in Germany and the UK. Through this explorative, open approach it was possible to gain an in-depth understanding of farmers' perceptions. The objective was to identify the traits which farmers associated with beneficial soil-microbes and key communication channels they used to obtain information with respect to such innovations. Interviews with adopter, dis-adopter and non-adopter groups revealed, that irrespective of the farmers' prior experience with similar innovations, the innovation was generally perceived as challenging. Participants found it difficult to observe effects from the innovation and perceived the innovation as complex to grasp and/or implement. Overall, adopter and dis-adopter groups had more positive perceptions of the innovation and discussed the relative advantages to a greater extent than the non-adopters. For farmers in all adopter groups the following sources were identified as especially relevant information channels: other farmers, extension services, and trade and manufacturers.

Secondly, a quantitative study with training farms in Germany was conducted, which aimed to identify determinates of farmers' intentions to use products based on soil-microbes. For that purpose, constructs were derived from behavioural theories and the technology acceptance model (TAM), as well as from other relevant empirical adoption studies. Based on 102 collected observations, various models were

estimated to explain farmers' intentions. The model which extended constructs from the theory of reasoned action with constructs from the TAM stood out as the superior model. In addition, the results of this study revealed that perceived usefulness is a key factor impacting intentions. Injunctive norms and attitudes towards these soil-microbes were also identified as influential determinants. Overall, the qualitative and quantitative farmer studies overlap in their findings on the importance of performance expectancy (that is, perceived advantages and usefulness), and the identified stakeholder/referent groups which can facilitate the communication and diffusion of innovations based on beneficial soil-microbes.

Thirdly, an experimental online study with consumers was conducted to assess the impact of information framing on consumers' acceptance of an end-product created using beneficial soil-microbes. When evaluating an unknown innovation, information can form a crucial basis for judgement. Thus, the objective was to assess how goal framing (i.e., loss and gain framing) can effectively impact consumers' attitudes and purchase intentions towards tomatoes which were produced using beneficial soil-microbes. The information treatments were implemented with short video clips explaining these soil-microbes. Using the data of 754 German consumers, the experiment demonstrated that goal framing, thus the communication which describes the potential consequences of innovation application or lack of application, led to stronger responses than a control video with no such information. This effect was observed on explicit attitudes, which also impacted purchase intentions. However, the impact of framing on implicit attitudes remained unclear. In contrast to our hypothesis, loss framing did not prove more effective than gain framing.

The results of this thesis offer a first orientation for actors who may engage with future development and diffusion of innovations based on beneficial soil-microbes and other similar innovations. This thesis provides direction for information provision and communication strategies focusing on farmers and consumers as the main stakeholders of interest. More broadly, it also offers insights about aspects which can facilitate the acceptance – and subsequent diffusion – of beneficial soil-microbes in the future.

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Abbreviations

AIC	Akaike information criterion
AM(F)	Arbuscular mycorrhiza (fungi)
AN(C)OVA	Analysis of (co-)variance
APE	Associative-propositional evaluation
AVE	Average variance extracted
BIC	Bayesian information criterion
CAP	Common Agricultural Policy
CI	Confidence interval
Coef.	Coefficient
DIT	Diffusion of innovation theory
EC	European Commission
ELM	Elaboration-likelihood model
EU	European Union
GM(O)	Genetically modified (organisms)
HTMT	Heterotrait-monotrait ratio
ISR	Induced systemic resistance
IT	Information technology
(ST) IAT	(Single target) Implicit association test
LM	Linear model
MANOVA	Multi-variate analysis of variance
MiRA	Microbe-induced resistance to agricultural pests
NGO	Non-governmental organisation
PBC	Perceived behavioural control
PEU	Perceived ease of use
PGPR	Plant growth-promoting rhizobacteria
PLS	Partial-least-square
PU	Perceived usefulness
RMSE	Root mean square error
SD	Standard deviation
SDG	Sustainable development goal
SEM	Structural equation modelling
SE	Standard error

TAM	Technology acceptance model
TPB	Theory of planned behaviour
TRA	Theory of reasoned action
UN	United Nations
USD	United States dollar
UTAUT	Unified Theory of Acceptance and Use of Technology
VIF	Variance inflation factor

1. Introduction

1.1. Problem statement, relevance and motivation

Human population growth is challenging earth resources and their usage. In the last 30 years, the world's population has grown from 5.37 billion in 1991 to 7.84 billion in 2021 (Worldbank, 2023). Projections also show that the world's population will continue to expand to about 10 billion in 2100 (United Nations, 2022), creating pressure to increase the global food supply to meet the growing demand (Kopittke et al., 2019; Tilman et al., 2011). The rise in global population has also led to considerable intensification of agricultural production over the last several decades; however, this intensification does not align with a sustainable usage of limited resources. Agricultural lands are limited not only quantitatively but also qualitatively, as the soil quality can limit the productive agricultural usage (Shukla et al., 2019). Thus, the efficient use of the available resources is vital.

Conventional forms of agriculture rely on biochemical inputs and come at high environmental cost (Rani et al., 2021). According to the planetary boundaries scheme (Steffen et al., 2015), intensive forms of agriculture disturb the natural flow of biogeochemical nutrients, contributing to the excess of one out of nine defined planetary boundaries; for example, agricultural fertiliser application results in high levels of phosphorus in watersheds. Through greenhouse gas emissions, agricultural practices also contribute to climate change (IPCC, 2023), which increases the occurrence of severe weather events that, in addition to other consequences, have detrimental effects for food production (Raza et al., 2019). Furthermore, several pests and pathogens have developed resistances to some of the commonly used agricultural chemicals (Gould et al., 2018). Accordingly, they are less or even no longer effective in protecting plants, leading to high yield losses and limiting the tools available and/or known to farmers. Hence, agriculture requires a transition of its production condition towards approaches which can address the current challenges; that is, meeting the demand of a growing population while also ensuring sustainable production.

The political outlook on sustainability transitions is, to a great extent, guided by the Sustainable Development Goals (SDGs) introduced by the United Nations (UN) (United Nations, 2022). The SDGs include sustainable production and consumption as one of the 17 goals. In accordance with this and other SDGs, the European Commission (EC) developed the "Farm to Fork Strategy", which envisages a sustainable European food sector and is intended to address the predicament of an agricultural sector dependent on harmful agricultural inputs (European Commission, 2020). Sustainable innovation in the agricultural sector has been identified as a contributing factor to achieving the SDGs (Herrero et al., 2021). The European Union (EU) specifically promotes and enables natural and sustainable solutions as potential substitutes to synthetic formulations (Drobek et al., 2019). To foster alternative inputs to conventional inputs, the EC has recently introduced rules for micro-organisms and biostimulants in

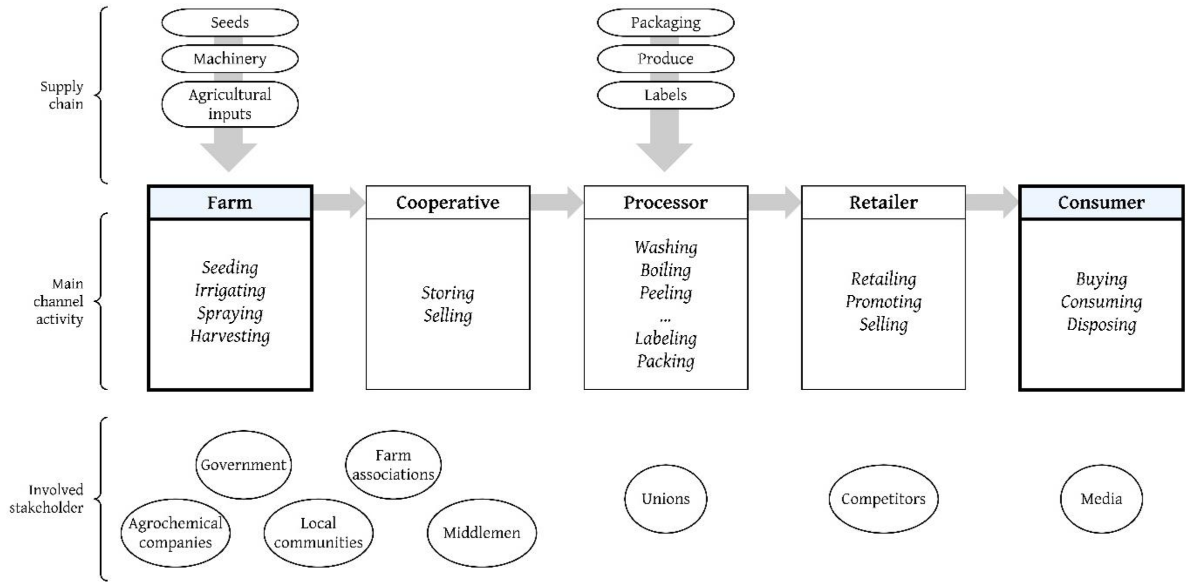
European regulations on fertilisers and plant protection (Regulation (EC) No 1107/2009, 2009/21/11/2022; Regulation (EC) No 2019/1009, 2019/16/03/2023). Previously, manufacturers of micro-organisms for agricultural application had to follow the same regulations as those for chemical substances, which did not account for many specific circumstances of the microbes (European Commission, 2022). Through this new regulation, the EU aims to ease the development and use of those inputs.

Beneficial soil-microbes have been identified as a promising alternative to chemical fertilisers and chemical plant protection products (Basu et al., 2018; Berg, 2009; Calvo et al., 2014; Ray et al., 2020). Although soil accommodates a multitude of soil-microbes, this thesis focuses solely on soil-microbes which can offer beneficial services to agricultural food production. A host plant can enter into a symbiosis with such beneficial soil-microbes and receive several advantages from this relationship. Some of these beneficial effects include increased plant health and growth, increased biocontrol, resistance and tolerance to stress, and other ecosystem services (Basu et al., 2018; Bhattacharyya & Jha, 2012; Du Jardin, 2015; Elnahal et al., 2022; Ferlian et al., 2018; Gianinazzi et al., 2010; Hamid et al., 2021; Kowalska et al., 2020; Pascale et al., 2018; Rouphael & Colla, 2020; Rouphael et al., 2015). Thus, these microbes offer a contribution to a more sustainable agricultural production. First commercial products based on beneficial microbes have already been developed and marketed, and further research for an application as a pest suppression product and a "second generation" of products is underway (Rouphael & Colla, 2018).

To foster a transition based on sustainable innovations - such as beneficial soil-microbes - the innovations themselves need to be communicated, tried, implemented and spread by the relevant actors in the value chain; a process which Rogers (1995) defines as the diffusion of innovations. Food production and consumption involves many different actors (Köhler et al., 2019). Accordingly, a transition towards a more sustainable food system needs to take a multi-stakeholder perspective, including farmers, food processors, traders and consumers (Djekic et al., 2021). Research linked to innovations introduced at the farm level have focused on farmers, but it is also crucial to consider the perspectives beyond the farmer (Bertolozzi-Caredio et al., 2021). An example agricultural supply chain for the case of tomatoes is illustrated in **Figure 1**.

Beneficial soil-microbes in agricultural production can create value for the farmers and their businesses, but also other stakeholders along the value chain, up to and including the consumer. In this dissertation, special emphasis is placed on the farmer (i.e., the producer) and the consumer, as both are key actors to consider in the implementation and acceptance of soil-microbes in the long-term.

Figure 1. Supply chain with focus on stakeholders of this dissertation.



Source: own illustration based on Anastasiadis et al. (2020), Busse et al. (2017).

For innovation adoption on the field level, the farmer is important as the enacting stakeholder. To ensure the economic success of an innovation, it is crucial that the innovations meet the demands of the user (Kline & Rosenberg, 2009). As the grower, the farmer is responsible for making on-farm decisions, the trialling of innovations and implementing long-term changes on the field level. In line with the outlined political goals and strategies, it is important to evaluate which mechanisms can support farmers in their adoption of sustainable agricultural production methods. In particular, beneficial soil-microbes work in unique ways, making it difficult to transfer insights from other innovations to the case of microbial applications. Therefore, to facilitate the uptake of beneficial soil-microbes, it is central to understand the farmers' perspective on this innovation.

Past developments have shown that consumers' acceptance can also impact the path of success for food innovations. Some consumers have expressed their opinions through political consumerism, meaning boycotts in their purchase decisions, which were also intended to target a change in production circumstances (Stolle et al., 2005). Particularly in Europe, negative attitudes towards genetically modified organisms (GMOs) have been observed among consumers (Sikora & Rzymski, 2021), and considerations and criticism of GMOs by various actors has impacted GMOs regulations on the European level (Levidow et al., 2000). Similarly, the case of herbicidal products illustrated how disagreement and protests by civil society led to stricter evaluations and consequently new or changed rules by the EC (Bazzan & Migliorati, 2020). A potential response to these consumer perceptions and reactions is information and communication. According to the knowledge deficit model, a lack of knowledge by the public can be countered with the provision of scientific information, which then has further impacts on the public's perceptions (Miller, 2001). However, it is not enough to merely provide information to achieve an impact – effective communication is crucial (Simis et al., 2016). Hence, this dissertation evaluates the consumer perspective by focusing on effective communication about beneficial soil-microbes.

1.2. Research questions and objective

The focus of this dissertation is on the acceptance and on perceptions of a sustainable agricultural innovation by farmers and consumers. The central research question addressed in this thesis is: *What influences farmers' evaluations and perceptions of agricultural innovations based on beneficial soil-microbes, and how can information effectively impact consumers' perceptions of such innovations?* This thesis aims to create a better understanding of mechanisms which impact the acceptance of innovative plant production methods by farmers and by consumers, and of related communications thereof. Consequently, the overall objective of this research is twofold: (a) to identify mechanisms and determinants which impact farmers' acceptance and (b) to identify effective communication strategies to address consumer perceptions. The results aim to increase our understanding of what aspects may facilitate or hinder future development and diffusion of beneficial soil-microbes. While in the case of farmers, the core question relates to their intentions to adopt the innovation on their farms. In the case of consumers, acceptance refers to their intentions to buy an end-product which was produced using new inputs or technologies. These behavioural intentions can be facilitated or guided by political programmes and information campaigns. Based on empirical studies in Germany and the UK, the research of this thesis provides insights on what determines innovation acceptance and on how the corresponding process of innovation diffusion may be communicated and promoted.

The central research question outlined above is investigated in three research papers, each focusing on a number of sub-questions.

The first study provides answers to the questions: *Which innovation traits appear to be crucial for adopting innovations based on soil-microbes? What are farmers' perceptions regarding those traits and how do they differ depending on farmers' experiences?* Due to the novelty of the object of interest, that is, beneficial soil-microbes in agriculture, first an explorative, qualitative research approach was applied, as it allowed for an in-depth understanding of farmers' perceptions. More specifically, qualitative interviews were conducted with German and UK farmers. The objective was to identify the traits which farmers associated with beneficial soil-microbes and key communication channels they used to obtain information with respect to innovations based on soil-microbes. In particular, perspectives of different adopter groups, namely, dis-adopter, non-adopter and adopter were considered.

In the second paper the following research question was addressed: *Which determinants drive farmers' intentions to adopt innovations based on beneficial soil-microbes in their potato cultivation*? The aim here was to analyse the relevance of different factors in determining farmers' behavioural intentions to try beneficial soil-microbes in their upcoming potato cultivation. Behavioural and technology acceptance theories, as well as insights from empirical studies, informed this research. Through an online survey, data from German potato farmers on hypothetical innovation adoption was collected.

The third research paper focused on consumers as relevant stakeholders, investigating the question: *How can framing of information in videos be used to increase consumer acceptance of an agricultural innovation*? Consumers were exposed to information prior to evaluating an innovation which was unknown to them. Due to the relevance of information exposure, the objective was to assess how different information framing can effectively impact consumers' attitudes and purchase intentions of an end-product (in this case, tomatoes) which was produced using beneficial soil-microbes. This information experiment was conducted with German consumers through the exposure to different video clips as the information treatment.

This introduction chapter continues as follows. First, the practical and theoretical background of this thesis is presented in subchapter 1.3. Subchapter 1.3.1 introduces the innovations based on soil-microbes, providing an account of identified benefits, but also challenges pertaining to the innovation. In subchapter 1.3.2, the theoretical background informing and guiding the empirical research is presented. Due to the novelty of the research subject, different methodological approaches were employed, which are introduced in subchapter 1.4. Finally, subchapter 1.5 provides an overview of this thesis's contribution and structure. An overview of empirical literature is integrated in the sequential chapters after the introduction.

1.3. Background

1.3.1. Background on the innovation

In order to turn an idea into an invention, initial plans to realise that idea must be developed, but it is only with the transfer of that idea into a commercial business that it become an innovation (Roberts, 1988). Research in the field of biology has illustrated that the idea of using soil-microbes in agricultural food production is being explored in lab experiments (Castiglione et al., 2021; Pascale et al., 2018). However, challenges such as unpredictability of effects has restrained product development and transfer to commercial business, which has led to products based on beneficial soil-microbes which only realise a fraction of their potential effects (Lee Díaz et al., 2021). Nonetheless, through advancements in scientific methods new insights into microbes can be gathered, which hold promises for more successful product formulations (Ray et al., 2020). This dissertation focuses on beneficial soil-microbes as a (hypothetical) agricultural innovation, which offers services in plant protection and nutrient uptake.

In the following sub-sections beneficial soil-microbes are defined, current advantages and disadvantages are outlined (1.3.1.1), potential agricultural product categories are described (1.3.1.2) and to get an overview of the potential economic value, market estimates are shortly presented (1.3.1.3).

1.3.1.1. Defining microbes and their effects in agriculture

There are many different soil-microbes which can be beneficial for agricultural usage. Recent research has highlighted that some soil-microbes have the potential to support a more sustainable and environmentally-friendly agriculture (Basu et al., 2018; Castiglione et al., 2021; Elnahal et al., 2022; Gouda et al., 2018; Hamid et al., 2021; Kumar & Verma, 2018; Nadeem et al., 2014; Pascale et al., 2018; Ray et al., 2020; Rouphael & Colla, 2020; Singh et al., 2011; Vejan et al., 2016). Among the many existing micro-organisms, several beneficial soil-microbes have been identified for use in agricultural production: plant growth-promoting rhizobacteria (PGPR), mycorrhizal fungi and Trichoderma (Berg, 2009; Castiglione et al., 2021; Rouphael & Colla, 2020; Seiber et al., 2014; Singh et al., 2011; Vejan et al., 2016). As an umbrella term PGPR captures several micro-organisms, including, among others, those from the genera azotobacter, bacillus or pseudomonas. PGPR interact with a plant by colonizing or by associating with the plant's root, and then through various modes of action they can impact the plant positively (Ahemad & Kibret, 2014). Mycorrhiza fungi describes a specific form of symbiosis between the fungus and plant roots, which benefits both plant and fungus (Ciancio & Mukerji, 2007). Specifically, the application of arbuscular mycorrhizal fungi (AMF) has received more and more attention in sustainable agriculture (Du Jardin, 2015; Shahrajabian et al., 2021). AMF is compatible with many host plants and the services that AMFs can provide are just as manifold (Gianinazzi et al., 2010). The genus Trichoderma is also a fungi, which can colonise different parts of a plant and thereby induce a positive effect on the plant's growth and support plant protection mechanisms (Błaszczyk et al., 2014).

Research in the field of biology has discovered a lot of beneficial effects and mechanisms that the application of soil-microbes can bring for agricultural production: they can support the uptake of nutrients, the efficiency in nutrient usage or change the availability of nutrients to the plant; they can increase and/or promote plant, root and yield growth; they can impact the plant's fitness, resistance and tolerance to various stresses (i.e. abiotic or oxidative stress, drought); enhance biocontrol; or fulfil additional ecosystem services (Basu et al., 2018; Bhattacharyya & Jha, 2012; Du Jardin, 2015; Elnahal et al., 2022; Ferlian et al., 2018; Gianinazzi et al., 2010; Hamid et al., 2021; Kowalska et al., 2020; Pascale et al., 2018; Rouphael & Colla, 2020; Rouphael et al., 2015). The microbes can also support a plant's defence mechanisms against insects or pests. This is the case because of a beneficial plant-microbe-insect interaction, in which the microbes can support the plant by triggering direct and indirect defence mechanisms (Biere & Bennett, 2013). This was termed induced-systemic resistance (ISR), which primes the plant's mechanisms to defend itself (Berg, 2009; Gouda et al., 2018; Pineda et al., 2017).

An overview of microbes used for inocula is presented in **Table 1**, and possible product categories are explained subsequently in section 1.3.1.2. An inoculum can be applied by farmers including a strain of microbe as a single key ingredient or a consortium of several microbes (Castiglione et al., 2021). Depending on the main effects and mechanisms that commercial products are developed for, the soil-microbes can be used for different product categories.

Table 1. Main microbial groups and genera used in inocula (Owen et al., 2015).

	Micro-organism	**Groups**		**Genera**
Inocula Biostimulants, biofertilisation, bioprotection, bioremediation	**Bacteria**	Intracellular		Rhizobium, Bradyrhizobium, Sinorhizobium, Azorhizobium, Mesorhizobium, Allorhizobium
		Inter / extracellular		Bacillus, Burkholderia, Paenibacillus, Erwinia, Pseudomonas, Arthrobacter, Cautobacter, Serratia Stenotrophomonas, Micrococcus Flavobacterium, Azospirillum, Chromobacterium, Agrobacterium, Actinomyces, Strepotmyces
	Fungi	Root-associated fungi		Aspergillus, Trichoderma, Penicillium, Saccharomycetes, Mortierella, Mucor
		Mycorrhizas	Ecto-mycorrhiza	Thelephora, Pisolithus, Rhizoogon, Scleroderma
			Arbuscular-mycorrhiza	Rhizophagus, Glomus Funneliformis, Claroideoglomus, Gigaspora, Scutellospora

However, there still exist a number of challenges that prevent the widespread successful application of soil-microbes in commercial agricultural fields. Many of the identified potential positive effects of beneficial soil-microbes hold under controlled conditions in a laboratory often focusing on, for example, one specific crop and one form of tillage, while their impact under field conditions and for a larger variety of influential external factors needs further research (Gianinazzi et al., 2010; Gouda et al., 2018). One of the differences between field and laboratory conditions is the presence of other native microbes, against which the microbes, that were introduced by the farmer, need to compete (Finkel et al., 2017). Further, agricultural practices, such as ploughing or applications of synthetic agricultural products, such as fertiliser or biocides, can impact the effectiveness of beneficial soil-microbes (Chen et al., 2018). Further factors, such as nutritional status of the plant, soil condition and abiotic pressure can also influence the effectiveness of the soil-microbes (Du Jardin, 2012). This context dependency (Ferlian et al., 2018; Lee Díaz et al., 2021) leads to a lack of reliability and predictability of the effectiveness of beneficial soil-microbes, thereby complicating the integration of this innovation in farming systems

(Le Mire et al., 2016; Lee Díaz et al., 2021). This has hindered commercialisation and slowed the transfer from the lab to the field (Pineda et al., 2017). In addition, because these microbes are living organisms, challenges with shelf life and stability can arise (Bashan et al., 2014).

1.3.1.2. Potential products based on microbes and product categories

The potential actions and effects that beneficial soil-microbes can achieve are manifold. Accordingly, they can be used for various agricultural product categories. These agricultural products have been grouped as biosolutions by Du Jardin (2015). Biosolutions refers, quite broadly, to products which are based on biological solutions (HBS Economics, 2021). Product categories assigned to biosolutions and definitions are provided in **Table 2**.

Table 2. Product categories and definitions of biosolutions (Du Jardin, 2015; Juwarkar et al., 2010).

Biosolutions	Definition
Biostimulant	"A plant biostimulant is any substance or micro-organism applied to plants with the aim to enhance nutrition efficiency, abiotic stress tolerance and/or crop quality traits, regardless of its nutrients content. By extension, plant biostimulants also designate commercial products containing mixtures of such substances and/or micro-organisms" (Du Jardin, 2015, p. 7).
Biofertiliser	"A biofertiliser is any bacterial or fungal inoculant applied to plants with the aim to increase the availability of nutrients and their utilization by plants, regardless of the nutrient content of the inoculant itself. Biofertilisers may also be defined as microbial biostimulants improving plant nutrition efficiency" (Du Jardin, 2015, p. 7).
Biocontrol	"The control of one organism by another. Biocontrol agents used in plant productions are living organisms protecting plants against their enemies, i.e. reducing the population of pests or diseases to acceptable levels. Modes of action may include competition, antibiosis, parasitism and also ISR which is mediated by the plant" (Du Jardin, 2015, p. 7).
Bioremediation	"Bioremediation is the use of micro-organisms' consortia or microbial processes to degrade and detoxify environmental contaminants" (Juwarkar et al., 2010, p. 217).

In Europe, two legal frameworks principally capture and define the development and usage of soil-microbes in agriculture: the regulation relating to plant protection products (Regulation (EC) No 1107/2009, 2009/21/11/2022) and the regulation regarding fertilising products (Regulation (EC) No 2019/1009, 2019/16/03/2023). The soil-microbes can offer benefits for nutrient uptake, which would mean they are covered by the Fertiliser Regulation; but should they claim to offer support in plant protection, they need to be marketed as a plant protection product (Caradonia et al., 2018). This illustrates that the legal framework has not yet taken into account the multitude of effects that beneficial soil-microbes can serve (Kowalska et al., 2020).

However, the challenge of context dependency has led to the registration of many products based on soil-microbes being sold as biostimulants or biofertilizers, despite their potential plant protection effects (Lee et al., 2021). Scientific interest and research on biostimulants have grown over the last years (Corsi et al., 2022), but the product category biostimulant has been referred with many different, yet related, terms in commercial products, including bioregulator, growth promoter, metabolic enhancer, organic biostimulant, plant growth regulator, or plant growth stimulant (Yakhin et al., 2017). The Fertiliser Regulation was amended in 2019, with amendments including the first specific inclusion and definition of biostimulants by European authorities (Du Jardin, 2020). The Fertiliser Regulation defines plant biostimulants as "a product stimulating plant nutrition processes independently of the product's nutrient content with the sole aim of improving one or more of the following characteristics of the plant or the plant rhizosphere: nutrient use efficiency; tolerance to abiotic stress; quality traits; availability of confined nutrients in soil or rhizosphere" (Regulation (EC) No 2019/1009, 2019/16/03/2023). Before this regulation the product category biostimulants was not defined or regulated by authorities.

1.3.1.3. Market overview

This section presents a short overview of the biostimulant market to provide a general account about the (potential) economic value and application potential of soil-microbes. In 2020, 32% of the market share of agricultural biological solutions globally was made up of 47% of biopesticides, 32% of biostimulants and 21% of biofertilizers (Statista, 2023). According to market reports, the global biostimulant market was worth 3.50 billion USD in 2022, and projections indicate a size of 10.25 billion USD in 2032 (Precedence Research, 2023). In contrast, the global fertilizer market size was 193.28 billion USD in 2021 and is projected to grow to 241.87 USD in 2030 (Statista Research Department, 2023). In comparison to the fertilizer market, although smaller, the biostimulant market is growing at a faster rate, and is projected to almost triple their global market size by 2032. The predicted growth in the biostimulant market is explained by an increased access to materials, a rise in demand for organic foods and for enhanced soil productivity, and the need to counter soil degradation (Hamid et al., 2021; technavio, 2022), or in other words, their potential to contribute to some of the challenges agricultural food production is facing.

The largest share of the global revenues of the biostimulant market is allocated in Europe with 38% in 2021 (Precedence Research, 2023). The relevance of the biostimulant market in Europe, in terms of production and application, is also shown in the corresponding research activities, which are carried out to a major extent in Europe (Corsi et al., 2022). Companies which produce biostimulants based on mycorrhizal fungi have also increased in Europe since the 1990s; about 10 companies existed in the 1990s, which had increased up to about 70 by 2017 (Chen et al., 2018).

With regard to application, 39% of biostimulants are used for row crops (Critchley et al., 2021), but they are also applied to a wide variety of vegetables, trees, vine legumes and horticultural crops (Du Jardin, 2015). These diverse fields of applications show that biostimulants have a wide range of usage potential.

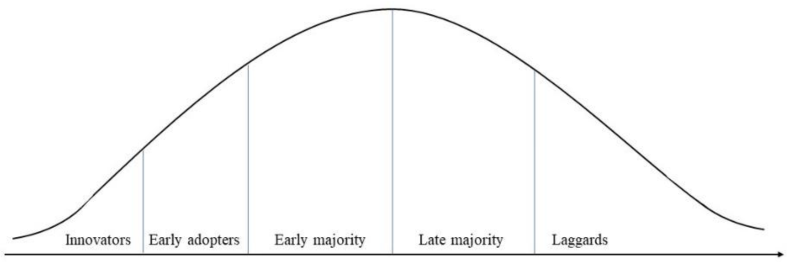
1.3.2. Theoretical background

This thesis is embedded in theoretical frameworks which deal with innovation diffusion, technology acceptance and adoption (Wisdom et al., 2014; van Oorschot et al., 2018). Acceptance of a (hypothetical) innovation can be captured using attitudinal evaluations or behavioural (adoption) intentions of the innovation in question. The theoretical approaches underpinning this thesis are based on the diffusion of innovations (1.3.2.1), the reasoned action approach (1.3.2.2), the technology acceptance model (1.3.2.3), the elaboration likelihood model and message framing (1.3.2.4).

1.3.2.1. Diffusion of innovations

Generally, research on innovations has been shaped extensively by Roger's diffusion of innovation (Rogers, 1995). The development of this diffusion approach was first inspired in an agricultural context, through the diffusion of corn seeds among farmers (Rogers, 2004). Rogers (1995) coined the term 'diffusion of innovations', a process of diffusion he describes as a bell-shaped curve (see **Figure 2**). As time since innovation launch and first innovation adoption progresses, the number of adoptions can be illustrated in this bell-shaped curve. Depending on the time of adoption, Rogers categorised different adopter groups. These can be distinguished as: innovators, early adopters, early majority, late majority and finally the laggards. It is assumed that these adopter groups can be differentiated based on various characteristics or behaviours (Läpple & van Rensburg, 2011; Rogers, 2004).

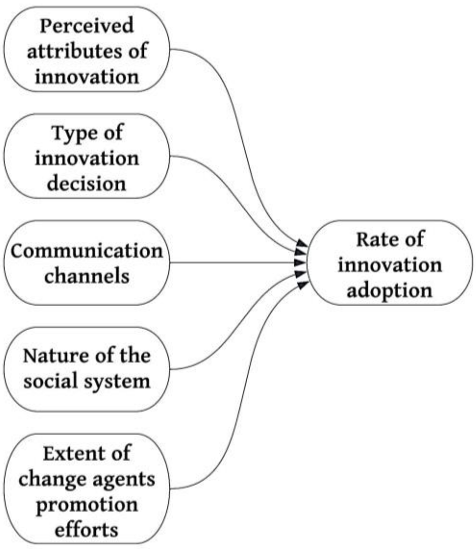
Figure 2. Innovation diffusion curve.



Source: own illustration based on Rogers (1995).

Rogers (1995) also defines factors which determine the rate of adoption, and which consequently impact the shape and progress on the diffusion curve: type of innovation decision, communication channels, nature of the social system, the extent of a change agents' promotion and perceived innovations' attributes (illustrated in **Figure 3**). The type of innovation decision that actors are able to make (optional, collective or authority driven) is informed by how they are confronted with innovations. The possibilities of communication channels determine the pathways through which the information on the innovation can be spread, for example, through mass media channels or between individuals. The social system encompasses a set of the actors which are all engaged to achieve an aim or solve a problem where the innovation adoption may take place. A change agent is a member of the social system who might influence others in their adoption behaviour. The perceived innovation's attributes as identified by Rogers (1995) are relative advantage, trialability, compatibility, complexity and observability.[1] A review of the innovation attributes highlighted that a specification of further attributes provides a better understanding of the effect that these traits can have on innovation adoption (Kapoor et al., 2014). The definition of innovation traits has thus been extended by concepts from other authors; including attributes such as cost, profitability, divisibility, communicability, and social approval of the innovation (Tornatzky & Klein, 1982), or voluntariness of use and image (Moore & Benbasat, 1991, 1996). The innovation traits are described in more detail in subchapter 2.2.

Figure 3. Factors determining rate of innovation adoption.



Source: own illustration based on Rogers (1995).

For the context of beneficial soil-microbes some of the identified factors which determine the rate of adoption appear more insightful than others. For example, the type of innovation decision will most likely be an optional, individual decision. However, a better understanding of the perceptions of the innovations' traits can inform future communication strategies about these innovations. Empirical

[1] A definition of Rogers' innovation traits (and extensions) is presented in **Table A1** on page 62.

research into relevant communication channels can also provide a better understanding for the future diffusion of beneficial soil-microbes. Empirical, qualitative research into the diffusion of beneficial soil-microbes and farmers related perceptions is offered in subchapter 2.2.

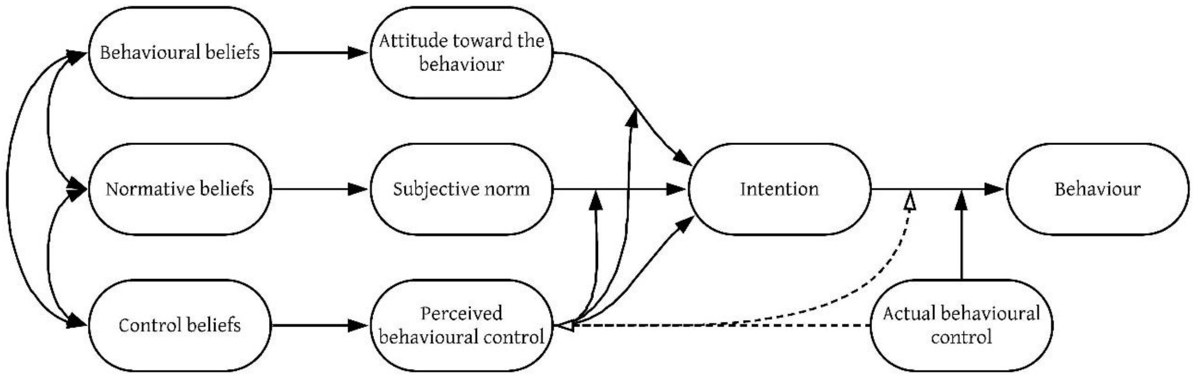
1.3.2.2. Reasoned action approach: the TRA and the TPB

The reasoned action approach captures the consolidation and recent accounts on the behavioural model by Fishbein and Ajzen, which originated with the theory of reasoned action (TRA) and the expectancy-value model (Fishbein & Ajzen, 2010). Out of these, the theory of planned behaviour (TPB) has become one of the most used theories to explain behaviour or behavioural intentions (Ajzen, 2011).

According to the TRA, the constructs attitude toward the behaviour and subjective norms influences behavioural intentions, which again impacts behaviour (Madden et al., 1992). The attitude toward the behaviour captures the agreeableness (or disagreeableness) of an individual with the behaviour of interest; social norms are constructed as perceptions about social approval (or disapproval) toward the object or behaviour (Fishbein & Ajzen, 2010). The TRA has also been identified as a theoretical framework for various studies dealing with innovation adoption (Otieno et al., 2016).

The TPB was originally developed by Ajzen and Fishbein to capture volitional behaviour. The theory emerged out of the TRA by adding the concept of perceived behavioural control (PBC) (Madden et al., 1992). PBC captures perceptions about barriers which may impede the individuals' execution of the behaviour in question (Ajzen, 2002). In total, the TPB is based on five core concepts: attitude, subjective norms, PBC, behavioural intentions and the actual behaviour in question (Ajzen, 1991). It is the theory's core premise that norms, PBC and attitude toward a specific behaviour will determine intentions to perform said behaviour. As Ajzen (2019) has noted on his website, the TPB has been extended with antecedents of attitudes, norms, PBC and the construct capturing actual behavioural control (see **Figure 4**). The TPB and reasoned action approach have both found wide application in empirical research, and various other explanatory variables have been added by other researchers to explain intentions or behaviour (Armitage & Conner, 2000; Manstead & Parker, 1995; Sok et al., 2020). A more detailed account of empirical research based on the reasoned action approach is presented in subchapter 2.3, where this theoretical framework informs empirical research on farmers' intentions to use beneficial soil-microbes in their potato cultivation.

Figure 4. Theory of planned behaviour.

