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Why smallholders (do not) adopt productivity-increasing technologies? Developing a smallholder adoption-process model through an in-depth qualitative study in Ethiopia

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ABSTRACT

Research and innovation have developed an impressive number of technologies that can increase the agricultural productivity of African smallholders. The impact of technology is nevertheless hindered by the heterogenous and unpredictable adoption patterns of smallholders. Most current studies examine farm-level constraints and environmental barriers (e.g., distance to market and access to financial capital) as the main explanation for variations in adoption. We take a complementary approach that draws on adoption theories from consumer psychology, thus considering the interplay between contextual barriers and the micro-level decision making processes of smallholders with regard to the adoption of technology. Qualitative data on the adoption of legume technologies by Ethiopian smallholders reveal barriers that hinder adoption at three stages of the process: as negative expectations, as impediments to translating adoption intentions into behaviour and as impediments to impact after adoption, thus hindering the continued use of technologies. To overcome adoption barriers, our findings suggest that more attention should be devoted to business innovations through effective product design and the marketing of the technologies, as well as to the development of value chains and business ecosystems within which to bundle technological products with other products and services.

1. Introduction

Ensuring food security for the population of sub-Saharan Africa, which will reach 2.5 billion by 2050, will require a doubling of current agricultural production (FAO, 2017; Van Ittersum et al., 2016). To meet this demand agricultural production largely depends on smallholder farmers (ECA, 2018, p. 116). The crop yields of most smallholders, however, are too small to meet the growth in food demand (de Haas & Giller, 2025). Tremendous efforts are therefore being invested in the development and dissemination of agricultural technologies (e.g., improved seed varieties, fertilizer and agronomic management) that could result in substantial productivity growth (Evenson & Gollin, 2003a; Giller et al., 2013, pp. 156–174). As reported in various studies, however, the adoption rates for technologies are heterogenous and seemingly unpredictable (e.g., Sheahan & Barrett, 2017), thereby hindering the sorely needed increases in production.

Most studies on smallholder adoption focus on assessing the effects of household and farm characteristics, as well as on the environmental influences of bio-physical, institutional and access factors as determinants of final decisions concerning adoption (Arslan et al., 2014; Simtowe et al., 2016). Such farm-level and environmental barriers (as we refer to them in this article) include inadequate access to agricultural technologies, capital constraints, lack of information and poor infrastructure (Asfaw et al., 2012; Moser & Barrett, 2006). The subsequent policy implications from such studies logically include interventions such as improvements to road infrastructure (Salami et al., 2010), the organization of input supplies through cooperatives (Eidt et al., 2012; Fisher et al., 2015; Shiferaw et al., 2014) and efforts to strengthen the dissemination of information (e.g. through ICT platforms (Tadesse & Bahiigwa, 2015)).

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Some researchers have, however, questioned the emphasis on adoption barriers in the smallholder adoption literature, pointing out key conceptual limitations and their practical implications (see, for example, Bukchin & Kerret, 2020b; Glover et al., 2016), and the need to consider smallholders as active decision-makers (see Bukchin & Kerret, 2020b; Montes de Oca Munguia et al., 2021). Few studies have attempted to explore the role of subjective variables, such as smallholders' perceptions and attitudes regarding technologies or practices (Bukchin & Kerret, 2020a). As a result, the specific technological features that shape adoption decisions, as well as their implications for policy, remain largely unexplored. Moreover, adoption is commonly conceptualized as a dichotomous, linear process, in which new technologies replace old ones (see Glover et al., 2016; Osrof et al., 2023), ignoring the underlying dynamic processes of change. Adoption is a complex, nonlinear process influenced by the interaction of contextual and subjective factors in the decision making process (Meijer et al., 2015). Even among the few studies that consider subjective influences, this dynamic interaction is largely absent.

We respond to these research gaps by focusing on the micro-level decision *process* of smallholder adoption of new technologies. More specifically, we develop a conceptual integration of farm-level and environmental adoption barriers with the smallholder adoption process. To this end, we draw on the literature on adoption from the fields of marketing and consumer research (in particular, the innovation diffusion theory developed by Rogers (2003)), as well as on in-depth qualitative data on smallholder adoption of legume technologies from four regions in Ethiopia. We use a sequential multiple-case method to develop the process model (De Vaus, 2001; Yin, 2013). The method is particularly well-suited to studying phenomena (in this case, the adoption process) within their own contexts, thus providing a more detailed conceptual understanding of the phenomena (Yin, 2013). The refined model, which is more complex than the initial, linear, innovation diffusion model, offers a fresh perspective on interventions aimed at stimulating smallholder adoption of new technologies. A more detailed understanding of the smallholder adoption process can contribute to the design of more precise interventions for eliminating barriers. The model also decreases the likelihood that remaining barriers will be overlooked, thereby contributing to adoption, increased productivity, and food security.

2. Conceptual framework

2.1. Smallholder adoption of agricultural technologies

The term *technology* refers to the systematic application of scientific knowledge for practical purposes (Dusek, 2006), such as increasing agricultural productivity. Technologies are manifested in new products, processes and systems, including the knowledge and capabilities needed to deliver functionality (cf. Dodgson et al., 2008). Within the context of smallholder agriculture, this could include improved seed varieties (Evenson & Gollin, 2003b), improved fertilizers (Dimkpa & Bindraban, 2016) and farming practices (e.g., Arslan et al., 2014).

The decisions that smallholders make with regard to the adoption of technologies have been conceptualized in a variety of ways (Doss, 2006). Some scholars treat adoption simply as a dichotomous decision either to use or not to use a new technology (e.g., Ali & Abdulai, 2010). Others argue that, to assess the long-term impact of a technology, adoption should be measured as the continued use of the technology over time (Arslan et al., 2014). Yet other authors have pointed out that adoption is not necessarily a discrete choice, but should be addressed as the extent to which a smallholder applies a specific new technology on the farm, as compared to alternatives (Sidibé, 2005). For example, Vanclay (1992), argues that farmers may apply only parts of some technologies, or may use them only on parts of their farms.

Given that smallholders, almost by definition, live in resource-scarce environments, it is not surprising that most studies consider adoption as a function of farm-level and environmental barriers (most notably, barriers pertaining to the household and the farm, as well as institutional and bio-physical characteristics). Institutional barriers include inadequate supply of inputs (Asfaw et al., 2012), as well as limited access to information and credit services (Simtowe et al., 2016), to input (Chirwa, 2005) and output markets (Barrett, 2008; Fischer & Qaim, 2012) and to extension services (Arslan et al., 2014; Yitayew et al., 2021). Bio-physical barriers include rainfall variability (Arslan et al., 2014) and shocks due to insects, pests and disease (Kassie et al., 2013; Simtowe et al., 2016). At the household and farm level, adoption may differ depending on wealth status, farm size and the availability of family labour, as well as facing barriers related to education and gender (Marenya & Barrett, 2007). Of these barriers, information has perhaps received the most attention, as information asymmetries can be overcome by creating *awareness* amongst smallholders with regard to the technology (for example, see Arslan et al., 2014; Asfaw et al., 2012; Feder et al., 1985). Many projects accordingly invest in communication tools (e.g. campaigns and demonstration farms), with the goal of increasing awareness and thus the likelihood of adoption by smallholders (Asfaw et al., 2012; Verkaart et al., 2017).

2.2. The adoption process

The literature on adoption in consumer behaviour suggests that creating awareness is an important, but not sufficient condition for fostering adoption. Such studies emphasize the micro-level adoption process for new products (De Bruyn & Lilien, 2008; Kotler & Armstrong, 2010), demonstrating that adoption is a mental decision process comprising multiple stages. More specifically, an individual passes from initial knowledge of a product, to persuasion (in which the individual forms an attitude towards the product based on perception), to a decision to adopt or reject the product, to the implementation and use of the new idea and, finally, to confirmation of the decision (Rogers, 2003). The literature also distinguishes between adoption intention and adoption behaviour (Arts et al., 2011). *Adoption intention* refers to a consumer's expressed desire to purchase a new product, and *adoption behaviour* refers to the actual purchase of that product. The distinction is important, as intentions do not always lead to behaviour (Sun & Morwitz, 2010). This is relevant to our study, as it suggests that adoption barriers could potentially hinder both the development of adoption intentions and the translation of those intentions into adoption behaviour (Esham & Garforth, 2013).