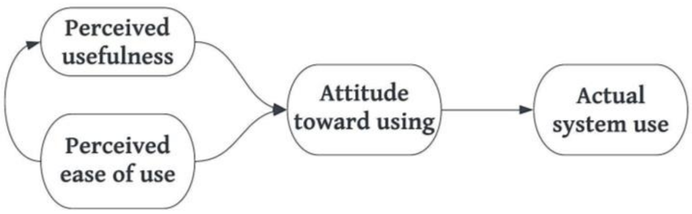


Source: own illustration based on Ajzen (2019).

1.3.2.3. Technology acceptance model

Davis (1985) adapted the TRA and the TPB and introduced the technology acceptance model (TAM) as a theoretical framework for understanding innovation acceptance or rejection in the information technology (IT) sector. In this model technology usage is determined by attitudes toward the technology, with attitudes being influenced by perceived usefulness and perceived ease of use of the respective technology (Davis, 1985) (see **Figure 5**). Over the last decades the TAM has been extended and combined with other behavioural models (Venkatesh & Davis, 2000; Venkatesh, 2016). In the majority of these extensions or adjustments, perceived usefulness and perceived ease of use directly predict behavioural intention, which then impacts use behaviour. A prominent extension of the TAM is the Unified Theory of Acceptance and Use of Technology (UTAUT), which combined various theoretical approaches – among them the TRA and the TPB – into one model (Williams et al., 2015). Although the TAM was developed for the IT sector, it has also found application in a wide range of fields (King & He, 2006; Marangunić & Granić, 2015). A more extensive description of the TAM and its application in agriculture can be found in subchapter 2.3. The TAM also informed empirical research among German farmers to explain their adoption intentions of beneficial soil-microbes.

Figure 5. The technology acceptance model.

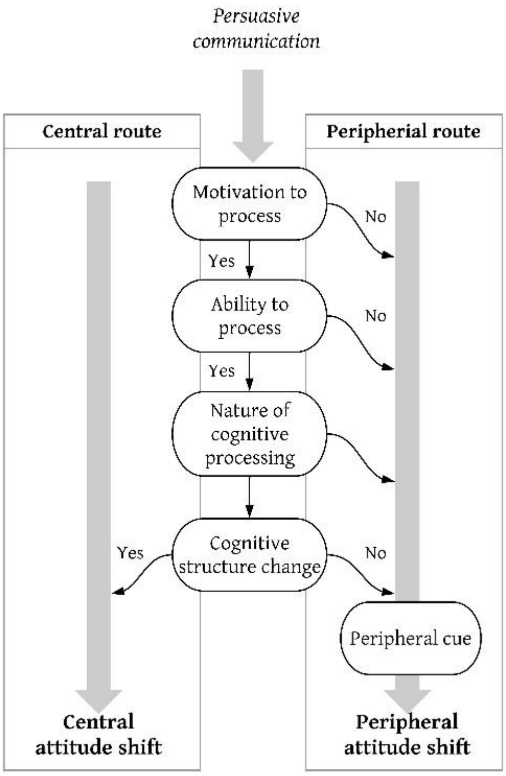


Source: own illustration based on Davis (1985).

1.3.2.4. Attitudinal change and message framing

Attitude is a latent concept which conveys favourable or unfavourable positions toward a certain object (Eagly & Chaiken, 1993). Attitudinal positions toward an object of interest may be influenced by information. The elaboration-likelihood model (ELM) was developed to capture attitude change induced by persuasive communications (Petty & Cacioppo, 1986). According to the ELM, information can be processed on a central or peripheral route, which also determines to what degree an attitude is changed upon receiving information. Whether a person adapts an attitude and on which route it is processed is influenced by the person's ability and motivation to process the information (see **Figure 6** for an illustration). The conditions which influence the route on which information is passed through can also be impacted by the message itself, that is, the message content and its perceived relevance (Petty & Cacioppo, 1986). By framing information, certain aspects about the communicated content are made more or less salient. Levin et al. (1998) developed a typology of framing which distinguishes between risky choice framing, attribute framing and goal framing. Goal framing focuses on the consequences or goals which can be achieved by a certain action, or the consequences of missing that goal by inaction. Thus, these goals can be framed in a gain-frame or loss-frame, where consequences of a certain behaviour are presented as potential gains or losses. In accordance with prospect theory, in scenarios of risk choices, Kahneman and Tversky (1979) found that individuals react more strongly to potential losses than to potential gains. Different goal framing can then lead to different route processing (O'Keefe & Jensen, 2008), and consequently to different levels of attitudinal changes.

Figure 6. Elaboration likelihood model.



Source: own illustration based on Petty and Cacioppo (1986).

Information or persuasive communication can impact facets of attitudes differently. Attitudes can be divided into implicit and explicit attitudes, which are also measured through distinct methods. Explicit attitudes are captured through a direct, self-reported measure, whereas measures for implicit attitudes usually rely on indirect, response-based tasks (Greenwald & Lai, 2020). Explicit attitudes represent the conscious process of evaluation, while implicit attitudes represent measurements which are evaluated through automatic, unconscious processes. The disparate effect of information on explicit and implicit attitudes is the subject of the associative-propositional evaluation (APE) model, which describes how implicit and explicit attitudes may change to a different degree after receiving an informational input (Gawronski & Bodenhausen, 2011). Depending on the route processing in the context of the ELM, this may also impact implicit and explicit attitudes differently (Gawronski & Bodenhausen, 2006). Further literature on information processing and framing is presented in subchapter 3.3.2. of the experimental study with consumers. In this consumer study, it is tested how goal framing can be used to effectively communicate about beneficial soil-microbes to impact consumers' attitudes and purchase intentions.

In conclusion, these theoretical approaches, which are building on innovation perceptions, attitudinal evaluations and behavioural intentions, underpin this thesis. Together, they provide a theoretical lens to gather insights into the overall acceptance of a hypothetical, yet promising, innovation from the perspective of farmers and consumers.

1.4. Multi-methods approach

Research in the field of agricultural economy could profit from an exchange between quantitative and qualitative research (Bitsch, 2005). It is the research question which determines what method is most suitable (Prokopy, 2011), and because the multi-stakeholder acceptance of an agricultural innovation is in the focus of this thesis, different methods needed to be considered to satisfy the unique circumstances for each stakeholder group. First, qualitative, explorative research was conducted among German and Scottish farmers. As it can be assumed that farmers' perceptions of the soil-microbes were unknown, a qualitative research approach was suitable to capture farmers' perceptions without having pre-defined restrictions, and as a result it was possible to capture emerging topics from the interviews (Ritchie & Lewis, 2003). Second, quantitative research about determinants of intentions to use beneficial soil-microbes was conducted in 2021. For a theory-driven and deductive approach, quantitative methods allow for the assessment of a theoretical framework conditional to the survey's circumstances (Babones, 2016). Third, through an information experiment it was possible to assess the effectiveness of different information frames, impacting consumer acceptance toward tomatoes produced with beneficial soil-microbes. Through experimental manipulations and otherwise consistent circumstances, experimental designs allow for claims of causality limited to the experiment's settings.

1.4.1. Qualitative methods: interviews and content analysis

Generally, a quantitative research approach requires set questions and hypotheses, which can be limiting when confronted with a new subject matter. Hence, to explore perceptions of an agricultural innovation, this study began with an open, unrestricted and in-depth qualitative approach.

Here, farmers were the target population of interest. Through the project "Microbe-induced Resistance to Agricultural Pests" (MiRA), various project partners were used for snowball sampling, resulting in the recruitment of several farmers in Scotland and Germany. Explorative, in-depth semi-structured interviews and one focus group discussion were conducted. The interview guide provided a framework for the interview, but also flexibility was given to acknowledge and to delve into specific circumstances of the participants. Focus group discussions are characterized by the possibility to interact, to learn from another and to build on the other participants' input; which makes focus group discussions an additional valuable tool of qualitative data collection. For example, having the possibility to interact allows the group to compare and to react toward each other's statements (Morgan, 1996), which can drive and deepen a discussion potentially more than an interview would. After interview transcripts were created, a content analysis was conducted. A mixed procedure was applied, where inductive and deductive coding was implemented following Mayring (2014). Deductive codes were informed by theory, mainly by the information traits as defined by Rogers (1995). The perceptions of these traits were then inductively coded by following the approach of a thematic analysis (Attride-Stirling, 2001). A thematic analysis allows for a reorganisation of qualitative data in a flexible approach, with one key advantage being the opportunity to work out differences and communalities (Braun & Clarke, 2006). The results were compared specifically to reflect on differences between three adopter groups: non-adopter, dis-adopter and adopter. To ensure coding reliability two coders independently of each other coded each transcript. NVivo, a software for qualitative data analysis was used to conduct the coding. A more detailed account of the methods and the results are presented in subchapter 2.2.

When researching consumer acceptance of an innovation which is assumed to be unknown to the consumer, consumers need to be informed about that innovation first (Nitzko, 2019). To evaluate the impact of information, an experiment with different information treatments was designed (see section 1.4.3). To ensure that the created materials for the information treatments provided sufficient and understandable information, a qualitative pre-study was conducted. By beginning with asking open-ended questions, participants are not restricted to the answer formats of a quantitative study, but instead can express their comments more freely (Haaland et al., 2023). For example, this open format is suitable for inquiring about the impressions, associations, pre-knowledge and general agreement/disagreement with the innovation presented in the information treatment. With the verbatim transcripts, the interviews were coded following an inductive approach (Mayring, 2014). Based on the results, refinement of the information materials could be implemented for the consumer experiment.

1.4.2. Quantitative methods: structural equation modelling

The results from the qualitative study with farmers provided guidelines on what information farmers need to evaluate an innovation, which, according to Rogers (1995), impacts the rate of innovation adoption. However, the specific composition of the innovation traits was still subject to development and was contingent on the final product formulation. Thus, the goal of the quantitative study with farmers was to focus on behavioural determinants of hypothetical adoption choices. Through quantitative research, a wider farmer sample than in qualitative research was recruited to test specific relationships between potential determinants of adoption. The identification of these determinants was embedded in behavioural and acceptance theories, as well as in empirical insights. Therefore, a mainly theory-driven deductive approach was necessary, but explorative elements were incorporated through extensions of theories. The impact of exogenous latent constructs on endogenous latent constructs can be tested using partial least square structural equation modelling (PLS-SEM), while simultaneously modelling complex relationships (Hair et al., 2021). PLS has increasingly become a popular method to estimate structural equation pathways (Hair et al., 2014). It offers various advantages, such as using formative and reflective constructs (Cenfetelli & Bassellier, 2009); however, various disadvantages were also identified, for example a lack of a model fit measure (Rönkkö & Evermann, 2013).

Nonetheless, methods surrounding PLS have continued to evolve, which has remedied some of the previously identified limitations (Hair et al., 2019).

German potato farmers were the target sample of the quantitative study with farmers. Data was obtained by distributing an online survey. Originally, a stratified random sampling strategy was employed, but a low response rate necessitated the use of the available contact information for a convenience sample. Measurements incorporated in the survey dealt with general demographics, farm characteristics, latent constructs from theory, risk attitudes and environmental attitudes. The collected variables could then be analysed using the programming language R, which can host useful packages for PLS analyses. More specific explanations and the findings are illustrated in subchapter 2.3.

1.4.3. Experimental methods: information treatment

Without prior knowledge, consumers need to be informed about beneficial soil-microbes first, before researchers can elicit consumers' acceptance. This highlights that information itself is a premise for further research. Therefore, with the experimental study with consumers, the effect of different information framing on consumer acceptance was tested. Data collection was conducted online using the survey software Qualtrics. Here, the information treatment in form of three video clips could be embedded: a control video, loss-framing video and gain-framing video about the usage of soil-microbes in tomato production. Post-treatment measures as indicators of acceptance included implicit attitudes, explicit attitudes and purchase intentions. A popular method of capturing implicit attitudes was developed with the implicit association test (IAT; Greenwald & Lai, 2020). In this experiment the IAT was conducted with only one object of evaluation, therefore, the single target IAT was implemented following Bluemke and Friese (2008). The IAT measure is calculated based on the speed at which participants fulfil a certain task, which makes this measure less liable to the limitations of self-reported measures (van de Mortel, 2008). The effects of information framing were then tested via group comparisons based on the experimental conditions and on a mediation analysis following Hayes (2022). A mediation analysis is characterised by testing the relationship between an independent and dependent variable and the mediation of that relationship by a third variable, a mediator (Hayes & Rockwood, 2017). Thus, the mediator has an impact on the dependent variable. The described method was applied in the consumer experiment. The created data is described in a data publication in subchapter 3.2, and the method as well as results are presented in subchapter 3.3.

This section of this thesis has presented three different methodological approaches. Each method was specifically created to fit the target groups, their circumstances relating to beneficial soil-microbes and the research questions. Taken together, these contribute to further our understanding of the acceptance of beneficial soil-microbes by focusing on consumers' and farmers' perspectives.

1.5. Contribution and structure of this thesis

This section outlines the structure of this thesis. Chapters 2 and 3 set out the empirical studies which investigated the farmers' and consumers' perspectives of soil-microbes, **Table 3** provides an overview of the empirical research conducted.

Table 3. Overview of empirical research and stakeholder groups.

Sub-chapter	**Research study**	**Stakeholder group**	**Location**	***n***	**Sub-research question**	**Key concept(s) of interest**	**Data collection and main analysis**
2.2	Qualitative study with farmers	Farmer: different adopter groups	UK and Germany	36	Which innovation traits appear to be crucial for adopting innovations based on soil-microbes, and what are farmers' perceptions regarding those traits?	Perception of innovation traits and communication channels	Semi-structured interviews and content analysis
2.3	Quantitative study with farmers	Farmer: training farms growing potatoes	Germany	102	What are key determinants of farmers' intention to adopt innovations based on beneficial soil-microbes in their potato cultivation?	Use intentions of beneficial soil-microbes in potato cultivation	Online survey and structural equation modelling
3.2 and 3.3	Experimental study with consumers	Consumer: general population	Germany	754	How can framing of information in videos be used to increase consumer acceptance of an agricultural innovation?	Purchase intentions of tomatoes produced with beneficial soil-microbes	Online survey and mediation analysis

Chapter 2 covers the farmers' perspectives on beneficial soil-microbes in agriculture. First, subchapter 2.1 presents a brief overview of the literature on technology adoption in agriculture based on a selection of reviews. Second, subchapter 2.2, "Sustainable innovations: a qualitative study on farmers' perceptions driving the diffusion of beneficial soil-microbes in Germany and the UK". provides a qualitative account on farmers' perceptions. This research contributes to the literature by providing insights into farmers' perceptions of different innovation traits associated with microbes, biostimulants or similar innovations. Due to the unique case of beneficial soil-microbes, to the best of my knowledge this is the first explorative farmer study dealing with this innovation. Thematic coding allowed for the identification of different subthemes associated with the innovation traits. The sample showed different levels of engagement and experience with biostimulants and soil-microbes, on which basis the sample could be split into different adopter groups. This research also contributes to the literature by providing the perspective of the dis-adopter. This group is hardly represented in literature, although their perspective as a past user, who decided against the innovation, also provides valuable insights about factors hindering innovation adoption.

Subchapter 2.3, "Sustainability transitions rooted in agricultural innovation adoption: what drives farmers' intentions to use soil microbes in potato cultivation", looks at farmers' intentions to use products based on soil-microbes. In this quantitative study, determinants are derived from theories dealing with behaviour and technology acceptance, as well as from other empirical adoption studies employing psychometric constructs. This combination of theory and empirically-derived determinants contribute to understanding the relevance of these different theories and additional constructs in the context of innovation uptake in agriculture. The results showcase which determinants and theoretical approaches are important in explaining farmers' intentions to use agricultural innovations. In addition, practical implications about influential referent groups and contents for communications about the innovation can be derived from this research.

Chapter 3 presents the consumers' perspective on soil-microbes, which was explored via a consumer experiment. First, an outline of selected research on aspects influencing consumer acceptance of food innovations is presented in a literature overview (3.1). Second, the data of the online experiment are described in subchapter 3.2, "Data of an information experiment with German consumers – framing innovative plant production technologies with videos". The tools and methods used for data collection are also presented in this subchapter. The main contribution here lies in fostering open science practices, by creating transparency and accessibility to the data, without analysis. The presented data and the following research article refer to the same consumer experiment.

Subchapter 3.3, "Frame by frame, attitude by attitude – the effect of information framing in videos on consumers' acceptance of sustainable food production innovations", contains the analysis and discussion of the consumer experiment. In this information experiment the consumers were exposed to the topic of beneficial soil-microbes via a video clip, and the effect of information framing (loss-, gain-framing and control) was explored. The analysis contributes to the literature by investigating the effect of goal framing on explicit and implicit attitudes. Furthermore, the unique combination of framing using visual and verbal cues in video clips was explored in this research. The results can provide implications for future research on communication strategies to foster consumer acceptance.

Finally, concluding remarks are provided in chapter 4. The main findings and some limitations of the research are discussed. This thesis concludes by discussing implications of this research and by providing directions for future research to come.

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2. The farmers' perspective

The agricultural sector is a sector which constantly undergoes change (Pardey et al., 2010) and faces new challenges and production conditions; this makes agricultural production an opportune field for the uptake of technological advancements and innovations. In parallel to the changing nature of agricultural production, innovations contribute to these changing dynamics by bringing in new production possibilities. Therefore, research is required to enhance our understanding of ongoing developments and potential future directions for progress. Research has shown that beneficial soil-microbes are considered a promising contribution to more sustainable food production (Elnahal et al., 2022). To ensure the success of this innovation, it is crucial to consider the user's perspective. In particular, the farmer, who needs to adopt innovations on the field, plays a central role in implementing change.

The following subchapter (2.1) outlines literature on innovation acceptance by farmers. The subsequent two subchapters deal with empirical research, one on farmers' perceptions of beneficial soil-microbes (2.2) and one on behavioural determinants which influence their potential adoption (2.3). To conduct this research, a mixed-methods approach was employed. The combination of qualitative and quantitative methods allowed for a wider understanding of the research subject, which would not have been possible if relying on one method only (Venkatesh et al., 2013).

2.1. Literature on the farmers' perspective

A lot of research has tried to identify the mechanisms which govern innovation adoption behaviour of farmers. This can be shown by the number of review articles which deal with the adoption of various practices on a farm level. To provide an overview of the main determinants of innovation adoption researched and identified in literature, a selected overview of literature reviews on technology acceptance and adoption is presented in this chapter (see **Table 4**). The selected literature is restricted to review articles published between 2007-2022, which were identified using the Web of Science database (using the search strings "farmer innovation adoption" and "farmer innovation acceptance"). This facilitated the collection of review studies on farmer innovation adoption or acceptance, focusing specifically on innovations and technologies which could be adopted by the farmers on their field. Review articles which focused on geographic regions outside of Europe, on specific farming businesses not relevant for this study context (i.e., aquaculture or animal husbandry), on specific crops not relevant for our context (i.e., rice or bananas) and on specific, restricted determinants were excluded. Articles without access granted by the University of Bonn library could also not be included. It needs to be noted that the presented reviews are not an exhaustive nor complete overview of relevant reviews, however, they serve as a snapshot to understand what has been researched and identified under the described research conditions.

The reviews capture technologies and practices of precision agriculture (Lee et al., 2021; Tey & Brindal, 2012), of sustainable farming practices (Hasler et al., 2017; Sapbamrer & Thammachai, 2021; Serebrennikov et al., 2020) and of various innovations and technologies (Dissanayake et al., 2022; Olum et al., 2020). The review articles were categorised according to four overall categories (see **Table 4**), which can again be grouped as micro and macro-level aspects: farm and farmer demographics; psychological constructs; technology/innovation related aspects; and institutional level aspects.

Table 4. Key findings in literature reviews sorted by micro and macro-level aspects.

Article	***n***	**Time period**	**Micro-level aspects**		**Macro-level aspects**	
			Farm and farmer demographics	**Psychological constructs**	**Technology/innovation related aspects**	**Institutional level aspects**
Tey & Brindal, 2012	10	1998-2012	○ Sociodemographic factors • Age • Education • Experience ○ Agro-ecological factors related to the farm	N.A.	○ Perceived usefulness ○ Perceived profitability ○ Willingness to adopt ○ Technology specification	○ Distance to dealer ○ Region ○ Use of contracts ○ Development pressure ○ Informational factors
Hasler et al., 2017	91	1945-2017	○ Sociodemographic factors • Age • Education • Gender ○ Farm size ○ Land ownership ○ Market access ○ Access to credit	N.A.	○ Expectation ○ Task-technology fit ○ Observability	○ Information ○ Quality of support ○ Involvement in external groups or co-operations
Olum et al., 2020	80	1995-2019	○ Sociodemographic factors ○ Biophysical factors	○ Attitudes ○ Environmental risk awareness ○ Risk aversion / perception ○ Expectations ○ Trust	○ Costs ○ Type of innovation ○ Usefulness ○ Ease of use ○ Cost/price	○ Credit and remittance ○ Incentives ○ Information and source ○ Market access

Article	*n*	Time period	Micro-level aspects		Macro-level aspects	
			Farm and farmer demographics	**Psychological constructs**	**Technology/innovation related aspects**	**Institutional level aspects**
Serebrennikov et al., 2020	23	2003-2019	○ Sociodemographic and household factors (i.e., age, education) ○ Farm structural characteristics (i.e., farm size)	○ Attitudes ○ Environmental attitudes ○ Beliefs	○ Technological attributes	○ Source of information ○ Institutional environment
Sapbamrer & Thammachai, 2021	50	1999-2021	○ Farmer and household factors • Education • Gender • Income • Marital status • Household size ○ Farming factors (i.e., farm experience, production cost, and farm ownership)	○ Attitudes ○ Normative and moral obligations ○ Others	N.A.	○ Training ○ Support ○ Organic farmer neighbors ○ Information acquisition ○ Membership of association ○ Extension contacts
Dissanayake et al., 2022	N.A.	1985-2020	○ Sociodemographic factors • Age • Education • Gender • Income ○ Farm size ○ Prior experience	N.A.	○ Affordability ○ Availability ○ Compatibility ○ Complexity ○ Trialability ○ Observability	○ Access to extension services ○ Inputs ○ Markets ○ Credit facilities

Note(s): n denotes the number of references included in the review; time period refers to the year of publication of included literature; N.A. = not applicable.

Farm and farmer demographics were consistently identified as relevant factors by all review articles; they pertain to sociodemographic characteristics describing conditions surrounding the farmer and farm. However, the focus on these sociodemographic characteristics as determinants of innovation adoption has also received criticism, as results are not consistent and thus not conclusive (Burton, 2014; Schulz & Börner, 2023). To clarify the role of farmer and farm characteristics and their potential influence on the adoption of beneficial soil-microbes, these aspects were taken up as control variables in the quantitative study with farmers in subchapter 2.3.

The identified psychological factors include the following constructs: attitudes, norms, beliefs, environmental beliefs, risk, trust and expectations. Some of these constructs are also integral elements of theoretical frameworks modelling behaviour or technology acceptance (i.e., the TPB or the TAM). Using the TRA as a base framework, the relevance of these constructs in impacting the adoption of soil-microbes is tested in subchapter 2.3. As other constructs have also shown relevance in innovation adoption, the role of environmental and risk attitudes is also investigated.

The category of determinants relating to the technology or innovation also partly reflects theoretical frameworks: the innovation attributes defined by Rogers (1995), the TAM by Davis (1985) and the task-technology fit theory by Goodhue and Thompson (1995). Some of the identified factors cannot yet be determined for the hypothetical innovation adoption of beneficial soil-microbes (for example, all determinants related to aspects of cost and finance). However, the current perceptions of similar innovations based on soil-microbes could be investigated through explorative qualitative interviews (see subchapter 2.2). Furthermore, the role of perceived usefulness of microbial applications was also integrated and investigated in the quantitative study with farmers.

Finally, determinants from the institutional level mainly refer to the following aspects: information, information sources, market structures, regional structures, farmer networks and support structures. Some of these aspects were also taken up in the qualitative and quantitative farmer studies. Relevant information sources were specifically investigated in the qualitative approach, and important referent groups were considered in the injunctive norm constructs in the quantitative approach. Hence, the results of the qualitative and quantitative studies provide insights into some aspects which may be relevant for actors at an institutional level, which can foster the diffusion and acceptance of innovations based on beneficial soil-microbes.

It can be seen that the presented selected review articles have engaged with a broad selection of identified factors which can impact innovation adoption by farmers. In the following research studies, we have considered and investigated some of these aspects, where they are suitable and provide insights within the context of beneficial soil-microbes.

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2.2. Sustainable innovations: a qualitative study on farmers' perceptions driving the diffusion of beneficial soil-microbes in Germany and the UK [2]

Abstract: Legislation and consumer preference for more sustainability in the food system require farmers to adopt more stringent sustainably measures without sacrificing business profitability. Scientific and technological innovations, such as beneficial soil-microbes for in-field application, may help to achieve this goal, but adoption rates have remained slow thus far. The adopter's perspective is essential to understanding why. This research investigates factors that drive the perceptions of soil-microbe solutions across three groups of (potential) adopters as an input to the design of effective communication strategies to accelerate technology diffusion. Factors included in the analyses are *relative advantage*, *compatibility*, *complexity*, *trialability*, *observability* and *image* of applying soil-microbes at the farm level. The analysis is based on 28 in-depth qualitative interviews in Germany and the UK, and a focus group discussion in the UK. Data were analysed via content analysis using deductive and inductive processes. Deductive codes were derived from the diffusion of innovations theory. Our results show that soil-microbes are still perceived as a challenging product in all three adopter groups, despite the acknowledgement of several advantages and benefits. Predominantly, farmers evaluate the innovation as complex. Furthermore, the observability of the soil-microbes was perceived as challenging, which also transfers to the trialability of the innovation. Despite this, in all adopter groups the need for the innovation was recognized.

Keywords: Diffusion of innovations; agricultural innovation; farmer perceptions; adopter groups; biostimulants; beneficial soil-microbes

Supplementary materials: The following supporting information can be downloaded at: https://osf.io/xdn3z/ (accessed on 9 December 2021, last edits on 9 May 2022).

[2] This subchapter is based on a paper that has been published as: Ploll, U., Arato, M., Börner, J., & Hartmann, M. (2022). Sustainable Innovations: A Qualitative Study on Farmers' Perceptions Driving the Diffusion of Beneficial Soil-microbes in Germany and the UK. *Sustainability, 14*(10), 1-23. https://doi.org/10.3390/su14105749

2.2.1. Introduction

Population growth and the related rise in consumption increase pressure on land use and contribute to greenhouse gas emissions and biodiversity losses (Shukla et al., 2019). To ensure and secure the correspondingly growing human need for food, scholars have called for increasing food provision capacity and thus growth in agricultural production (Barber, 2003). Due to restricted land capacities, growth in agricultural production often means more intensive production. Yet, intensive forms of agricultural production modes are creating unsustainable environmental impacts (Sattler & Nagel, 2010). Furthermore, some of the necessary agricultural inputs are rendered less effective partly due to increasing resistance by pests or diseases. Additionally, severe weather events induced by climate change are putting more strain on agricultural production.

In parallel, increasingly informed societies also recognize the limitations of intensive agricultural production and their effects of environmental and ecological exploitation, calling for more sustainable production practices (Scerri, 2009). As a result, new regulatory frameworks are being designed to pave the way towards more sustainable agricultural systems. For example, international initiatives related to plant protection products limit the possibilities of input use, thereby increasing the need to develop innovative means of production. With its new Green Deal (European Commission, 2020), the EU addresses those needs by promoting solutions based on natural formulas, which may substitute for chemical ingredients (Drobek et al., 2019). Recently, several acts were endorsed by EU member states which will allow for easier registration and approval of biological plant protection products based on soil-microbes (European Commission, 2022). Should these acts come into force, it will make the process of product development easier. One way to address this demand for sustainable food production is by adopting more sustainable innovations on the field-level application.

2.2.1.1. Background on soil-microbes in agriculture and related challenges

In the fields of plant protection and pest suppression, products based on beneficial soil-microbes were identified as a potentially valuable contribution to sustainable agricultural production (Basu et al., 2018; Singh et al., 2011). “Beneficial microbes” is an umbrella term for various microbes that can form a relationship with the plant and, consequently, create beneficial effects for the plant through biological processes. The promising beneficial microbes are PGPR, AMF and nitrogen-fixing bacteria, among others (Lee Díaz et al., 2021; Rouphael & Colla, 2020). For improved readability, the term “soil-microbes” is used to refer to beneficial soil-microbes, precluding harmful soil-microbes. One way to apply these microbes to the field is via biostimulants. Du Jardin (2012) defined biostimulants as “substances and materials, with the exception of nutrients and pesticides, which, when applied to plant, seeds or growing substrates in specific formulations, have the capacity to modify physiological processes of plants in a way what provides potential benefits to growth, development and/or stress response” (p. 27). Drobek et al. (2019) provided an overview of several sources of biostimulants and the effects they can achieve. Among others, they mentioned effects on growth and yield, protection against stress, increase in soil fertility and increased resilience towards infections (Drobek et al., 2019). On the farm level, a product based on soil-microbes can take various forms. Bashan et al. (2014) identified five carriers of inoculants of PGPR: soils, waste plant materials, inert materials, plain microbial cultures, and liquid inoculants. Concerning the application of AMF, external factors, such as ploughing, or application of other inputs, needs to be considered for application (Chen et al., 2018). As challenges for an efficient and sustainable usage of microbial inoculums on the field, Ray et al. (2020) mention potential obstacles, e.g. previous land-use, other microbiota present in soils or agricultural management practices, such as tillage. The application of AMF and its functions are manifold; these include increasing nutrient and water uptake, resistance to root pathogens, or strengthening resistance to stress factors (Gianinazzi et al., 2010). The application of mycorrhizal fungi is tightly connected to sustainable agriculture because the fungi itself thrives better under conditions of sustainable farming than under high-intensity conventional agriculture (Harrier & Watson, 2004). Chen et al. (2018) showcased how offers of products based on AMF rose over the last three decades in Europe. Between 1990 and 2017, the number of companies producing AMF increased from 10 to 75 (Chen et al., 2018). This highlights the manifold opportunities and growth potential offered by soil-microbial biostimulants.

Through the development of "next-generation sequencing" (p. 3), researchers from the field of biology could contribute new insights which advance the understanding of microbes and their potential for field usage (Ray et al., 2020). These advances added to other promising results regarding soil-microbes over the last 30 years; however, limitations to establish a successful application as a measure for plant protection in commercial agriculture still exist (Lee Díaz et al., 2021). Pineda et al. (2017) highlight how microbes can be less effective when applied with conventional agricultural management practices; additionally, their effects may only appear when exposed to external stress. Moreover, Rouphael and Colla (2020) identified past as well as future challenges of plant biostimulants, but because of the high potential in research advancements, the authors argued and identified possibilities for what they call the "next generation of biostimulants" (p. 4). Drobek et al. (2019), while highlighting the wide potential and positive impact which biostimulants can trigger, also point to the lack of use of this innovation by farmers; the authors attribute insufficient knowledge and specificity of application conditions as the major barriers for farmers. Assuming the potential of this technology is as large as experimental studies suggest, research must be centred on farmers' perspectives. This will enable us to gain insights into potential barriers and facilitators as well as promising diffusion processes to develop measures that facilitate the adoption process at the farm level.

2.2.1.2. Research approach

Innovations can shape and support an overall transition towards more sustainable agricultural practices. However, adoption is a prerequisite for the success of an innovation. According to Rogers' (1995) diffusion of innovation theory (DIT), the process of adoption and diffusion can be captured in a bell-shaped curve, differentiating between innovators and early adopters of innovation at the beginning of the diffusion process, all the way to the laggards at its end. Early adopters and their experiences crucially shape the diffusion of innovations, which is also influenced by other stakeholders who manage knowledge and information c.f. (Läpple & van Rensburg, 2011). Rogers (1995) identified the characteristics of the innovation and the social network of the potential adopters as key aspects influencing diffusion. In line with the DIT, this research looks at the perceived innovation traits of soil-microbes from farmers' perspectives, comparing specific farmer groups at different points on the diffusion curve. In this research, farmers were clustered into three groups: non-adopters, dis-adopters, and adopters. Due to the new and unknown aspects that are inherent to innovations, an open, explorative, and qualitative research approach has been selected to gain insights into factors influencing the (non)adoption of soil-microbes. More specifically, this research explores which innovation traits appear to be crucial for adopting innovations based on soil-microbes and what farmers' perceptions are regarding those traits. Additionally, communication channels important for innovation diffusion are investigated, as they can play an important role in shaping farmers' perceptions and drive innovation diffusion. Lastly, by implementing the DIT, we gain insights as to whether the theory fits and is reflected in farmers' discussions, indicating the theory's relevance and meaning to understanding farmers' perceptions of soil-microbes.

2.2.2. Theoretical framework

To explore the perception and willingness to adopt an innovation, such as soil-microbes, this study applies an extension of the DIT by Rogers (1995) as its theoretical framework. According to Rogers (1995), the uptake and diffusion of innovations is influenced by the *relative advantage* of an innovation compared to the status quo, its *compatibility*, *complexity*, *trialability* and *observability*. A number of other studies also focused on identifying attributes influencing the uptake and diffusion of an innovation (**Table A1**). Several of those are already covered by Rogers' (1995) DIT and are, therefore, not included as additional determinants in this study. This holds for the four attributes suggested by (Tornatzky & Klein, 1982): *cost*, *profitability*, *divisibility*, and *communicability*. *Cost* and *profitability* are already captured in the trait relative advantage of the DIT. Divisibility, as Tornatzky and Klein (1982) note, is closely linked to Rogers' (1995) innovation trait *trialability*. *Communicability* is related to *observability*, because *observability* as defined by Rogers (1995, p. 244) also captures the communication about the innovation. The attribute *voluntariness of use* has been recommended by Moore and Benbasat (1991). However, it is not applicable to our case because no political or social pressure specifically concerning the adoption of soil-microbes exists. The attribute *image* proposed by Moore and Benbasat (1996) is not considered in Rogers' framework (1995). Tornatzky and Klein (1982) picked up a similar attribute referring to it as *social approval*. We extend the framework by considering this dimension in addition to the five innovation traits suggested by Rogers (1995**).** **Table A1** presents an overview of the factors influencing the uptake and diffusion of innovations as derived by Rogers (1995) and other sources. The key premise underlying and justifying the relevance of the DIT is the assumption that innovation traits can influence the acceptance and consequently the adoption of an innovation (Fichman, 1992; van Ittersum et al., 2006). Kuehne et al. (2017) describe the DIT by Rogers (1995) as a key theory that captures factors influencing adoption. According to the authors, the value of the theory is that it allows for a conceptualisation of adoption, but its focus is less on prediction through quantitative approaches.

Besides innovation traits, innovation diffusion is shaped by communication networks. Nutley et al. (2002) defined and categorized sources of communication into: (1) interpersonal communication channels and (2) mass media communication channels. In this study we focus on interpersonal communication to grasp the network around the farmer which is important for diffusion.

2.2.3. Material and methods

By definition, an innovation entails a new subject or idea; therefore, research dealing with innovations requires a suitable methodology that can explore the new and unknown. Tornatzky and Klein (1982) highlighted that the perceptions of the adopter should be at the centre of research which attempts to capture innovation characteristics. An open and qualitative research approach facilitates the exploration of such a new sustainable technology. Accordingly, our analysis is based on in-depth, qualitative interviews and a focus group discussion, to gain insights into farmers' perceptions and the mechanisms driving farmers' (intentions of) adoption with respect to agricultural innovations, such as soil-microbes.

Supplementary Materials, such as the consent form, interview guide, and more materials on the results can be found here https://osf.io/xdn3z (accessed on 9 December 2021, last edits on 9 May 2022). 3.1. Sampling and Participants Qualitative research is often based on small samples. However, in qualitative research, the size of the sample or its representativeness matters less than the depth and breadth of individual opinions that are covered (Boddy, 2016). Corbin and Strauss (1990), who largely coined grounded theory, argue for a "representativeness of concepts, not of persons, that is important" (p. 421). The sampling strategy of our study was based on a snowball sampling approach through partners of the EU-financed MiRA (Microbe-induced Resistance to Agricultural Pests) project in Germany and the UK. As the study focuses on potatoes, locations with relatively high potato production in the area were the starting points for farm visits and interviews with farmers and other stakeholders from the potato industry in both countries. In total, 51 participants from Germany and the UK took part, consisting of 36 farmers and 15 agricultural advisors and other stakeholders. The insights gained from interviews with agricultural advisors and other stakeholders close to potato production were used to triangulate the insights from farmers and put them into wider perspective. However, this study presents the results from the farmer sample only. Overall, our sample size is in line with previous studies. In a review on publications which deal with soil health practices in the United States, the sample sizes of the evaluated qualitative studies ranged from 5 to 17 participants (Carlisle, 2016). The analysis of sample size in qualitative research by Mason (2010) showed that average sample size in selected studies was 28 and Morse (2000) and Bernard (2000) identified that a sample size between 30 and 50 is a suitable sample size to reach saturation in qualitative research. Interviews between the participants and the first author were conducted face-to-face. In a few cases, interviews were conducted with two farmers together or other family members were present during the interview. Most interviews were held in situ on the farms or at the locations of contact, such as event sites. One focus group was organized with farmers from an agricultural advisory group in Scotland. All interviews and the focus group were audio recorded. Before the start of the recording, the interview participants were informed about the research project and the purpose of the interview, and their consent was collected via signature on a consent form.

2.2.3.1. Interview guide and transcripts

Semi-structured interviews were conducted with 36 farmers applying an interview guide. Semi-structured interviews allow the interviews to develop organically, giving more room and flexibility to each respondent's unique background, circumstances, and perspectives. At the same time, it enables the interviewer to address all topics of relevance to the research. No pre-defined categories or quantitative measurements are restricting the participants in their expression, thus, facilitating the expression of subjective views and experiences (Krippendorff, 2004).

The interviews focused on innovations based on soil-microbes and farmers' related perceptions, adoption processes, information, and experiences. The interview guide did not follow a specific theoretical framework, but rather explored farmers' perceptions of the technology and their association or experience with respect to its adoption. This way, a pre-defined theoretical framework that might influence the interviewer, the interview and the created material could be avoided.

All interviews and the group discussion were transcribed. Intelligent verbatim transcripts formed the basis for the content analysis. To ensure the anonymity of all participants, we replaced identifying information, such as names and places, thus creating a pseudonymisation of the transcripts.

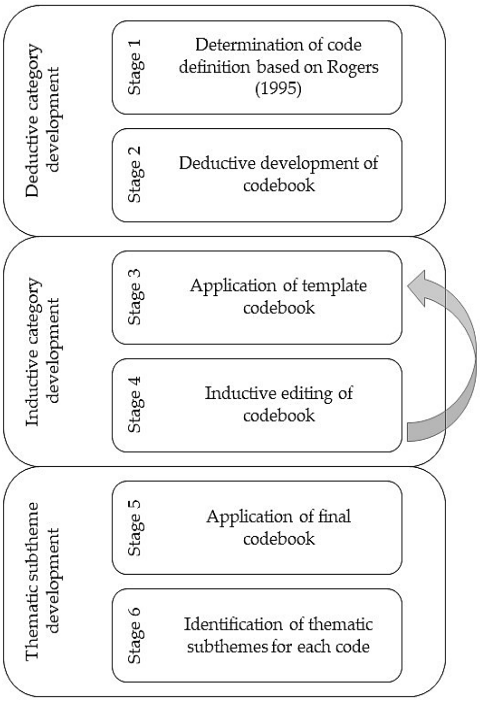
2.2.3.2. Codebook and content analysis

The transcribed interviews were analysed through content analysis. Content analysis tries to capture meaning which is inherent in a text given a particular context (Attride-Stirling, 2001). In this case, the text was created in the context of interviews which addressed perceptions and experiences with innovations. First, the nodes for the content analysis were informed deductively by an extension of

Rogers’ (1995) DIT as derived in Section 2, see Stage 1 in **Figure 7**. Second, the first author tested the codebook with all transcripts; with categories and subcategories arising from data, the framework and codebook were extended inductively. This way, a mixed coding method was applied, using deductive and inductive coding strategies. After the development and adjustment of the template codebook, a random selection of four transcripts was coded by three coders. Divergence in coding was discussed, and minor adjustments implemented. A second round of test coding was conducted with another random selection of two transcripts, and subsequent adjustments were implemented. All three coders conducted the final coding, with each transcript being coded by two coders separately (Stage 5 in **Figure 7**). The data analysis was carried out utilising the software NVivo 13. The final codebook applied is depicted in **Table A2**. Once the transcripts were coded according to the codebook, subthemes were identified within each code inductively. Attride-Stirling’s (2001) thematic analysis approach informed the formation of subthemes: topics that arose at each node were grouped according to an overarching common theme and formed a new subtheme. One coder developed the sub-themes for some of the nodes, another coder screened these sub-themes and the first author finally merged them together. With these sub-themes, the number of occurrences was captured in terms of the number of coded statements. Percentages of the frequency of mentioned statements per code were calculated from the total amount of coded statements per group. Similar to Jabbour et al., it will be assumed that higher occurrences of concepts or subthemes indicate a greater importance of said concept in the decision or adoption process (Jabbour et al., 2014).

On the one hand, the results provide insights about the applicability of the suggested framework for the investigated innovation, which reflects the theory-driven deductive approach. On the other hand, results from the sub-themes highlight in more detail the perceptions and perceived barriers and opportunities of the innovation. These themes can inform future communication strategies towards potential adopters.

Figure 7. Stages of the applied coding process and development of thematic subthemes.



2.2.3.3. Reliability of the coding

Inter-coder reliability was calculated using Cohen's Kappa which provides a common measure of the reliability of two independent assessments. Values below 0.40 are considered to represent poor, values between 0.40–0.75 moderate, and values above 0.75 good reliability (Gisev et al., 2013). Cohen's Kappa between the principal coder and "coder A" is 0.67 and between the principal coder and "coder B" 0.61, thus the overall intercoder reliability can be evaluated as moderate, and, therefore, sufficient. These values were calculated after the first complete round of coding. Subsequently, discussion among all coders with respect to codes of disagreement allowed for small adjustments.

2.2.4. Results

2.2.4.1. Overall sample and adopter groups

The majority of participants were male, reflecting the reality of the agricultural sector, where more than 90% of farmers in Germany and 82% in the UK are male (Bundesministerium für Ernährung und Landwirtschaft, 2019). The share of organic farmers in our sample—36% for the German, and 5% for the UK sample—is large compared to the overall farmer populations of the respective countries. In 2020, 13% of agricultural producers in Germany (Kaufmann et al., 2009) and about 2% of farmers in the UK (Department for Environment Food and Rural Affairs, 2020; Statista, 2022) farmed organically. The farm sizes of the German sample range between 68 and 945 hectares and thus lie well above the average German farm size of 63 hectares in 2020 (Destatis, 2022). In Scotland, the average farm size was 112 hectares in 2019 (Department for Environment, Food and Rural Affairs, 2021), while the farm size in our sample ranges between 161 and 2400 hectares, thus also comprising mostly larger farms. An overview of demographic statistics can be found in **Table 5**.

Table 5. Data collection and sample descriptive statistics by geographical samples (percentage from total, *n* = 36).

		Germany	UK
Data collection period		10–11/2019	02–03/2020
Participants		*n* = 14 (39%)	*n* = 22 (61%)
Interview duration		32–76 min	30–68 min
Mode of production	Conventional production	*n* = 9 (25%)	*n* = 21 (58%)
	Organic production	*n* = 5 (14%)	*n* = 1 (3%)
Hectare (range)	Smallest farm size	68 hectares	161 hectares
	Largest farm size	945 hectares	2400 hectares
Age range		27–63 years old	22–77 years old
Gender	Male	*n* = 14 (39%)	*n* = 19 (53%)
	Female	*n* = 0	*n* = 2 (6%)

Before investigating attributes relevant to the perception and potential adoption of biostimulants and soil-microbes, we investigated farmers' knowledge and experience with respect to these innovations. Thus, all participants were asked whether they had any knowledge or experiences and had adopted biostimulants or similar innovations on their farm. Eighteen of thirty-six farms had no experience at all, whereas the level of adoption and the innovative products applied varied among the ones with experience. Montes de Oca Munguia et al. specifically referred to an adoption process as a fluent pathway with different adoption status (Montes de Oca Munguia et al., 2021); they defined dis-adopters as those who had used the innovation in the past but stopped using it. Based on their indicated level of experience the participants were assigned to one out of three adopter groups: (1) no experience, nonadopter, (2) experience but no adoption, dis-adopter and (3) adopter. An overview of the farmer adopter groups is provided in **Table 6.**

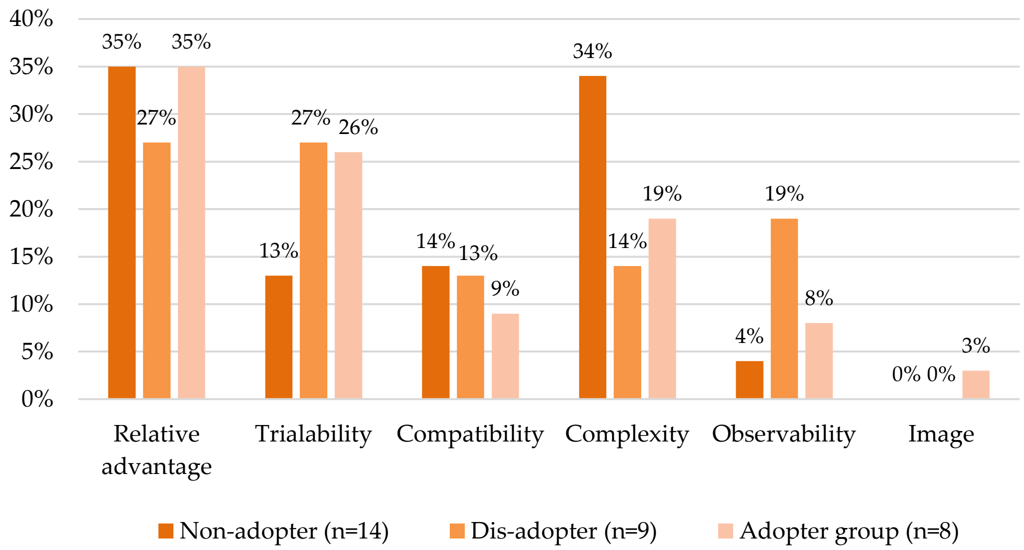
Table 6. Overview of the three adopter groups and corresponding innovations.

Group	*n*	Location	Innovation Adopted or Experienced
No experience, no adoption (non-adopter)	14	Germany: *n* = 3 UK: *n* = 11	Not applicable
Experience but no adoption (dis-adopter)	9	Germany: *n* = 5 UK: *n* = 4	Bacteria, biostimulant, mycorrhiza, plant strengthener, soil additives
Adopter	8	Germany: *n* = 6	Bacteria, biostimulant, ginger quartz, mycorrhiza, plant strengthener, seaweed extract, soil rejuvenator

2.2.4.2. Innovation traits per group

Figure 8 presents an overview of the percentage of coded statements per innovation trait per group. This illustrates how the innovations traits were identified and discussed to a different degree in each adopter group. Altogether, *relative advantage* received most attention compared to the other innovation traits. The non-adopter group discussed aspects of perceived *complexity* strikingly often, whereas statements referring to *trialability* and *observability* were identified less often than in the other groups. The dis-adopter group discussed *observability* relatively often compared to the other groups.

Figure 8. Percentage of coded statements per innovation trait per group.



Detailed results of identified sub-themes of the innovation traits for each group follow.

Non-adopter group

The non-adopter group can be defined as the sub-sample with neither experience nor adoption of innovations, such as biostimulants or similar innovations. Yet, their perspective is valuable from two perspectives: first, their perceptions might provide insights into factors which have hindered adoption and/or diffusion to date. Second, despite their current status as non-adopters, they can be potential late adopters, thus belonging to the group of farmers positioned further right (a later stage) on the diffusion curve. Hence, they are also an important target audience to reach in future efforts to diffuse such innovations.

Sample and context

The non-adopter sample consists of a high share of farmers from the United Kingdom. **Table 7** presents an overview of farmers' socio-demographics. As shown in **Table 7**, the only two female farmers of the sample are both in the non-adopter group. The age and the years of experience of the respondents varies in this sample, between 22 and 65 years, and 2 and 42 years, respectively, with a mean of 44 years and 18 years, respectively.

Table 7. Summary table of socio-demographic statistics of non-adopter sample (*n* = 14).

Demographic Categories		***n***	**Answer Range**
Age		14	22–65 years old (mean: 44 years old)
Experience as farmer (in years)		10	2–42 years of experience (mean: 18 years)
Gender:	Male	12	
	Female	2	

An overview of the farm characteristics of the non-adopters is shown in **Table 8.** It reveals that the sample consists of a strikingly high share of farmers who engage with animal husbandry. This could indicate more diversified farm businesses, and that arable farming plays a minor role in their business. Their farm sizes range from 68 to 800 hectares. Compared to the average of the other adopter groups, the non-adopter group consists, on average, of the smaller farms in our sample, though they are still large compared to the average of the overall population of farmers in their respective country.

Table 8. Summary table of farm statistics of adopter sample (*n* = 14).

Farm Categories	***n***	**Mean**	**Min–Max**
Farm size (h in hectare)	13	310 hectares	68–800 hectares
Organic production	1		
Meadows and forestry	6		
Animal husbandry	10		

Innovation traits

Table 9 shows the identified sub-themes per innovation trait for the non-adopter group.

Table 9. Deductive and inductive coding of innovation traits by non-adopter sample (n = 14).

Relative Advantage			
	Themes	**Occurrences**	**Percentage**
Direct economic factors	Concerns about limitations in resources needed to adopt	12	13.64%
	Concerns about receiving value (for money)	5	5.68%
	Benefit of application delayed after application	2	2.27%
Other factors	Benefits for the plant: health, vitality, growth	4	4.55%
	Support and/or positive effect on yield	3	3.41%
	Benefits regarding nutrients or nutrient uptake	3	3.41%
	Environmentally friendly	3	3.41%
Trialability			
	Themes	**Occurrences**	**Percentage**
	Preference/willingness to test product themselves	7	7.96%
	Concerns about resources needed	5	5.68%
Compatibility			
	Themes	**Occurrences**	**Percentage**
Farm compatibility	Compatibility to other farm practices or measures (need/concern)	3	3.41%
Needs	No other choice left/other choices are decreasing	6	6.82%
	No need identified	4	4.55%
Complexity			
	Themes	**Occurrences**	**Percentage**
Physical effort	Concerns about how to operate the innovation/technology	7	7.95%
	Need for knowledge	2	2.27%
Mental effort	Interactions and functioning unclear	9	10.23%
	General lack of knowledge/understanding	6	6.82%
	Unclear effects and/or variability of effects	4	4.55%
	Complex soil structure	3	3.41%
Observability			
	Themes	**Occurrences**	**Percentage**
	Criteria to evaluate effect of technology	4	4.55%

Note(s): Occurrences are the number of coded statements, and the percentages are based on all occurrences in the non-adopter sample.

Within the trait *relative advantage*, it can be seen that direct economic factors dominate non-adopter farmers' perceived concerns. The non-adopter group has frequently expressed their concern about economic aspects, such as resources required to adopt such innovations, or the (partly insufficient) return they might receive from its application. One farmer in Germany expressed, “[. . .] if it wouldn’t incur so many costs, then this would certainly be something where one says: yes, let’s have a look”. (Farmer ID 41, personal interview, 30 October 2019, quote reference 01, refer to “selected quotes” in the Supplementary Materials). Furthermore, the potentially delayed benefit of using such innovations was expressed. Yet, other aspects of the trait *relative advantage* which do not relate directly to economic factors show that despite the perceived economic challenges the potential advantages for the plant, yield, or regarding nutrients, are acknowledged.

The perceived economic concerns regarding resources needed also played a role with respect to the innovation trait *trialability*. The concern about limitations in required resources was mentioned with regard to trying the innovation. This could potentially be a reason for no experience or, subsequently, no adoption. This need for accessible trials is also indicated with statements referring to farmers’ preferences in conducting their own trials. One farmer in Germany indicated his willingness to trial: “I believe I wouldn’t have a problem trying something. If you look in a small setting whether it works or not. Because if you really wait until others try it, I think a lot of time can pass […]”. (Farmer ID 46, personal interview, 20 November 2019, quote reference 02).

However, despite their lack of experience or adoption, about half of the non-adopter group has expressed the need for such innovations. Several statements expressed this need, such as, “But I think that they [note: biostimulants] will be a part that will become more prevalent in both organic and conventional [farming]. Because especially against the background of the limited available capacities, we already have to think about it”. (Farmer ID 51, personal interview, 26 November 2019, quote reference 03). This indicates that the potential of such innovations is acknowledged. Otherwise, the *compatibility* related to their farm conditions was mentioned as a necessary need or concern.

The coded statements related to *complexity* describe a high degree of perceived uncertainty and perceived complexity of the innovation among the non-adopters. This holds for both the mental ability to understand the innovation and also the physical implementation. The required costs to overcome their lack of understanding or perceived physical effort could form an additional barrier to adoption.

The *observability* of the innovation itself, or mainly of its effectiveness, has been described as an important criterion to evaluate the innovation. This was pointed out by a farmer in the UK:

> Whereas, if I put this can of something on, it is going to increase my, you know, I think the cause is not necessarily something that the everyday farmer can see. So it is a bit of an unknown. [. . .] You don’t have to take all the samples, send them away to a lab and get them analysed, you know. And I think that is potentially you know, a barrier and a fact that is kind of, it is the unknown. (Farmer ID 18, personal interview, 21 February 2020, quote reference 04)

Lastly, no statements relating to the user's *image* were coded more often than once in the non-adopter group.

Dis-adopter group

The sub-sample identified as dis-adopters or experienced farmers can be defined as those farmers that have experience with the innovation, such as conducting trials or temporary implementation on their fields, but discontinued the application. This group may also be called dis-adopter due to the termination of product application. Strictly speaking, this sub-sample would not be allocated on the diffusion curve by Rogers (1995). They cannot be categorized as adopters, but are also different from those without experience. Their perceptions of the innovation are valuable, as they can speak from their unique experience and highlight barriers which may have caused their dis-adoption. Their contribution is valuable to shed light on potential causes of discontinuation of innovation usage after experience.

Sample and context

The dis-adopter sample consists solely of male farmers in Germany and the UK. **Table 10** presents an overview of socio-demographic characteristics of this group. On average, this sub-sample is slightly older (mean 46 years) and slightly more experienced (mean 25 years) compared to the non-adopter group (mean 44 years and 18 years, respectively).

Table 10. Summary table of socio-demographic statistics of the dis-adopter sample (*n* = 9).

Demographic Categories		***n***	**Answer Range**
Age		8	27–63 years old (mean: 46 years old)
Experience as farmer (in years)		8	13–39 years of experience (mean: 25 years)
Gender:	Male	9	

On average, these nine farmers manage 490 hectares, with more than half also being involved in animal husbandry or in managing either meadows and/or forestry. See **Table 11** for an overview.

Table 11. Summary table of farm statistics of the dis-adopter sample (*n* = 9).

Farm Categories	***n***	**Mean**	**Min–Max**
Farm size (h in hectare)	9	490 hectares	70–1200 hectares
Organic production	2		
Meadows and forestry	6		
Animal husbandry	5		

Innovation Traits

The identified sub-themes per innovation trait for the dis-adopter sample are presented in **Table 12**.

Table 12. Deductive and inductive coding of innovation traits by the dis-adopter sample (*n* = 9).

Relative Advantage			
	Themes	**Occurrences**	**Percentage**
Direct economic factors	Concerns about limitations in resources needed to adopt	12	8.16%
	Concerns about receiving value (for money)	12	8.16%
	Advantage by cost of product and/or receiving value for money	2	1.36%
Other factors	Benefits for the plant: health, vitality, growth	6	4.08%
	Benefits for the soil	4	2.72%
	Support with extreme (external) conditions	4	2.72%
Trialability			
	Themes	**Occurrences**	**Percentage**
	Trial experience (in the past)	18	12.24%
	Preference/willingness to test product themselves	8	5.44%
	Call or need for trials	6	4.08%
	Concerns about resources needed	6	4.08%
	Call for support with trials	2	1.36%
Compatibility			
	Themes	**Occurrences**	**Percentage**
Farm compatibility	Compatibility to biophysical circumstances on field or farm level (need/concern)	4	2.72%
	Compatibility to equipment or machinery (need/concern)	4	2.72%
Needs	Need to support plant (soil, water, pest resistance, nutrients)	6	4.08%
	No other choice left/other choices are reducing	3	2.04%
	No need	2	1.36%
Complexity			
	Themes	**Occurrences**	**Percentage**
Physical effort	Concerns about how to operate the innovation/technology	12	8.16%
	Need for knowledge	3	2.04%
Mental effort	Interactions and functioning unclear	3	2.04%
	General lack of knowledge/understanding	3	2.04%
Observability			
	Themes	**Occurrences**	**Percentage**
	Observed results from technology: neutral results	13	8.84%
	Observed results from technology: positive results	4	2. 72%
	Concerns/challenge to observe effect	4	2.72%
	Observed results from technology: negative results	3	2.04%
	Criteria to evaluate effect of technology	3	2.04%

Note(s): Occurrences are the number of coded statements, and the percentages are based on all occurrences in the dis-adopter sample.

Similarly, to the non-adopter sample, it can be seen that within the *relative advantage* concerns related to the innovation's adoption are dominated by direct economic factors in the dis-adopter sample. When comparing the number of occurrences between the two groups, we see that these concerns are frequent in both groups. One farmer described financial return as a reason for dis-adoption:

> But then that fell asleep a bit, because that also cost money, you have to be honest. And I think we also tried something in that direction and tried something out. But somehow we never stuck with it. Because then somehow, it's just a question of money, you simply have to see it that way. It costs money, and if it is not to be recognized then afterwards in the purse, then one leaves again. (Farmer ID 45, personal interview, 19 November 2019, quote reference 05)

However, potential advantages in terms of reduced costs and created value were also identified within the direct economic factors. The majority of advantages created by the innovation were identified in the other factors, through aspects such as benefits created for the plant, the wider environment, and other support mechanisms.

The *trialability* node also revolved around the past experiences and trials that this group had with relevant innovations. Yet, despite their experience as dis-adopters, this group expressed the need for trials as well as for support, and a preference and willingness to conduct further trials. However, concerns about the required resources to conduct trials were also expressed and calls for support were voiced. In this context, one farmer described his experience and time restrictions in conducting trials:

> We have then also, as I said, employed, laid out rows and so on, such an attempt. Well, now we have not evaluated it to the smallest, we have not done that of course. Because there is time missing to do that. (Farmer ID 45, personal interview, 19 November 2019, quote reference 06)

Regarding *compatibility*, in the category farm compatibility, the fit to biophysical circumstances on the farm and with farm equipment was equally expressed as a concern and/or need for adoption. In the needs sub-category, the innovation was identified to meet needed support for the plant but also to meet needs of farmers because there is a decline in the use of conventional products due to stricter legislation. However, in two instances, such innovations were specifically mentioned to be unnecessary.

In the subcategory *complexity* the coded statements reflect the general perceived incomprehensibility in terms of physical and mental effort. In terms of occurrences, these statements were coded even more frequently than in the group of the non-adopters. One farmer indicated his lack of understanding also in a lack of clear guidance:

> What are the kind of guidelines, you know, we know don't put fungicides on during the rain and so on and so forth. There are very simple rules about that. But these things [note: soil-microbes], how do they work, […] where is the guidance to the usage, that is the stuff that is

> going to be tricky and that is going to take time. (Farmer ID 17, personal interview, 19 February 2020, quote reference 07)

The content which deals with *observability* captures mainly how farmers describe the results they could observe from innovation usage. These observed results were described in negative, but also positive terms, both in small frequencies. The majority of observed results were referred to in neutral terms, which could mean that those farmers did not observe any results. Therefore, despite a neutral description of the observed effects, farmers' conclusions or evaluations of the innovation might be negative. The importance of observability was also specifically highlighted by some respondents, as the visible observation of effects is used as a criterion to evaluate the innovation. Thus, the lack of observability of effects has been acknowledged as a concern and/or challenge of such innovations. A farmer in the UK described the challenge of visibility in comparison to fungicides:

> Because, you put a fungicide on a plant or an herbicide on a weed. And the weed either dies, half dies, or doesn't die, and you can visually measure it. The disease either stops in its tracks or never appears in the first place. And you can measure it against a control. Whereas, if you put biology on the soil, you can stick a spade in the ground and, I would imagine the bit of soil next to the bit that you have treated would look exactly the same as the bit that you treated for a while. (Farmer ID 17, personal interview, 19 February 2020, quote reference 08)

Finally, also in the dis-adoption group, no statements related to the user's *image* were coded more often than once.

Adopter group

The adopter group is defined by the fact that they have adopted innovations, such as biostimulants, on their farm at the time of the interview. Given the novelty of the innovation in question, these respondents could potentially be termed so-called early adopters.

<u>Sample and context</u>

The adopter sample consists, on average, of the oldest farmers from the total sample; the mean age is 51 years old. With a mean of 20 years, they remain in the middle field of farming experience; see **Table 13** for an overview.

Table 13. Summary table of socio-demographic statistics of adopter sample (n = 8).

Demographic Categories		***n***	**Answer Range**
Age		8	39–58 years old (mean: 51 years old)
Experience as farmer (in years)		8	9–31 years of experience (mean: 20 years)
Gender:	Male	8	

In terms of farm size, the adopter sample farms span an average of 396 hectares; see **Table 14** for an overview. This group consists of only two farmers (25%) that engage in meadows forestry and one that is involved in animal husbandry.

Table 14. Summary table of farm statistics of adopter sample (*n* = 8).

Farm Categories	***n***	**Mean**	**Min–Max**
Farm size (h in hectare)	8	396 hectares	100–1400 hectares
Organic production	2		
Meadows and forestry	2		
Animal husbandry	1		

Innovation traits

Table 15 presents the adopter group's innovation traits and identified sub-themes (*n* = 8).

Table 15. Deductive and inductive coding of innovation traits by adopter sample (*n* = 8).

Relative Advantage			
	Themes	**Occurrences**	**Percentage**
Direct economic factors	Benefits through the reduction of other inputs	13	9.77%
	Concerns about limitations in resources needed to adopt	10	7.52%
	Concerns about receiving value (for money)	8	6.02%
	Advantage by cost of product and/or receiving value for money	2	1.50%
Other factors	Environmentally friendly	4	3.01%
	Support and/or positive effect on yield	3	2.26%
	Benefits for the soil	3	2.26%
	Benefits for the plant: health, vitality, growth	2	1.50%
	Benefits regarding disease and/or pest protection	2	1.50%
Trialability			
	Themes	**Occurrences**	**Percentage**
	Trial experience (in the past)	10	7.52%
	Call or need for trials	8	6.02%
	Concerns about trial evaluation and/or assessment	6	4.51%
	Preference/willingness to test product themselves	6	4.51%
	Concerns about resources needed	4	3.01%

Compatibility			
	Themes	**Occurrences**	**Percentage**
Farm compatibility	Compatibility to biophysical circumstances on field or farm level (need/concern)	5	3.76%
	Compatibility to equipment or machinery (need/concern)	3	2.26%
Needs	Need to support plant (soil, water, pest resistance, nutrients)	2	1.50%
	No other choice left/other choices are reducing	2	1.50%
Complexity			
	Themes	**Occurrences**	**Percentage**
Physical effort	Concerns about how to operate the innovation/technology	5	3.76%
	Product application unclear	2	1.50%
Mental effort	General lack of knowledge/understanding	9	6.77%
	Interactions and functioning unclear	6	4.51%
	Unclear effects and/or variability of effects	3	2.26%
Observability			
	Themes	**Occurrences**	**Percentage**
	Observed results from technology: positive results	4	3.01%
	Observed results from technology: neutral results	3	2.26%
	Observed results from technology: negative results	2	1.50%
	Concerns/challenge to observe effect	2	1.50%
Image			
	Themes	**Occurrences**	**Percentage**
	Positive evaluation of user	2	1.50%
	Negative judgement/association of user	2	1.50%

Note(s): Occurrences are the number of coded statements, and the percentages are based on all occurrences in the adopter sample.

Within *relative advantage*, the sub-theme direct economic factors consists of more positive factors than was the case in the interviews with the non-adopter and dis-adopter groups. More specifically, benefits through the substitution or reduction of other inputs are mentioned often. However, negative aspects, such as concerns about resources needed for adoption and the potential value they receive, are referred to quite frequently in this group. Other factors in the category relative advantage capture various positive effects for the environment, yield, soil, or plant, which can be potentially achieved when using the innovation. A farmer in Germany also links these advantages to his personal benefits: “So the advantage is actually, if one agrees to work with this product, that the environment agrees with it better than with active substances that I have to choose somehow. Then I have actually already done something for myself”. (Farmer ID 47, personal interview, 18 November 2019, quote reference 09).

The node *trialability* consists of statements about their trial experience in the past but also consists of their concerns regarding the conduct of trials. Farmers expressed a need to implement their own trials and also showed willingness to conduct their own trials.

Concerning *compatibility*, several factors related to the fit of the innovation to specific farm conditions were identified. On the one hand, a concern and need to fit to biophysical circumstances was mentioned. A German farmer described his experience as follows:

> But it is also the case that what was known in the first place is that it does not fit on all soils or all locations or forms of farm business, I say it this way now, and that it does not bring the same success everywhere. (Farmer ID 44, personal interview, 29 October 2019, quote reference 10)

On the other hand, compatibility towards the existing equipment or machinery on the farm was mentioned as an important need or concern. General needs were identified in terms of necessary support for the plant itself. The necessity to establish new products was also mentioned as an important development for the future, mainly because conventional options or alternatives are reducing.

Statements coded under *complexity* indicated, despite their experience and adoption, that the innovation is still perceived as rather complex and unclear. Understanding how the innovation works and how its implementation on the field can look seems challenging.

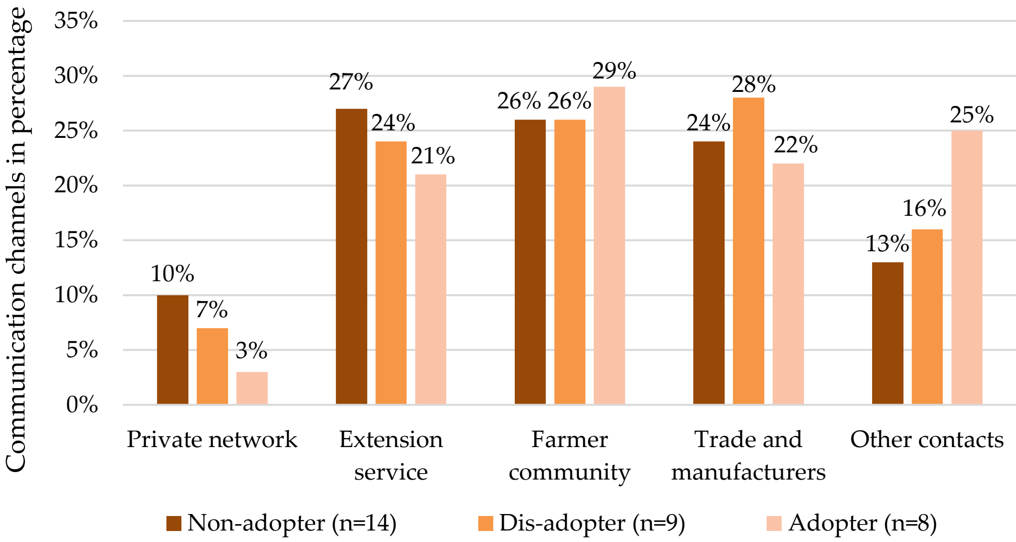
Observability mainly describes the results that farmers of this group have witnessed. The evaluation of these effects appears to be mixed, with slightly more positive than neutral or negative observed results. The challenge to see results was also mentioned in this group.

In the *image* category, both positive and negative evaluations of the user were expressed. One farmer described his view of others experimenting with such innovations and microbes this way: “But there are all these short videos, if you look at it that way. Where they, yes, the freaks I say it that way now, where they report on it and talk about it”. (Farmer ID 44, personal interview, 29 October 2019, quote reference 11).

2.2.4.3. Communication channels

Figure 9 illustrates the relationships respondents mentioned in the interviews as information source for innovations, such as soil-microbes. Identified stakeholders were grouped into several communication channels (see **Table A3** for the absolute numbers of how often each channel was mentioned and the definition of each channel).

Figure 9. Mentioned communication channels in percentage per group.



The identified communication channels reveal that all groups have relatively high percentage scores on the same channels: “extension service”, “farmer community”, and “trade and manufacturers”. Together these three groups account for more than 70% of channels mentioned to obtain information with respect to innovations (72% adopters, 78% dis-adopters and 77% non-adopters). The biggest gap between the different groups appears to be between the relevance of the channels “private network” and “other contacts”. The adopter group clearly engages more with other actors which do not fall in any of the created channels. Whereas, within the “private network” channels, the adopter group engages less than the dis-adopter and non-adopter group.

2.2.5. Discussion

Overall, the comparison between the three adopter groups highlighted that qualitative differences exist in this sample’s perceptions. Striking differences between the groups became clear in the different perceptions related to direct economic factors. More positive aspects were mentioned by the adopter group and dis-adopter group than by the non-adopter group. Another potential obstacle identified in all groups is the challenge and need to observe the effects of the innovation. Due to the nature of how these soil-microbes work, farmers tend to miss any visible proof or demonstration of their effects. A lack of visible proof could also indicate non-effectiveness of the soil-microbes, given that specific conditions (e.g. soil condition or weather) can impact their effectiveness. In an assessment of the traits which influence the adoption of conservation measures, Sattler and Nagel (2010) found that observability came second to risks as a category important for adoption by German farmers. All adopter groups perceive the innovation as rather complex to understand and/or apply. Furthermore, Drobek et al. (2019) mention a lack of knowledge and understanding regarding the functions and application mechanisms of biostimulants as a reason for low adoption rates. In order to come to a decision, trials conducted by farmers themselves appear to be an important step in the decision process. However, those trials must be accompanied by information on the correct application of the innovation. Furthermore, guidance on how to evaluate the effects (visibly or otherwise) is important. Pannell et al. (2006) argued that trialling of innovations will appear more useful to the adopter if high observability can be ensured, as this will allow for more conclusive trials. Concerns were voiced regarding resources and observability, which also applies to trials. This stresses again the need for support to be offered to potential adopters. Despite their different levels of experience, the need for such innovations was acknowledged in all groups. All in all, perceptions that refer to challenges linked to adoption could be identified in all groups, and also for those farmers who already adopted such innovations.

From a theoretical point of view, all concepts were identified in the discussions with farmers. Only the extension of the theoretical framework by the concept image of the user was found solely in the adopter group. In a review of diffusion studies, Kapoor et al. (2014) show that many studies increasingly incorporate attributes that go beyond the DIT framework. However, in our study the theoretical extension proved relevant only in few instances.

Farmer networks are known to moderate farmers' perceptions of innovations and thus also diffusion patterns. Wood et al. (2014) results indicate that innovation processes in agriculture are also determined to a great extent by the farmers' own networking processes. Diederen et al. (2003) researched adoption of agricultural innovations in the Netherlands. The authors found that the farmer network, measured as the number of farmers' memberships in agricultural initiatives, is positively related to adoption. Across the three farmer groups studied here, three stakeholders proved to be especially important in providing innovation-related information to farmers: actors from the extension service, from manufacturers and trade, and the farmer community. Blasch et al. (2022) determined that the chances of adoption of precision farming technologies rise with farmers who can observe the technology being used by other farmers. In the context of no-till farming in England, Skaalsveen et al. (2020) network analysis showed that no-till networks spread geographically over wide areas, as neighbouring farmers are not necessarily engaging with the same innovative practice. Hence, this supports the conclusion that other farmers, especially from their network, can play an important role in the diffusion of innovations. Blasch et al. (2020) also found that for Italian farmers the information of advisors from extension service are the most relevant source of information. Strikingly, in our sample the adopter group also frequently referred to a variety of other stakeholders, which were not explicitly categorized for this study. This indicates that other, more fragmented communication channels appear more frequently among the adopter group.

This study focused on the farmer as the main decision maker in the adoption of soil-microbes. Yet, other stakeholders or communication channels can still play an important role in the diffusion of soil-microbes and biostimulants. An additional fifteen interviews were conducted with a variety of stakeholders from the potato industry in Germany and the UK. Results of these interviews are reported in the Supplementary Materials and generally reinforce our findings based on the farmer sample. However, future research could focus more on perspectives of key up- and downstream stakeholders who are important for the diffusion of innovations.