In the process of generating adoption intentions, consumers and more broadly users including smallholder farmers develop perceptions pertaining to product characteristics that drive the rate of adoption for that product (Arts et al., 2011). In this regard, the innovation diffusion theory (Rogers, 2003) and technology acceptance model (Davis, 1989) are notable. The technology acceptance model postulates that users' behavioral intentions are determined by perceived usefulness and ease of use of the technology. Rogers' (2003) classic innovation diffusion theory conceptualizes six perception dimensions and thus provides a broader theoretical perspective to study smallholder adoption process. Meta-analytical evidence has identified that, of these dimensions, *relative advantage* (the degree to which a product is perceived as better than the product it supersedes, such as perceived yield benefits of new versus old legume seeds) and *compatibility* (the degree to which a product is perceived as being consistent with the existing values, past experiences and needs of potential adopters) have the strongest and most positive effects on the adoption decisions of consumers (Arts et al., 2011). It also shows that perceived *complexity* (the degree to which an innovation is perceived as difficult to understand and use) and *uncertainty* (a lack of predictability, of structure, or information regarding the products offered to the customers) have strong, but negative effects on adoption. In general, however, perceived *observability* (the degree to which the results of a product are visible to others) and *trialability* (the degree to which an innovation may be experimented with) have no significant effect on the adoption decisions of consumers (Arts et al., 2011; Tornatzky & Klein, 1982). Other scholars have stressed that these dimensions should not be neglected, however, because their importance varies depending on the product or service that is being offered (Liu & Wei, 2003) and the context of the adopters (Araujo et al., 2016; Arts et al., 2011; Overby et al., 2005). For this reason, our study addresses all six perception dimensions.

One important implication of the central role of perceptions in the adoption process is that adoption decisions can be influenced by the design of the products in which the technology is used. From the abundant literature on this topic, we include a basic framework that distinguishes three levels of the product design: the core product, the basic product and the augmented product (Kotler & Armstrong, 2010). The *core product* represents the central, problem-solving benefits of the product. Within the context of smallholders, the core products are obviously the yield-increasing new technologies. The *basic* (or *actual*) *product* represents various features of the product or service (e.g. design, quality level, brand name, packaging). The *augmented product* includes additional services (e.g. delivery, credit) and after-sale services (Armstrong et al., 2014). As such, consumers see products as complex

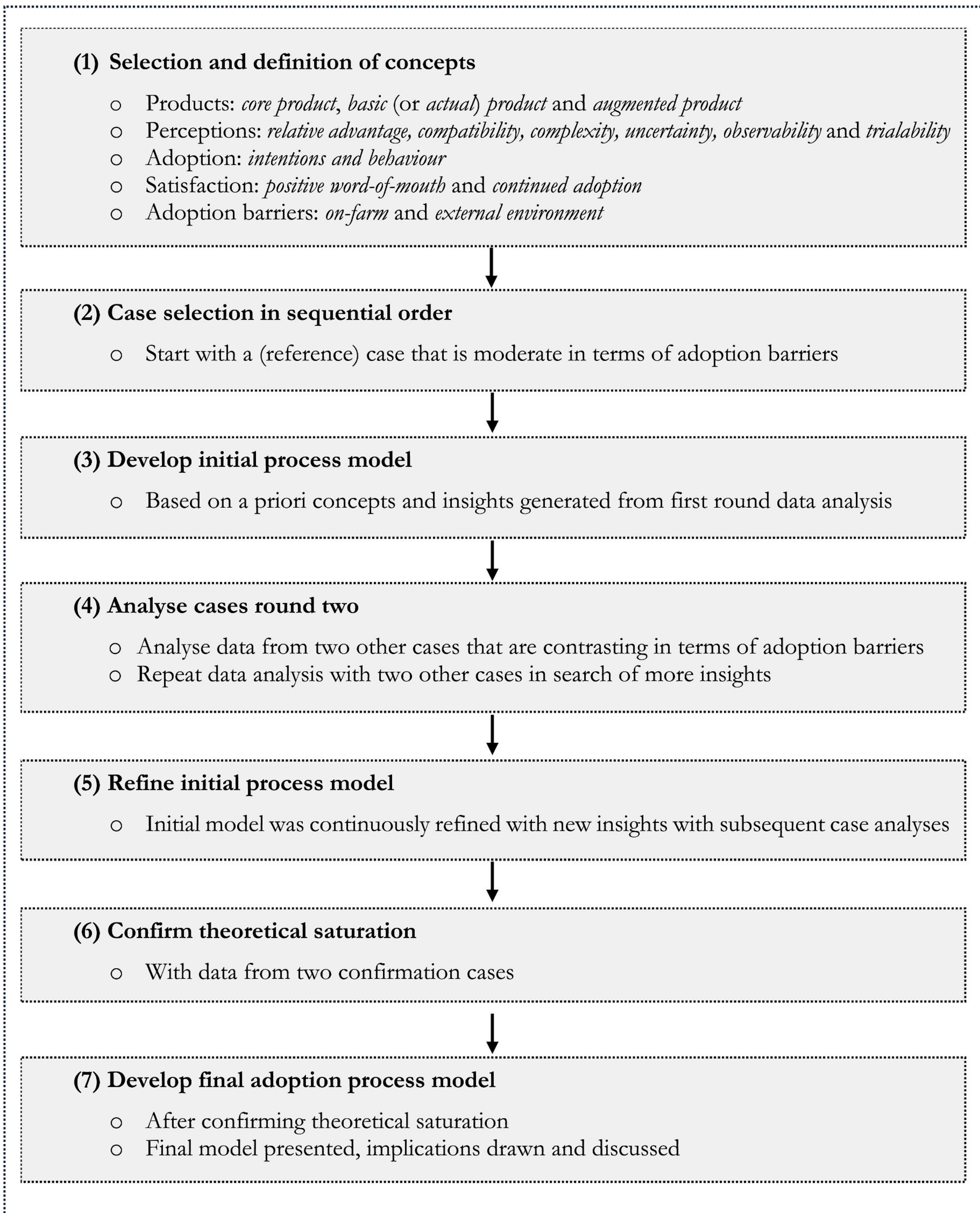

Fig. 1. Flow chart summarizing the steps followed in developing smallholder adoption process model.

bundles of benefits that satisfy their needs (Kotler & Armstrong, 2010), and not merely as specific technologies *per se*, as emphasized by most studies on smallholder adoption. If users are satisfied after trying a new product, they are more likely to confirm their adoption decisions by purchasing the product again, and they will eventually use it on a routine basis (Olsen, 2002). Continued use obviously matters with regard to the long-term adoption of technology (Verkaart et al., 2017), but it also leads to positive word-of-mouth, which further stimulates the diffusion of the product to new users (Homburg et al., 2005; Kozinets et al., 2010).

Fig. 1 presents a summary of the steps followed in developing the smallholder adoption process model, beginning with the selection and definition of concepts based on existing literature. Subsequent steps are detailed in the methods section.

3. Methods

Given that case study methods are particularly well-suited to the in-depth study of phenomena within their own contexts (Eisenhardt, 1989; Gibbert et al., 2008; Yin, 2013), we applied this approach to develop a detailed process model for smallholder adoption. More specifically, we used the sequential multiple-case method, in which we compare a variety of cases in order to arrive at a theoretical framework (De Vaus, 2001).

3.1. Research context

We conducted our study within the N2Africa project (www.N2Africa.org), which involved the development of grain legume technologies to enhance the productivity of the legumes themselves, as well as that of subsequent crops by enhancing soil fertility (Franke et al., 2018; Giller et al., 2013, pp. 156–174). To achieve these goals, smallholders would have to adopt improved seeds, rhizobium inoculant (a biofertilizer that stimulates biological nitrogen fixation and yield of the grain legume crops) and phosphorus fertilizers—all of which are technological options that are new to the farmers—in addition to engaging in related practices (e.g. row and plant spacings). The combined use of improved seeds with inoculant results in a grain-yield increment of 21 %, with a grain yield increment of 25 % for improved seeds with fertilizer (Ronner et al., 2016; Wolde-meskel et al., 2018). Regardless of these improvements, however, the rate at which smallholders adopted the technologies varied widely. For example, in the Northern and North Western regions of Ethiopia, adoption rates ranged from 5.1 % to 44.7 % amongst groups of smallholders (Dontsop et al., 2020). This variability thus provides a particularly suitable context within which to study the adoption processes of smallholders using the case study method.

We focus on Ethiopia which is highly dependent on smallholder agriculture while accommodating a rich diversity of farming systems and supporting market services (Spielman et al., 2010). Because of this diversity, the N2Africa project adopted a decentralized approach to implementing the technologies. More specifically, the implementation was organized by seven regional public-private partnerships (PPPs), each consisting of several stakeholders bearing joint responsibility for creating awareness and disseminating legume technologies within a particular region. Depending on the context, the partnerships included private input suppliers, grain buyers, unions, governmental organizations and non-government organizations. The PPPs spanned seven sub-regions across four major administrative regions of Ethiopia: namely, the Northern region (Amhara), the North Western region (Benishangul Gumuz), the Central region, the South Eastern region, the Western and South Western regions (Oromia) and the Southern region (South Nations, Nationalities and Peoples). We used these PPPs as the unit of case analysis in our study. The PPPs were contextually highly diverse in that they covered different types of legumes, inputs, market arrangements and cohesion between stakeholders (see Table 1). Such variation amongst cases allows us to incorporate as many new insights as possible when building a model for smallholder adoption, and increases theoretical generalizability (Eisenhardt & Graebner, 2007).

3.2. Case selection and sequence

We used a sequential multiple-case study design (De Vaus, 2001), with their inclusion and order of selection determined according to contextual characteristics (Table 1) (Reandeau & Wampold, 1991; Wampold & Kim, 1989). These characteristics include the main purpose of the target legume crops, status of input and output market arrangements, stakeholder cohesion/synergy and degree of competition amongst farm enterprises. We first selected the Northern region case which had average scores on these characteristics, thus providing a suitable starting point for building the model. We subsequently compared this case to those of the Central region and the South Eastern regions, as they are characterized by adoption barriers that were considerably lower (Central) and higher (South Eastern) than were those in the Northern region. We repeated this process in order to obtain further insight, selecting the Southern region and the South Western regions for the same reasons. Finally, to assess whether theoretical saturation had been reached in the theory-building process (Bowen, 2008), we selected the North Western region and the Western regions, which were also relatively average in terms of key characteristics.

3.3. Data collection and respondent selection

We drew on both secondary and primary sources to collect data on the various cases. Secondary sources consisted of research reports and archived interview data from the N2Africa project, including interviews with smallholders on their preferences for legume technologies, interviews with agro-dealers about barriers to input marketing and focus groups consisting of male and female smallholders discussing the performance and challenges of legume technologies. These data helped us to become familiar with the context of the cases, as well as to obtain preliminary insights into smallholders' evaluation and adoption decisions of legume inputs and related practices, and to triangulate evidence from primary data sources (Yin, 2013).

The primary data sources included interviews, focus-group discussions and observations conducted specifically for the present study. In all, 43 individual interviews were conducted across the seven cases (see Table 1 for information on the interviews for each case). The data were collected during field visits that the first author made to the case study sites. Interviews were planned with smallholder farmers, researchers, experts, extension officers and legume-input suppliers (e.g. cooperatives, unions and private companies). Development agents with knowledge about the specific context and who spoke local languages assisted in the selection of the smallholders. Three focus-group discussions were conducted, each involving smallholders, experts from bureaus of agriculture and managers of cooperatives. These discussions complemented the interviews, as they allowed individual participants to reflect on and respond to each other's answers, thereby enhancing the reliability and validity of the insights obtained (Yin, 2013). During the visits, observations were recorded by taking notes and photographs as an additional data source (Eisenhardt & Graebner, 2007).

We used a semi-structured interview protocol based on literature research on the smallholder adoption process and the contextual influences of barriers on that process. More specifically, the interviews were based on case study concepts concerning awareness, perceptions, barriers and adoption decisions, drawing on the theory explained in the conceptual framework section. The use of *a priori* concepts for developing smallholder adoption process model follows recommendations from case study methodologists to be transparent about the use of *a priori* theories and concepts from the literature, in the form of case study concepts that guide the development of interview questions (Eisenhardt & Bourgeois III, 1988; Gehman et al., 2018; Yin, 2013) (See Table 2 for sample interview questions). The interviews started by discussing

Table 1
Cases in order of sequence of selection and analysis, and description of interviewees.

No.	Cases	Case category	Key contextual characteristics defining the cases[a]	Legume types	Description of target interviewees			
					Interviewees	Interviewee codes[b]	Organization or village	Occupation (position)
1.1.	Northern region	Reference case (R)	Average input supply arrangement and stakeholder synergy Good output market access and low enterprise competition	Dual-purpose, both market-based and home consumption (chickpeas and faba beans)	Farmer 1	Farmer1R	Das Dinzaz (village)	Mixed cereal-legume farming
					Farmer 2	Farmer2R	Konch Goshiye (village)	Mixed cereal-legume farming
					Expert 1	Expert1R	Bureau of Agriculture	Das Dinza village extension agent
					Expert 2	Expert2R	Bureau of Agriculture	Yilmana Densa district crop expert
					Researcher 1	Researcher1R	Gondar Research Centre	Researcher, Socioeconomics
					Researcher 2	Researcher2R	Adet Research Centre	Researcher, Socioeconomics
					Cooperative 1	Coopmanager1R	Avola Goshiye Seed cooperative	Chair
					Union 1	Unionmanager1R	Tsehay cooperative union	General manager
2.1.	Central Region	Low barrier case 1 (LB1)	Good input supply arrangement, but average stakeholder synergy Good output market access and low enterprise competition	Dual-purpose, both market-based and home consumption (chickpeas)	Farmer 3	Farmer3LB1	Adadi Gole (village)	Mixed cereal-legume farming
					Farmer 4	Farmer4LB1	Adadi Gole (village)	Mixed cereal-legume farming
					Expert 3	Expert3LB1	Bureau of Agriculture	Gimbichu district crop expert
					Focus group 1	FGD1LB1	Abdi Boru Seed cooperative	Mixed
					Union 2	Unionmanager2LB1	Erer cooperative union	General manager
2.2.	South Eastern Region	High barrier case 1 (HB1)	Low input supply arrangement and stakeholder synergy Low output market access and high enterprise competition, reinforcement for mechanization services	Dual-purpose, both market-based and home consumption (chickpeas and faba beans)	Farmer 5	Farmer5HB1	Ebisa (village)	Mainly cereal farming
					Farmer 6	Farmer6HB1	Ali (village)	Mainly cereal farming
					Expert 4	Expert4HB1	Bureau of Agriculture	Ebisa village extension agent
					Expert 5	Expert5HB1	Bureau of Agriculture	Ali village extension agent
3.1.	Southern Region	Low barrier case 2 (LB2)	Good input supply arrangement, but average stakeholder synergy Good output market access and low enterprise competition	Dual-purpose, both market-based and home consumption (common beans)	Farmer 7	Farmer7LB2	Shello Elancho (village)	Mixed cereal-legume farming
					Farmer 8	Farmer8LB2	Awara Gama (village)	Mixed cereal-legume farming
					Farmer 9	Farmer9LB2	Haba Gerera (village)	Mixed cereal-legume farming
					Expert 6	Expert6LB2	Bureau of Agriculture	Shalla district crop expert
					Expert 7	Expert7LB2	Bureau of Agriculture	Haba Gerera village extension agent
					Researcher 3	Researcher3LB2	Hawassa University	Research assistant, Agronomy
					Cooperative 2	Coopmanager2LB2	Kayo seed cooperative	Chair
					Union 3	Union3LB2	Sidama Elto union	Marketing director
					Focus group 2	FDG2LB2	Gudina seed cooperative	mixed
					Cooperative 3	Coopmanager3LB2	Fatie Muruta seed cooperative	Chair
					Union 4	Unionmanager4LB2	Damota Wolayita union	Planning head
					Agro-dealer 1	Agro-dealer1LB2	Mirko Micro Enterprise	Business owner
					Agro-dealer 2	Agro-dealer2LB2	Tadesse Mega Agro-dealer	Business owner
3.2.	South Western Region	High barrier case 2 (HB2)	Low input supply arrangement, but good stakeholder synergy Low output market access and high enterprise competition	Only market-based (soybeans)	Farmer 10	Farmer10HB2	Dacha Nadhi (village)	Mainly cereal farming
					Expert 8	Expert8HB2	Facilitator for Change (NGO)	Development facilitator
					Researcher 4	Researcher4HB2	Jimma Research Centre	Researcher, Agronomist
					Focus group 3	FGD3HB2	Gafo Burka Baso Farmers' Marketing Organization	Mixed