2.2.6. Conclusions

During the start of data collection in Germany, many German farmers engaged in protests to show their disagreement with political decisions and perceived external pressures potentially threatening their businesses (Deutschlandfunk, 2019). These farmers were voicing their concerns over the future viability of agriculture as we know it today. These concerns point towards a need to integrate the farm perspective in the development of technological and institutional solutions or innovations for sustainable agriculture. Our study provides first insights regarding drivers of perceptions of one such innovation—the uptake of beneficial soil-microbes.

However, some caveats of this study are worth noting. Given the qualitative nature of our study and our, accordingly, relatively small sample size consisting of potato farmers from two regions, no conclusions can be drawn towards the overall farmer population in the UK nor in Germany. Instead, our focus was on the depth and breadth of opinions, which exhibited a remarkable degree of nuance and diversity. Another limitation lies in the process of data generation and analysis. The process of data generation and analysis emerged from the same research process. However, because the theoretical framework of the content analysis was not yet defined at the time of data collection, we can assume that the interviews were still conducted without a bias in this direction. Another common bias in personal interviews is a possible social desirability bias. The participants' answers may be biased towards more acceptable and desirable answers. Knowing that the interviewer conducts research on soil-microbes may have contributed towards a less critical conversation about biostimulants or soil-microbes with the farmers. On the other hand, the fact that at the time of interviews, farmers in Germany were protesting against environmental and farm animal regulation, could have made farmers more critical with respect to the topic.

Considering these limitations, this research provides explorative insights into perceptions of beneficial soil-microbes from the (potential) adopters' perspectives, which were previously hardly discussed in an academic context. Our research has shown that farmers in Germany and the UK still perceive soil-microbes and biostimulants as challenging products for adoption, despite different levels of experience with such innovations. Simultaneously, positive aspects were acknowledged by all adopter groups, specifically with slightly more positive perceptions in the groups with more experience. The concepts of the innovation traits by Rogers (1995), relative advantage, compatibility, complexity, trialability, and observability, helped capture perceived challenges or advantages. As potential barriers for diffusion, the traits complexity and observability were often perceived negatively or as a challenge. Within perceived relative advantages and compatibility, aspects which can contribute positively but also aspects which can challenge a diffusion of the soil-microbes were mentioned. Future communication efforts of such innovations could benefit from taking up the identified perceived challenges and concerns. Possible actors who might engage in such communication strategies are those from extension services and manufacturers themselves. Additionally, many farmers refer to other farmers from their network; thus, communication between farmers can serve as an important channel for exchange and diffusion.

Appendix

Table A1. Definition of innovation characteristics identified by Rogers (1995) and additional sources.

Innovation Characteristic	Definition	Reference
Relative advantage *	Relative advantage is the degree to which an innovation is perceived to be better than the idea it supersedes. The degree of relative advantage is often expressed as economic profitability, social prestige, or other benefits.	Rogers, 1995, p. 212
Cost	The cost of an innovation.	Tornatzky and Klein, 1982, p. 36
Profitability	Profitability is the degree to which an innovation may create profit through adoption, this may not be applicable to all innovations.	Tornatzky and Klein, 1982, p. 37
Compatibility *	Compatibility is the degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters. An innovation that is more compatible is less uncertain to the potential adopter and fits more closely with the individual's life situation.	Rogers, 1995, p. 224
Complexity *	Complexity is the degree to which an innovation is perceived as relatively difficult to understand and use. Any new idea may be classified on the complexity–simplicity continuum.	Rogers, 1995, p. 242
Trialability *	Trialability is the degree to which an innovation may be experimented with on a limited basis. New ideas that can be tried on an instalment plan are generally adopted more rapidly than innovations that are not divisible.	Rogers, 1995, p. 243
Divisibility	Divisibility is the "extent to which an innovation can be tried on a small scale prior to adoption", which is closely related to trialability. This trait describes to what degree the innovation can be tried only in separate parts.	Tornatzky and Klein, 1982, p. 37
Observability *	Observability is the degree to which the results of an innovation are visible to others. The results of some ideas are easily observed and communicated to others, whereas some innovations are difficult to observe or to describe to others.	Rogers, 1995, p. 244
Communicability	Communicability is the degree to which an innovation can be communicated to others, which is closely related to observability.	Tornatzky and Klein, 1982, p. 36
Image *	Image is the degree to which using an innovation is perceived to enhance one's image or status in one's social system.	Moore and Benbasat, 1996, p. 173
Social approval	Social approval is the degree to which status can by gained due to adoption.	Tornatzky and Klein, 1982, p. 37

Innovation Characteristic	Definition	Reference
Voluntariness of use	The degree to which use of the innovation is perceived as being voluntary, or of free will.	Moore and Benbasat, 1991, p. 203

* Innovation traits included in theoretical framework and codebook (deductive codes).

Table A2. Codebook.

Code	Description	Literature / Reference	Coding Rule
Relative advantage	Relative advantage is the degree to which innovation is perceived as being better than the idea it supersedes. The degree of relative advantage is often expressed as economic profitability or other benefits. The nature of the innovation determines what specific type of relative advantage is important to adopters.	Rogers, 1995, p. 212	Any statements related to social advantage or prestige code under 'image'.
Direct economic factors	Code perceptions about relative economic advantages and disadvantages associated with the innovation.		
Non-economic factors	Code perceptions about relative non-economic advantages and disadvantages associated with the innovation.		
Compatibility	Compatibility is the degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters. A more compatible idea is less uncertain to the potential adopter and fits more closely with the individual's life situation. Such compatibility helps the individual give meaning to the new idea to be regarded as familiar.	Rogers, 1995, p. 224	Only code in subcodes.
Sociocultural values *	Perceived compatibility or incompatibility with sociocultural values and beliefs.	Rogers, 1995, p. 224	
Previous ideas	Perceived compatibility or incompatibility with previously introduced ideas/previously adopted ideas.	Rogers, 1995, p. 224	
Needs	Perceived compatibility or incompatibility with (the farmers') needs for the innovation.	Rogers, 1995, p. 224	
Farm compatibility	Perceived compatibility or incompatibility with farm-specific conditions, infrastructure, and environment. This includes, for example, available equipment or machinery.		
Other (compatibility) *	Other aspects of perceived compatibility.		
Complexity	Code perception of the innovation's complexity. Complexity is the degree to which an innovation is perceived as relatively difficult to understand and use. Some innovations are clear in their meaning to potential adopters whereas others are not.	Rogers, 1995, p. 242	Only code in subcodes.

Code	Description	Literature / Reference	Coding Rule
Mental effort	Code perceived complexity with regard to mental effort or difficulty.	Davis, 1985, p. 26	
Physical effort	Code perceived complexity with regard to physical effort or difficulty.	Davis, 1985, p. 26	
*Other (complexity) **	Other perceptions regarding complexity.		
Trialability	Code perception of the innovation's trialability. Trialability is the degree to which an innovation may be experimented with on a limited basis. New ideas that can be tried on the instalment plan are generally adopted more rapidly than innovations that are not divisible. Some innovations are more difficult to divide for trial than are others. The personal trying-out of an innovation is a way to give meaning to an innovation, to find out how it works under one's own conditions.	Rogers, 1995, p. 243	Code observability in trials or observability due to trials in "observability" code
Observability	Code perception of the innovation's observability. Observability is the degree to which the results of an innovation are visible to the farmer (user), others and potential adopters. The results of some ideas are easily observed and communicated to others, whereas some innovations are difficult to observe or to describe to others.	Rogers, 1995, p. 244	
Image	Code perceptions of image changes. Image is the degree to which using an innovation is perceived to enhance one's image or status in one's social system. Social approval is the degree to which one's status can be increased due to the innovation.	Moore and Benbasat, 1996, p. 137; Tornatzky and Klein, 1982, p. 37	
Image (positive)	Positive enhancement of one's image due to the innovation.		
Image (negative)	Negative enhancement of one's image due to the innovation.		
Adoption	Statements describing the participant's actual and/or previous direct usage or direct experience with innovations (behavioural response). This includes statements about current and past usage and experiences.		Only code in subcodes. Code yes or no statements if generic answers, code innovation itself if innovation-specific statements are given.

Code	Description	Literature / Reference	Coding Rule
			Only applicable for farmer sample.
Yes (general)	Statements describing previous usage or experience with innovations. Can be undefined time commitment/implementation phase or long-term integration/adoption.		
Yes (past)	Statements describing previous usage or experience with innovations but discontinued the usage (so no long-term implementation), that is, trials only.		
No (use)	Statements describing no usage nor experience with innovations.		
Communication channels	Statements or simple terms and phrases that mention the stakeholder relevant for sources of information or diffusion, contact points which provide information/innovation or similar. This refers to general contact points (not innovation-specific). Subcodes: Extension service (private), extension service (public), manufacturers, agricultural trade, farmers (neighbourhood), farmers (network), family, friends, neighbours (non-farmer), academia/researcher, other stakeholder		Only code in sub-codes. Ordinal subcodes. Only mark the term/name for the stakeholder.

* Codes excluded due to low occurrence/low number of coded statements.

Table A3. Communication channels.

Channels	Explanation	Non-Adopter		Dis-Adopter		Adopter	
		n	*%*	*n*	*%*	*n*	*%*
Private network	Family, friends, neighbours	12	10	6	7	3	3
Extension service	Private and public extension services	31	27	21	24	23	21
Farmer community	Farmer neighbours, networks, associations	30	26	23	26	32	29
Manufacturers and trade	Manufacturers and trade	28	24	25	28	24	22
Other contacts	I.e. academia, staff, organic organizations	15	13	14	16	28	25
Total		116	100	89	100	110	100

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2.3. Sustainability transitions rooted in agricultural innovation adoption: what drives farmers' intentions to use soil microbes in potato cultivation [3]

Abstract. Beneficial soil microbes have been identified as a promising tool for sustainable food production. They can support a plant on a variety of levels, and adoption of these microbes could result in a reduced usage of pesticides and fertilisers. However, for this transition in farming practices, the farmer needs to implement the innovation. Therefore, it is crucial to understand what drives farmers' intentions to adopt innovations based on beneficial soil microbes. Our study contributes to the literature by applying and extending the Theory of Reasoned Action with elements of previously used theoretical frameworks, thereby gaining insights into factors driving innovation adoption. The results highlight that attitudes, norms and perceived usefulness impact farmers' intentions to use soil microbes. Perceived usefulness in particular stands out as a core construct. Risk, environmental attitudes, and control beliefs, however, were not found to have an effect. This demonstrates that innovation-specific measures have a greater impact than general personality and attitudinal related constructs. These insights could be useful for initiatives to promote the diffusion of soil microbes, with e.g. communication efforts focusing on the innovation's usefulness being especially promising. Furthermore, our findings indicate that other farmers and agricultural advisors stand out as a potential suitable communication channel to foster the diffusion of beneficial soil microbes.

Keywords: Farmer Acceptance; Innovation Adoption; Sustainability; Soil microbes; Behavioural Theories; Diffusion

Supplementary materials: Data is shared and available in the following OSF folder: https://osf.io/4yarw/?view_only=c1380847a0fb4241b26288782920cf78

[3] This subchapter is based on a paper that has been submitted as: Ploll, U., Yeh, C.-Y., Hüttel, S, J., & Hartmann, M. (2023). Sustainability transitions rooted in agricultural innovation adoption: what drives farmers' intentions to use soil microbes in potato cultivation. *Journal of Agricultural Economics.*

2.3.1. Introduction

Agricultural production systems are subjected to growing pressure to adapt to changing external conditions and simultaneously to reduce the environmental harm that they are causing. Synthetic pesticides are increasingly rendered less effective due to the development of resistances (Gould et al., 2018), and their application also poses risks to the environment and human health (Rani et al., 2021). In response, more and more active ingredients have had their acceptance revoked in the European Union (EU) or are in the process of losing their license. Additionally, agricultural production conditions will be increasingly challenged by the consequences of climate change, such as severe weather events (Raza et al., 2019). Therefore, new approaches with a sustainable perspective are needed to overcome this intensification of challenges and constraints in previously available and/or desired production instruments. In line with these developments, the EU fosters solutions for pest control based on natural formulas to replace synthetic ingredients (Drobek et al., 2019). One promising example of promoting sustainable production systems is products based on beneficial soil microbes (Elnahal et al., 2022; Rouphael & Colla, 2018; Singh et al., 2011). Such soil microbes enter into a relationship with a host plant through its roots and provide various beneficial effects; for example, they can support plants' health and resilience to pests and pathogens (Castiglione et al., 2021; Ferlian et al., 2018; Pascale et al., 2018). Recently, the EU included microorganisms for the first time as potential substances in relevant regulations (Kowalska et al., 2020): in the fertiliser regulation (Regulation (EC) No 2019/1009), but also in the regulation on plant protection products (Regulation (EC) No 1107/2009). This shows that there is political interest in microbial applications in agriculture, and new regulations are providing new frameworks for development and marketing.

To foster a successful transition of agricultural production conditions, it is crucial to understand which factors motivate and support farmers to implement changes on a farm level. This paper contributes by studying behavioural determinants of German farmers adopting innovations involving beneficial soil microbes to enhance sustainable production. By focusing on behavioural factors (innovation-specific, personality-related, and attitudinal), the study examines how these influence farmers' intentions to use such products, using potatoes as a model crop due to their value and established benefits of soil microbes (Caradonia et al., 2022). This research adds to the existing literature, aiming to promote the diffusion of sustainable agricultural practices through understanding farmers' adoption behaviour. While insights into beneficial soil microbes have been promising (Rouphael & Colla, 2020), widespread adoption remains limited. To facilitate this adoption, understanding farmers' decisions is crucial. Various studies have explored behavioural determinants in on-farm decisions, leading to diverse theoretical applications and extensions (Dessart et al., 2019; Foguesatto et al., 2020; Giua et al., 2021; Prokopy et al., 2019; Sok et al., 2020). This study builds upon the Theory of Reasoned Action (TRA), incorporating elements from the Theory of Planned Behaviour (TPB), Technology Acceptance Model (TAM), and insights on risk and environmental attitudes.

This paper examined adoption intentions among potato farmers through a self-reported survey in spring 2021. The study builds on the theory of reasoned action (TRA) and extended models, such as an added perceived usefulness (PU), a construct from the technology acceptance model (TAM). Data analysis using partial-least-square structure-equation-modelling (PLS-SEM) and ordinary least square analyses (OLS) support the results that the TAM-based extension was the most successful, with PU playing a central role in explaining attitudes and intentions. Notably, only innovation-related constructs contribute to explaining intentions, while generic personality and attitudinal traits do not enhance our understanding of adoption intentions.

2.3.2. Background and literature review

Beneficial soil microbes occur naturally in untreated soils and can extend their potential via an inoculation to commercial agricultural fields (Calvo et al., 2014; Ray et al., 2020). They are increasingly marketed as biostimulants (Corsi et al., 2022). The functions that beneficial soil microbes can provide for plants include increased health, robustness and protection; for example, supporting plants' defence mechanisms and providing support under drought conditions (Elnahal et al., 2022; Ferlian et al., 2018; Kowalska et al., 2020). Beneficial soil microbes work in symbiosis with a host plant and can affect the plant's original root architecture (Siddiqui et al., 2008). By means of this symbiosis, the nutrient status and nutrient uptake of the host plant can be improved, leading to an overall improved fertilization efficiency (Gianinazzi et al., 2010). Specific to potato production, research has also shown that microbial applications increased growth, tolerance to stress, tuber size and nutrient content (Caradonia et al., 2022).

Their potential effects offer sustainable alternatives to synthetic fertilizers and pesticides (Elnahal et al., 2022). However, effectiveness can be context-dependent, influenced by factors like soil tillage, irrigation, and chemical presence (Lee Díaz et al., 2021; Santos et al., 2019; Rouphael et al., 2015). Nonetheless, ongoing research improved our understanding, hinting at future formulations that could enhance their commercial agricultural application (Ray et al., 2020).

For commercial agricultural field applications, farmers would apply beneficial soil microbes through an inoculum, inoculant carrier or seed coating (Bashan et al., 2014; Parnell et al., 2016). When using an inoculum, the microbes establish a symbiotic relationship with the host plant underground; they can be applied either with seeds or plantlets. Unlike visible or more disruptive innovations, this process lacks visibility, preventing the transfer of insights from other adoption research.

To the best of our knowledge, only two studies addressed the acceptance of soil microbes among farmers. One Dutch study found that risk-loving farmers tend to have higher intentions to use microbe-based products, while another study involving Dutch and German farmers identified factors such as trust, knowledge about microbes, and application support as key determinants of adoption (Tensi & Ang, 2023; Tensi et al., 2022). The latter study applied the behaviour change wheel framework by

Michie et al. (2011, 2014), although its implementation was challenging due to missing validated scales and numerous required responses (Tensi et al., 2022). Thus, our approach employs a versatile behavioural framework adaptable to the agricultural sector, incorporating theoretical insights and empirical findings. In the agricultural context, reasoned action approaches have been applied in a wide field of farmers' management decisions including those related to innovation (Sok et al., 2020). Within this framework, attitudes and norms determine behavioural intentions (Madden et al., 1992). In the TPB, behavioural intentions are additionally explained by perceived behavioural control (PBC) (Ajzen, 1991). For instance - as defined by theory - attitude, norms and PBC predicted farmers' intentions to reduce pesticide usage (Bakker et al., 2021). Numerous agricultural studies that employed the TPB showed that all of its constructs are important predictors of behavioural intentions (i.e., adopting improved grassland: Borges et al., 2014; Borges et al., 2016; supplying biogas plantation: Chin et al., 2016; implementing conservation programs: Deng et al., 2016; organic farming: Läpple & Kelley, 2013; implementing environmental measures: van Dijk et al., 2016). While some agricultural studies partially support TPB constructs (i.e., conservation behaviour: Beedell & Rehman, 2000; application for support: Stojcheska et al., 2016; water conservation behaviour: Yazdanpanah et al., 2014).

The TAM, introduced by Davis (1985) for studying technology acceptance, has found widespread applications in innovation acceptance (King & He, 2006). It models attitude using PU and PEU (Davis, 1985), later expanded as „TAM2" and „TAM3" by Venkatesh (2000, 2008). In these adaptations PU and PEU directly impact intentions, but also other factors were included. These theoretical adaptations highlight that the TAM and TPB are frequently combined or extended to better understand adoption decisions (Venkatesh et al., 2003). As one of its key constructs, it has been shown that PU plays a determining role in technology adoption also in the agricultural context (Aubert et al., 2012; Caffaro et al., 2020; Flett et al., 2004).

As a general personality characteristic, several studies have illustrated that a perceived stronger internal locus of control (LOC) relates to a stronger belief in change due to one's actions (Giefer et al., 2019; Kollmuss & Agyeman, 2002; Wuepper et al., 2020). In the agricultural field, studies have shown that (internal) LOC can play an important role in impacting adoption decisions or behavioural intentions (i.e., in technology adoption: Abay et al., 2017; adoption of biogas technology: He & Veronesi, 2017; adoption of modern farm technologies: Taffesse & Tadesse, 2017).

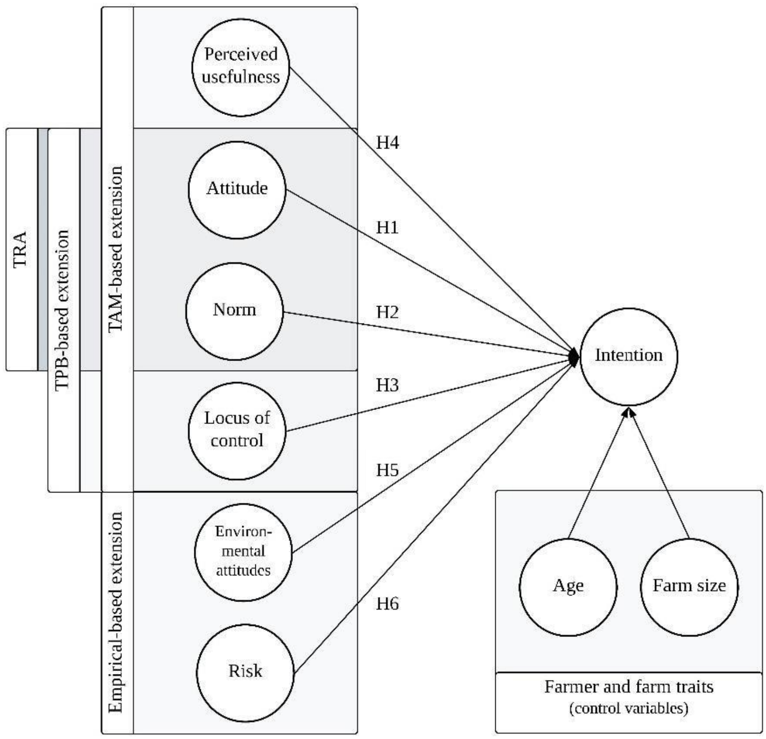
Environmental awareness has been shown to positively influence adoption of best management farming practices (Baumgart-Getz et al., 2012). Bakker et al. (2021) showed that a stronger belief in environmental benefits from pesticide reduction drives farmers' intentions to reduce pesticide usage. Further, ecological worldviews shape farmers' assessment of bioeconomy measures' external aspects (Wensing et al., 2019). Reviews highlight environmental threat awareness driving adoption in conservation agriculture (Knowler & Bradshaw, 2007) and sustainable soil management (Bartkowski & Bartke, 2018), alongside economic considerations.

Research indicated that farmers' risk attitudes influence farmers' adoption of innovations and sustainable production measures (Baerenklau, 2005; Dessart et al., 2019; Kallas et al., 2010). Generally, European farmers also exhibit risk aversion (Iyer et al., 2020; Meraner & Finger, 2018). To increase the predictive abilities of the TAM, King and He (2006) identified risk as one of the major extensions in TAM-related research. Finally, as Tensi & Ang (2023) have shown, risk attitudes served as an important predictor of farmers adoption intentions of microbial products.

2.3.3. Theoretical approaches and hypothesis

The overall approach of this research builds on three theories: the TRA (Ajzen & Fishbein, 1980), the TPB (Ajzen, 1991) and the TAM (Davis, 1985). Attitudes and social norms are elements from the TRA and the TPB. Perceived behavioural control from the TPB, however, we measure general control beliefs through the LOC. PU is investigated as a key element from the TAM. These theoretical approaches were further extended with relevant constructs from empirical research: risk and environmental attitudes. **Figure 10** depicts the investigated conceptual model(s) and tested hypothesis.

Figure 10. Investigated models and relationships.



Note(s): H = Hypothesis.

The TRA is based on two constructs: attitude and norms. Attitudes can be divided in two components of attitudes: affective and cognitive evaluations (Ajzen, 2001). Given that evaluation of beneficial soil microbes takes place in the context of a business decision, we assume that cognitive evaluations are of superior relevance.

The concept of normative pressure, distinguishes between descriptive and injunctive norms. Descriptive norms are normative beliefs as to whether important others engage in the behaviour in question; injunctive norms are determined by the perceived expectations of important others and degree to which a person wants to comply with their opinions (Ajzen, 2020; Fishbein & Ajzen, 2010). Because our behaviour of interest deals with the adoption of a new production method, it can be assumed that farmers cannot observe this behaviour by other farmers. For that reason, we focus on injunctive norms.

PBC captures beliefs about one's abilities to perform a behaviour (Ajzen, 1991). Our study focuses on a hypothetical product with inherent application uncertainties, potentially affecting individuals' ability to judge control over adoption. Hence, we use a more generic construct, Locus of Control (LOC), to capture control beliefs influencing intentions (Abay et al., 2017; He & Veronesi, 2017; Taffesse & Tadesse, 2017). LOC, rooted in social learning theory, measures whether behavioural outcomes arise from personal capabilities, external factors, or luck (Rotter, 1966). Different control allocations are termed internal and external LOC. Transferring the relationships modelled in the TRA and the TPB, the following hypotheses were formulated for our research on the potential adoption of soil microbes:

Hypothesis 1: Favourable attitudes toward adopting beneficial soil microbes have a positive impact on intentions to use beneficial soil microbes in potato cultivation.

Hypothesis 2: Social norms that are in favour of innovation adoption have a positive impact on intentions to use beneficial soil microbes in potato cultivation.

Hypothesis 3: A strong internal LOC has a positive impact on intentions to use beneficial soil microbes in potato cultivation.

In the TAM, key concepts are PU and PEU (Davis, 1985), whereby, PU and PEU impact behavioural intentions and then intention impacts behaviour (Venkatesh, 2008). Similar to PBC, we assume that an evaluation of PEU is only possible with more specific information on product application processes; therefore, it is not part of our analysis. As a central concept of the TAM, it is hypothesised that the PU is relevant in explaining innovation adoption and we thus add:

Hypothesis 4: Perceived usefulness of beneficial soil microbes positively impacts intentions to use beneficial soil microbes in potato cultivation.

Against the backdrop of the research subject, additional relevant psychological constructs were included in this study. Because beneficial soil microbes can be classified as sustainable agricultural innovation, we formulated the following hypothesis:

Hypothesis 5: Environmental concerns positively impacts intentions to use beneficial soil microbes in potato cultivation.

It was shown that risk attitudes can play an influential role in impacting intentions to adopt microbial applications (Tensi & Ang, 2023). However, risk attitudes can vary over the context or domain in which the risk choices or behaviour take place (Dohmen et al., 2011; Finger et al., 2023). Therefore, we test the relevance of a domain-specific risk measure. It is hypothesised that:

Hypothesis 6: A high level of risk aversion negatively impacts intentions to use beneficial soil microbes in potato cultivation.

In addition to the psychological characteristics of the farmer, often socioeconomic characteristics have been included to explain farmer behaviour or adoption choices. Other research has considered demographics such as farm size, age, income or education in adoption studies (Adrian et al., 2005; Aubert et al., 2012; Baumgart-Getz et al., 2012; Blasch et al., 2020; Defrancesco et al., 2008; Foguesatto et al., 2020; Hasler et al., 2017; Lemken et al., 2017; Pierpaoli et al., 2013). Burton (2014) questions the causal relationship often identified in research between farmers' demographic characteristics and environmental behaviour, and attributed his criticism to various limitations such as a lack of framework or inconsistencies in results. Taking these factors into account, socioeconomic characteristics such as farm size and age are included as control variables in the model.

2.3.4. Materials and methods

2.3.4.1. Study context and data collection

The online survey was conducted in early spring 2021 among recognized potato-cultivating training farms in Germany. These farms, officially registered and regulated by local authorities (BBiG, 2005/2022), provide apprenticeships for agricultural vocational training, functioning as knowledge transmitters. Participants were recruited from websites in nine German federal states, employing a stratified random sampling of 50% of available contact points out of 951. Participants were incentivized with the chance to receive a trial package of a product based on soil microbes. After contacting via phone and email, 63 complete observations resulted as the initial sample. Due to a low return rate, the strategy was adjusted, resulting in a final convenience sample of 102 complete responses (11% response rate) after dataset cleaning. This study was pre-registered before data collection. The required sample size was calculated using the inverse square root method following Hair et al. (2021). For the calculation, the path coefficient was determined by taking the average of coefficients of relevant constructs in other studies conducted in the agricultural context (Aubert et al., 2012; Bakker et al., 2021; Borges et al., 2014; Borges et al., 2016; Chin et al., 2016; Deng et al., 2016; Hüttel et al., 2020; Läpple et al., 2013; Mohr & Kühl, 2021; Van Dijk et al., 2016). Thus, using a path coefficient of 0.245, a significance level of 5% and statistical power of 80% resulted in a sample size of 103.

2.3.4.2. Information provision

With a hypothetical product based on beneficial soil microbes, there will inherently be many unknown details. This can substantially impact the farmers' evaluation of beneficial soil microbes. To ensure that our participants had the same initial starting point and no bias due to understanding of the innovation, an information sheet about beneficial soil microbes was provided to participants (see Appendix, **Figure A1**). A comprehension check was conducted after the information sheet was provided to check understanding.

This information sheet was developed by considering the unique aspects of this innovation and incorporating feedback from an agricultural advisor. Above-ground effects on the plant are described: generally stronger and healthier plants, less harm by pests, bigger canopy and support under stress conditions (Gianinazzi et al., 2010; Rouphael et al., 2015; Singh et al., 2011). In relation to the underground aspects, the information sheet outlined: reduced phosphate soil status is preferred, the effect on nutrient status and the required application next to the roots (Basu et al., 2018; Chen et al., 2018). Further aspects were presented: (1) compatibility with organic and conventional farming; (2) timing of application; (3) cost related information; and (4) performance variability and observability deficits (Ferlian et al., 2018; Lee Díaz et al., 2021; Parnell et al., 2016).

2.3.4.1. Measurement scales

In the survey, three core blocks of data were collected: (1) descriptive items about the farm and farmer; (2) items measuring innovation-specific constructs: intention, attitude, injunctive norms, and PU; and (3) items measuring personality and attitudinal characteristics: LOC, risk attitudes and environmental attitudes. All latent constructs and corresponding items can be found in the Appendix, **Table A4**. The complete survey and further supplementary materials can be found in the OSF folder. [4]

Innovation-specific constructs

The key dependent variable of interest is the „intention to use beneficial soil microbes". The latent construct was measured with three items based on Fishbein and Ajzen (2010). Attitudes toward the usage and trialling of innovations were measured with four bi-polar items (based on Ajzen & Driver, 1992; Borges et al., 2014; Lynne et al., 1995). PU was measured with three survey items adapted from Naspetti et al. (2017). Some studies on the adoption of farming methods or participation in agricultural schemes have illustrated that social norms in the form of injunctive beliefs play an important role in influencing behaviour (i.e., adopting improved grassland: Borges et al., 2014; scheme participation: Defrancesco et al., 2008 and Le Coent et al., 2018; digital fertilisation: Hüttel et al., 2020). Injunctive norms are determined by injunctive normative beliefs (b) about a certain referent group or individual

[4] OSF folder: https://osf.io/4yarw/?view_only=c1380847a0fb4241b26288782920cf78.

(i); and the motivation to comply (m) with the referent group or individual in question (i) (Fishbein & Ajzen, 2010). Thus, injunctive norms per referent group are then operationalised by multiplying belief strength (b_i) with the motivation to comply (m_i). Based on literature, several referent groups were formulated: agricultural advisors (Bakker et al., 2021; Borges et al., 2014; Hüttel et al., 2020; Kaufmann et al., 2009; Läpple & Kelley, 2013; Läpple & van Rensburg, 2011; Skaalsveen et al., 2020), farmers from the region (Borges et al., 2014; Defrancesco et al., 2008; Hüttel et al., 2020), farmers from their network (Lalani et al., 2016; van Dijk et al., 2016), non-governmental organisations (Beedell & Rehman, 2000; Lalani et al., 2016) and end-consumers (Kaufmann et al., 2009). All of the abovementioned items were measured on a 7-point answer scale.

Personality characteristics and attitudinal constructs

LOC was measured with the short scale developed in German by Jakoby and Jacob (2014). Internal and external LOC each consist of three items, all measured on a 5-point answer scale.

A common risk measure involves a lottery task by Holt and Laury (2002); however, Dohmen et al. (2011) illustrate that also a single general risk measure turned out to be a reliable predictor of certain risky behaviour (Dohmen et al., 2011). Therefore, risk was first measured generally, and then measured once with regard to plant protection in potato production. The analysis was conducted with the domain specific risk measure, which captures risk attitudes in potato production.

One way to measure environmental concerns or attitudes is the new ecological paradigm (NEP) scale (Dunlap & van Liere, 1978). A version of the NEP scale with 12 items was tested using a farmer sample to prove its reliability, validity and dimensionality (Albrecht et al., 1982). In our study, a short version of the NEP scale was implemented based on Hawcroft and Milfont (2010), with German translations taken from Schleyer-Lindenmann et al. (2018). Answer formats were implemented with a 5-point Likert scale.

2.3.5. Analysis

First, a confirmatory factor analysis (CFA) was conducted to verify that the measured items represent the key latent constructs of intention, attitude, social norms, PU, the NEP scale and LOC. Second, five PLS-SEM approaches and four OLS regressions were estimated. Because of the need to integrate injunctive norms as a formative construct, the following result section focuses on the PLS approaches. The detailed results of the OLS regressions can be accessed in the Appendix and the OSF folder.

All constructs were measured as reflective latent constructs, except injunctive norms. Because injunctive norms are measured on the basis of different referent groups, this construct is included as a formative measure (Cenfetelli & Bassellier, 2009). The different models estimated were assessed with regard to their formative and reflective measurement recommendations, calculations for predictive power and model comparisons following Hair et al. (2021). Bootstrapping procedures were applied using confidence intervals of 95% and 10,000 resamples. Predictive power of the models was evaluated through a training and holdout sample, where the out-of-sample predictive error (root mean square error, RMSE) can be compared to the naïve linear model (LM) benchmark. Finally, all PLS models were compared by calculating the Bayesian information criterion (BIC) and the BIC-based Akaike weights. The analysis was conducted using the software environment R, and the corresponding R code of the conducted analysis can be found in the supplementary OSF folder. [5]

2.3.6. Results

2.3.6.1. Data cleaning and sample

Following our preregistered plan, participants were excluded if they were not potato farmers, failed attention and pattern checks, or didn't complete the survey. After applying these criteria, the final sample comprised 102 observations (refer to **Table 16**). Because the sampling strategy consisted of two different sampling procedures (1st phase: stratified random sample, 2nd phase: unused contacts of 1st phase), we tested whether these two sub-samples differ. No differences with regard to demographics were detected (age, farm size, gender, income, education); testing was conducted using either a Chi-Square test or a *t*-test. A comparison of the mean scores of the constructs used in the analysis (intention, attitude, usefulness, norms and environmental attitudes) also indicated that there are no differences between the samples; the two-sample two-tailed *t*-tests resulted in 95% confidence intervals (CIs) which include a zero. In the same way no differences in the risk construct were detected.

Table 16. Overview data collection and exclusion criteria.

	1st data collection	2nd data collection	All
Recorded observation	117	63	180
Exclusion: Screening items	14	1	15
Exclusion: Attention and pattern check	12	4	16
Exclusion: Incomplete observations	28	19	47
Final sample	63	39	102

Note(s): the 1st phase of data collection comprises participants from the stratified random recruitment process, the 2nd phase of data collection was based on the unused contacts from the 1st phase.

Table 17 provides a comparison of our sample characteristics with the farm management population in Germany. Overall, our recruitment strategy targeted training farms in Germany which cultivate potatoes. In comparison to the German farmer population, our sample appears to be younger, have a slightly higher level of education, and consists of farmers who operated on larger farms than the average German farmer population.

[5] OSF folder: https://osf.io/4yarw/?view_only=c1380847a0fb4241b26288782920cf78.

The variable „farm size” in hectare was calculated by adding owned and rented hectares. Here, for 8 observations, outliers were excluded and/or (resulting) missing values were substituted with the mean value. Outliers were defined as observations which were below the 1% percentile and above the 99% percentile. No other variable required adjustments due to outliers or missing values. Due to a programming error the variable capturing education had 33 missing observations; here no substation of the missing observations was implemented.

Table 17. Demographic characteristics of the sample (n = 102).

Demographic variable	**Category**	**Sample** *n*	*%*	**German population**
Gender	Woman	93	91	11%
	Man	9	9	89%
Age	24-34 years old	28	27	8% *
	35-44 years old	15	15	8%
	45-54 years old	34	33	16%
	55-66 years old	25	25	47% **
Turnover per year	0 - €150,000	8	8	-
	€150,000 - €250,000	8	8	
	€250,000 - €500 000	25	25	
	€500,000 or more	61	60	
Education	Secondary or high school graduate	23	23	Agricultural education only: Vocational training or apprenticeships: 28% School of agriculture: 15% Master in agriculture: 22% Other: 35%
	Master of agriculture	23	23	
	Other (agricultural)	21	21	
	Other (non-agricultural)	2	3	
	Missing	33	32	
Average farm size	272 hectares (ranging from 13-1500)			63 hectares

Note(s): categories with no observations are not displayed. Statistics on gender distribution in 2020: Bundesinformationszentrum Landwirtschaft (2022); statistics on age and education in 2020: Statistisches Bundesamt (2023); average farm size from Destatis (2021). * 34 years old and younger, ** 55 years old and older.

2.3.6.2. Information and credibility

The majority of participants selected the Chamber of Agriculture or other substitute bodies as a trustworthy information source (selected 60 times), followed by agricultural journals (56 times), science (44 times) and other farmers in their network(s) (37 times). In the information provision scenario farmers received the information from the Chamber of Agriculture or other similar regional bodies. The perceived credibility of all of these bodies was measured, which resulted in an average of 3.69 (SD = 0.81, scale ranging from 1-5), indicating respondents slightly trust these bodies. 87.26% (n = 89) use advisory services offered by the Chamber of Agriculture and/or regional substitute bodies of the Chamber of Agriculture, and 77.45% (n = 79) use private agricultural advisory services.

2.3.6.1. Constructs and measurement evaluation

All included items were rescaled to a one to five-point scale to enhance the comparability of results and avoid high kurtosis in the data. Due to poor fit values of the CFA ($\chi^2(309) = 388.547$, $p = 0.001$, root mean square error of approximation, RMSEA = 0.050, comparative fit index, CFI = 0.904), low factor loadings and violations of some of the necessary criterions for the PLS analysis, some indicators could not be considered for the final analysis. The requirements for reflective measurement model comprise the following thresholds: ≥ 0.708 for indicator loadings, Cronbach's α and rho_c recommended between 0.80 to 0.90 (internal consistency reliability), average variance extracted (AVE) ≥ 0.50 for convergent validity and Heterotrait-Monotrait Ratio (HTMT) below 0.85 (Hair et al., 2021). The formative measurement model was assessed by evaluating collinearity and statistical relevance of indicator weights and indicator loadings (Hair et al., 2021).

The following indicators had to be removed from the analysis. From the reflective constructs, external LOC had to be excluded because of insufficient factor loadings of two of the three items (loadings: 0.08 and 0.18, respectively) and low Cronbach's α (0.11). For the NEP scale several PLS criterions were insufficiently met (low factor loadings of 0.06 for items 1, and low values for α = 0.58, AVE = 0.30, rho_C = 0.67), thus NEP 1 to 3 were excluded. As injunctive norms resulted in low factor loadings in the CFA (Consumer referent group: 0.26; NGO referent group: 0.28), the referent groups consumers and NGOs were excluded. Thereby, the injunctive norm construct captures referent groups solely from the agricultural sector.

The fit measures of the final CFA indicate a generally good suitability. The non-significant chi-square value ($\chi^2(137) = 154.12$, $p = 0.151$), a RMSEA value of 0.035 and a CFI of 0.976 indicate a good fit (DiStefano & Hess, 2005; Hox, 2021). **Table 18** provides an overview of the final constructs, means, standard deviations and standardized factor loadings from the CFA.

Table 18. Survey items, internal consistency reliability (rho$_c$ and Cronbach's α), convergent validity, AVE and standardised factor loadings of CFA.

Constructs		Mean	S.D.	Std. factor loading
Intention (α = 0.92, AVE = 0.86, rho$_C$ = 0.95)				
int1	I intend to use beneficial soil microbes on part of my potato acreage next season.	3.12	1.50	0.95
int2	I will try to use beneficial soil microbes on part of my potato acreage next season.	3.35	1.52	0.82
int3	I want to use beneficial soil microbes on part of my potato acreage next season.	334	1.54	0.92
Perceived usefulness (α = 0.75, AVE = 0.67, rho$_C$ = 0.86)				
use1	I think the use of beneficial soil microbes in potato production improves the profitability of my farm.	3.14	1.14	0.76
use2*	All in all, I think the use of beneficial soil microbes in potato production would not prove a benefit to my farm.	3.85	1.21	0.61
use3	I think the use of beneficial soil microbes in potato production would be beneficial to my farm.	3.59	1.20	0.77
Attitude toward adoption (α = 0.85, AVE = 0.69, rho$_C$ = 0.90)				
att1	Bad - good	4.20	0.97	0.73
att2	Harmful - beneficial	4.25	0.89	0.78
att3	Useless - useful	4.19	1.05	0.82
att4	Unimportant - important	4.13	1.04	0.74
Injunctive Norms (α = 0.67)				
adv	Advisor: motivation to comply * normative belief	3.61	1.34	0.55
reg	Regional farmer: motivation to comply * normative belief	2.74	1.43	0.66
net	Farmer network: motivation to comply * normative belief	3.59	1.24	0.74
Internal Locus of Control (α = 0.64, AVE = 0.58, rho$_C$ = 0.80)				
loc1	I like to take responsibility.	4.28	0.58	0.62
loc2	It has proven good for me to make decisions myself instead of relying on fate.	4.32	0.70	0.76
loc3	In the face of problems and opposition, I usually find ways and means to prevail.	3.72	0.71	0.50
New Ecological Paradigm Scale (α = 0.56, AVE = 0.50, rho$_C$ = 0.73)				
nep4*	Changing the environment for human use rarely causes serious problems.	4.03	0.93	0.65
nep5*	For nations like Germany, there are no limits to growth.	4.21	0.78	0.53
nep6*	Humans are born to rule over the rest of nature.	4.00	0.94	0.49

Note(s): * are reverse coded items, values are corrected accordingly. All measures can range between 1-5.

The reflective and formative measurement models were assessed following Hair et al. (2021) for all five models. In the following, we present only the criteria of the empirical-based extended model, which includes all constructs. The assessments for the other models are more or less in line with those results and are, therefore, not reported here. The complete output of all analyses can be accessed with the supplementary materials in the OSF folder. Confidence intervals of all indicators for each model are presented in Appendix, **Table A5**.

For the reflective constructs, the HTMT measuring discriminant validity between constructs was smaller than 0.81 – thus below the threshold value of 0.85 – indicating discriminant validity between all constructs. Cross loadings showed that all indicators load highest on their corresponding construct. Indicator loadings show that „loc1" and „nep6" are below the recommended threshold of 0.708 but above the cut-off threshold of 0.40. Some of the values for convergent validity for the NEP and LOC constructs are partly below the recommended threshold (refer back to **Table 3**).

For the formative construct, injunctive norms, collinearity was not a problem (Variance inflation factor (VIF) below the threshold of 3). The evaluation of the indicator weights showed that not all indicators are of statistical significance, assuming a random sample (based on a two-tailed *t*-test, *t* between 0.59 and 2.39, all 95% CI between [-0.41, 1.00]). However, the indicator loadings met the requirements set out by Hair et al. (2021), which enabled the inclusion of the three agricultural referent groups. Indicator loadings are above the threshold of 0.50 (indicator loadings for all three referent groups between 0.67-0.84); and for all three indicator loadings we can reject the null hypothesis (all $t > 3.42$, all 95% CI between [0.19, 0.99]).

2.3.6.2. Evaluation of the structural models

As the study is based on a convenience sample results presented below need to be interpreted with caution as statistical inference in its strict sense can only be interpreted under the willingness to assume random sampling. Reported PLS coefficients are standardised, and serve as an indication of the effect size; standardised coefficients below 0.2 represent a small effect, between 0.2 and 0.5 a medium effect and above 0.5 a large effect (Fey et al., 2023).

For the evaluation of the structural models, all models were assessed with regard to collinearity, the relevance of the relationships, the models' predictive power and R^2. There was no problem of collinearity in any of the models; for all models VIF values ranged between 1.003-1.946. An overview of all results is presented in section 5.7 (see **Table 20**).

Base model

The first PLS model (base model) tests the relevance of the TRA in explaining farmers' intention to adopt beneficial soil microbes in their potato production.

Overall, the model explains 31% of the variance in intentions (adjusted R^2). Attitude showed a medium-sized effect ($\beta = 0.48$, $t = 5.81$) with a positive 95% CI [0.30, 0.62]. We also found a medium-sized effect ($\beta = 0.28$, $t = 3.25$) for injunctive norms, with a positive 95% CI [0.13, 0.46]; however, the CIs shows that a potential effect in the population could range from a small to medium effect. The weight of the different referent groups shows that advisors play the largest relative contribution to injunctive norms (ω = 0.62, t = 2.38, with a 95% CI of [0.00, 1.00]), followed by farmers from the region (ω = 0.48, t = 1.85, 95% CI [-0.09, 0.94]). See Appendix, **Figure A2** for a graph of the results. These results indicate support for H1 and H2: attitude and social norms appear to have a positive, medium-sized effect on intentions to try beneficial soil microbes.

TPB-based extension

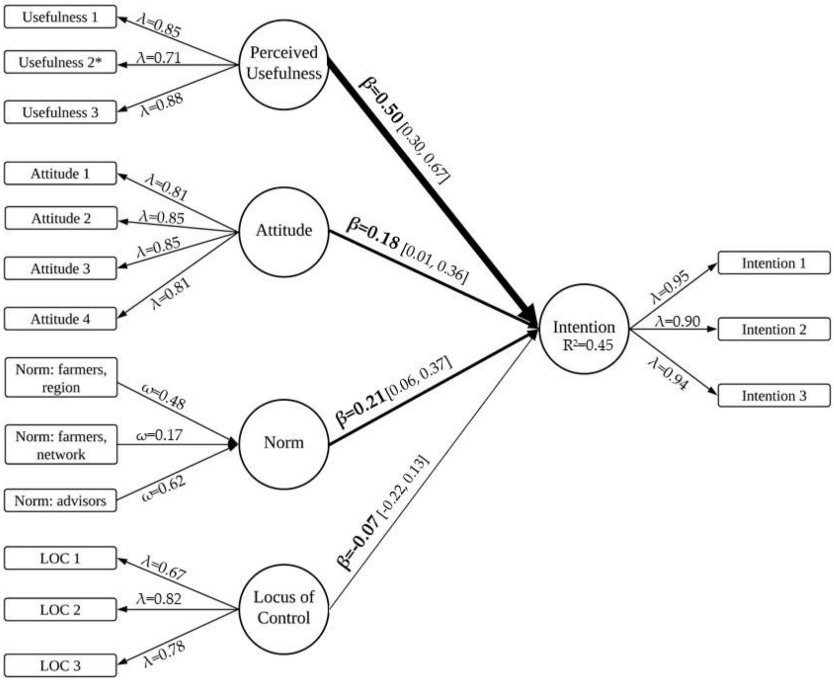
The TPB-based model extension of the base model includes, in addition, to the constructs of attitude and social norms, the personality characteristic LOC (as a substitute measure for PBC). Attitude and social norms remained predictors of similar magnitude compared to the base model. Internal LOC, however, shows a small coefficient with a wide CI, that is, we cannot find an effect on intentions (β = - 0.06, t = -0.63), and the CIs also indicate only a potential small effect (95% CI [-0.24, 0.15]). The results reaffirm the support for H1 and H2. However, the results do not substantiate H3, and thus, that LOC has a positive impact on intentions. Overall, the model explains 31% of the variance in intentions, see Appendix, **Figure A3** for the results.

TAM-based extension

The TAM-based extension captures all previous constructs and in addition integrates PU (see **Figure 11**). Findings reveal a smaller impact of attitude and social norms compared to the previous model; attitude showed a small effect size (β = 0.18, t = 2.04, 95% CI [0.01, 0.36]) and norms a medium effect (β = 0.21, t = 2.61, 95% CI [0.06, 0.37]). In both cases the CIs show that the size of the effect could range from small to medium. Again, we cannot find an effect of internal LOC on intention (β = -0.07, t = -0.84, 95% CI [-0.22, 0.13]). These results replicate our previous findings with regard to H1, H2 and H3, albeit with a smaller effect. PU has a large effect on intentions (β = 0.50, t = 5.32, 95% CI [0.30, 0.67]), with a CI ranging from a medium to large effect. This indicates that our results offer support to H4; PU appears to have a positive impact on intentions. The explained variance in intentions increased to 45%.

Additionally, and more closely following the TAM, the previous model was extended by not only including the direct effect of PU on intention but also considering the indirect effect via attitude, see Appendix, **Figure A4**. PU shows a positive impact of large effect size on attitude (β = 0.65, t = 9.29, 95% CI [0.50, 0.76]). The indirect effect of PU via attitude on intention ($\beta_{use\text{-}atti} * \beta_{atti\text{-}int}$) resulted in a coefficient of 0.12 (t = 1.86, 95% CI [-0.00, 0.25]), the CIs indicate that the indirect effect could range from no to a medium effect. Estimations of the other coefficients did not deviate extensively to the TAM-based extension model.

Figure 11. PLS results of TAM-based extension model.

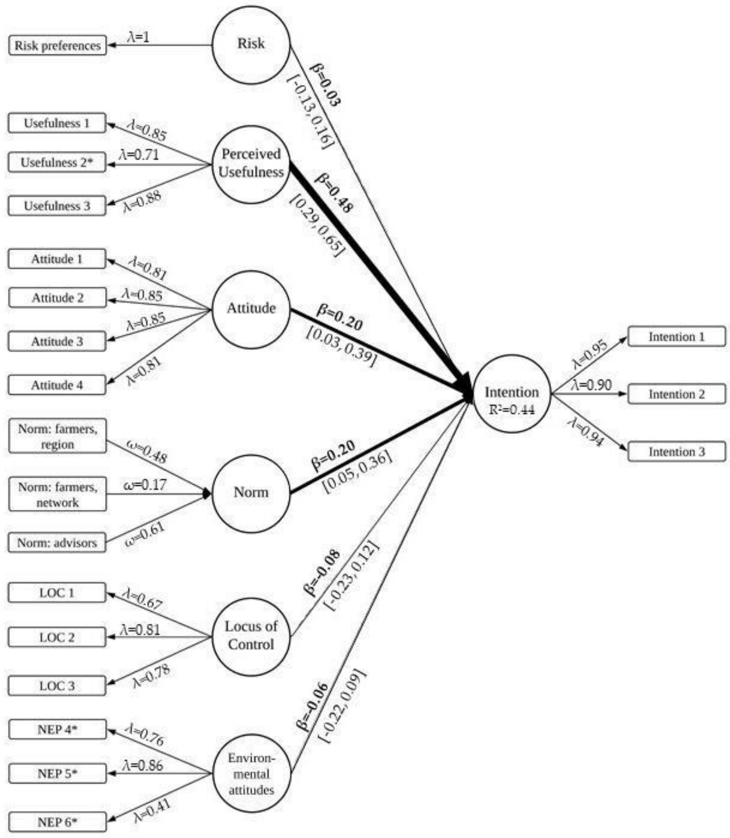


Note(s): Path coefficients, confidence intervals, loadings for reflective measures, weights for formative measures and adjusted R^2. Line thickness represents the magnitude of the effect, squared brackets contain the 95% CIs. Age and farm size are not presented in the figure, both age (β = -0.012, 95% CI [-0.16, 0.12]) and farm size (β = -0.053, 95% CI [-0.20, 0.08]) indicate minor or no effect on intentions.

Empirical-based extension

The empirical-based extension model explores the additional relationships between environmental attitudes and risk attitudes with intentions. Both environmental attitudes (β = -0.06, t = -0.77, 95% CI [0.22, 0.09]) and risks (β = 0.03, t = 0.34, 95% CI [-0-13, 0.16]) resulted in minor coefficients. The results therefore offer no support to H5 and H6, that environmental attitudes have a positive and risk aversion a negative effect on intentions. Compared to the TAM-based extension model, the magnitude of the effects by the other constructs was hardly impacted by the additional exploratory factors, as was the explained variance in intentions (adjusted R^2 = 0.44). See **Figure 12** for the results.

Figure 12. PLS results of empirical-extension model.



Note(s): Path coefficients, confidence intervals, loadings for reflective measures, weights for formative measure, and adjusted R^2. Line thickness represents the magnitude of the effect, squared brackets contain the 95% CIs. Age and farm size are not presented in the figures, both age (β = -0.013, 95% CI [-0.15, 0.13]) and farm size (β = 0.052, 95% CI [-0.19, 0.08]) are of minor or no effect size.

2.3.6.3. Predictive power and comparisons

A comparison of the LM out-of-sample prediction error and LM out-of-sample prediction showed that in all models, the predictive error was smaller than the naïve LM model benchmark for all indicators (see **Table 19**). This indicates that all our models have high predictive power (Hair et al., 2021).

Table 19. Results of model's predictive power (running 10 replications, 10 folds employed).

		RMSE values	LM benchmark
Base model	Int1	1.347	1.411
	Int2	1.369	1.438
	Int3	1.333	1.358
TPB-based extension	Int1	1.339	1.474
	Int2	1.374	1.487
	Int3	1.329	1.441
TAM-based extension	Int1	1.230	1.336
	Int2	1.221	1.335
	Int3	1.254	1.350
Exploratory model	Int1	1.231	1.353
	Int2	1.256	1.355
	Int3	1.009	1.335
Empirical-extension	Int1	1.229	1.396
	Int2	1.235	1.372
	Int3	1.251	1.379

Note(s): RMSE = root mean square error, LM = linear model.

From the metrics for model comparison, it can be seen that the TAM-based extension of the TRA achieved the strongest BIC-based Akaike weights and the smallest BIC metrics, followed by the exploratory model, and the empirical-extension model (see **Table 20**). The TAM-based extension model also explains the most variation in intentions.

Table 20. Comparison between model results and their impact on intentions (and attitude for the exploratory model). Estimates, adjusted R^2 and BIC / BIC Akaike weights metrics for model comparison.

Latent variable	**Base model**	**TPB-based extension**	**TAM-based extension**	**Empirical based extension model**	**Exploratory**	
					Intention	**Attitude**
Attitude	0.476	0.489	0.184	0.200	0.187	-
Norms	0.277	0.284	0.210	0.197	0.220	-
LOC	-	-0.062	-0.073	-0.082	-0.071	-
Use	-	-	0.496	0.482	0.481	0.645
Risk	-	-	-	0.026	-	-
NEP	-	-	-	-0.061	-	-
Age	-0.004	-0.002	-0.012	-0.013	-0.010	-
Farm size	-0.089	-0.087	-0.053	-0.052	-0.059	-
Adj. R^2	0.313	0.310	0.451	0.444	0.440	0.410
BIC	-20.37	-16.30	-36.01	-27.52	-33.93	
BIC Akaike weights	0.000293537	0.000038365	0.730247061	0.011032526	0.258388511	

Note(s): BIC = Bayesian information criterion.

2.3.6.4. OLS regression analyses

The analysed PLS models were also estimated using OLS regressions, as preregistered. The constructs of all models were created by calculating a mean score of the same indicator variables used in the PLS models. An overview of all OLS models is presented in Appendix, **Table A6**. Overall, it can be seen that the results from the OLS estimation reflect the ones from the PLS.

2.3.7. Discussion

This paper aimed to investigate behavioural factors of innovation uptake and their influence on farmers' intentions to try a product based on beneficial soil microbes in their potato cultivation. We explored the suitability of the TRA and various extensions based on the TPB and TAM as well as on constructs derived from the empirical literature to explain the potential adoption of innovations based on soil microbes in potato cultivation. We addressed the question: which determinants drive farmers' uptake of innovations based on beneficial soil microbes for farms in Germany that cultivate potatoes?

2.3.7.1. Relevant determinants

Our findings reveal that attitude positively impacts farmers' intentions to use beneficial soil microbes in potato production in our sample; this lends support to H1. In other farmer studies investigating farmer adoption and behaviour studies, attitude was shown to be an important predictor of intentions (Sok et al., 2020). However, the magnitude of this effect changed once PU was added in the TAM-based extension, it reduced the impact of attitudes. Usefulness had a strong, positive impact on intentions, in line with our argumentation of H4. Through an exploratory analysis we could not detect a mediating effect of attitudes between PU and intentions. However, our results highlight that in the context of innovation adoption, PU is a key predictor, which reduces the impact of attitudes on intentions.

Norms remained an influential construct in all our models, providing support to H2 for our sample. A closer look at the construct reveals that different referent groups contribute differently to the formation of injunctive norms. Advisors appear to have the largest impact, followed by farmers from the region and, finally, farmers from their network. This suggests that farmer decisions on microbial-based inputs could be steered by their advisors to some extent, which is in line with other studies (Wuepper et al. 2021). Agricultural extension services and other farmers were the most used communication channels about products like soil microbes (Ploll et al., 2022).

Internal LOC was not found to contribute to intentions in any of the models; this is in contrast to what we hypothesised in H3. However, potentially our model was not able to detect this effect from the retrieved sample. Our results indicate that LOC appears insufficient to explain behavioural intentions. Kormanik & Rocco (2009) highlight that LOC is limited as a predictor of behaviour, because it serves as a measure to capture personality traits.

The hypothesis that environmental attitudes positively impact intentions to use soil microbes (H5) was also not supported by our results. We acknowledge that our questions may have been too broad; for instance, Baumgart-Getz et al. (2012) emphasise that the evaluation of environmental effects requires highly specific measures that directly address environmental consequences of the behaviour of interest. Another complication pertains to the NEP scale itself. The NEP scale has been criticised on various accounts (Bernstein & Szuster, 2019), for example for the potential multi-dimensionality of the so-called facets of the NEP scale.

In our context of beneficial soil microbe application, we could not ascertain that domain-specific risk attitudes play a decisive role for our sample (H6), despite existing evidence that risk attitudes are a notable and relevant predictor of intentions to adopt microbial applications (Tensi et al., 2023). If farmers see soil microbes as a substitution of pesticides or of fertilisers, their reference point for the evaluation of associated risks might differ compared to farmers who perceived the adoption of soil microbes as a pure add-on. Such a varying perception might have impacted our results.

Farmer age and farm size did not play a determining role in our study. Although some studies have previously identified the effect of farmers' age or farm size (Adrian et al., 2005; Baumgart-Getz et al., 2012; Blasch et al., 2020) in farmer adoption and behaviour research, other studies could not find supporting evidence (e.g. Aubert et al., 2012; Lemken et al., 2017), which was also the case in the context of microbe applications (Tensi et al., 2022). Based on these criteria, no conclusions for farmers' demographics regarding innovation adoption can be drawn.

A separation between innovation-specific and general personality and attitudinal factors became evident in our analysis. The constructs measured in relation to our innovation of interest (attitudes, norms, usefulness) impact intentions from a small to a large effect. Constructs which capture general personality characteristics (internal LOC) or attitudes not directly linked to the behaviour of interest (environmental and risk attitudes) did not provide supporting evidence within the restrictions of our study. In the defining article by Ajzen (1991), Ajzen highlights that the TRA and TPB allow for the incorporation of other determinants, if they contribute to the explanation of endogenous constructs; which was also supported by other research (Conner, 2015; Manstead & Parker, 1995; Sok et al. 2020). However, Ajzen (2020) also assumes that if the TRA or the TPB are extended by other variables these should follow the principle of compatibility. Added variables should be measured in relation to the behaviour in question. We deviated from this principle. Other studies that extended the TPB and followed the principle of compatibility could explain intentions better than studies which failed to follow this principle (Sok et al., 2020). This implies that in order to predict innovation adoption, future research should use measures which are adjusted to the adoption behaviour of interest.

2.3.7.2. Implications and limitations

Our results offer some insights for policy to advance the diffusion of beneficial soil microbes with communication programs. Our study found that PU of the innovation influences both attitudes and intentions, thus communication efforts could focus directly on the innovation's usefulness.

To communicate about usefulness, the innovation's characteristics and limitations need to be considered; particularly the current lack of visibility of soil microbes (Ploll et al., 2022). Here, field demonstrations may offer a suitable solution. To pass on and communicate the usefulness of soil microbes to farmers, other farmers and agricultural advisors in particular stand out; additionally, agricultural journals could contribute to information dissemination.

To properly discern the role of environmental perceptions, future research should investigate whether perceptions of environmental consequences due to innovation adoption (or lack thereof) impact adoption intentions. In this way, the construct of environmental attitude would also follow the principle of compatibility. This notion has also been supported by Baumgart-Getz et al. (2012) for best management practices and by Bakker et al. (2021) for reduced pesticide usage.

In our study, potentially different perceptions of risks related to the innovation could have influenced participants' evaluation of the innovation. This risk evaluation might differ for organic and non-organic farmers. In light of this aspect, future studies should consider this potential bias by controlling for farmers' risk evaluation of the innovation in question. Further, it remains questionable whether a self-reported single-item risk measure provides enough insights into risk attitudes.

The results need to be interpreted in light of some limiting circumstances. Firstly, the base for analysis is shaped by the available dataset. Recruitment of a representative farmer sample remains a challenge for research in agricultural economics (Weigel et al., 2021). The final data set is based on a convenience sample, which limits the external validity of our results (Sarstedt et al., 2018). From our sample characteristics we cannot clearly evaluate whether and how our sample deviates from the target population, German training farmers that grow potatoes. Such sample limitations challenge statistical inference and usage of CIs, which could bias our results (Amrhein et al., 2019). Participation was also voluntary and may have been subjected to a self-selection bias. Furthermore, we have no insight into the conditions under which participants filled out the survey; however, to increase data quality a comprehension and attention check was conducted. The latent constructs which were measured with regard to innovation usage are based on a hypothetical, future adoption situation with limited information. This restrains the transfer of our results to a real-life situation.

2.3.8. Conclusions

Understanding which factors drive farmers' decisions is crucial to facilitate a wider comprehension of adoption dynamics and to foster sustainable transitions on the farm level. This study provides insights into the role of behavioural determinants in the context of innovation adoption. The promising innovation of interest, beneficial soil microbes, can potentially reduce farmers' dependence on hazardous pesticides and inorganic fertilisers. From a theoretical perspective, this study illustrated that innovation adoption is best explained by latent constructs related to the innovation in question. Our results show that adoption intentions are driven by norms of agricultural stakeholders, attitudes and perceived usefulness toward innovation usage. Future research which deals with innovation diffusion on the farm level could expand on the role of different stakeholders and perceived usefulness. Policy efforts for innovation diffusion may centre their communication strategy on agricultural stakeholders and particularly focus on the innovation's usefulness.

Appendix

Table A4. Latent constructs and original survey items and answer formats.

Latent Construct	**Items**	**Answer scale**	**Reference**
Locus of control (LOC)	I like to take responsibility. It has proven good for me to make decisions myself instead of relying on fate. In the face of problems and opposition, I usually find ways and means to prevail. Success is often less dependent on performance than on luck. I often have the feeling that I have little influence on what happens to me. When making important decisions, I often base my decisions on the behaviour of others.	5-point Likert scale	Jakoby & Jacob, 2014
New ecological paradigm (NEP) scale	The balance of nature is very delicate and easily destroyed. The earth is like a spaceship with little space and few resources. Plants and animals do not exist primarily for human use. Changing the environment for human use rarely causes serious problems. For nations like Germany, there are no limits to growth. Humans are born to rule over the rest of nature.	5-point Likert scale	Adapted from Schleyer-Lindenmann et al., 2018
Attitude toward adoption	I conceive the application and testing of innovations (such as soil microbes and mycorrhizae) in my potato production to improve soil quality as well as plant health and pest resistance to be... Bad – good Harmful – beneficial Useless – useful Unimportant – important	Bi-polar 7-point answer scale	Adapted from Fishbein & Ajzen, 2010
Perceived usefulness	I think the use of beneficial soil microbes in potato production improves the profitability of my farm. All in all, I think the use of beneficial soil microbes in potato production would not prove a benefit to my farm. I think the use of beneficial soil microbes in potato production would be beneficial to my farm.	7-point Likert scale	Adapted from Naspetti et al., 2017
Risk attitudes	How do you perceive yourself on a scale of 1 to 7, where 1 means "not at all willing to take risks" and 7 means "very willing to take risks"? How willing are you to take risks in general? How willing are you to take risks with regard to plant protection in your potato production?	7-point Likert scale	Adapted from Dohmen et al., 2005

Latent Construct	Items	Answer scale	Reference
Intention to adopt	I intend to use beneficial soil microbes on part of my potato acreage next season. I will try to use beneficial soil microbes on part of my potato acreage next season. I want to use beneficial soil microbes on part of my potato acreage next season.	7-point Likert scale	Adapted from Fishbein & Ajzen, 2010
Injunctive norms: Motivation to comply	The opinion of … … agricultural advisors is important to me. … other farmers from my region is important to me. … other farmers from my network(s) is important to me. … non-governmental organisations* is important to me. … consumers is important to me. *for example, Greenpeace or the World Wildlife Fund (WWF)	7-point Likert scale	Adapted from Fishbein & Ajzen, 2010
Injunctive norms: normative beliefs	Please indicate below whether the following stakeholders think you should implement and try innovative, new products to improve soil quality as well as plant health and pest resistance. Other farmers in my region think that I should implement and try innovative, new products to improve soil quality as well as plant health and pest resistance. Other farmers from my network(s) think that I should implement and try innovative, new products to improve soil quality as well as plant health and pest resistance. Agricultural advisors that are important to me think that I should implement and try innovative, new products to improve soil quality as well as plant health and pest resistance. In general, non-governmental organisations* think that I should implement and try innovative, new products to improve soil quality as well as plant health and pest resistance. In general, consumers think that I should implement and try innovative, new products to improve soil quality as well as plant health and pest resistance.	7-point Likert scale	Adapted from Fishbein & Ajzen, 2010

Latent Construct	Items	Answer scale	Reference
Source credibility	Please answer the following questions about the Chamber of Agriculture (1); Info Service Agriculture - Food - Rural Areas (2); Bavarian State Research Centre for Agriculture (LfL) (3); State Office for Agriculture Hesse (LLH) (4); State Office for Agriculture, Food Safety and Fisheries (LALLF) (5); Office for Agriculture, Land Consolidation and Forestry (ALFF) (6) in your region. can be trusted – can't be trusted is accurate – is inaccurate is fair – is unfair tells the whole story – doesn't tell the whole story is biased – is unbiased [Programming of item text: (1), (2), (3), (4), (5), (6) are offices that are specific to some German Federal States; the text appeared in accordance with the location of the farm]	Bi-polar 7-point answer scale	Meyer, 1988

Table A5. 95% confidence intervals for indicator loadings / weights per model.

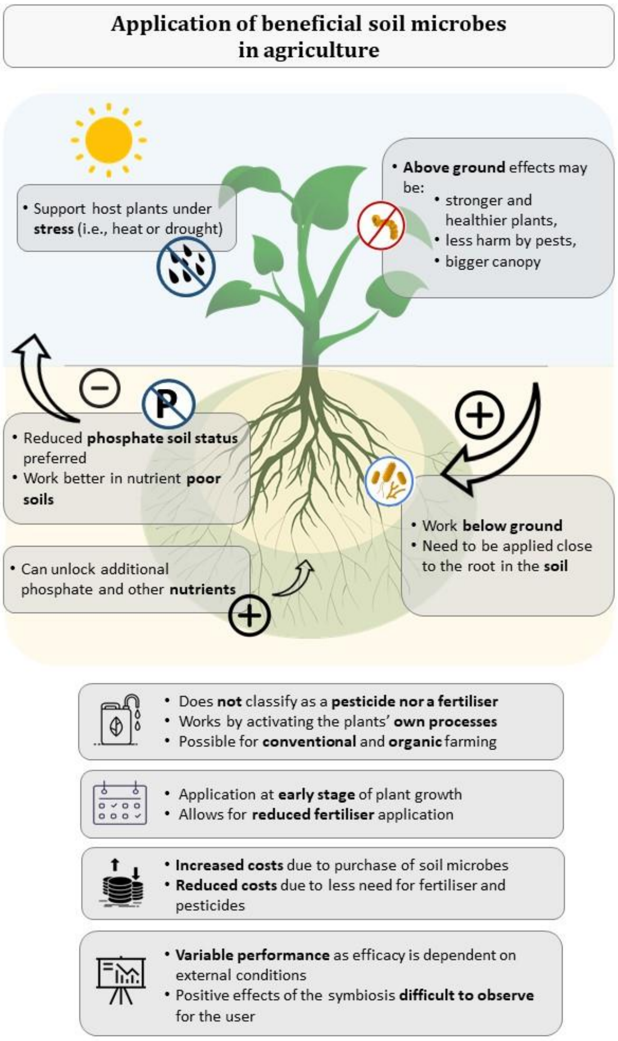
Item	Construct	Base model		TPB-based extension		TAM-based extension		Empirical-based extension		Exploratory model	
		2.5%	97.5%	2.5%	97.5%	2.5%	97.5 %	2.5%	97.5%	2.5%	97.5%
int1	Intention	0.92	0.97	0.92	0.97	0.92	0.97	0.92	0.97	0.92	0.97
int2	Intention	0.82	0.95	0.81	0.95	0.83	0.95	0.83	0.95	0.83	0.95
int3	Intention	0.91	0.97	0.91	0.97	0.90	0.97	0.90	0.97	0.90	0.97
att1	Attitude	0.62	0.92	0.62	0.92	0.65	0.92	0.62	0.92	0.62	0.92
att2	Attitude	0.75	0.92	0.75	0.92	0.74	0.92	0.75	0.92	0.75	0.92
att3	Attitude	0.76	0.91	0.76	0.91	0.77	0.91	0.76	0.91	0.76	0.91
att4	Attitude	0.68	0.89	0.68	0.89	0.69	0.89	0.68	0.89	0.68	0.89
adv	Norms	-0.01	1.00	-0.01	1.00	-0.00	1.00	0.00	1.00	0.01	1.00
reg	Norms	-0.09	0.94	-0.07	0.93	-0.90	0.93	-0.09	0.93	-0.10	0.93
net	Norms	-0.41	0.75	-0.40	0.74	-0.43	0.75	-0.41	0.76	-0.41	0.74
loc1	LOC			-0.35	0.97	-0.35	0.97	-0.35	0.97	-0.34	0.98
loc2	LOC			-0.33	0.97	-0.29	0.97	-0.28	0.98	-0.29	0.98
loc3	LOC			-0.37	0.98	-0.39	0.98	-0.37	0.98	-0.37	0.98
use1	Use					0.74	0.92	0.70	0.93	0.70	0.93
use2	Use					0.56	0.86	0.46	0.85	0.47	0.85
use3	Use					0.77	0.91	0.82	0.93	0.82	0.93
nep4	NEP									-0.30	0.97
nep5	NEP									-0.41	0.98
nep6	NEP									-0.50	0.97

Note(s): Confidence intervals for indicator weights are presented for norms, all other intervals refer to indicator loadings.

Table A6. Comparison between OLS model results (standardized coefficients, 95% CIs and adjusted R²) and their impact on intentions.

Latent variable	**Base model**		**TPB-based extension**		**TAM-based extension**		**Empirical-based extension**	
	Coef.	95% CI	Coef.	95% CI	Coef.	95% CI	Coef.	95% CI
Attitude	0.476	[0.52, 1.12]	0.492	[0.55, 1.15]	0.197	[-0.01, 0.69]	0.214	[0.01, 0.73]
Norms	0.270	[0.14, 0.59]	0.279	[0.15, 0.61]	0.221	[0.08. 0.51]	0.211	[0.07, 0.50]
LOC	-	-	-0.075	[-0.69, 0.27]	-0.076	[-0.65, 0.22]	-0.084	[-0.67, 0.21]
Use	-	-	-	-	0.465	[0.39, 0.97]	0.457	[0.37. 0.96]
Risk	-	-	-	-	-	-	0.017	[-0.16, 0.19]
NEP	-	-	-	-	-	-	-0.093	[-0.54, 0.13]
Age	0.011	[-0.16, 0.19]	0.011	[-0.16, 0.19]	0.000	[-0.16, 0.16]	0.003	[-0.16, 0.17]
Farm size	-0.091	[-0.30, 0.09]	-0.090	[-0.30, 0.09]	-0.066	[-0.25, 0.10]	-0.069	[-0.26, 0.10]
Adj. R^2	0.306		0.305		0.427		0.424	

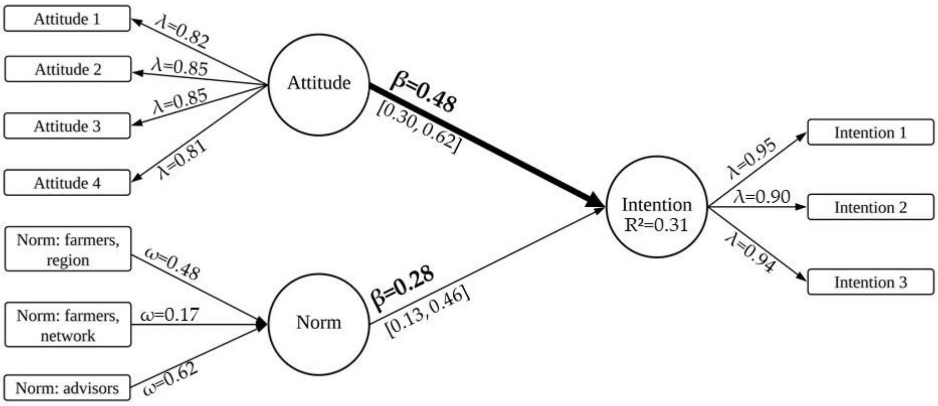
Figure A1. Information sheet provided in the survey.