(*continued on next page*)

Table 1 (*continued*)

No.	Cases	Case category	Key contextual characteristics defining the cases[a]	Legume types	Description of target interviewees			
					Interviewees	Interviewee codes[b]	Organization or village	Occupation (position)
4.1.	North Western Region	Confirmation case 1 (C1)	Average input supply arrangement, but good stakeholder synergy Poor output market access, but low enterprise competition	Mainly market-based (soybeans)	Farmer 11	Farmer11C1	Village-4 (Felege Selam)	Mixed cereal-legume farming
					Expert 9	Expert9C1	Bureau of Agriculture	Pawe district extension leader
					Union 5	Unionmanager5C1	Mama union	General manager
					Seed supplier 1	Seedsupplier1C1	Tesfa commercial farm	Business owner
4.2.	Western Region	Confirmation case 2 (C2)	Average input supply arrangement, but good stakeholder synergy Average output market access and high enterprise competition, reinforcement for mechanization services	Mainly market-based (soybeans)	Farmer 12	Farmer12C2	Oda Haro (village)	Mainly cereal farming
					Farmer 13	Farmer13C2	Gambella Tare (village)	Mainly cereal farming
					Expert 10	Expert10C2	Bureau of Agriculture	Oda Haro village extension agent
					Expert 11	Expert11C2	Bureau of Agriculture	Bako district extension leader
					Expert 12	Expert12C2	Bureau of Agriculture	Gambella Tare village extension agent
					Researcher 5	Researcher5C2	Bako Research Centre	Researcher, Agronomist
					Union 6	Union6C2	Bore Bako union	General manager
					Seed supplier 2	Seedsupplier2C2	Anno Agro Industry Farm	General manager

[a] Key characteristics were identified through observation by the authors and used for case sequencing. Confirmation was obtained from the project that provided the cases for the current study.

[b] *Interviewee codes refer to the name and cases of the interviewees. For example, Farmer1R refers to Farmer 1 from the Reference case.*

awareness of legume inputs and related practices, followed by perceptions of inputs and practices, and barriers, including how the barriers relate to perceptions and, ultimately, to adoption decisions. For the other interviews, the protocols were adjusted to the various stakeholders according to their specific roles in the respective case studies. The first author conducted all of the interviews in person. In the Southern region, development agents assisted by interpreting the interview questions into the local languages (Sidama and Wolaitta).

Table 2
Case study concepts as used in interviews with smallholder farmers.

Case study concepts	Examples of interview questions
Awareness	Have you ever grown legume crops? Have you ever heard of input products that improve the productivity of legumes? Have you ever participated in demonstrations of such inputs or farmers' field-day events? Which input products were provided to you? Did you know how to use them? Did you know how they increase yield? Which related practices did you learn? Did you know how to use them? Did you know how they increase yield?
Perceptions	What do you think about legume seeds, inoculant, fertilizer and practices? How do you evaluate their benefits? How difficult do you think it will be to use them? How do you evaluate your capability to buy the inputs? Do you think that the inputs are in line with your needs/practices? Why or why not?
Barriers	What has stopped you from using seeds, inoculant, fertilizer and related practices? How and why did you stop using them? Do you expect to encounter any other challenges in the future with regard to your current usage? Do you expect any challenges to arise? Why or why not?
Adoption	After having heard about the inputs or participated in the demonstration activities, are you currently using or do you intend to use the inputs? Why not?
Confirmation	Do you think you will use the inputs next season? Why or why not? Do you talk about the inputs when you meet with your neighbours or fellow farmers? About which aspects of the inputs do you talk?

3.4. Data coding and analysis

For each case, data were coded and analysed using ATLAS.ti software (Woods et al., 2016). We read the transcripts and other materials carefully and coded quotations of critical passages (Woods et al., 2016). The stages of the psychological decision processes of smallholders with regard to the adoption of technology were coded in comparison with and following the innovation diffusion theory developed by Rogers (2003). We searched in the interviews how smallholders think about the inputs and how this affected their decisions after having been exposed to the inputs. To obtain insight into how the process concepts were reflected within the context of the smallholders, we first developed new codes (e.g. 'gives high yield', 'inexpensive to buy', 'difficult to practice', and 'fear lack of buyers'), which we then categorized under the respective perception dimensions of relative advantage, compatibility, complexity and uncertainty. These codings thus connected the more abstract concepts of the decision process to the concrete contexts of smallholders. We coded the various barriers according to an initial coding scheme that emerged from the literature (Woods et al., 2016). We then developed new categories of barriers based on where the barriers interfered in the adoption process. Because our paper aims to develop a model that incorporates both the adoption decision-making process—including perceptual dimensions—and contextual barriers, we start the theory building with existing concepts. We develop codes for the included case study concepts that were determined *a priori* and consistently we used deductive coding. In addition, we remained open to emerging insights by allowing the data "to speak for themselves" as we read through the interview transcripts. We included the option for open coding when the data pointed us at additional insights, thus, we used inductive coding (for more details on these approaches, see Gehman et al., 2018). The latter scheme was specifically used in finding connections or interactions between decision-making processes and barriers.

Data were first analysed within cases on the various stages of the adoption process, as well as on which barriers interfered with the process and in which ways. We then compared the results across cases to develop a more refined understanding of the impact that barriers have on adoption and to enhance the reliability and validity of the findings (Yin, 2013). We analysed data in order of sequence (as presented in

Table 1). Analysing data from the Northern region case we developed an initial model on the smallholder technology-adoption process and the barriers that have an impact on that process. To obtain deeper insight into the barriers, we collected data from two cases with relatively high barriers and two cases with relatively low barriers. Finally, to confirm that saturation had been reached, we analysed data from two cases with relatively average barriers (Eisenhardt, 1989). In the following section, we report the most interesting insights emerging from this analysis, starting with the adoption process and proceeding to the roles of the barriers.

4. Results

4.1. The smallholder adoption process

Perceptions driving intentions. Consistent with existing literature on adoption by consumers (Arts et al., 2011), perceptions of relative advantage, compatibility and complexity emerged as the strongest drivers of adoption intentions in the current study (see Annex 1 for representative quotes on the perceptions).

With regard to *product advantage*, smallholders evaluated new seed varieties in terms of yield, buyer preference for the variety, convenience, and nutritional value. They evaluated fertilizer and inoculant primarily in terms of their potential to increase yield (fertilizer) and enhance soil fertility (inoculant) relative to the use of no fertilizer. This was already evident from archived data from the N2Africa project. Smallholders also evaluated the combination of the inputs, particularly in terms of yield and whether the quality of the harvest was indeed attractive to buyers (see examples in Annex 1).

Smallholders develop their perceptions of relative advantage by comparing both the benefits and the associated costs of the various alternatives. For example, one issue that emerged during the N2Africa focus-group discussions was the relatively large amount of labour required to apply inoculant. Expert6HB1 and Researcher5C2 further commented that, for the cereal crops that farmers grow as their main staple, they are accustomed to having access to relatively better mechanization and spraying services than are available for legumes. These findings are important, as they indicate that perceptions are not based solely on the technology-holding products and their attributes, but also on their cost/prices and accompanying services in the actual and augmented products (Kotler & Armstrong, 2010). Even if a technology is superior, however, and even if the product holding the technology is well-designed, the product is likely to be perceived as a relative disadvantage if it lacks accompanying services comparable to those available for alternatives.

With regard to *compatibility*, Expert5HB1 argued that most inputs were sold in packages that were too large for most smallholders, therefore obliging them to resell what is left over to their peers, or even to dispose of leftover inputs. On average, smallholders have plots of land less than 1 ha in size (Headey et al., 2014), and only a small portion of this land is used for legumes. Nevertheless, fertilizers and other farm inputs are often sold in bags that can cover several such plots. Such packaging affects perceptions of compatibility, as it does not take affordability for smallholders into account (e.g. Agro-dealer1LB2). Farmer6LB1 indicated that inoculant is inexpensive (i.e. affordable) for most smallholders, thus enhancing compatibility. In terms of *complexity*, Researcher1R and other respondents referred to the difficulty of planting in rows, as smallholders are accustomed to the traditional practice of planting, which consists of simply scattering seeds. Farmer9LB2 indicated that following the step-by-step procedure for applying inoculant to seeds is a complex task for many smallholders.

We found less evidence that smallholders develop perceptions concerning observability and uncertainty with regard to the agricultural inputs, and we found no evidence that they perceive inputs in terms of their trialability. These findings are probably due to the fact that many farmers have observed trials with the inputs by other farmers in their community, witnessed them at demonstration farms or tried comparable inputs that had been distributed to them for free (e.g. by N2Africa project). As such, our results do not suggest that observability is unimportant for creating awareness of technologies. Indeed, extensive research highlights the role of observation in raising awareness (e.g. Ensor & de Bruin, 2022; Marra et al., 2003). However, we found relatively little evidence that *perceived observability*—which occurs at a later stage in the psychological process than initial awareness of inputs—constitutes a significant barrier to adoption.

Observability appeared to be particularly problematic for fertilizer and inoculant, as the causal relationship between the use of these inputs and productivity was not obvious to all farmers. With regard to *uncertainty*, several smallholders expressed doubts concerning the future performance of products. Particularly with regard to fertilizer, Farmer4LB1 reported being afraid that, if they were to start using fertilizer, the soil might become accustomed to, or even dependent on it. Most of these quotations, however, indicate that farmers perceive uncertainty about products when facing specific conditions (e.g. pests or changing market conditions). Uncertainty is thus most salient when taking into account the environment and its barriers to adoption. We return to this point in greater detail in the next section.

Adoption and intentions. The results of our analysis confirm that the adoption of the technology-holding products is neither widespread nor straightforward amongst smallholders (e.g. Expert3LB1; Farmer6HB1). The adoption of legume seeds takes the form of several farmers sharing a single bag of seeds in order to experiment with and compare them to seeds from their own harvest in the previous season. Some also use new generations of seeds for several planting cycles (see Annex 2 for representative quotes on adoption and intention). We also observed that the smallholders use legume seeds without fertilizer, inoculant or both. This decreases the yield impact of the technologies, as the combination of the three has been proven to work best in combination with proper practices (e.g. row planting) (Ronner et al., 2016; Wolde-meskel et al., 2018). Some of the farmers who had adopted the technologies stated that they had experienced a positive impact. For example, Farmer2R and Farmer11C1 reported positive consequences on farm productivity, nutritional value and soil fertility after implementing the technologies. This is consistent with literature reporting on systematic tests of the impact of technology adoption on agricultural productivity in randomized control trials (e. g., Asfaw et al., 2012; Verkaart et al., 2017).

With regard to the adoption process, our results provide evidence that the adoption processes of smallholders are not fundamentally different from those of other decision-makers (Rogers, 1983). The data reflected a distinction between the stages of adoption intention and behaviour (see Annex 2), as well as the notion that perceptions of the products holding the technologies drive the intent to adopt. For example, smallholders referred to such products by their local names (e. g. Wolki), rather than according to the technologies on which the products are based. This finding confirms that adoption is indeed driven by perceptions of the products holding the technology and their attributes, rather than by the technology itself.

The conditional role of awareness. As shown in Annex 3, *awareness* appears to correspond to the three types discussed in the literature (see Rogers, 2003): awareness that the technology exists (awareness-knowledge), awareness of how to use the technology (awareness-application) and awareness of how the technology functions (awareness-functioning). Researcher1R indicated that smallholders need to know in advance that the products exist and conceive a need for it (or a need to request it), as also indicated by Expert7LB2. Some respondents (e.g. Farmer6HB1) noted that it is also important to know how to use the inputs. Without this knowledge, smallholders are likely to perceive greater complexity and uncertainty. *Awareness* of the existence of technologies and *awareness* of how to use them thus act as fundamental conditions for the adoption process. This finding is in line with the importance that is assigned to awareness in the existing literature on smallholder adoption (e.g., Arslan et al., 2014; Asfaw et al., 2012).

Our findings also point towards a third type of awareness: with regard to the functioning of the technology. As demonstrated by the quotations in the bottom rows of Annex 3, awareness concerning the functioning of a technology influences perceptions in the adoption process. Unlike awareness concerning the existence and use of the technology, however, awareness concerning its functioning is not a necessary condition for the process. As discussed later, this type of awareness plays a more subtle role in the process.

Confirmation and purchase in the next season. Finally, some evidence provides insight into the continuity of adoption. According to the results of the interviews, smallholders might reverse their previous adoption decisions when exposed to conflicting messages about the inputs. In this regard, Farmer2R stated that he had decided to continue using the inputs because he had experienced a positive yield impact after testing them. In contrast, Expert6HB1 indicated that it is difficult for smallholders to continue using fertilizer, as they are not convinced of its positive impact (see Annex 4). This indicates that the decision to adopt or reject a technology is not the last resort, also within the adoption decision processes of smallholders, thus giving rise to the confirmation stage (see, Rogers, 2003). Further, some evidence pointed to the role of positive word-of-mouth in the dissemination of inputs (Homburg et al., 2005). For example, Farmer5HB1 indicated that he was using the new seed variety because a fellow farmer had told him that the new variety is resistant to disease.

In short, the results of our study provide evidence that smallholders undergo an adoption decision process in which awareness, perceptions and purchase intentions are created with regard to what is being offered to them. In conceptual terms, this is no different from other contexts of adoption. The adoption decisions of smallholders are rendered challenging by the barriers that are typical to their contexts and that can hinder the adoption process.

4.2. How barriers hinder the adoption process

While the adoption processes of smallholders are highly comparable to those of other adopters that have been studied in the adoption literature (in most cases, consumers), the smallholder context is fundamentally different, in that it is highly unpredictable. The environment affects the adoption process in three ways: (1) as *actual barriers* at the time of decision-making about purchases; (2) as *unexpected barriers* that affect the consequences of the purchased technology-holding products after purchase; and (3) as *anticipated barriers* that influence perceptions before purchase. These barriers are represented by the influence of the availability and affordability of inputs, as well as by labour and land, weather and climate, crop diseases and pests, and the functioning of the output market, which together constitute new categories of barriers (see Annexes 5, 6 and 7). In this respect, the findings suggest that the relationship between the environments within which smallholders operate and the processes through which they adopt new products that hold the technologies is far more complex than has thus far been recognized in the literature on smallholder adoption.

Actual barriers. The actual barriers impact on the adoption process in between the intention and behaviour stages. In other words, although smallholders might intend to adopt technology-holding products, changes in the environment can lead them to decide not to make the intended purchase. It is because of such barriers that it is important to distinguish between adoption intention and behaviour. The existing literature on smallholder adoption takes a comparable stand towards barriers by treating them as factors that impede farmers from adopting new technologies (see, for example, Simtowe et al., 2016). Actual barriers hinder both the availability and the affordability of technology-holding products (the latter as a function of price and purchasing power). With regard to availability, examples emerging from our results (Annex 5) include products simply not being in stock at times when smallholders visit agro-dealers and the lack of complementary products, which leads smallholders to change their planting decisions at the last moment. Affordability was also identified as a factor that hinders smallholders from purchasing products. Strictly defined, affordability is a combination of a product characteristic (price) and a barrier (purchasing power). The combination of these two aspects may make a product too expensive for smallholders, thus influencing their choice of which products to buy.

Comparison of the results between the High Barrier and Low Barrier cases indicates that the lack of preferred input package sizes was the most pressing barrier in the High Barrier case 1 from the South Eastern region. In the High Barrier case 2 from the South Western region, adoption was hindered by a lack of inputs and services that are supposed to complement seeds (e.g. inoculant). These findings provide the new insight that, for the smallholders to adopt technology-holding products, they also need to be supplied with the accompanying services and products: augmented and actual products (see, Kotler & Armstrong, 2010). Barriers like not having inputs in stock on time during planting seasons, high input prices and not having enough money to make purchases were also reported in the Low Barrier cases, thus suggesting that adoption continues to be hindered by the availability and affordability of the products that hold the technologies. These insights are confirmed by the evidence from Confirmation Case 2 from the Western region.