Note(s): For icon credits, see below.

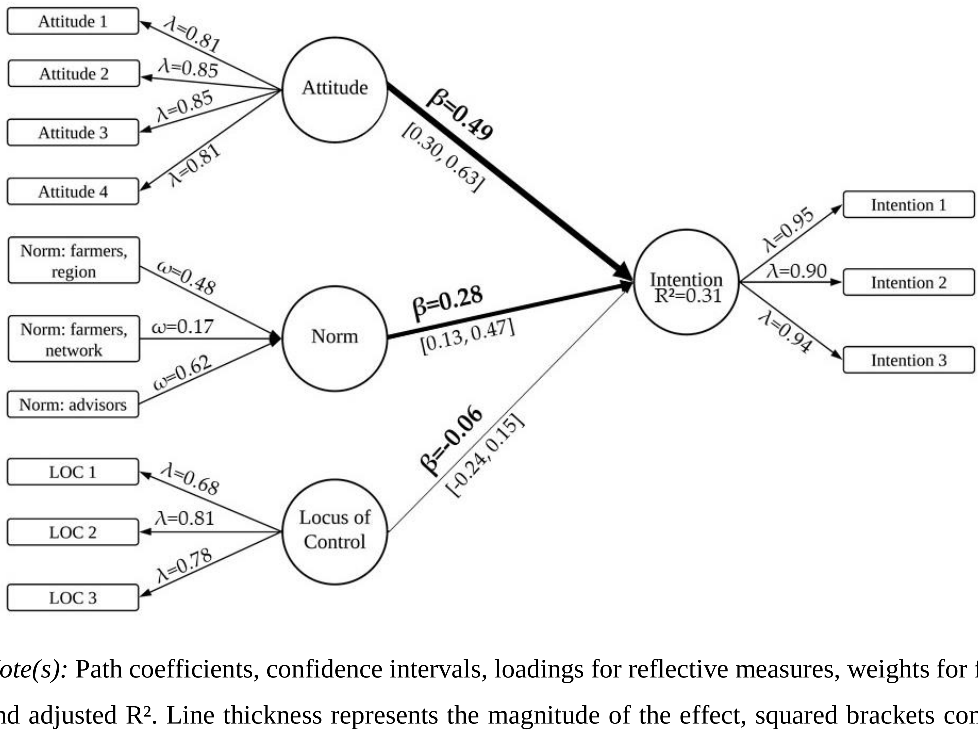
Sun icon: By "Ladalle CS" Title: Hot, sun, weather icon This work is licensed under a Creative Commons Attribution 3.0 Unported License (CC BY 3.0). https://www.iconfinder.com/icons/4102328/hot_sun_weather_icon	Rain drops: By "VectorSquare" Title: Rain, water, cloud icon https://www.iconfinder.com/icons/727683/rain_water_cloud_drop_forecast_weather_icon	Minus symbol: By "Feather Icons" Title: Minus, circle, remove icon This work is licensed under a Creative Commons Attribution 4.0 International (CC BY 4.0). https://www.iconfinder.com/icons/8666813/minus_circle_remove_icon
Plus icon: By "Sabr Studio" Title: +, add, circle icon This work is licensed under a Creative Commons Attribution 3.0 Unported License. https://www.iconfinder.com/icons/4781840/+_add_circle_create_expand_new_plus_icon	Arrow: By "Becris." Title: Arrow, curve, forward icon https://www.iconfinder.com/icons/3209443/arrow_curve_forward_point_right_icon	Container: By "WHD ICON" Title: Agriculture, ecology, fertilise icon This work is licensed under a Creative Commons Attribution 3.0 Unported License. https://www.iconfinder.com/icons/3449989/agriculture_ecology_fertilize_fertilizer_garden_leaf_icon
Calender: By "Goran Babic" Title: Calendar, date, meeting icon https://www.iconfinder.com/icons/2290847/calendar_date_meeting_reminder_time_icon	Coins: By "Flatart" Title: Capital, coins, finance coin https://www.iconfinder.com/icons/3957638/capital_coins_finance_gold_income_icon	Chart: By "Becris." Title: Board, chart, graph icon https://www.iconfinder.com/icons/3209445/board_chart_graph_presentation_teach_icon

Figure A2. PLS results of base model.



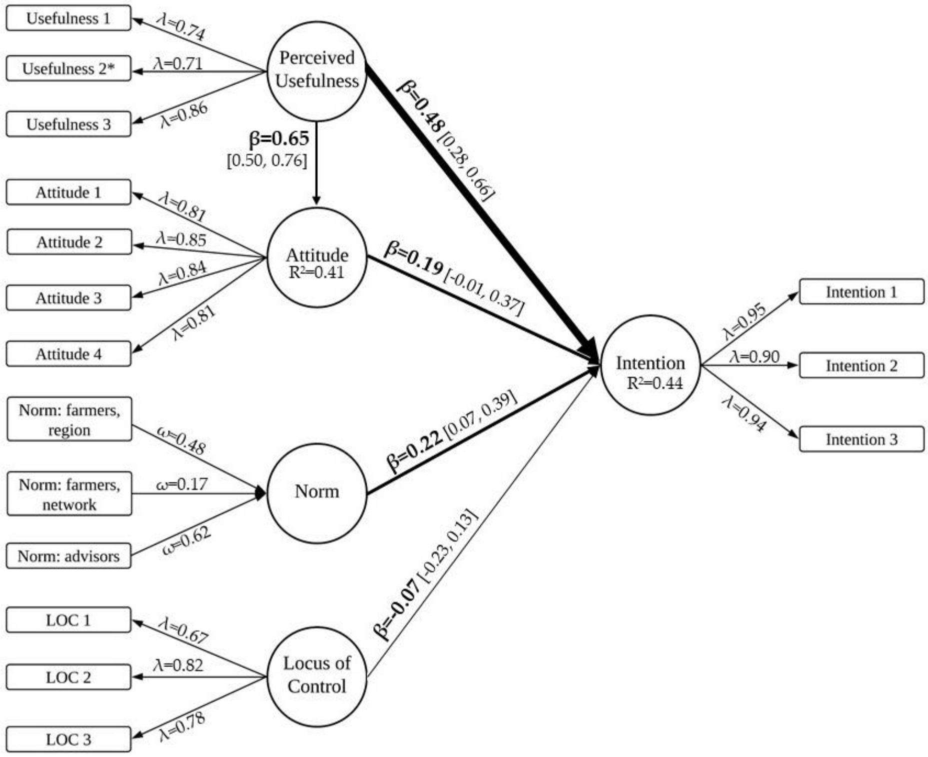
Note(s): Path coefficients, confidence intervals, loadings for reflective measures, weights for formative measure and adjusted R^2. Line thickness represents the magnitude of the effect, squared brackets contain the 95% CIs. Age and farm size are not presented in the figure, both age (β = -0.004, 95% CI [-0.16, 0.16]) and farm size (β = - 0.089, 95% CI [-0.26, 0.07]) resulted in minor effect sizes.

Figure A3. PLS results of TPB-based extended model.



Note(s): Path coefficients, confidence intervals, loadings for reflective measures, weights for formative measure and adjusted R^2. Line thickness represents the magnitude of the effect, squared brackets contain the 95% CIs. Age and farm size are not presented in the figure, both age (β = -0.002, 95% CI [-0.17, 0.16]) and farm size (β = - 0.087, 95% CI [-0.27, 0.08]) showed minor effect sizes.

Figure A4. PLS results of exploratory TAM-based extension.



Note(s): Path coefficients, confidence intervals, loadings for reflective measures, weights for formative measure and adjusted R^2. Line thickness represents the magnitude of the effect, squared brackets contain the 95% CIs. Age and farm size are not presented in the figure, both age (β = -0.010, 95% CI [-0.15, 0.13]) and farm size (β = - 0.059, 95% CI [-0.20, 0.08]) indicate minor or no effect on intentions.

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3. The consumers’ perspective

Consumers engage with beneficial soil-microbes in a different manner to farmers. Unlike farmers, consumers will only be exposed to soil-microbes indirectly, via the consumption of vegetables or other crops produced with these microbes. Soil-microbes are applied on the field and also create benefits on the field environment, where the consumer is not able to observe or discern any differences in the final produce. This makes the application and effects of beneficial soil-microbes a credence attribute, which needs to be communicated to the consumer.

The following subchapter (3.1) provides an overview of selected literature reviews and empirical studies on the consumers’ perspective to illustrate the state of research in food innovation acceptance. The two consecutive subchapters (3.2, 3.3) illustrate a first endeavour at formulating and assessing the effect of different information frames about beneficial soil-microbes. Subchapter 3.2 is based on a data article, and subchapter 3.3 is based on the related research article describing the empirical consumer research.

3.1. Literature on the consumers’ perspective

An overview of selected review papers which illustrate the state of research on the topic of consumer acceptance of food innovations is presented in **Table 21**. It needs to be noted that there is a wide field of possible innovations in the food sector, for example, food innovations can cover changes in food production processes, changes in packaging, and/or changes to product ingredients. The selected reviews were identified by researching for review papers on the topic of consumer acceptance of innovations in the food sector. Literature reviews published between 2007-2022 which deal with the acceptance of innovative food products which the consumer can (hypothetically) purchase were considered for this overview; reviews on organic food and on alternatives to animal proteins were excluded.

In all reviews and despite different food innovations as the subject matter, it can be seen that information and/or communication has been identified as a key finding. The identified aspects related to information and/or communication of each review are highlighted below.

Table 21. Key findings in literature reviews.

Article	*n*	Innovation / behaviour	Time period	Key findings
Ronteltap et al., 2007	55	Technology-based food innovations	1989 - 2005	Three broader categories of determinants were identified: ○ proximal determinants: perceived cost/benefit considerations, perceived risk and uncertainty, perceived behavioural control and subjective norms; ○ distal determinants: innovation features, consumer characteristics, social system characteristics; and ○ communication: information (trust, confidence, etc.).
Frewer et al., 2011	134*	Emerging food technologies	N.A.	Illustrated factors which influence technology acceptance: ○ perceived personal benefits; ○ perceived societal benefits; ○ differential accruement of risks and benefits; ○ ethical concerns; ○ perceived efficacy of regulatory framework; ○ cognitive associations/attitude activation; ○ public awareness; ○ perceived scientific knowledge/uncertainty; ○ perceived naturalness; ○ controllability/choice; ○ level of involvement in development; ○ trust in science and regulation; and ○ socio-cultural differences.
Giles et al., 2015	32	Nano-technology in agri-food production	2004 - 2015	Key findings/themes of the thematic analysis: ○ type and application of agri-food nanotechnology; ○ benefits and risks of food nanotechnology; ○ socio-demographic influences; ○ creating an informed and trusting consumer; ○ characteristics of food nanotechnology; ○ link to historical agri-food technology concerns; ○ marketing and commercialisation; and ○ future applications of agri-food nanotechnology.
Kamrath et al., 2019	169	New food technologies	2006 - 2017	Key determinants impacting technology evaluation: ○ trust in institutions; ○ information assessment; ○ perceived risks and benefits; ○ attitudes toward the product or technology; ○ perceived behavioural control; ○ quality perception of the product; and ○ impact on health.
Abrahamse, 2020	23	Sustainable food choices	2011 - 2020	Identified interventions to foster behaviour change: ○ nudging; ○ carbon and environmental labels; ○ provision of information; ○ visual prompts; and ○ social norms. Identified mediators and moderators: ○ past behaviour; ○ universalism values; and ○ attitudes and beliefs.

Article	*n*	Innovation / behaviour	Time period	Key findings
Aschemann -Witzel & Stangherlin, 2021	18	Waste-to-value in food and drinks	2010 - 2020	Identified factors which influence acceptances or consumer reactions: o individual factors (demographic variables, interest, specific consumer segmentations, attitude, perceptions of the brand, trust); o context-related factors (comparison to organic products, information about environmental benefits, sustainability and food waste avoidance); and o product-related factors (food neophobia, food technophobia, type of product, taste, vice or virtue product category).

Note(s): n denotes the number of references included in the review; time period refers to the year of publication of included papers and/or range considered in literature search. N.A. = not available. * additionally, other literature than journal articles were included.

The literature review by Ronteltap et al. (2007) mapped determinants of acceptance of innovations generally in the field of nutrition and of food in order to develop a conceptual framework. In this framework, communication was identified as a key determining factor which creates a link between the distal and proximal constructs. Another review determined key factors by evaluating the literature on seven specific food innovations, including, for example, GM foods and high-pressure processing (Frewer et al., 2011). Not all identified factors (listed in **Table 21**) were applicable to all food innovations, however, the findings provide an insight into the wide variety of potential influential factors. Here, the category "perceived knowledge and uncertainty" highlights that uncertainty about the technology and a lack of knowledge can impact consumer acceptance, irrespective of the technology in question. The review by Giles et al. (2015) evaluated key themes which were identified in literature to impact acceptance of agri-food nanotechnologies. The authors identified an 'informed consumer' as one of these themes; they highlight that a lower degree of knowledge can be associated with lower acceptance levels. Kamrath et al. (2019) systematically reviewed literature on general food innovations and compiled the results across all innovations. The authors note that a unifying model for the evaluation of technologies in the food sector is missing, but they point out that their findings reflect results from other reviews on technology evaluation. For example, they also found that more knowledge or awareness about an innovation is positively associated with a positive evaluation of that innovation. In the short review by Abrahamse (2020), the author focuses on interventions which can support sustainable food choices and related moderators or mediators. Their findings suggest that information provision alone does not lead to significant changes in behaviour, but information provision combined with motivational or norm statements is considered more promising. Food and drink technologies from the sustainable bio-economy are the focus of the systematic review by Aschemann-Witzel and Stangherlin (2021). They also identified information and communication as important tools to increase familiarity, which again has been associated with an increased acceptance. Additionally, they identified several gaps in the literature including, among other issues, the need for a better understanding of communications on environmental and health benefits.

These reviews highlight that literature on consumers' evaluation of innovations in the food sector has identified a wide spectrum of influential determinants. Not all identified factors will be relevant to all included technologies and innovations, as because of the wide variety of possible innovations, specific circumstances or mechanisms may render some of the factors irrelevant for certain innovations. However, it is crucial for consumers to be informed about technologies first in order to evaluate the innovation or technology in question. As can be seen, communication and/or information were identified as important aspects to facilitate consumer acceptance in all reviews. These findings on the importance of communication and information for increasing consumer acceptance are also taken up in the empirical research on innovations based on beneficial soil-microbes.

In Europe, the cases of GMOs and herbicidal product application have shown how consumers' rejection of a (production) technology can impact an innovation's development (Bazzan & Migliorati, 2020; Levidow et al., 2000; Sikora & Rzymski, 2021). One recommendation to counter this rejection of GM in crop production was to inform consumers about the technology, its advantages and disadvantages (Ishii et al., 2016; Lucht, 2015). In line with this recommendation, it was shown that a description about CRISPR (clustered regularly interspaced short palindromic repeats-Cas9) or GM technologies can achieve a change in consumers' evaluation of these technologies (Shew et al., 2018). In addition, in the context of pesticide usage, information on pesticides had a significant impact on willingness to pay for differently produced apples (Bazoche et al., 2013). Generally, in order to facilitate the distribution of scientific information, research on information dissemination to do with GMOs has recommended to use popular media channels for dissemination (Wunderlich & Gatto, 2015), which, for example, could encompass the video format.

More information on food production conditions also fosters more transparency in the food supply chain. German consumers indicated that information on production methods is one of the key topics for them with regard to transparency needs (Nitzko, 2019). This emphasises that the public has an interest in production conditions which goes beyond just the consumption of an end-product, hence, is interested in non-market goods (Hall et al., 2004). These attributes of a product can also be called credence qualities. They are qualities that cannot be evaluated at consumption level, but are nonetheless valuable to the consumer (Darby & Karni, 1973). For example, organic farming is a credence quality which describes certain food production conditions. Beneficial soil-microbes are applied on the field and through their usage various advantages can be created; however, these effects would go unnoticed to the consumer without communicating them. Furthermore, it can be assumed that beneficial soil-microbes are an innovation unknown to the majority of consumers, which reinforces how important communication about them is, as a necessary first step to create consumer acceptance.

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3.2. Framing sustainable food production technologies with videos – data from an experiment with German consumers [6]

Abstract. This pre-registered dataset was generated to investigate the effect of framing on consumer acceptance of beneficial soil-microbes in tomato production. For this purpose, an online experiment was conducted with 754 consumers in Germany in 2022. A market research agency recruited participants from their online panel, and quotas for a representative sample of the adult German consumer population were applied. Participants were randomly assigned to one of the following three experimental groups: gain-framing, loss-framing or a control group. Each group received a short video clip with information about beneficial soil-microbes, in which either gain-framing, loss-framing or no framing was applied. The following constructs were surveyed before video exposure: demographics, tomato consumption frequency, attitudes towards conventionally produced tomatoes and subjective knowledge of soil-microbes. The items and constructs collected after video exposure were: purchase intentions, explicit and implicit attitude towards tomatoes produced with beneficial soil-microbes, organic consumption behaviour and an evaluation of different food production methods. A single-target category implicit-association test (ST-IAT) was used to measure the implicit attitude, and all other constructs were measured through self-reported survey items. The main concept of interest is the acceptance of beneficial soil-microbes, which can be inferred from consumers' intentions and attitudes after video exposure. The dataset can be used to analyse the effect of video-based communication on consumer acceptance. Moreover, the effect of video-based communication on other outcome variables can be analysed, such as the evaluation of different production methods and other exploratory purposes. Further, it can be explored whether organic consumption behaviour or socio-demographic statistics play a mediating role on the effect of information framing. This might be of relevance for other researchers to determine the potential of video-based communication to influence consumers' acceptance of future innovations in the food sector.

Keywords: Consumer Acceptance; Videos; Implicit Attitude; Information Framing; Agricultural Innovation

[6] This subchapter is based on a data article that has been submitted as: Ploll, U., Weingarten, N., Hartmann, M. (2023). Framing sustainable food production technologies with videos – data from an experiment with German consumers. *Data in Brief.*

3.2.1. Specification table

Table 22. Specification table.

Subject	Social and Personality Psychology
Specific subject area	Effects of information framing in video clips about agricultural innovations on attitudes on and purchase intentions of the innovation.
Data format	Cleaned raw data, partially analysed
Type of data	Table
Data collection	An online panel was used for data collection. Quotas on age, gender, education and occupation were applied. Participants were randomly assigned to one out of three treatment conditions. Further exclusion mechanisms incorporated technical requirements, comprehension items and consistency checks. Participants who answered the IAT too slowly and too quickly (c.f. improved algorithm by Greenwald et al., 2003) were excluded.
Data source location	Institution: University of Bonn City/Town/Region: Bonn Country: Germany
Data accessibility	Repository name: Open Science Framework (OSF) Data identification number: not applicable yet Direct URL to data: https://osf.io/n9xj5/?view_only=02e0e9f1f0fd4905b23661514074b896 (anonymous peer-review link)
Related research article	U. Ploll, N. Weingarten, M. Hartmann. Frame by frame, attitude by attitude – the effect of information framing in videos on consumers' acceptance of sustainable food production innovations, *Journal of Environmental Psychology*. Submitted.

3.2.2. Value of the data

- The dataset can be used to evaluate the effect of information framing in video clips on consumer acceptance towards an agricultural innovation. Acceptance is conceptualized by measuring implicit attitudes via an ST-IAT, explicit attitudes and purchase intentions.
- The effects of video clips with (a) loss-framing, (b) gain-framing and (c) a neutral control condition about beneficial soil-microbes in agriculture can be compared.
- The mediating role attitudes have regarding the effect of framing on purchase intentions can also be explored.
- Researchers or other actors in the food sector, who are engaging with innovation diffusion or transformation processes, can benefit from gaining insights into the role and potential of video-based information framing and its effect on consumer acceptance.
- Researchers may explore whether subjective knowledge, organic consumption behaviour or socio-demographic characteristics impact the effect of information framing on consumer acceptance. The effect of information framing on the evaluation of conventional production methods, organic production methods and production using beneficial soil-microbes can also be explored.

This dataset was generated to investigate the impact of framing of sustainable food production technologies in videos on consumer acceptance of beneficial soil-microbes in tomato production. Nowadays, consumers are exposed to many forms of video-based communications. However, research on the effect of videos as a communication medium remains limited (Bschaden et al., 2020). This dataset contributes to understanding the potential impact of video-based communication strategies. Thus, the aim of this dataset is to enable analyses on the effect of information framing applied in videos on consumer acceptance. To evaluate acceptance, data on intentions and implicit and explicit attitudes was collected. It can be assumed that information provision changes both implicit and explicit attitudes, but Gawronski and Bodenhausen (2006) illustrated that this is not necessarily always the case. Empirical research has also shown that the mediating role of implicit and explicit attitudes requires further exploration (Weingarten & Hartmann, 2022). Therefore, this dataset enables further investigation on this relationship.

The associated research article focuses on a conducted mediation analysis. This data article provides in-depth information about the source of the data and the process of data generation, which could support additional exploratory analysis.

3.2.3. Data description

The data file is based on an online experiment among German consumers, and consist of 745 complete responses. The following data cleaning was conducted and exclusion measures were implemented: (1) Participants with a low frequency of tomato consumption were excluded. (2) After exposure to the video, participants' comprehension was checked with three questions about the content of the video. (3) An attention check item was included in the intention measure matrix. (4) Participants who indicated that they had never come across beneficial soil-microbes before, but had a mean score on the subjective knowledge scale (ranging from -3 to +3) higher than 1, were excluded. (5) Participants who answered the IAT too slowly or too quickly were excluded following the improved algorithm by Greenwald et al. (2003). Consequently, trials exceeding 10,000 milliseconds and participants who answered in under 300 milliseconds in more than 10% of the trials were excluded. If participants encountered any technical problems and their answers to the IAT could not be recorded, they were also excluded. Thus, the dataset consists of only complete cases with no missing values. Short descriptions and descriptive statistics of the main variables in the dataset can be found in **Table 23**. A detailed description of each variable, the corresponding survey text and coded answer options can be found in the codebook in the OSF folder.

Table 23. Descriptive summary of main variables.

Short description	Variable name	N	Mean	SD	Min	Max
Mean score: purchase intentions	int	745	1.49	1.18	-3.00	3.00
Implicit attitudes (D-score)	atti_impl	745	0.25	0.33	-0.84	1.01
Mean score: explicit attitude towards tomatoes produced with soil-microbes	atti_expl	745	2.14	1.00	-3.00	3.00

Note(s): SD = standard deviation, Min = lowest possible value, Max = highest possible value.

3.2.4. Experimental design, materials and methods

The pre-registered experiment followed a between-subjects design. Participants were assigned to one out of three treatment groups by exposure to a video: loss-frame video (n = 200), gain-frame video (n = 322) or control video (n = 223). The difference in sample sizes emerged due to the comprehension check after video exposure. Participant who answered one out of three comprehension questions incorrectly were excluded. Pre- and post-treatment measures were identical for all participants, only the video comprehension items differed between the groups. See **Table 24** for an overview of all elements included in the experiment.

Table 24. Overview of materials and descriptions.

Materials	Description
Tomato consumption	Frequency of tomato consumption. Low frequency of tomato consumption led to exclusion.
Demographics	Age, gender, education, occupation. Quotas were applied to all demographic measures.
Attitudes towards conventional tomatoes	Bi-polar attitude scale. Order of items was randomised.
Subjective knowledge	Subjective knowledge scale. Order of items was randomised.
Information treatment (video)	Exposure to video clip (one out of three), followed by three questions of comprehension. Wrong answers for one or more of the comprehension questions led to exclusion.
Purchase intention	Hypothetical purchase intention scale. Order of items was randomised.
Explicit attitude*	Bi-polar scale. Order of items was randomised.
Implicit attitudes*	Sing-target IAT.
Organic consumption behaviour	Frequency of organic consumption and percentage of organic groceries.
Evaluation of production methods	Evaluation of conventional production, production with beneficial soil-microbes and organic production. Evaluation related to their perceived (a) naturalness, (b) healthiness, (c) environmental-friendliness. Matrix items were randomised.

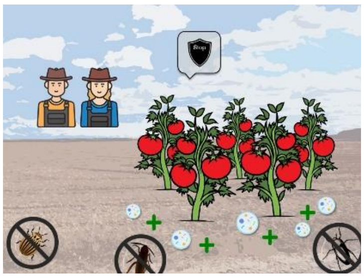
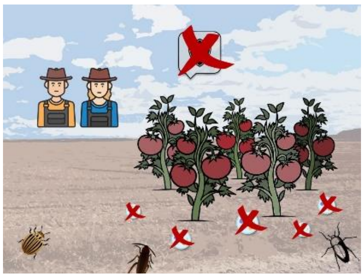
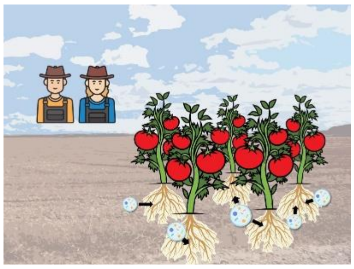
Note(s): The order in the table conforms to the sequence of items in the questionnaire. * Implicit and explicit attitudes were counterbalanced.

3.2.4.1. Video materials

Three different videos with the corresponding framing were created lasting between 1:43 and 1:55 minutes. Generally, the three video clips were structured and arranged in the same manner. The videos explained what soil-microbes are and how they can interact with a plant. In the gain-framing video, advantages due to microbial application for the environment and for human health were portrayed, while in the loss-framing video, disadvantages due to the absence of microbial application were depicted. The design of the control group did not correspond to a true control group, as it is not possible to communicate the overall same content without any reference to benefits and harms. Hence, the control video instead explained in more detail how soil-microbes work.

The voice-over narration communicated the verbal framing stimuli. To increase the salience of the framing, visual cues were integrated in the videos. In the loss-framing video, wherever suitable, the colour red was used, while in the gain-framing video, the colour green was used, and in the control group grey colour tones were integrated. Sample screenshots of the three different videos can be seen in **Table 25**; the videos can be found in the OSF folder.

Table 25. Exemplary frames of the video clips.

Gain-framing video	Loss-framing video	Control video
		

3.2.4.2. Measures

The measures “subjective knowledge”, “explicit attitudes” and “purchase intention” were all measured using a 7-point Likert scale. To ensure consistency and facilitate comparison with the D-score measure for implicit attitudes, the range of these measures was adjusted to span from -3 to +3. Thereby, for all measures, a score of “0” denotes a neutral evaluation, positive scores indicate favourable evaluations, and negative scores represent unfavourable evaluations.

Subjective knowledge

Subjective knowledge was measured with four items that were adapted from Flynn and Goldsmith (1991). Answers were coded on a 7-point Likert scale, ranging from “strongly disagree” (-3) to “strongly agree” (+3). The order of items was randomised. The four items were the following:

- “I know quite a lot about beneficial soil-microbes,”
- “I do not feel very well informed about beneficial soil-microbes,”
- “Compared to most other people, I know a lot about beneficial soil-microbes,”
- “When it comes to beneficial soil-microbes, I really don’t know much.”

Items two and four of the subjective knowledge scale were reverse-coded. The recoded variables and the mean score variable are in the dataset.

Explicit attitudes towards conventionally produced tomatoes

The evaluation of conventional tomatoes was measured on a 7-point semantic bipolar scale. Six items measuring participants’ attitudes were implemented based on Richetin et al. (2007), where the “bad–good” bipolar scale was added. Finally, the following bipolar scales were implemented: “unhealthy–healthy”, “negative–positive”, “bad–good”, “unattractive–attractive”, “unpleasant–pleasant”, “unenjoyable–enjoyable”. The order of each bipolar item was randomised. The bipolar scales were coded between -3 and +3. A mean score variable was created from these items, which is also included in the dataset.

Video comprehension

A binary variable indicates whether the video was re-watched by participants. After exposure to the video, participants' comprehension was checked with three questions about the content of the video. If participants failed to answer at least one of these three comprehension items, they were excluded from the survey. The first question asked for a definition of soil-microbes; two answer possibilities were provided: "Small living organisms in the soil" or "A small rock in the soil." The second and third questions were adjusted depending on the corresponding framing group. The second question asked how soil-microbes affect the tomato plant. Two answer possibilities were provided: "The tomato plant becomes more resistant" and "The tomato plant reaches inflorescence earlier." The third question asked at what level or how farmers need to adjust their production when using or not using beneficial soil-microbes. The first answer dealt with changes in crop protection measures and the second answer with changes in mechanical soil cultivation. The framing of the answers in the third question differed slightly according to the experimental groups. As it is written here, the first answer is always the correct answer; for participants the order of answers was randomised.

Purchase intention

Purchase intention was measured with three items based on the intention scale by Fishbein and Ajzen (2010). Answers were coded on a 7-point Likert scale, ranging from "strongly disagree" (-3) to "strongly agree" (+3). The order of items was randomised, and a mean score variable was created. The three items were the following:

- "I intend to purchase tomatoes produced using beneficial soil-microbes,"
- "I plan to purchase tomatoes produced using beneficial soil-microbes," and
- "I will try to purchase tomatoes produced using beneficial soil-microbes."

Explicit attitude towards tomatoes produced using beneficial soil-microbes

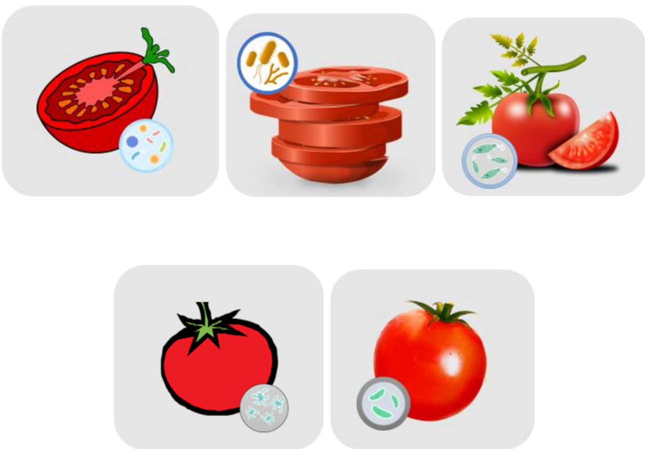
The explicit attitude towards "tomatoes produced using beneficial soil-microbes" was measured with the same scale and items as the explicit attitude towards "conventionally produced tomatoes." A mean score variable was created from all six items.

Implicit attitude

The implicit attitude towards "tomatoes produced using beneficial soil-microbes" was measured by conducting a Single Target-Implicit Association Test (ST-IAT) following Bluemke and Friese (2008).

The programming of the IAT was implemented using an R script by following Carpenter et al. (2019). In this way, the ST-IAT could be integrated in the online survey. Through the IAT plug-in, necessary records are stored in the variables Q1-Q16. These variables were needed for the creation of the D-score, which is already calculated and stored in the dataset. The D-score of differences was calculated by implementing the improved D-score algorithm of Greenwald et al. (2003). The code for the D-score can be found in the analytic script. Four different sets of the IAT were randomly displayed to the participants: the hypothesis-compatible pairing, where "positive" and "tomatoes produced with soil-microbes" were displayed together, and hypothesis-incompatible pairing where "negative" and "tomatoes produced with soil-microbes" were displayed together. 20 trials were conducted for the practice blocks and 74 for the test block. The images and categories used are displayed in **Table 26**.

Table 26. Images and words used in ST-IAT.

Images used in IAT	**Categories used in IAT**	
"Tomatoes produced with soil-microbes"	**"Positive"**	**"Negative"**
	healthy, attractive, pleasant, enjoyable, good	unhealthy, unattractive, unpleasant, unenjoyable, bad

Organic grocery shopping

Frequency of organic purchases was measured on a 6-point ordinal scale. Participants had to indicate how often they had bought organic food in the last 3 months: (1) "More than once a week", (2) once a week", (3) "2 to 3 times per month", (4) "Once a month", (5) "Less than once a month", and (6) "Never".

Additionally, the percentage of regular food expenditures on organic food was measured on a 9-point scale: (1) "Less than 10 percent", (2) "About 11-20 percent", (3) "About 21-30 percent", (4) "About 31-40 percent", (5) "About 41-50 percent", (6) "About 51-60 percent", (7) "About 61-70 percent", (8) "About 71-80 percent" and (9) "More than 81 percent".

Evaluation of production methods

The evaluation of different production methods was measured using three matrix items where participants had to evaluate (a) organic production methods, (b) production using beneficial soil-microbes, and (c) production following conventional production methods. Participants had to indicate how they perceived each of these three production methods with regard to (a) naturalness, (b) healthiness, and (c) environmental-friendliness on a five-point scale. The answer scales for naturalness ranged from (1) “not at all natural” to (5) “extremely natural”; the answer scale for healthiness from (1) “not at all healthy” to (5) “extremely healthy”; and the answers for environmental-friendliness from (1) “not at all eco-friendly” to (5) “extremely eco-friendly”.

3.2.5. Limitations

The three experimental groups consist of different group sizes. This difference is an outcome from the comprehension check after video exposure; when answering at least one out of three questions wrongly, participants were excluded from further survey participation.

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3.3. Frame by frame, attitude by attitude - the effect of information framing in videos on consumers' acceptance of sustainable food production innovations [7]

Abstract. Innovations in the agricultural sector were identified as key drivers for the transition towards more sustainable food production. To achieve consumer acceptance, it is necessary to communicate about innovations and sustainable food production processes effectively. This study investigates the effect of loss and gain framing on consumers' implicit and explicit attitudes towards, and purchase intentions of, agricultural innovations, using the example of beneficial soil-microbes in tomato production. We conducted a pre-registered, online, experimental study with a between-subjects design among German consumers *(n* = 754). To test the effect of communication, three video clips were created: a control video, a loss-frame video and a gain-frame video. The control video described the innovation on a technical level without specific framing. Through the usage of videos, visual and linguistic framing cues could be applied. Group comparisons of the different types of framing did not result in significant differences, yet, our descriptive results suggest that loss-framing had a slightly stronger effect on explicit attitudes than the other frames. Results of a serial mediation analysis show that explicit attitudes play an important role in the model. The effect of both loss and gain framing in relation to the control video resulted in a significant effect on explicit attitudes, and these in turn had a significant effect on purchase intentions. Findings from this study suggest that information videos that describe the consequences of innovation application (loss or gain framing) contribute more strongly towards innovation acceptance than more technical and neutral accounts (our control video) of the innovation.

Keywords: Consumer Acceptance; Implicit Attitude; Information Framing; Agricultural Innovation; Videos

Supplementary materials: Supportive materials can be downloaded at:
https://www.doi.org/10.17605/OSF.IO/N9XJ5.

[7] This subchapter is based on a paper that has been submitted as: Ploll, U., Weingarten, N., Hartmann, M. (2023). Frame by frame, attitude by attitude - the effect of information framing in videos on consumers' acceptance of sustainable food production innovations. *Journal of Environmental Psychology*. Status: undergoing second round of revisions.

3.3.1. Introduction

With the 'Farm-to-Fork-strategy' in the European Green Deal, the European Union (EU) made the agri-food sector one of the cornerstones in the transition towards a healthier and more sustainable EU (European Commission, 2019). Innovations can be key in this process. They are crucial e.g. in efforts to accelerate the route towards an agriculture less dependent on hazardous pesticides and inorganic fertilisers (European Union, 2020). In this respect, beneficial soil-microbes, such as bacteria or fungi, are considered a promising while sustainable innovative contribution (Singh et al., 2011). Beneficial soil-microbes have the potential to enhance the plants' health and resilience, thereby increasing crop yield and quality while reducing the dependence on agrochemicals, and thereby contributing to sustainable food production. This possibility of microbial applications in commercial agriculture to specifically support sustainable food production has been identified by several researchers (Hamid et al., 2021; Rouphael & Colla, 2020).

Societal acceptance of innovations is a critical factor for the success of a transition towards a more sustainable food system. Early dialogue with respect to new food production methods can enhance public awareness, allows for an informed choice, and can help to overcome the 'farm-to-table knowledge gap' (Jeong & Lundy, 2015; Sutherland et al., 2020). It also provides a promising avenue to prevent confusion, scepticism and open resistance with regard to technologies, as in the case of genetically modified (GM) food (Hess et al., 2016).