Our findings on *actual barriers* add an important refinement to previous studies on smallholder adoption. More specifically, they reveal that, in addition to the availability (see, for example, Asfaw et al., 2012; Simtowe et al., 2016) and affordability (see, Doss, 2006; Takahashi et al., 2020) of the technologies underlying products, adoption is hindered by shortcomings in the design of the actual and augmented products.

Unexpected barriers. Unexpected barriers, influence the process in between the adoption decision and the moment that the consequence of the adoption becomes visible. These barriers include factors that hinder agronomic performance, as well as those that are related to weather and climate (e.g. unexpected rainfall variability, moisture stress or frost) or to crop diseases and pests, which affect the biological process (see Annex 6). Unexpected barriers are relevant to adoption, as farmers do not always attribute harvest failures to the unexpected changes in conditions. Some may also blame such failures on shortcomings of products that they had bought. They take these experiences with them when purchasing inputs for the next season, thereby causing lower perceptions of product advantage and leading to non-adoption. Literature on customer experience also suggests that product experiences influence repurchase decisions by shaping either favourable or unfavourable perceptions (see Lemon & Verhoef, 2016). Scarcity of labour and land also emerged as barriers that were unexpected at the time inputs were purchased. Smallholders who implemented the technologies reported that they faced a shortage of labour for weeding and the application of inputs (e.g. inoculant). They also indicated that row planting requires more land than they had expected, probably because the smallholders tend to allow particularly large spaces between rows. According to our data, the functioning of the output market is another domain in which unexpected barriers frequently occur. Several informants mentioned that, even despite a successful harvest, buyers offered prices that were lower than expected, refused particular varieties or even failed to show up.

Anticipated barriers. Regardless of the importance of actual and unexpected barriers to the adoption process, the third category—anticipated barriers—emerged particularly strongly from the case evidence. Anticipated barriers are barriers that *may* happen, rather than those that are currently happening now or that have happened in the past. They affect the adoption process by influencing the development of perceptions. Given that farmers operate within an uncertain environment, they tend to develop 'what if' scenarios. For example, with regard to the availability of labour, a farmer might wonder, 'What if I can't find enough people to help with weeding on my land?' or, with regard to affordability, 'What if my daughter gets married this year and I need to pay for the wedding'. In relation to weather and climate, a farmer might consider, 'What if this season is as dry as, or even drier than it was last year?' They develop similar scenarios for diseases and pests, as well as for the functioning of the output market (see Annex 7 for representative quotes).

Smallholders make subjective risk assessments about such potential barriers in combination with the products that they are evaluating. For example, our analysis of perceptions revealed many pieces of evidence pointing towards perceptions of uncertainty, all of which were related to how the products would perform under particular conditions (see the quotations under uncertainty in Annex 1). In turn, perceptions of uncertainty have a negative impact on adoption intentions, thereby decreasing the likelihood of adoption (Arts et al., 2011). In comparison, existing studies have also indicated that the likelihood of uptake for futures contracts by farmers is influenced by their risk perceptions (Pennings & Leuthold, 2000).

As anticipated barriers affect the adoption process through the development of perceptions, and because perceptions depend on awareness, the type of awareness logically influences the magnitude of the impact that anticipated barriers have on perceptions. If smallholders have developed awareness about the existence of particular products and their application, anticipated barriers are likely to have a greater impact on perceptions than they do when a smallholder has also developed a deep awareness of how the technology functions. In the latter case, smallholders understand the functioning of the products and therefore they will be able to make more reliable assessments about the extent to which the performance of these products will be influenced by various conditions. For example, FGD1LB1 commented that, if the smallholders had been aware of the relative performance of Kabuli chickpea varieties (functioning), they would not have worried much about seed prices and market advantage (Annex 5).

In summary, smallholders expect that some of the actual and unexpected barriers that they have previously encountered will recur in the future. For example, within-case analyses of our results indicate that the availability of seeds emerged as an actual barrier under the code 'seeds not present on time' and as an anticipated barrier under the code 'inputs may not be present on time' in the Northern region case. Similarly, the functioning of the output market was regarded as both an unexpected and an anticipated barrier in Confirmation case 2 of the Western region.

5. The smallholder adoption process model

The theoretical model of the smallholder adoption process is presented in Fig. 2. The lower horizontal boxes represent the adoption decision process. The downward arrows from the barriers on top indicate the points within the causal flow at which specific barriers influence the adoption process. Notably, and consistent with conceptual frameworks in the fields of psychology and consumer behaviour (e.g., Zeithaml, 1988), the observable concepts are displayed in boxes, with unobservable concepts existing in the minds of smallholders (e.g. intentions, perceptions and mental representations) depicted as ellipses.

Our explanation of the model starts with the *core product*, as it represents the technologies that are intended to have an impact through their adoption by smallholders. The core of the product affects how the product is perceived in terms of relative advantage (the benefits that smallholders realise from adopting the product, as compared to alternatives), observability (the extent to which the impact of the product is visible or obvious to smallholders) and uncertainty (whether the expected gains indeed effectuate, whether the product is indeed as good as expected). While the technologies are somewhat abstract at the core, they are made more concrete and tangible through the *actual product* that a smallholder brings home after purchasing it. The actual product influences relative advantage (in terms of the costs that smallholders incur in relation to the product, as compared to alternatives), compatibility (in terms of the product's consistency with the size, budget and other characteristics of farms), complexity (in terms of the relative difficulty of application) and uncertainty (in terms of the predictability of the product's quality and potential to result in a good yield).

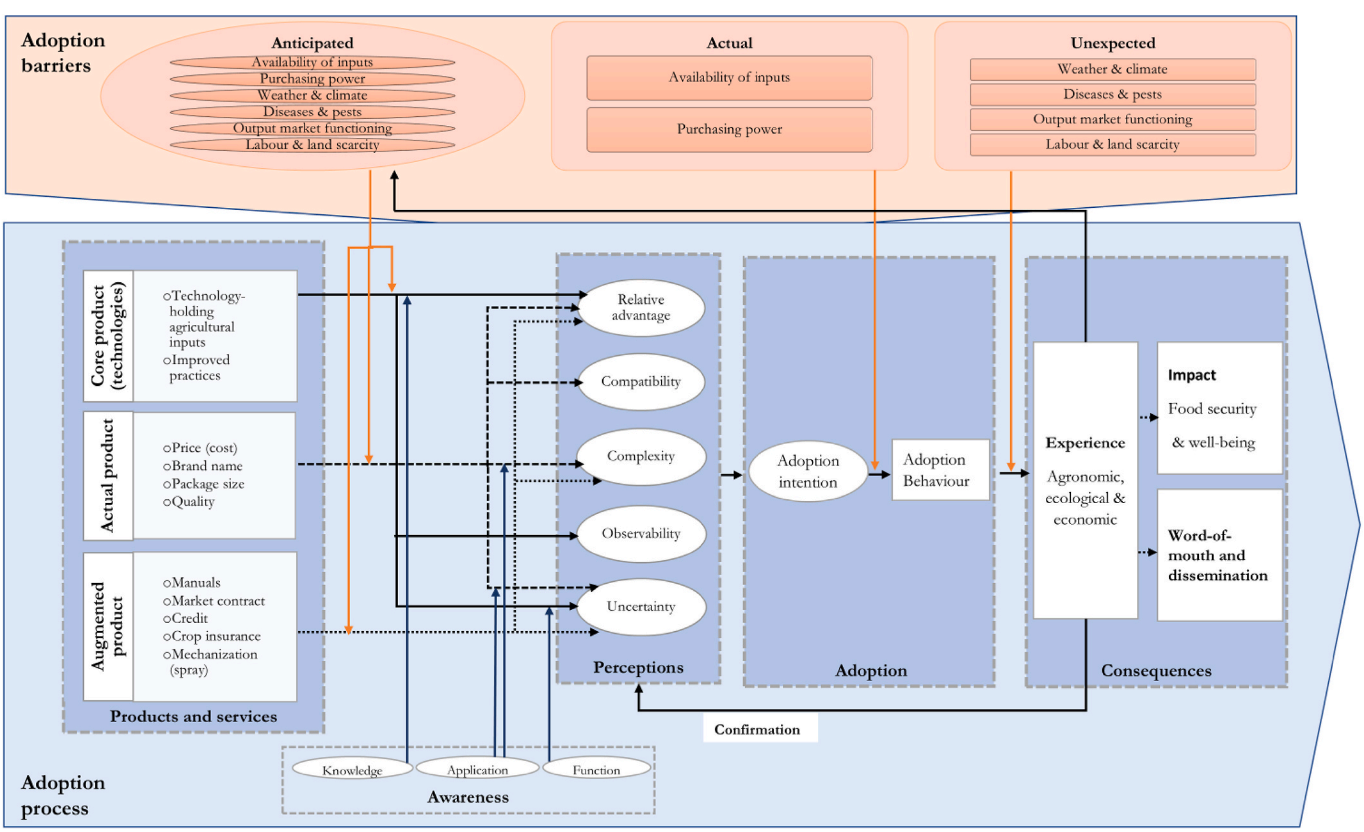

Fig. 2. Smallholder adoption process model.

The actual products may be accompanied by additional services captured in the *augmented product*. These services also influence relative advantage (e.g. by strengthening marketability through output market contracts, or by enhancing convenience through mechanization services) and compatibility (e.g. micro-loans that increase the affordability of the products). Augmented products also influence complexity through manuals that reduce the difficulty of implementing the products, and uncertainty through such services as market contracts (thereby reducing market uncertainty) and crop insurance services (thereby reducing uncertainty relating to weather and/or pests and diseases).

Awareness also influences how the product is perceived. *Awareness-knowledge* is required to assess the relative advantage of the product's core technology. If smallholders are not aware that a new technology exists, the main benefits of that technology will be lost on them. *Awareness-application* typically influences the development of complexity and uncertainty perceptions from the augmented product, in that smallholders who have little awareness concerning how to use it within the contexts of their own farms are likely to perceive the product as more complex and more uncertain. *Awareness-function* plays a special role in the model, as smallholders with high degrees of awareness-function have a better understanding of how the core technology works in the product, and can better estimate how the product is likely to perform under specific conditions that they anticipate. *Awareness-function* thus compensates for the effects of anticipated barriers that increase the smallholders' uncertainty perceptions.

Consistent with the adoption literature, perceptions influence *adoption intention* and, subsequently, *adoption behaviour* (decision-making). A decision to adopt leads to *experience* with the product (including the technology) within the farming context in which smallholders evaluate the product's *agronomic, ecological* and *economic* performance. The ecological performance of legume technology adoption is specifically important as legumes are promoted to enhance soil fertility through nitrogen fixation (Giller et al., 2013, pp. 156–174). If the technologies perform as expected, smallholders are likely to experience the social impact of the product (e.g. improved food security and well-being), as envisaged by adoption scholars. The news about the performance will spread through word-of-mouth, thus influencing the dissemination of the technology.

While this largely psychological process is not essentially different from the decision processes of other adopters, the adoption barriers faced by farmers create a particularly challenging context for adoption by smallholders. Barriers enter the process at three stages, and they are labelled accordingly as anticipated, actual and unexpected barriers. *Anticipated barriers* differ from the other two types, as actual and unexpected barriers are real environmental conditions, while anticipated barriers are mental representations of what may happen. Because anticipated barriers could potentially pertain to everything that could happen in the future, they comprise all barriers that are also included as actual or unexpected. Anticipated barriers can potentially affect all relationships between the product (core, actual and augmented) and perceptions, as they take the form of 'what if' scenarios. The interactions between the two concepts can result in the product being perceived as less favourable in the situation within which the 'what if' scenario actually occurs. Alternatively, these interactions could lead to the perception that the product offers attributes that eliminate the concerns. In particular, the augmented product can be seen as a 'storage place' for accompanying services that eliminate anticipated barriers. Examples include crop insurance (for concerns relating to weather or climate conditions), output market contracts (for concerns relating to changing prices on the output market or the failure of buyers to show up) and micro-loans (for concerns relating to lack of cash).

Actual barriers are those that impede positive adoption intentions from being translated into behaviours. They can be regarded as 'last minute' barriers, which could potentially disturb the process even when smallholders are in the store to make their purchases. They are therefore of only two types: availability (e.g. the farmer comes to the shop to buy seed, but it is not on the shelf) and purchasing power (e.g. prices are higher than what the farmer can currently afford). Even if all perceptions are positive, thereby leading to strong positive adoption intentions, such barriers may prevent smallholders from actually purchasing specific products.

Unexpected barriers occur even after a purchase decision has been made. They prevent the adoption decision from resulting in positive experiences. They thus include factors that cannot be controlled, like weather, climate, pests, diseases and changing market conditions. As such, unexpected barriers can hinder both the agronomic and the economic experiences of smallholders. Even though they occur after the decision, unexpected barriers are relevant to adoption, as they are likely to influence adoption decisions for the next planting season, and perhaps thereafter. The influence of experience on subsequent decisions is incorporated in the model through two feedback loops: the *confirmation* arrow (which affects future perceptions) and the arrow moving to anticipated barriers (and the emergence of new ones). Unexpected barriers are thus particularly relevant to adoption in the long term. It is important to note that these processes are subjective. For this reason, even if the product is of good quality and unexpected barriers cause it to underperform, smallholders might nevertheless attribute the underperformance to the product itself, thereby decreasing the likelihood that they will purchase it again in the next planting season.

6. Discussion and implications

The model presented in Fig. 2 contributes to the understanding of technology adoption by smallholders in several ways, leading to several implications for private companies, public policy-makers and other stakeholders. In this study, we combine the literature on smallholder adoption with the literature on consumer adoption. The combination clearly reveals that the process of adoption by smallholders is not essentially different from that of other adoption decision-makers. The context of smallholders is nevertheless much more complex. Examining smallholder adoption as a decision-making process enables identification of how and where the environment can interfere with the process, thereby posing barriers to adoption.

The barriers included in our model are conceptualized from the perspective of the decision-making smallholder. This approach is in contrast to the existing literature, which conceptualizes such barriers primarily from the perspective of the environment within which the smallholder operates (e.g. the quality of the infrastructure rather than the availability of inputs). The new conceptualization of barriers is therefore more refined in terms of where they interfere in the process, as well as with regard to how they interfere. For example, poor infrastructure could create barriers to the delivery of inputs, as well as to the sale of outputs and seasonal labour. When conceptualized from a smallholder perspective, these barriers appear separately in the model. This makes it possible to develop more specific interventions for overcoming specific barriers. Examples could include the provision of cost-efficient logistical solutions for sending inputs (e.g. combining several inputs in a single trip), in addition to the extremely expensive and, in many cases, unrealistic short-term implications of improving the road infrastructure to reach remote smallholders.

The user-centric conceptualization of barriers to adoption also goes beyond the literature on institutional gaps (see, Parmigiani & Rivera-Santos, 2015; Rivera-Santos et al., 2012), in which barriers are described primarily from an environmental perspective. Our model corresponds to this literature by suggesting that adoption problems are most likely to be resolved when all potential barriers/gaps are eliminated simultaneously, as even a single barrier can be a reason for not adopting a technology-holding product.

Our approach to barriers shares many features with the '4 A's' at the base of the income pyramid (as presented in the marketing literature): Acceptance, Awareness, Availability and Affordability. The 4 A's are presented as a user-centric alternative to the company-centric marketing instruments known as the 4 P's (Product, Promotion, Place and Price), which have been criticized as being unsuitable for the context of the poor (see, Babah Daouda et al., 2020; Sheth & Sisodia, 2012). In our model, acceptance is represented by the adoption decision. In the interviews, however, affordability (as a function of price and purchasing power) and availability emerged as barriers, while awareness (a long-standing concept in the adoption literature) also acts as a barrier by moderating the relationship between the product and smallholder perceptions. Our findings go beyond the (merely managerially-oriented) literature on this subject by integrating the four variables into a solid theoretical structure.

Another line of literature to which our model corresponds is that concerning the development of value chains (see, Gereffi, 2018). Our findings suggest that the availability of inputs and the conditions on the output market both act as potential barriers to adoption. As such, the model implies the need for connections between actors in the input and output markets, and for organization 'around' smallholders, to eliminate barriers at both stages in collaboration, thereby streamlining the value chain.