The communication format and media used for presenting information can play a decisive role in gaining consumers' attention (Perrin, 2011), and thus influencing technology acceptance. There is increasing evidence that videos are a suitable communication medium to inform consumers about a range of complex topics; such as, climate change (Goldberg et al., 2019), sustainable animal-husbandry systems (Risius & Hamm, 2017) or obesity prevention (Cheung et al., 2017), where videos have been shown to be more successful than text material (e.g. Cheung et al., 2017; Goldberg et al., 2019) in influencing attitudes and behaviour. Message framing has been shown to be an effective technique to inform people and motivate behaviour change (Li & Su, 2018). Information framing entails communication that is based on the selection of specific content and on making this particularly salient (Entman, 1993). A common type of framing is the so-called goal framing (Levin et al., 1998). In this respect messages can emphasize the expected benefits of a specific behaviour (gain-frame) or the possible loss if a specific behaviour is not followed (loss-frame; Rothman and Salovey, 1997). Using this method, information presenting an innovation can emphasise the positive outcomes associated with introducing an innovation (i.e., a gain-frame) or the negative outcomes if that innovation is not adopted (i.e., a loss-frame).

The objective of the present study is to investigate the effect of information framing in videos on consumer acceptance of an agricultural innovation. More specifically, we focus on beneficial soil-microbes in tomato production and investigate the effect of gain- and loss-framing in videos on consumers' explicit and implicit attitudes towards and purchase intention of tomatoes produced using this technology. We extend previous research twofold: First, we investigate the effects that loss and gain framing may have not only on explicit but also on implicit attitudes. Second, we apply goal framing using video clips, as a mode for communication. To the best of our knowledge, this has hardly been employed in the framing literature and is lacking with respect to agricultural and food innovations.

3.3.2. Literature review

3.3.2.1. The relevance of attitudes and intentions

If consumers will adopt a new technology, adoption behaviour can be predicted by their attitude and behavioural intentions (Fishbein & Ajzen, 2010; Kamrath et al., 2019). While the attitude expresses the degree of favour with which consumers evaluate a technology (Eagly & Chaiken,1993), behavioural intentions indicate whether consumers plan to adopt the technology in the future. According to the theory of planned behaviour, a positive attitude towards adopting innovations causally leads to increased behavioural intentions to adopt the technology (Fishbein & Ajzen, 2010).

An attitude has different facets and can be distinguished in explicit and implicit attitudes. Explicit attitudes are deliberate, conscious evaluations that can be assessed through self-reported measures (Greenwald & Banaji, 1995). In contrast, implicit attitudes are automatic, spontaneous evaluations that cannot be consciously reported by consumers (Gawronski & Bodenhausen, 2006). Instead, researchers use response-time tests which allow to draw inferences about the underlying implicit attitude. A common method is the implicit association test (IAT) (Greenwald et al., 1998; Greenwald & Lai, 2020). Response-time measures are less prone to potential biases of self-report measures, such as social desirability (van de Mortel, 2008). Therefore, the inclusion of an implicit attitude measure allows for a more holistic representation of consumers' attitude, compared to an explicit measure only. An example of the use of implicit and explicit attitude measures in the domain of agricultural food production, specifically regarding different cop protection methods, is provided by Römer and colleagues. They found an explicit-implicit attitude gap and conclude that studies of attitudes towards agricultural production methods would lack potential explanation possibilities without the inclusion of implicit attitudes (Römer et al., 2019). Although this study did not include a measure of behavioural intentions, other research has shown that both implicit and explicit attitudes serve as predictors for behavioural intentions (Baum et al., 2021; Perugini, 2005; Ratcliff et al., 2017;), which is in line with the TPB (Ajzen, 1991).

According to the associative-propositional evaluation (APE) model, communication can influence both implicit and explicit attitudes (Gawronski & Bodenhausen, 2006). Empirical support for this notion is offered by several studies (e.g., Ackermann et al., 2018; Baum et al., 2021; Weingarten & Hartmann, 2023; Whitfield & Jordan, 2009). Furthermore, attitudes are not only directly influenced by information, but implicit and explicit attitudes also mutually influence each other. As shown by Weingarten and Hartmann (2023), explicit attitudes fully mediated the effect of information provision on implicit attitudes, whereas implicit attitudes only partly mediated the effect of information provision on explicit attitudes. Moreover, consistent with the TPB, if communication affects attitudes this should also influence behavioural intentions (Fishbein & Ajzen, 2010). Therefore, we test whether communication serially influences explicit attitudes, implicit attitudes, and intentions.

3.3.2.2. The effect of loss and gain framing

There are various ways how information can be framed when communication is targeting consumers. According to prospect theory, consumers are more sensitive to potential losses than to potential gains of a decision or action, as consumers place more weight on losses than gains (Kahneman & Tversky, 1979). Thus, information outlining potential losses of a specific behaviour is assumed to impact consumers' attitude and intention more strongly, compared to the description of potential gains when abstaining from that behaviour (O'Keefe and Jensen, 2006). In the literature, this kind of goal-framing is referred to as loss and gain framing (Homar & Cvelbar, 2021; Levin et al., 1998).

The superiority of loss-frames might be due to the depth with which consumers deal with loss- versus gain-related information. According to the ELM (Petty & Cacioppo, 1986), information can be processed via two different routes. The first route is the peripheral route involving superficial message processing, which is associated with a weak attitude change. Alternatively, information can be processed via the central route; this route involves the systematic in-depth processing of information, which is associated with stronger attitude changes (Petty & Cacioppo, 1986). Whether the first or second route is used for information processing depends on a number of conditions, such as the perceived relevance of the message. It can be assumed that loss-framed messages will induce stronger central route processing than gain-framed messages. According to O'Keefe and Jensen (2008) this could be the case because: (1) of the threat perception communicated in a loss-frame and (2) of the required reaction to avert this threat. In a systematic review on information framing related to environmental decisions, the authors demonstrate that loss-framing is more effective (Homar & Cvelbar, 2021).

Previous research demonstrated how goal-framing can be applied in the context of specific agricultural production conditions. For example, Britwum and Yiannaka (2019) evaluated loss- and gain-frames in a choice experiment regarding preferences for cattle treatments against infections. In line with other studies, the authors demonstrated that loss-frames led to a higher willingness-to-pay compared to gain-frames. Or for the case of GM vegetables, negative framing impacted its' perceptions more than positive framing (Heiman & Zilberman, 2011). In the case of products produced with/without genetical modification and antibiotics recall effects were stronger for the loss group than for the gain group (Jeong and Lundy, 2015). Theoretical insights and the majority of empirical research generally suggest a superiority of loss-frames (Homar & Cevalbar, 2021), however, some researchers obtained deviating results. For example, with regard to organic lettuce, negative framing had a stronger effect (Shan et al., 2020); research on organic seafood showed that positive framing increased purchase intentions (Cucchiara et al., 2015). No differences between framing could be detected in a study on chicken labelling (Abrams, 2015).

Yet, a common limitation of many empirical studies that evaluate the effect of framing, is the lack of a control group (i.e. Abrams, 2015; Anghelcev et al., 2020; Baum et al., 2021; Shan et al., 2020). These studies provide only insights about the relative effect of loss and goal framing, but do not allow to draw a conclusion about the effect of framing versus no framing. Among the few studies which incorporate a control group, different approaches to designing the control information can be found. First, the control group only received parts of the information, whereas the experimental groups received additional information with the framing (Britwum & Yiannaka, 2019). However, in such a treatment design the groups receive a different extent of information. Second, the control group received a historical account of the phenomenon in question. A study on climate change reporting used a text describing the history of climate change reporting for the control group, whereas the treatment groups received text in the form of newspaper articles (Nabi et al., 2018). Also, here the information provided in the control group is not comparable to the other treatment groups. Third, other research used information irrelevant to the research topic for the control group (Gray & Harrington, 2011; Weingarten & Hartmann, 2022). In this case, the effect of the same information in absence of the specific framing cannot be tested. Lastly, the study by Cucchiara et al. (2015) is an example of a framing experiment where information is provided to the control group in a neutral manner. While respondents in the positive and negative frame group are informed about the health benefits of consuming organic seafood or about the potential detrimental health effect if abstaining from consumption, participants in the neutral frame obtained information on organic certification for seafood. Therefore, the present study tests the effect of framing versus no framing and additionally compares the relative effects of loss versus gain framing.

3.3.2.3. Video-based communication

When communicating an innovation, developers or marketers not only need to select the appropriate format (i.e. framing), but also the communication medium. While the application of video clips in marketing and communications is prevalent, research studies using video clips as an information tool remain scarce (Bschaden et al., 2020). For the communication of abstract or complex subject matters, videos were identified as a helpful communication medium (Goldberg et al., 2019; Goodwin et al., 2018; Krantz et al., 2016) and led to stronger effects than text-based communication (Cheung et al., 2017; Goldberg et al., 2019). In text-based communication framing can only be expressed through linguistic features (i.e. words), whereas video-based communications can use also additional means, such as colours, images and animations. For example, gains can be accentuated through different colours, then losses. Red is mostly associated with negativity (Elliot & Maier, 2014), whereas the colour green is often associated with more positive perceptions (Moller et al., 2009). A study on perceived healthiness of products showed that green labels lead to higher health evaluations than red labels with the same information (Schuldt, 2013). Research on loss- and gain-framing combined with colours has demonstrated that participants who were exposed to loss-framing together with red colour elements showed significantly higher behavioural intentions (Gerend & Sias, 2009). The usage of colours in food packaging highlighted that package colour influences the perception of healthiness, which in turn has an effect on purchase intentions (Huang & Lu, 2016). Therefore, the present study utilizes video-based communication instead of text-based communication.

3.3.3. The present study

The present study focuses on beneficial soil-microbes, such as bacteria or fungi, as an innovation to improve nutrient use efficiency and pest resistance (Berg, 2009; Chen et al., 2018; Singh et al., 2011). Through these effects, beneficial soil-microbes have the potential to reduce the dependence of agricultural production on chemical fertilizer and plant protection products, thereby contributing to sustainable food production. As the context of application and commercialization is still in development (Lee Díaz et al., 2021), food produced with beneficial soil-microbes are of little relevance in the market yet. In the long-term, the success of this innovation heavily depends on consumers' acceptance. While at present consumers know little about this production method, the question is how information must be designed to promote a positive assessment.

The objective of the present study is to investigate how framing influences consumers' acceptance of agricultural food innovations at the example of beneficial soil-microbes in tomato production. To conceptualize consumers' acceptance, we investigate consumers' purchase intention of, and their implicit and explicit attitudes towards, tomatoes cultivated with this innovation. As a communication tool, we use video clips. We apply a combination of visual and linguistic framing in the format of short explanatory video clips and consider besides a gain and a loss frame also a neutral frame. To disentangle the effect of goal framing on its own, we created a control video which only explains the mechanisms of beneficial soil-microbes, avoiding any framing in the direction of loss or gain framing. Thereby, we can elicit the contribution of goal framing compared to no framing and the relative effects of loss and gain framing. We hypothesise that video clips which emphasise consequences of adoption or the lack thereof (loss- and gain-framing) have a stronger effect on: (a) explicit attitudes; (b) implicit attitudes; and (c) purchase intentions than an information video with no specific goal-framing. According to the literature on framing effects, we expect that the effect of loss-framing is stronger compared to gain-framing on both attitude levels as well as on purchase intentions. Furthermore, we assume that the effect of video-based frames on purchase intention is serially mediated by explicit and implicit attitudes. Based on Baum, Bröring and Lagerkvist (2021), and Weingarten and Hartmann (2023) we assume that framing significantly influences explicit attitudes, which influences implicit attitudes, which influences intentions. The pre-registration, experimental material, data and analytic script can be viewed here: https://www.doi.org/10.17605/OSF.IO/N9XJ5.

3.3.4. Material and methods

3.3.4.1. Data and design

We conducted an experimental online study with German consumers. The study followed a between-subjects design with three treatment conditions (loss-frame vs. gain-frame vs. no frame). Participants were randomly assigned to one out of the three conditions by watching a video. Recruitment occurred via a market research agency in 2022, and was designed to be representative of the adult population living in Germany with respect to age, gender, education and occupation status. To qualify for participation, respondents had to be regular consumers of tomatoes and had to fulfil technical pre-requisites, such as a device with functioning audio and a keyboard. Non-eligible participants were automatically screened out. All participants who completed the experimental study were reimbursed through a bonus point system of the market research agency.

Sample size was defined according to an a priori power analysis with G*power (Faul et al., 2009). We calculated the power to detect small effect size (f^2 = 0.013) with a multivariate analysis of variance (MANOVA), a power of 1-β = 0.90 and an α = 0.05. The minimal required sample is n = 675. To account for possible exclusions, we decided to recruit approximately 750 participants. The study was conducted in accordance with the Declaration of Helsinki and received ethical approval by the ZEF Research Ethics Committee (certificate number 9_ILR_21).

The online study was programmed using Qualtrics. First, we collected participants' informed consent, assessed screening criteria, and measured socio-demographics. In the second part of the survey, respondents were requested to provide information with respect to their attitudes towards conventionally produced tomatoes and their subjective knowledge about beneficial soil-microbes. Participants who indicated that they had never come across beneficial soil-microbes before, but subsequently had a mean score on the subjective knowledge scale higher than 5 were excluded. Next, participants were requested to watch a short video clip, followed by a video comprehension check based on three questions about its content. We directly screened out participants who failed to answer these questions correctly. The fourth section of the survey contained the main dependent variable of the study, purchase intentions, and the mediators, implicit and explicit attitudes. The order of the implicit and explicit attitude measure was counterbalanced. The final section of the questionnaire solicited information regarding consumers' organic grocery shopping behaviour and their evaluation of different cultivation methods — conventional, organic and those based on beneficial soil-microbes. After finalizing the survey, participants received a debriefing.

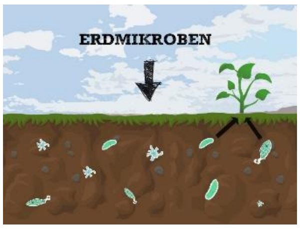
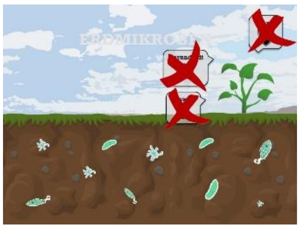
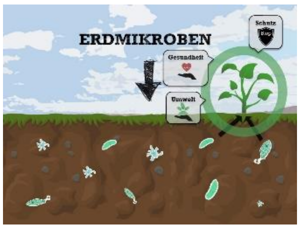
3.3.4.2. Video material

Respondents saw one of three video clips, which lasted between 1:43 and 1:55 minutes. All three clips followed the same structure and explained what beneficial soil-microbes are and how they interact with plants (see OSF folder [8]). In all videos the text was read by the same male narrator as a voice-over. To construct the different framing treatments, verbal and visual stimuli were used. For linguistic framing, information was formulated in such a way that it either expressed a gain- or loss-frame while communicating the same meaning. The goal framed videos described advantages or disadvantages, respectively, which could be gained or lost due to the application of or negligence of beneficial soil-microbes. Those consequences referred to (reducing or preventing) potential harm associated with conventional farming practices with respect to the environment and human health. In contrast, the control group received a video clip with explanations about beneficial soil-microbes and their interaction with the soil and the plant — as did the other groups — however, without explicitly pointing to the positive or negative effects on human health or the environment

Regarding the visual manipulation, special care was taken to secure the similarity of the images in all three presentations. Visual framing primarily focused on colours to enhance the goal framing messages where appropriate, with the loss-framing making use of the colour red, the gain framing of the colour green and the control video applying grey tones. Animations aligned with the loss-framing by elements disappearing and, vice-versa, elements appeared in the gain-framing video. See **Table 27** for an example of the applied textual and visual framing cues.

[8] Control video: https://osf.io/cjxas
Gain-framed video: https://osf.io/56qnd
Loss-framed video: https://osf.io/rcux2

Table 27. Example of texts and visuals used in the three video clips.

Framing	Narration	Visual
Control	These soil-microbes interact and cooperate with the plant below the soil.	
Loss	Without soil-microbes, the plant as well as the environment and our health are less well protected.	
Gain	Soil-microbes help to better protect the plant as well as the environment and our health.	

Note(s): The underlined text shows different linguistic cues for framing. Meaning of German text in the videos: Erdmikroben = soil-microbes, Schutz = protection, Gesundheit = health, Umwelt = environment.

Prior to the main study, we conducted a qualitative (n = 27) and a quantitative pre-study (n = 238) to test how the videos were perceived, whether the videos were understandable, what participants associated with the videos and whether/what effects the videos had on participants. Based on the findings of the pre-studies, we simplified the design and adjusted some of the information about beneficial soil-microbes.

3.3.4.3. Measures

Subjective knowledge

Subjective knowledge about beneficial soil-microbes was measured with four items adapting the short scale of Flynn and Goldsmith (1999). Answers to the four items ‘I know quite a lot about beneficial soil-microbes’, ‘I do not feel very well informed about beneficial soil-microbes’, ‘Compared to most other people, I know a lot about beneficial soil-microbes’, ‘When it comes to beneficial soil-microbes, I really don’t know much’, were captured on a 7-point Likert scale from 1=strongly disagree to 7=strongly agree. The scale had a good internal consistency (Cronbach’s $\alpha = 0.804$). We used a rescaled mean score (ranging from -3 to +3) of the four items for further analyses. The second and fourth item were reverse coded so that higher values stand for higher subjective knowledge and vice versa.

Explicit attitude

Explicit attitude towards ‘tomatoes produced with beneficial soil-microbes’ was measured on a 7-point semantic bipolar scale based on Richetin et al. (2007) — unhealthy–healthy, negative–positive, unattractive–attractive, unpleasant–pleasant, unenjoyable–enjoyable —, and an additional sixth item, bad–good. The construct exhibited excellent internal consistency (Cronbach’s α of 0.971). A mean score variable of all six attitude items was created for further analyses, where values ranged from - 3 to +3.

The attitude towards ‘conventionally produced tomatoes’ was measured using the same six items. Construct reliability was as well excellent (Cronbach’s α of 0.964).

Implicit attitude

For measuring implicit attitude towards ‘tomatoes produced with beneficial soil-microbes’ a Single Target-Implicit Association Test was used following Bluemke and Friese (2008). In this computer task, the association is measured between a target category, in this case, tomatoes produced with beneficial soil-microbes, and a bipolar outcome category (e.g. negative-positive). The target category was depicted with images of a tomato together with a symbol for microbes. The stimulus words referring to the attribute category positive/negative consisted of the same 12 words used for the explicit attitude measure without positive and negative, namely: unhealthy, healthy, unattractive, attractive, unpleasant, pleasant, unenjoyable, enjoyable, bad and good. The ST-IAT consisted of five blocks (see **Table 28**) starting with a general practice block in which participant are requested to categorize the stimulus words into one (e.g. positive) or the other (e.g. negative) attribute category. In a second practice block, the target category —tomatoes produced with beneficial soil-microbes — has to be paired additionally with one of the attributes (e.g. positive attribute category). The latter block recurs, which is the first test block. Blocks 2 and 3 are repeated, however, with reversed pairing (e.g. tomatoes with the negative category). Participants needed to assign pictures and words to the correct outcome categories using the ‘E’ and ‘I’ key on their keyboard as quickly as possible. If participants provided a wrong response a red X appeared and they needed to adjust their answer. It is assumed that someone with a positive (negative) implicit attitude towards tomatoes produced with beneficial soil-microbes will find it significantly easier to react to the combination of tomatoes and the positive (negative) category, than to tomatoes and the negative (positive) category on the same side. Taking the difference between the reaction times of the two test blocks provides an indication of the implicit attitude strength. In this study, the differences were calculated using the improved D-score algorithm by Greenwald et al. (2003) with a D-score value of 0 expressing no association and higher (lower) values indicating a positive (negative) association. The internal consistency of the ST-IAT was tested by calculating the Spearman-Brown split-half reliability, which resulted in a good reliability estimate of 0.831. The IAT was programmed using an R script provided by Carpenter et al. (2019). This allowed for an integration of the IAT task in the Qualtrics survey flow.

Table 28. Description of blocks in the ST-IAT.

<table>
<tr><th rowspan="2">Block</th><th rowspan="2">Block function</th><th rowspan="2">Number of trials</th><th rowspan="2">Description</th><th colspan="2">Exemplary process ST-IAT (set: compatible, left)*</th></tr>
<tr><th>E-key response</th><th>I-key response</th></tr>
<tr><td>1</td><td>Practice</td><td>20</td><td>Evaluative words (positive and negative), no tomatoes with microbes</td><td>Positive words</td><td>Negative words</td></tr>
<tr><td>2</td><td>Practice</td><td>20</td><td rowspan="2">Evaluative words and tomatoes with microbes</td><td rowspan="2">Positive words and tomatoes</td><td rowspan="2">Negative words</td></tr>
<tr><td>3</td><td>Test</td><td>74</td></tr>
<tr><td>4</td><td>Practice</td><td>20</td><td rowspan="2">Evaluative words and tomatoes with microbes, tomatoes switched sides</td><td rowspan="2">Positive words</td><td rowspan="2">Negative words and tomatoes</td></tr>
<tr><td>5</td><td>Test</td><td>74</td></tr>
</table>

* Four randomised ST-IAT order versions/sets were implemented. The four starting positions at block 2 for each set are: (1) tomatoes with beneficial soil-microbes on the right side with positive words (compatible, right), (2) tomatoes with beneficial soil-microbes on the right side with negative words (incompatible, right), (3) tomatoes with beneficial soil-microbes on the left side with positive words (compatible, left), (4) tomatoes with beneficial soil-microbes on the left side with negative words (incompatible, left). Each participant conducted the IAT based on one order/set of blocks.

Purchase intention

Purchase intention of tomatoes produced with beneficial soil-microbes was measured on a 7-point Likert scale (-3 = strongly disagree; +3 = strongly agree) based on the three items intention scale of Fishbein and Ajzen (2010). The statements were formulated in the following way: 'I intend to purchase tomatoes produced with beneficial soil-microbes', 'I plan to purchase tomatoes produced with beneficial soil-microbes' and 'I will try to purchase tomatoes produced with beneficial soil-microbes'. The scale yielded an excellent Cronbach's α of 0.957, which allowed the use of a mean score in the further analysis.

3.3.4.4. Data analysis

First, as a randomization check, we tested for differences between all conditions with regard to their socio-demographics, attitude towards 'conventionally produced tomatoes' and subjective knowledge about beneficial soil-microbes with one-way analysis of variance (ANOVAs) and chi-square tests. In case of significant differences, we included the variable as covariate in the main analysis. Second, a MANOVA was conducted with implicit attitude, explicit attitude and purchase intention as dependent variables and framing (control, loss-frame, gain-frame) as the independent variable. Third, using PROCESS model 6 (Hayes, 2018), we tested whether the effect of information framing on purchase intention is serially mediated by implicit attitude and explicit attitude. Bootstrapping was used to obtain bias-corrected 95% confidence intervals of the indirect effects. Furthermore, we conducted an exploratory analysis using PROCESS model 4 (Hayes, 2018), to investigate the mediation effect of explicit and implicit attitudes on intentions separately. All analyses were conducted using the statistical computational language R. The R code for the analyses as well as the dataset can be found in the supplementary materials folder on OSF.

3.3.5. Results

In total, 759 participants completed the survey. 13 participants were excluded, as they encountered technical problems when conducting the ST-IAT or performed the IAT too slowly or too quickly according to the D-score algorithm by Greenwald et al. (2003). One participant was excluded due to inconsistent answers about their subjective knowledge. Thus, the final sample consists of 745 complete observations, with 223 participants being part of the control group, 200 of the loss group, and 322 of the gain group. Differences in group size came about by programmed screen-out criteria after participants watched the videos. **Table 29** shows that the final sample (*n* = 745) reflects the structure of the German population aged 18–65 years old with respect to sociodemographic characteristics very well.

Table 29. Socio-demographic characteristics of the sample and of the German population.

Demographic variable	**Category**	***n***	**Sample (%)**	**German population (%)** 18–65 years*
Gender	Man	355	47.7	48.3
	Woman	389	52.2	51.7
	Non-binary/other	1	0.1	-
Age	18–29	142	19.1	19.8
	30–39	127	17.1	19.4
	40–49	134	18.0	18.0
	50–59	179	24.0	23.7
	60 years and above	163	21.9	19.1
Education	Basic education (still in school/training or general school education)	154	20.6	20.9
	Intermediate (apprenticeship, vocational training, or technical school diploma)	443	59.4	59.4
	Advanced (bachelor’s degree, master’s degree, or doctorate)	148	19.9	19.7

Demographic variable	**Category**	***n***	**Sample (%)**	**German population (%)** 18–65 years*
Occupation	Employed	554	74.4	73.9
	Unemployed, social welfare	47	6.3	6.2
	Pension, retirement	35	4.7	4.9
	Other (e.g. in education, stay-at-home-parent)	109	14.6	15.1

* References on the demographics: Statistics on gender: Statistisches Bundesamt, 2022a; statistics on age: Statistisches Bundesamt, 2022b; statistics on education: Statistisches Bundesamt, 2022c; statistics on occupation: Statistisches Bundesamt, 2020.

The randomisation check revealed no significant difference between the groups concerning socio-demographics and attitude 'towards conventional tomatoes' (all *p*'s > 0.061). Though, subjective knowledge is low in all three groups, significant differences exist between the groups ($F(2, 742) = 3.527$, $p = 0.030$, and $\eta_p^2 = 0.009$) with the control group having the highest subjective knowledge ($\bar{X}_{\text{Control}} = -1.570$, SD = 1.270), followed by the participants exposed to the gain video ($\bar{X}_{\text{Gain}} = -1.784$, SD = 1.289). The loss-frame group revealed the lowest knowledge ($\bar{X}_{\text{Loss}} = -1.888$, SD = 1.248). Therefore, we included subjective knowledge as the covariate in the MANCOVA (section 3.3.5.2).

3.3.5.1. Construct evaluation

An exploratory factor analysis with oblique rotation was conducted to investigate construct validity. The items representing the constructs purchase intention, explicit attitude towards tomatoes produced with microbes and subjective knowledge were included in the factor analysis. The Kaiser–Meyer–Olkin measure representing sample adequacy ranged between 0.641 and 0.950, which indicates a suitable sample size (Williams et al., 2010). The factor structure replicated the intended structure of the constructs. Factor loadings for each item ranged between 0.712 and 0.966; only one reversed item for subjective knowledge scored relatively low, with 0.434. Further descriptive statistics and correlations of the constructs can be found in **Table 30**. A comparison of the mean scores of the attitude toward conventional tomatoes and the attitude toward tomatoes produced with soil-microbes highlights, that already through the exposure of the control video did participants evaluate the tomatoes produced with soil-microbes quite positively (2.028 out of a scale ranging from -3 to 3) and much higher than the conventional tomatoes. Further, from the mean values it can be seen that for purchase intentions and explicit attitudes the gain group has the highest mean values, followed by the loss group. For implicit attitudes the loss group has the highest average D-score and the gain group the lowest. Subjective knowledge is generally very low, where the control group has the highest mean. The highest significant correlation can be found between explicit attitudes and purchase intentions. Of smaller magnitude are the significant correlations between the explicit attitude and (a) the implicit attitude and (b) the attitude towards conventional tomatoes, respectively.

Table 30. Descriptive statistics and correlation of constructs for attitude towards conventional tomatoes, purchase intentions of, subjective knowledge of and attitude measures of tomatoes produced with beneficial soil-microbes.

		Control group (n = 223)	**Gain group** (n = 322)	**Loss group** (n = 200)	**Correlation**			
					Conv. tomatoes	**Tomatoes produced with beneficial soil-microbes**		
		Mean (SD)	**Mean (SD)**	**Mean (SD)**	**Expl. attitude**	**Expl. attitude**	**Impl. attitude**	**Purchase intentions**
Conv. tomatoes	**Expl. attitude**	1.167 (1.286)	1.297 (1.403)	1.120 (1.355)	1			
Tomatoes produced with beneficial soil-microbes	**Expl. attitude**	2.028 (1.029)	2.174 (0.989)	2.210 (0.986)	0.264***	1		
	Impl. attitude	0.247 (0.322)	0.268 (0.335)	0.209 (0.331)	0.045	0.086	1	
	Purchase intentions	1.365 (1.184)	1.527 (1.143)	1.557 (1.224)	0.062	0.660***	0.050	1
	Subjective knowledge	-1.570 (1.270)	-1.784 (1.248)	-1.888 (1.289)	-0.004	-0.033	0.053	-0.016

Note(s): Explicit attitudes, purchase intention, and subjective knowledge can range between -3 and 3. Pearson correlation coefficients. **, *** indicate a significance level at 5%, and 1%, respectively. SD = standard deviation.

3.3.5.2. Effect of goal framing on explicit and implicit attitudes

To test whether the framing (control, loss-frame, gain-frame) had a significant impact on implicit attitude, explicit attitude and purchase intention we conducted a MANOVA. The group comparisons using Pillai's Trace test resulted in non-significant values, with $F(6, 1482) = 1.454$, $p = 0.191$, and $\eta_p^2 = 0.006$. **Table 30** shows that the mean values for purchase intentions as well as explicit attitude are higher in the loss group than the gain group and the control groups; however, these are not significant differences. Implicit attitudes are highest for the loss group, but are then followed by the control group and lowest values can be observed in the gain group.

As an exploratory analysis, independent sample t-tests were conducted to investigate whether there was a significant difference between the control group and the goal framing groups together. Explicit attitudes showed significant differences ($t(743) = -1.996$, $p = 0.046$) with an effect size (Cohen's d) of 0.160. Differences between these two groups were insignificant for the implicit attitudes (t(743 = 0.060, $p = 0.952$, and Cohen's $d = -0.005$) and purchase intentions ($t(743) = -1.844$, $p = 0.066$, and Cohen's $d = 0.148$)

To rule out that our results have been influenced by differences in subjective knowledge between the treatment groups, we conducted a MANCOVA. We found no significant effect of the covariate subjective knowledge ($F(3, 739) = 0.881$, $p = 0.451$, $\eta_p^2 = 0.004$) on the outcome variables, intention, explicit and implicit attitudes. Therefore, subjective knowledge was excluded in the proceeding analysis.

3.3.5.3. Mediation analysis

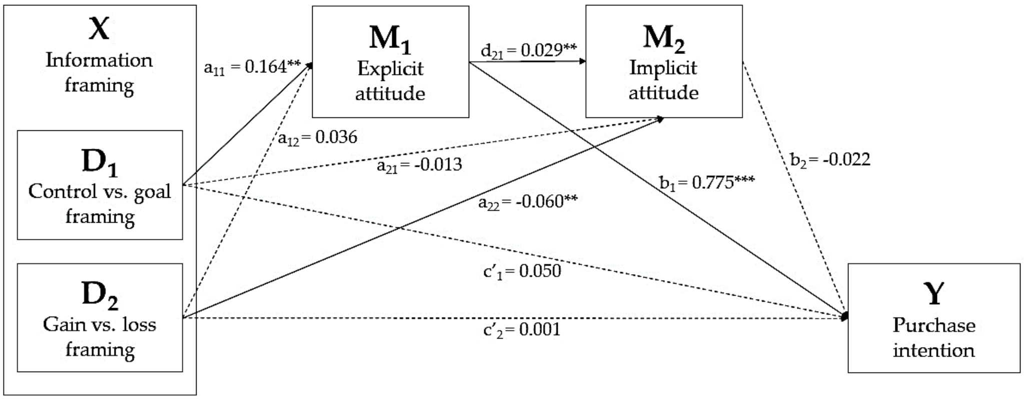
Using PROCESS (model 6; Hayes, 2022), we tested whether implicit and explicit attitude serially mediated the effect of framing on purchase intention. We considered explicit attitude as the first and implicit attitude as the second serial mediator. As the independent variable consists of three categories (control, loss frame, gain frame), we followed the recommendations by Hayes and Montoya (2017) to apply Helmert coding. Through Helmert coding we compare the average effect of goal framing (loss and gain; D_1) relative to the control condition, and the relative effect between the gain and loss group (D_2; Hayes, 2018; Hayes & Montoya, 2017). **Table 31** provides an illustration of the applied coding scheme. We used bootstrapping (with 10,000 bootstrap samples) to obtain bias-corrected 95% confidence intervals of the indirect effects generated by the independent variable on the dependent variable through the mediator variables.

Table 31. Applied Helmert coding.

Group	**D_1**	**D_2**
Control group	$-{}^2/_3$	0
Gain group	${}^1/_3$	$-{}^1/_2$
Loss group	${}^1/_3$	${}^1/_2$

Results of the serial mediation analysis show that goal-framing compared to no framing has a significant positive effect on explicit attitude ($a_{11} = 0.164$, $p = 0.043$; see **Figure 13**). Hence, the goal framing group (which received either loss or gain framing) showed a positive impact on explicit attitudes in comparison to the group which received the control video. In contrast, no significant difference between gain versus loss framing could be observed on the explicit attitude ($a_{12} = 0.036$, $p = 0.693$). Gain framing, in addition, lead to a significant, more positive implicit attitude compared to loss framing ($a_{22} = -0.060$, $p = 0.045$), which implies that gain framing is superior to loss framing in influencing implicit attitudes. Albeit, no support was found for a significant effect on the implicit attitude when considering loss and gain framing together in comparison to the control video ($a_{21} = -0.013$, $p = 0.621$). Moreover, the model showed that explicit attitudes were significantly related to implicit attitudes ($d_{21} = 0.029$, $p = 0.017$) and purchase intentions ($b_1 = 0.775$, $p = 0.000$), but no relationship between implicit attitudes and purchase intentions was found ($b_2 = -0.022$, $p = 0.826$).

Figure 13. Results of the serial mediation analysis.



Note(s): Results of the serial mediation analysis examining relative effects of video framing on purchase intentions serially mediated by explicit and implicit attitudes. **, *** indicate a significance level at 5%, and 1% respectively, dashed lines indicating insignificant relations.

We analysed the indirect effect to evaluate mediational effects. **Table 32** shows that 95 per cent confidence intervals (10,000 bootstrap samples) for all indirect effects include zero. This implies that no mediation effect could be detected. Hence, neither explicit, nor implicit attitudes can causally explain the relationship between information framing and purchase intention.

Table 32. Relative indirect effects of serial mediation analysis.

	Path	**Coeff. (SE)**	**Lower Limit CI**	**Upper Limit CI**
D_1: control vs. goal framing	D_1 -> M_1 -> M_2 -> Y	-0.000 (0.001)	-0.001	0.001
	D_1 -> M_1 -> Y	0.127 (0.064)	-0.001	0.252
	D_1 -> M_2 -> Y	0.000 (0.003)	-0.005	0.007
D_2: gain vs. loss framing	D_2 -> M_1 -> M_2 -> Y	-0.000 (0.000)	-0.007	0.001
	D_2 -> M_1 -> Y	0.028 (0.070)	-0.111	0.162
	D_2 -> M_2 -> Y	0.001 (0.006)	-0.012	0.015

Note(s): Using 95% confidence interval bootstrapping, 10,000 resamples. Coeff. = coefficients, SE = standard errors, CI = confidence interval, M_1 = explicit attitude; M_2 = implicit attitude; Y = purchase intention.

To single out whether gain or loss framing alone has an effect, we also conducted the same serial mediation analysis using indicator coding. Indicator coding allows for the comparison of each experimental condition to the control condition. The results show that neither loss framing nor gain framing in comparison to the control video had a significant effect on any of the dependent variables, not on explicit attitudes, on implicit attitudes nor on intentions (see Appendix, **Table A7**). No indirect effect of the serial mediation could be detected either (see Appendix, **Table A8**).

Lastly, as pre-registered exploratory analyses, we tested the mediation effect of explicit and implicit attitudes on intentions separately using again Helmert and indicator coding. Therefore, we ran PROCESS mediation model 4 (Hayes, 2018) four times, where the effect of information framing on purchase intentions was mediated either (a) by explicit attitudes or (b) by implicit attitudes. The results mainly reflect the outcomes of the serial mediation analysis with the equivalent coding [9]. Magnitude of indirect effects as well as significance levels are similar to the results of the main analysis. The effect of goal framing vs. control was significant on explicit attitudes, and the effect of loss vs. gain framing on implicit attitudes. The single mediation analyses using indicator coding did not result in any significant coefficients, except for that of explicit attitudes on intentions. No mediation effect was detected in any of the models.

3.3.6. Discussion

This study is one of the first to investigate the effect of information framing using video clips on consumers acceptance. Also, the impact that different information framing has on implicit and explicit attitudes is, to the best of our knowledge, a gap not addressed in literature yet. Our research focused on the effect of information-framing on consumers' explicit and implicit attitudes and purchase intentions of tomatoes produced with beneficial soil-microbes. We used short video clips as the communication modality for the information treatments. Although, we could not confirm most of our hypothesis, tendencies seem to support the hypothesised effects of information framing for explicit measures.

3.3.6.1. Effects of information framing

The results partly confirmed the first hypothesis. Goal framing is significantly more effective than no framing in influencing explicit attitudes. This indicates that highlighting the environmental as well as health-related benefits of using, or losses of abstaining from using beneficial soil-microbes are more effective than neutrally formulated information. These findings are in line with research on offshore wind-energy, where, on average, the no-framing group showed the lowest acceptance for wind-energy compared to the framing groups. As in our study, the control group was presented more general information without highlighting specific benefits (Walker et al., 2014). Also, in research on food products with aesthetical imperfections, goal-framing was more effective than the control treatment in improving preferences; the authors suggest that it is the salience of the framed messages which create stronger effects, and not the framing itself (Lagerkvist et al., 2023). In line with the studies discussed above, our results show that goal-framing impacts the explicit evaluations more than information with no specific framing. However, our analysis could not detect an effect attributed solely to goal or loss framing in comparison to the control group. For this particular analysis, the sample size was smaller

[9] For detailed results, see OSF folder: https://osf.io/rk9wq

than that employed in the main analyses, which potentially led to an underpowered test, which lacked the capacity to detect any framing effects.

Contrary to our expectations, the effect of goal framing could not be observed for implicit attitudes. According to dual-construct approaches, implicit associations reflect more stable attitudes that are the results of learning processes and socialisation over longer time periods (Gawronski & Bodenhausen, 2006; Greenwald & Banaji, 2017). The impact of information on implicit attitudes in the field of innovations is something that has not been researched to a wide degree yet. Several studies involving information provision about new concepts or products highlight the impact information can have on implicit attitudes; for example, short information cues about various fictious products can impact implicit attitudes towards those products (Ackerman et al., 2018), and serve a mediating role in the effect of information on purchase intentions of cultivated meat (Baum et al., 2021) or the effect of information on attitudes towards genome editing (Nguyen et al., 2022). However, in our study, with the introduction of tomatoes with beneficial soil-microbes, implicit attitudes may have not taken shape yet. Our subjective knowledge measure shows that in all three groups subjective knowledge is rather low (mean scores between -1.57 and -1.89 on a scale from -3 to +3). This indicates that there is hardly any past knowledge which may have shaped implicit attitudes before our information treatment. Research has shown that implicit attitudes towards a branded product may be transferred to another product from the same brand, irrespective of the other product's traits (Ratliff et al., 2012). This was also illustrated with attitudes towards individuals by Ranganath and Nosek (2008), who highlight that implicit associations may be transferred from one to another. This holds potential consequences for innovations; a consumer may form implicit attitudes based on another familiar product, which they can relate to the innovation in question. Therefore, for the case of innovations, implicit attitudes towards certain innovations may only be susceptible to information if consumers can base it on a similar concept or category. Nguyen, Ben Taieb, Moritaka, and Fukuda (2022) also come to similar conclusions about GM foods and gene editing, where consumers' implicit evaluation of gene editing may be explained by consumers' evaluation of GM food and aligned information. For the case of cultured meat, the authors also infer that attitudes are transferred from another related category towards the new object in question (Bekker et al., 2017). For the case of beneficial soil-microbes, we believe that at this point, there might be no other concept that consumers may infer or base their implicit attitudes on, which could explain the inconclusive implicit attitudes regarding tomatoes produced with soil-microbes. This poses a question for future research, to investigate to what degree innovations and new concepts can impact implicit attitudes and whether these play a role in the formation of acceptance of innovations in the long term.

Based on prospect theory, the second hypothesis predicted that a loss-frame would lead to a stronger attitudinal change as well as stronger purchase intentions compared to a gain-frame. We found no significant difference between gain- and loss-framing on explicit attitudes nor on purchase intention.

One explanation for the absence of an effect might lie in the formulation of the loss-frame. The formulation of losses in a video about the additional use of beneficial soil-microbes resulted in phrases which may have appeared unusual to some participants, although our pre-test indicated that our videos were understandable and clear. Yet, this could have limited the persuasiveness of the loss-framing video. Contrary to our second hypothesis, we found an opposite effect of gain- and loss-framing on the implicit measures in the mediation analysis. According to our findings, implicit attitudes were more strongly influenced by gain-framing compared to loss-framing. Previous research found a similar pattern in the domain of health behaviour, where gain-framing appeared to be generally more effective than loss-framing (Gallagher & Updegraff, 2012; Gray & Harrington, 2011; O'Keefe & Jensen, 2006, 2007, 2008). A possible explanation for this effect is offered by Cucchiara et al. (2015). The authors argue that the consumption of organic food can be considered prevention-driven behaviour, and thus part of the health behaviour domain. This suggests that the effect of loss- and gain-framing dealing with certain food-related topics could follow the same pattern as health-related behaviour. Since the video clips in the present study referred to both environmental and health impacts in the goal-framing, the relative persuasiveness of gain- and loss-framing becomes less clearly defined. Thus, the inclusion of these argumentation lines could have interfered with the relative effectiveness of loss- and gain-framing. However, it remains unclear why the effect of the described consequences related to human health might have been detected only in participants' implicit attitudes. This remains a potential research subject for future studies, which may evaluate the effect of gain- and loss-framing related to health behaviour and its effect on implicit attitudes. Furthermore, to the best of our knowledge, the effect of goal framing on implicit attitudes is a research topic that has been hardly addressed so far.

Thirdly, we hypothesized that the effect of information framing on intentions would be serially mediated by both attitudes. Our results did not detect a serial mediation. Nonetheless, regarding the explicit measure, a trend towards the mediation effect could be seen. This indicates that explicit attitudes may play an important role as a single mediator, rather than one mediator with both attitudes in the serial mediation model. In particular, implicit attitudes do not appear to explain purchase intentions. However, as previously discussed, aspects such as the inclusion of health consequences in goal-framing or a lack of implicit attitude formation may have interfered with the implicit attitude measurement.

3.3.6.2. Limitations

When interpreting the results, some limitations should be considered. The first limitation concerns the design of the control video. Due to the novelty of the innovation and consumers' lack of knowledge, it was necessary to provide also the control group with information prior to the elicitation of attitudes and intentions. The control video does not contain any framing of gains or losses of applying or not applying the innovation; however, it provides information such as that soil-microbes are useful for the plant, i.e., allowing an adjustment of pesticide applications. The mean values indicate that this already motivated a positive attitude toward tomatoes produced with beneficial soil-microbes (above 2 on a scale from -3 to 3), which was also close to the positive evaluations from the goal framing groups, and much higher than for conventional tomatoes. This could indicate a ceiling effect (Chyung et al., 2020), meaning that all our participants scored toward the maximum range of our direct measures. This positive effect of the control video could have then impacted the analysis consequentially, as the tests may not have been able to detect the (more) positive effects of the goal framing. As previously discussed, other studies have used diverse solutions, which shows that there is no sole procedure on how to implement a control condition in research on information framing. Especially when the presented information deals with innovations, which encompass inherently new elements, information provision about the innovation prior to its evaluation is necessary. Yet, with the inclusion of a control video, we were able to elicit the effectiveness of goal-framing in relation to general information provision. Second, our sample consists of heterogenous participants, thus the effect of framing may also differ based on different consumer segments (Just & Goddard, 2023). Future research can consider exploring the effect of information framing for different consumer groups. Third, because of the research and development stage of beneficial soil-microbes, food products using this technology are not available on the market. Consequently, a hypothetical description of the innovation was used in the videos and only attitudes and the intention to purchase the innovation could be researched. Fourth, our study only provides a snapshot into hypothetical consumer acceptance. As our results illustrate, it remains unclear to what degree information provision can have a long-term effect on attitudes (in particular on implicit attitudes), intentions and consequently behaviour. Future research dealing with the acceptance of an unknown innovation could benefit from exploring the long-term effect of (repeated) information provision on attitudes. Yet, our results provide guidelines - on a population level - about how information framing can impact attitudes and behavioural intentions also for other future agricultural technologies. Fifth, in order to strive for successful adoption of innovations in the future, consumers' acceptance in the form of purchasing behaviour itself has to be investigated. A significant amount of research has addressed the gap between attitudes and behaviour in various domains of behaviour (i.e., ElHaffar et al., 2020; Glasman & Albarracín, 2006; Kollmuss & Agyeman, 2002). Therefore, this study remains limited in its potential to provide predictions about future purchasing behaviour; albeit, it provides a first starting point. Sixth, the actual environmental impact that the acceptance and increased purchase of foods produced with beneficial soil-microbes can induce is contingent on many specific circumstances on the field. The current status of research indicates that beneficial soil-microbes can offer various benefits, which can result in a reduced usage of harmful chemicals by the farmer (Elnahal et al., 2022). However, further research and development is needed for successful long-term applications on agricultural fields and consequently environmental impacts (Lee Díaz et al., 2021). Lastly, we could not detect any effects of gain or loss framing individually in comparison to the control group; albeit, this may be attributed to sample size. Nonetheless, this issue should be taken up in future research.

3.3.6.3. Implications

Looking ahead, a transition towards more sustainable food production will require changes and the implementation of innovations on the field. To ensure success, all stakeholders should be considered in such a process. In order to foster transparency in food production processes and the acceptance thereof, communication campaigns about such processes or changes are necessary. Consumer attitudes with regard to innovations such as beneficial soil-microbes will, in many instances, be influenced by available information about such changes or agricultural innovations. Therefore, effective information provision is essential to ensure innovation acceptance by a wide range of stakeholders. With regard to the construction of communication approaches, we have taken a step towards the usage of visual and linguistic framing. Plenty of communication targeted at consumers uses video clips as their communication modality, thus our insights line up with such popular means of communication. This may entail outreach communication about sustainability programs, such as the Farm-to-Fork strategy by the European Union or the Common Agricultural Policy (CAP), which both specifically address changes at the agricultural level. Also, retailers or producers who intend to inform their consumers about innovative products with new production methods may consider our results when designing communication campaigns.

3.3.7. Conclusion

Many scientists have highlighted the extensive impact that agricultural and food production create with regard to the environment. Thus, there is a call and urgency to change production processes in the food value chain, which is also reflected in various programs at the European level. To support this process, beneficial soil-microbes have been recognized as a potential tool for more sustainable agriculture. Our study investigated whether different information framing can contribute to fostering consumer acceptance of beneficial soil-microbes. According to our findings neither explicit, nor implicit attitudes can causally explain the relationship between information framing and purchase intention. However, the results indicate that communication about innovations with goal framing has a positive effect on explicit attitudes. The frames individually (goal or loss framing) did not appear to be effective on their own. Video clips that illustrate environment- and health-related consequences of innovation application turned out to be more persuasive than a video with a general description of beneficial soil-microbes. The findings on implicit attitude remain somewhat inconclusive. Future research may build on these insights by focusing on relevant consequences of innovation application.

Appendix

Table A7. Relative effects of serial mediation analysis using indicator coding, *n* = 745.

	M_1: Expl. attitudes	**M_2: Impl. attitudes**	**Y: Intention**
	Coeff. (SE)	Coeff. (SE)	Coeff (SE)
D_1: gain vs. control framing	a_{11}: 0.146 (0.087)	a_{21}: 0.017 (0.029)	c'_1: 0.050 (0.078)
D_2: loss vs. control framing	a_{12}: 0.182 (0.097)	a_{22}: -0.043 (0.032)	c'_2: 0.050 (0.087)
M_1	-	d_{21}: 0.029 (0.012) **	b_1: 0.775 (0.033) ***
M_2	-	-	b_2: -0.022 (0.099)

Note(s): Using 95% confidence interval bootstrapping, 10,000 resamples. Coeff. = coefficients, SE = standard errors, M_1 = explicit attitude; M_2 = implicit attitude; Y = purchase intention. **, *** indicate a significance level at 5%, and 1%, respectively.

Table A8. Relative indirect effects of serial mediation analysis (using indicator coding).

	Path	**Coeff. (SE)**	**Lower Limit CI**	**Upper Limit CI**
D_1: gain vs. control framing	D_1 -> M_1 -> M_2 -> Y	-0.000 (0.000)	-0.001	0.001
	D_1 -> M_1 -> Y	0.113 (0.069)	-0.020	0.250
	D_1 -> M_2 -> Y	-0.000 (0.003)	-0.008	0.007
D_2: loss vs. control framing	D_2 -> M_1 -> M_2 -> Y	-0.000 (0.000)	-0.002	0.001
	D_2 -> M_1 -> Y	0.141 (0.077)	-0.012	0.289
	D_2 -> M_2 -> Y	0.001 (0.005)	-0.009	0.013

Note(s): Using 95% confidence interval bootstrapping, 10,000 resamples. Coeff. = coefficients, SE = standard errors, M1 = explicit attitude; M2 = implicit attitude; Y = purchase intention.

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4. Discussion and concluding remarks

There is an urgent need to meet the demands of a growing population, while simultaneously considering the needs of future generations; a certainty highlighted as early as 1972 with the publication of the limits to growth (Meadows et al., 1972). Due to already irreversible effects of climate change, many scientists have appealed for mitigation and adaptation measures as soon as possible (IPCC, 2023). This call for more sustainability requires changes on many levels, and agriculture is an important field which can contribute to achieving the SDGs. In the framework of the transition theory by Geels and Schot (2007), an agricultural innovation (such as beneficial soil-microbes) could be part of a ‘niche-in-the-making’, for example, as organic farming (El Bilali, 2019). Soil-microbes are organisms which exist to different extents and in different genera in natural, untreated soils irrespective of human interventions. Through targeted inoculation in commercial agricultural fields, via plantlets or in the soil directly, their potential for food production can be more fully exploited. Innovations based on soil-microbes can bring many beneficial effects to the plant, the soil and the environment (Castiglione et al., 2021; Rouphael & Colla, 2018), however, their successful diffusion requires support and actions by several stakeholders. This thesis evaluated farmers’ and consumers’ perspectives on these soil-microbes for more sustainable food production. Both stakeholders can play a decisive role in influencing the pathway of development and diffusion of innovations based on beneficial soil-microbes, and they are therefore crucial to consider from an early stage onwards. This research set out to address the overall research question: *What influences farmers’ evaluations and perceptions of agricultural innovations based on beneficial soil-microbes, and how can information effectively impact consumers’ perceptions of such innovations?* This research question was addressed by conducting empirical research among farmers in Scotland and Germany and among consumers in Germany. This chapter will begin by summarising the main findings (subchapter 4.1). As these findings must be interpreted in light of several restricting circumstances, limitations of this dissertation are then addressed (subchapter 4.2). This dissertation ends with implications of this research and with directions for future research (subchapter 4.3).

4.1. Summary of main findings

An overview of the main findings, their implications and remaining research gaps for future research are presented in **Table 33**.

Table 33. Overview of key insights.

Sub-chapter	Research study	Sub-research question	*n*	Main findings	Implications	Future research
2.2	Qualitative study with farmers	Which innovation traits appear to be crucial for adopting innovations based on soil-microbes, and what are farmers' perceptions regarding those traits?	36	Compatibility was a particularly frequent topic among non-adopters; dis-adopters discussed observability more often; adopters engaged in more diversified communication channels. All groups acknowledged the need for innovations such as beneficial-soil microbes, but also pointed to a number of challenges and needs: ○ challenge to observe effects, ○ perceived complexity, ○ need to conduct trials.	○ Information provision on innovations' economic advantages, and information to help reduce perceived complexity. ○ The following communication channels may be referred to: extension services, farmer community, trade and manufacturers. ○ Policy supported trials (spread over regions) that increase easy access to observability (or proof of effectiveness).	○ Research on other up- and downstream stakeholder groups with relevance for diffusion (i.e., from extensions service or manufacturers). ○ Large-scale quantitative evaluation of innovation traits with an exemplary product and its impact on adoption behaviour.
2.3	Quantitative study with farmers	What are key determinants of farmers' intention to adopt innovations based on beneficial soil-microbes in their potato cultivation?	102	An extension of the TRA with the TAM based construct perceived usefulness best explains farmers' intention to use beneficial soil microbes. Perceived usefulness is a key predictor. General personality and generic attitudinal constructs have little explanatory power.	○ Information provision focusing on innovation's usefulness. ○ Diffusion via communication channels from the agricultural sector most promising.	○ Comparison of theoretical models (i.e., TPB or TAM) and their extensions. ○ Analysis with real (not hypothetical) products and/or actual observed behaviour.

Sub-chapter	**Research study**	**Sub-research question**	***n***	**Main findings**	**Implications**	**Future research**
3.2 and 3.3	Experimental study with consumers	How can framing of information in videos be used to increase consumer acceptance of an agricultural innovation?	754	Goal framing is more effective than the control video in impacting explicit attitudes. Implicit and explicit attitudes do not mediate the effect of information framing on consumers' purchase intention.	○ Communication strategies should highlight the consequences of innovations.	○ Further research on the formation of implicit attitudes towards innovations (i.e., longitudinal studies). ○ Replication or evaluation of framing in video clips.

4.1.1. Summary of the farmers' perspective

The farmers' perspective was explored by conducting qualitative and quantitative research among farmers in Germany and the UK. Three main aspects were highlighted by these two studies: (1) the perception of the innovation's traits, (2) relevance of communication channels and (3) determinants of farmers' behavioural intentions to use the innovation.

Based on the interviews from the qualitative study, the innovation's traits were compared among three different adopter groups: non-adopters (who never applied the innovation), dis-adopters (past users who discontinued use) and adopters (current users at the time of the study). The number of statements coded per innovation trait revealed differences and similarities between the groups (see **Figure 8**, page 47). In particular, adopter and dis-adopter groups had more positive perceptions of the innovation and discussed the relative advantages to a greater extent than the non-adopter group. Findings from all groups – including the one with farmers who had such innovations in place at the time of the interviews – revealed that all participants found it challenging to observe effects from the innovation and perceived the innovation as complex to grasp and/or implement. Research shows that a lack of knowledge associated with a lack of understanding can contribute to low adoption rates (Drobek et al., 2019), and that the evaluation of trials and observability are important factors for innovation adoption (Blasch et al., 2022; Pannell et al., 2006). Hence, a potential lack of observability (also when conducting trials) could hinder uptake of beneficial soil-microbes in farming. The evaluation of farmers' practices regarding communication channels revealed that the adopter group makes use of a variety of information channels, while this is less so for the other two groups. This finding is supported by other research, which suggests that farmers' innovation adoption status and the type of innovation implemented depends on the network of information channels they engage with (Lambrecht et al., 2014). In line with the literature, for famers in all adopter groups, the following information sources were identified as especially relevant: communication and exchange via the farmer community (Rust et al., 2022; Skaalsveen et al., 2020; Wood et al., 2014; Wu & Zhang, 2013), via trade and manufacturers (Knierem et al., 2018), and via extension services (Knierem et al., 2018; Wuepper et al., 2021).

The quantitative study with farmers makes use of the TRA framework to explore the impact of TRA-based and other theory-based constructs, as well as factors derived from empirical research. Several reviews on adoption behaviour have shown that farmers' demographic characteristics are a factor often considered in adoption studies (Foguesatto et al., 2020; Kamrath et al., 2019; Knowler & Bradshaw, 2007; Liu et al., 2018; Pierpaoli et al., 2013; Prokopy et al., 2019; Prokopy et al., 2008). However, reviews also have highlighted that there are inconsistences regarding the effect of these characteristics in literature (Burton, 2014; Schulz & Börner, 2023). In our quantitative study, no significant effect was detected regarding farm and farmer characteristics. Instead, the results emphasise the relevance of three predictors of intentions to use beneficial soil-microbes: attitudes, norms and perceived usefulness. These latent constructs consistently show an effect on intentions in all tested models (see **Table 20**, page 87 for an overview). The results of this thesis are in line with other studies investigating drivers of innovation adoption in agriculture, which have also identified attitudes (Borges et al., 2014; Borges et al., 2016; Chin et al., 2016; Deng et al., 2016; Läpple & Kelley, 2013; Sok et al., 2016; van Dijk et al., 2016) and injunctive norms (Borges et al., 2014; Hüttel et al., 2020; Le Coent et al., 2018; Rehman et al., 2007) as relevant predictors of intentions to use or adopt an innovation. The present study showed that the effect size for attitudes and norms decreased once perceived usefulness was added to the model. The exploratory analysis suggested that perceived usefulness is not only a relevant direct predictor of intention to try an innovation, but it was also identified as an influential antecedent of attitude. This singled out usefulness as a key driver of intentions to use soil-microbes. Other literature on the adoption of agricultural innovations has also indicated that perceived usefulness plays an important role (Amin & Li, 2014; Caffaro et al., 2020; Lima et al., 2018; Naspetti et al., 2017; Sharifzadeh et al., 2017). The comparison of the models' metrics indicated that the TAM-based model extension achieved the best model metrics. The relevance of other, general constructs tested in the analysis – for example LOC – proved to have no explanatory power in this study. Those constructs were operationalized in a generic manner, and did not directly relate to the behaviour under investigation. This illustrates the relevance of the principle of compatibility (Ajzen, 2020), meaning that latent constructs should be measured in relation to the behaviour of interest.

The qualitative explorative study and the quantitative study overlap in their findings on perceived usefulness, relative advantage and stakeholder/referent groups. Fichman (1992) points out in a review on technology diffusion that the construct perceived usefulness from the TAM and relative advantage from the innovation traits are comparable constructs. In the UTAUT framework, the construct performance expectancy is rooted, among others, in the constructs perceived usefulness and relative advantage (Venkatesh et al., 2003). As previously revealed, relative advantage was the core innovation trait frequently discussed in all adopter groups in the qualitative interviews. The quantitative study supports the relevance of these innovation traits by identifying perceived usefulness as the most influential factor. Using the broad construct from the UTAUT, our results indicate that farmers' evaluation of the innovation's performance expectancy is a key factor impacting innovation adoption.

The results of the qualitative and quantitative farmer studies also reveal which stakeholders can serve as supporters of innovation diffusion. Fellow farmers, for example neighbours or contacts through other farmers networks, serve as an influential referent group; they can foster shared learning and peer-based support, which can encourage innovation adoption. Actors from extension services, such as agricultural advisors, can provide information to farmers through their expertise, direct contact and accessibility, and can impact farmers' decisions to adopt innovations. Recognizing the decisive roles these stakeholders play can help policymakers and practitioners to design interventions and communication strategies which take these stakeholder groups and networks into account for diffusion. In particular, communication strategies should highlight aspects of the innovation's potential performance expectancy in order to increase innovation adoption and diffusion. Overall, the results on the farmers' perspective expand our understanding in relation to the perception of the innovation's characteristics, to important referent groups and to the determinants of usage behaviour.

4.1.2. Summary of the consumers' perspective

Consumers' acceptance of food products which were grown applying new technologies is an important determinant for the success of an innovation and needs attention in research. To the extent that consumers have no or very little knowledge with respect to an innovation – as is the case regarding beneficial soil-microbes – information provision is a necessary prerequisite prior to conducting research. The objective of this study was to assess how different information framing can impact consumers' attitudes and purchase intentions towards tomatoes produced with beneficial soil-microbes.

The results highlight that the communication of the potential consequences of innovation application, or lack thereof (irrespective of gain or loss framing) elicited a stronger response than the control video with no information about the consequences of (or lack of) application. The results did not support our hypothesis, that loss framing has a stronger impact than gain framing. The communicated information in the video clips also described a potential decrease of harmful pesticides due to the application of soil-microbes; however, by referring to a reduction of harmful products used in food production, consumers were made aware of the remaining presence of these damaging products. Consequently, in other research this information did not achieve a strong effect from consumer reactions; information on complete omission of these products could create stronger resonance (Möhring et al., 2020). This could have hindered the effectiveness of the information treatments. Literature on the effect of goal framing in food choices also appears more heterogenous; contrary to our results a recent review highlighted that gain framing of food product attributes elicited stronger reactions than loss framing (Dolgopolova et al., 2022). In our consumer experiment, goal framing did have an effect on explicit attitudes. This conclusion is in line with research from other contexts, where a higher effectiveness of goal framing compared to a control condition has been shown as well (Lagerkvist et al., 2023; Walker et al., 2014). Furthermore, no serial mediation effect of explicit and implicit attitudes was observed.

The impact of framing on implicit attitudes remains somewhat unclear, as we could not find support for the hypothesised effect on implicit attitudes. Contrary to our findings, in Greenwald et al.'s (2009) review on the predictive validity of the IAT, the authors found a moderate correlation between explicit measures and the IAT, and recommended the use of the implicit measure together with explicit measures to predict behaviours. However, Marchery (2022) has questioned the measure of implicit attitudes, highlighting in his review several weaknesses related to the measure and challenging the construct. Especially in the context of innovation acceptance, implicit attitudes may not provide a suitable measure of acceptance. As one potential explanation could be attributed to the fact that implicit attitudes might not have fully developed following video exposure. Research concerning organic and GM products similarly concluded that implicit attitudes towards GM products had not yet solidified during the time of measurement (Tenbült et al., 2008). Another perspective to consider is the likelihood of implicit attitudes being transferred from another object. Findings suggest that implicit attitudes towards novel objects can be transmitted from a familiar and related object to the new object under consideration (Bekker et al., 2017; Nguyen et al., 2022; Ranganath & Nosek, 2008). However, when pursuing this possibility for beneficial soil-microbes, it remains unclear what other concept or product the implicit attitudes measure is based on. What is more, the results align with the different measurement procedure of the latent constructs. Both explicit attitudes and intentions rely on direct self-reported measurements, whereas implicit attitudes are measured using a response-time test. Our results may therefore reflect a methods bias, where results are biased by the measurement method but are not caused by the construct itself (Podsakoff et al., 2003).

In conclusion, the consumer study has raised and tried to address several questions regarding the effectiveness of goal framing in contrast to a control information and regarding the development of implicit attitudes when dealing with an unknown innovation. The findings provide first grounds for future research on innovations in the food sector. In particular, this study was unique in its research of framing effects on implicit attitudes and in its application of video clips for the information treatments.

4.2. Limitations

In this subchapter, common limitations which apply to (almost) all of the conducted research activities are presented. These include conducting research with a hypothetical product or scenario, issues referring to sample and sampling strategy, methodological limitations and the innovations potential impact and realisation.

Generally, this thesis builds on an innovation still in development. Research in plant sciences has provided insights into microbial products and product combinations as well as options for their application and their potential benefits in agricultural production (Rouphael & Colla, 2018). However, the transfer to a consistently effective product which can provide a multitude of services under commercial agricultural conditions is still in progress. Therefore, two different approaches were implemented in the empirical research of this dissertation: (a) reference not to a specific product but to similar products based on beneficial soil-microbes (qualitative study with farmers) and (b) description of a hypothetical product based on or produced with beneficial soil-microbes (quantitative study with farmers and consumer study). Due to the multitude of possible products and their effects, providing reference only to the general product category means that farmers' answers can refer to a variety of different products with somewhat heterogeneous characteristics. The respective results can nonetheless provide a first indication of farmers' perception of beneficial soil-microbes given that a number of characteristics (e.g., observability) are similar for related products, including beneficial soil-microbes. For the quantitative study with farmers and the experimental study with consumers, information on a fictional product was created, by referring to literature reviews and by incorporating feedback from agronomists and biologists of the MiRA project. The content of the developed information differed for the two stakeholder groups: farmers received primarily information about the field applications and effects of the microbes, while consumers received general information defining the microbes and describing their effects on the environment. Evaluations of the innovation were therefore limited to the information that participants received. Several aspects pertaining to the information could have impacted their evaluations, for example, their understanding, attentiveness, other associations or general impressions of the information could have biased the results. Precautions were taken to avoid several of these limitations (including attention checks and conducting a pre-test), however, it is not possible to rule them out entirely. Due to the nature of the study design, only stated preferences for the fictional product, and not revealed preferences (i.e., actual behaviour) could be measured, limiting the ability to predict actual (future) behaviour. Literature also illustrated that there remains an intention-behaviour gap to be addressed in more extensive research (Carrington et al., 2010, 2014; Grimmer & Morgan, 2016; Hassan et al., 2016).

What conclusions and interpretations can be drawn from the results also hinge upon the underlying sample and recruitment process. The size and structure of the sample determines two key aspects: what analysis can be conducted with how much power, and whether the results obtained can be generalized to the population in question. In qualitative research, representativeness is not the main objective of data collection, but rather to achieve depth and variety in opinions and perspectives (Kubacki & Rundle-Thiele, 2017; Mason, 2010). In this thesis, the network of the MIRA project partners and a snowball sampling strategy was used to recruit farmers in Scotland and Germany. By relying on this strategy, only farmers who were directly or indirectly linked to this network could be part of the recruitment, and therefore of the sample. For the quantitative study with farmers, at first a stratified random sampling strategy was devised. For several German states the contact information of training farms (which produce potatoes) was available, and from those contacts, a random selection of potato farmers was contacted to participate in the study. However, because of a low return rate, the sampling strategy needed to be changed and all available contacts of training farms producing potatoes were used. For the consumer sample, a market research agency was used, who recruited participants using their online panel as a basis. To reflect the German consumer population, quotas for age, gender, education and occupation were set. As a critical aspect regarding the sample in this study, it should be noted that there may be a selection bias with respect to people who decided to become part of the panel and those who did not. Thus, although the sample fulfilled the quotas, thereby reflecting the German population with respect to a number of sociodemographic characteristics, the degree to which a self-selection bias exists remains an open question. A self-selection bias may likewise have impacted the quantitative farmer sample, and systematic discontinuance in survey participation may also be an issue in both quantitative, online surveys (Heckelei et al., 2021).

Lastly, the employed methods entail several limitations. In all three empirical studies, the data collection methods relied on self-reported information and assessments by the participants, which could lead to biases of different kinds. Given the topic – a more sustainable food production method – responses may have been influenced by social desirability bias, which can impact the degree of validity of the collected data (van de Mortel, 2008). Face-to-face interviews can be more susceptible to this bias than online surveys, where participants are anonymous and not observed; therefore, they can feel less constrained by perceived social desirability. Such limitations fall under the common method bias, that is, findings may be biased and explained by the measurement method and not by the underlying construct that it intends to measure (Podsakoff et al., 2003). In the process of online data collection with farmers and consumers, several measures were implemented to limit these biases: some items were counterbalanced, anonymous data collection was ensured, and a response-time measure was included in the consumer experiment, which provides an alternative measurement to self-reported measures.

A growing body of research has shown that the application of beneficial soil-microbes holds promise to contribute to sustainable agricultural practices (Basu et al., 2018; Castiglione et al., 2021; Elnahal et al., 2022; Gouda et al., 2018; Hamid et al., 2021; Kumar & Verma, 2018; Nadeem et al., 2014; Pascale et al., 2018; Ray et al., 2020; Rouphael & Colla, 2020; Singh et al., 2011; Vejan et al., 2016). However, it is essential to acknowledge the existing limitations and uncertainties surrounding their practical implementation and, consequently, the limitations of potential effects they can achieve. There exist several reported uncertainties surrounding their on-field application and their effectiveness under commercial field conditions (Ferlian et al., 2018; Le Mire et al., 2016; Lee Díaz et al., 2021). Potentially, media attention and marketing efforts could have skewed perceptions of the effectiveness of such innovations. Therefore, it is important for researchers, policymakers, and agricultural advisors to critically evaluate the available evidence and new research findings and consider those in all efforts linked to the diffusion or adoption of beneficial soil-microbes. Continued research, robust experimental designs, on-field evaluations under various conditions and collaboration between scientists and industry stakeholders will be essential in determining the actual capabilities and impact of beneficial soil-microbes. Therefore, this dissertation is based on cautious optimism when considering the potential role beneficial soil-microbes may play in future sustainable agricultural practices.

Finally, the findings can only present a snapshot of farmers' and consumers' perceptions. It can be assumed that circumstances, attitudes and experiences are constantly changing. This means that the results provide an assessment of beneficial soil-microbes by different stakeholders solely in that moment, which, although limited, nonetheless can form a solid point of reference and provide a basis for future research.

4.3. Implications and future research

4.3.1. Implications

The results presented in this thesis hold several implications for promoting the implementation of beneficial soil-microbes as an innovative production method. First and foremost, this thesis highlights the relevance of information and communication strategies. Reviews on farmer adoption studies showed that information, access to information and also sources of information are important aspects in the innovation diffusion and adoption process (Baumgart-Getz et al., 2012; Hasler et al., 2017; Kamrath et al., 2019; Prokopy et al., 2008). The insights generated from the qualitative study with farmers provide some indications about how negative perceptions of attributes of such innovations can hinder their uptake. What is more, the qualitative and quantitative study with farmers showed that perceived advantages and perceived usefulness are core constructs when it comes to the evaluation of the soil-microbes. Those findings can guide the focus of communication strategies which aim at diffusing innovations based on beneficial soil-microbes.

The results also highlight that certain actors or sources for information are more suitable than others to promote the diffusion of such innovations. Manufacturers and traders are important because they potentially supply farmers with the innovation in question, and extension services provide advice to farmers. Both are crucial communication channels for distributing insights and information about products based on beneficial soil-microbes. However, of foremost importance is the fact that farmers communicate and spread ideas in their networks (Chaudhuri et al., 2021; Wood et al., 2014). The construct of injunctive norms has shown that their opinions can impact adoption, as other farmers were also identified as an important communication channel in the qualitative interviews. These insights are valuable for policy makers, as they can provide support for the set-up of communication programs or networking possibilities to facilitate the diffusion process (Klerkx et al., 2010; Weiss & Tschirhart, 1994).

For targeting consumers, the results indicate that communication efforts could profit from conveying the potential consequences of an innovation. Thus, communication strategies should consider and design their content based on these insights. Using videos appeared to be a suitable choice for our case, though it is not possible to conclude whether other formats of information provision may have achieved a better effect. However, other studies also support the usage of videos, especially when complex topics or technologies are the subject of communications (Goldberg et al., 2019; Goodwin et al., 2018; Krantz & Monroe, 2016).

4.3.2. Directions for future research

Firstly, various stakeholders are relevant when it comes to the diffusion of products based on beneficial soil-microbes. In this thesis, the farmer and the consumer were in the spotlight, and thus two specific stakeholder groups. However, other stakeholder groups along the food value chain can also support or hinder the uptake of agricultural innovations. Thus, future research could add to the presented findings by considering the perspectives of these stakeholders. Results generated could then be triangulated providing a more holistic perspective. Furthermore, within the farmer population, future research could profit from distinguishing between different adopter statuses and farmers' experiences with the innovation in question.

Secondly, from a theoretical point of view, the presented findings showed that the TRA is a useful framework for investigating farmers' intentions to use beneficial soil-microbes, but that an extension of the TRA by the construct perceived usefulness from the TAM achieved the best results in understanding farmers' adoption behaviour. These findings leave room for additional more extensive theory-driven applications. Moreover, in case researchers decide to test extensions of theories through additional constructs, they should follow the principle of compatibility; as my results support the necessity of this principle.

Thirdly, to the best of my knowledge, only few studies measure implicit attitudes in the context of innovation acceptance. The results of the consumer study on implicit attitudes did not offer support to our hypothesis. One explanation for this is the possibility that – given the novelty of the innovation – implicit attitudes may not have been formed yet. However, the collected data does not allow the testing of this explanation. Considering that the food sector will continue to engage with innovations and innovative production methods, a deeper understanding of what drives the formation of consumers' implicit attitudes towards food products grown with innovative processes and how those attitudes influence purchase intentions remain important topics for future research agendas.

Fourthly, this thesis offers a unique application of information framing by making use of video clips. Other studies offer limited insights into the impact of video-based communication on consumer acceptance of new technologies. Considering the extensive exposure to video clips consumers face in their everyday lives, it is essential to further our understanding of the impact that this communication medium can have.

Finally, future research on innovation adoption and innovation acceptance should consider an actual and concrete product and/or actual real-life behaviour. Both aspects remain major limitations to this dissertation. To contribute to the transformation towards a more sustainable food system it is crucial to target a behavioural change to secure the diffusion of sustainable agricultural innovations. By conducting research with a definitive product and with observed behaviour, future research can address the challenge of an attitude-behaviour or intention-behaviour gap.

In conclusion, this dissertation was able to offer first insights into pertinent factors which can foster future acceptance of beneficial soil-microbes among farmers and consumers prior to their (large-scale) introduction. As a result, the outcomes can facilitate and give first directions to support a diffusion of beneficial soil-microbes from the outset of their development and application.

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