One feature that our model has in common with the marketing literature is the observation that 'technology adoption' is actually an indirect concept, as smallholders do not adopt technologies as such. Technologies offer benefits that can be incorporated into input products, and these products may or may not be adopted by smallholders. The model acknowledges that the technologies at the core of the product offer new benefits to smallholders and, in some cases, they address associated issues in terms of observability and uncertainty. Relative advantage, observability and uncertainty are therefore the three most important criteria for screening technologies before they are developed into actual products directed towards smallholders. Smallholders evaluate actual products according to advantage, compatibility and uncertainty. The first two aspects concern how well the product is designed to incorporate the needs of and eliminate the barriers faced by smallholders. We argue that more attention should be devoted to design processes in the development of new products or the further development of existing products (cf. Kotler & Armstrong, 2010). Uncertainty is largely dependent on the stability of product quality, thus highlighting the need for efficient processes of production and distribution (for products that are vulnerable to damage during transport).

The importance of selecting the appropriate technologies and of designing and producing the products should not be underestimated as tasks that eventually foster adoption by smallholders. In the short term, these aspects can easily be overcome by offering inputs to farmers free of charge. In the longer term, however, this is likely to be a dead-end strategy, despite the best intentions to stimulate trials of new technologies. Offering inputs free of charge may lead to erroneous economic experiences and expectations regarding affordability, thereby creating rather than eliminating adoption barriers for future sales.

Our findings suggest that smallholders are best served if they are not offered the technology-holding products alone, but together with accompanying services that eliminate other barriers. In this respect, our model also relates to the emerging literature on bundling for smallholders (Tsan et al., 2019). We are thus not the first to argue that adoption will increase when products are combined with services like micro-loans and crop insurance (also see, Mukherjee et al., 2017). Bundling inputs and services into a single offer has several important advantages: (1) Smallholders receive everything they need in a single package, thus preventing difficult decisions when only some of the inputs are available. (2) The adoption of the products for which the smallholders do not see an immediate need but that are technologically important to reach the intended impact is less of an issue, as all inputs are offered together. (3) Because all inputs are provided together, the amounts can be easily adjusted to fit the same plot of land, based on the needs of the average smallholder in the region. (4) All inputs are transported together in a single package, thus saving transport and other transaction costs and potentially enhancing affordability. (5) Financial and insurance services can easily reach the target audience (i.e. the smallholders who will plant the targeted crops without further promotion and selection efforts) (6) Input providers and other partners (e.g. output buyers and service providers). must inevitably coordinate their efforts in the composition of the bundle. For example, financial institutions can pay micro-loans directly to input providers, while output buyers return the money to the lenders without imposing any further complex administrative burden on the actual beneficiaries. Such bundling efforts should obviously be developed in a manner that does not require smallholders to become 'locked in', after which they could become easy targets for price reductions. For this reason, the involvement of farmer organizations or non-governmental organizations to secure their interests is likely to be desirable in many cases. The recommendation above to engage in well-organized design processes is thus not limited to the physical aspects of the (actual) product, but pertains to the entire bundle of the (augmented) product. By demonstrating the complexity of the smallholder adoption process and emphasizing the importance of holistically addressing its multifaceted barriers, our model can further contribute to efforts by researchers developing the Adoption and Diffusion Outcome Prediction Tool (ADOPT) to improve predictions of adoption rates (Kuehne et al., 2017).

In terms of public policy, our results highlight the importance of cooperation amongst private businesses within the context of a value chain and in collaboration with NGOs within the business ecosystem surrounding smallholders. One way policy can make such development possible is by creating a business environment that is conducive to input suppliers and other companies. For countries that still have strong regulatory constraints on input markets (e.g. Ethiopia), this includes liberalizing the input market sector to ensure that these actors are free to engage with smallholders in generating market information, as well as in the design and marketing of input products.

Orchestrators in the innovation system (see, for example, Daum et al., 2025; Klerkx et al., 2012) should be aware of all adoption barriers, including those that are anticipated and only exist in the minds of farmers. If a farmer fears that he/she will be unable to implement a certain technology, or if he/she perceives complexity which he may think will require more effort to understand and implement, he/she may refrain from adopting the technology. This implies, for example, that innovation orchestrators should adopt an innovation bundling approach to remove all adoption barriers simultaneously. In this regard, it is important to build the capacity of the orchestrators to move out of the typical one-sided innovation delivery approach and to adopt a systems approach (see, Klerkx et al., 2012) to design, develop and implement bundled solutions for smallholder systems. Such a capacity building will foster the continued execution of the procurement or product and service supply chains even after projects and programs phase out.

Finally, we would like to draw the attention of the readers to some limitations of the study and directions for future research. An important limitation is that while the smallholder adoption process model is theoretically generalizable in that is formulated at a level of abstraction that applies to all smallholder contexts, it cannot be taken as empirically generalizable. The model is developed based on data collected from a specific crop type (legumes), and in one country), even though we considered different species of legumes and regions within Ethiopia. The model is therefore not empirically generalizable to other kinds of technologies such as sensors, digital platforms and precision tools, but given its theoretical generalizability it may certainly be helpful in studying adoption processes for such technologies. Future research should therefore validate the model for different countries, contexts, crop types and technologies. In particular staple crops, like maize and wheat, would be interesting to study because these crops have, relatively, a more developed infrastructure, seed system and established value chain relations than legumes.

We used literature on consumer marketing to gain a deeper insight into the psychological aspects of the smallholder adoption process. While researchers on smallholder farming can draw important lessons from this field, the application of theories from consumer research should also come with caution as the context of smallholders is obviously very different from that of affluent economies. We accounted for this by not applying the theories one-on-one in a smallholder context, but rather by using them as input for a qualitative study that gave ample room for contextual insights, and we developed these combined insights into a new smallholder-specific conceptual model. More research in different contexts, including also slightly more developed contexts like peri-urban regions in emerging economies, can create more insight in the ways in which consumer adoption theories apply to smallholder farmers.

7. Conclusions

In this article, we examine the decision-processes of smallholders regarding the adoption of new technologies to understand the factors underlying the wide variations in adoption rates, despite the considerable potential of these technologies to improve productivity. The results indicate that smallholder technology adoption is not an outcome of a simple dichotomous 'yes-no' decision; rather, it involves a multi-stage decision-making process. The results show that smallholder intentions to adopt are shaped by their perceptions of product and service attributes—of which technologies are one component—which, in turn, influence their actual adoption behaviour. The continued use of technologies by smallholders is determined by their experiences of the technologies, which in turn influence their perceptions with regard to the technologies. This highlights another key takeaway from the study: the initial decision to adopt a technology is not the final stage in the adoption process. The study also shows that barriers interfere and hinder the adoption process at three stages: as negative expectations, as impediments to translating adoption intentions into behaviour and as impediments to impact after use, thus hindering the continued adoption of technologies. Specifically, the results on the occurrence of barriers in the form of negative expectations and anticipations reveal that barriers to adoption also exist in the minds of smallholders. The availability of properly selected technologies, products designed with smallholders' needs in mind, and accompanying services that address the adoption barriers is likely to substantially increase adoption rates—ultimately increasing agricultural productivity, food security and the overall well-being of smallholders.

CRediT authorship contribution statement

Tamiru Amanu Abetu: Writing – review & editing, Writing – original draft, Visualization, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Paul T.M. Ingenbleek:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Conceptualization. **K.E. Giller:** Writing – review & editing, Validation, Supervision, Resources, Methodology, Funding acquisition, Conceptualization. **Endalkachew Wolde-Meskel:** Writing – review & editing, Supervision, Resources, Project administration. **Edward Baars:** Writing – review & editing, Supervision, Resources.

Declaration of interest statement

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

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Appendix

Annex 1
Representative quotations relating to smallholder perceptions

Representative quotations	Codes
Relative advantage	
'The improved faba bean variety, Wolki, is a high yielder—almost double—as compared to the local variety'. (Farmer2R)	Gives high yield
'Farmers appreciate the technologies in terms of their performance in yield and marketability […]'. (Researcher2R)	Preferred by buyer
'Soybeans are the poor man's cow. They are a source of protein and energy. Soybean […] production also allows the use of its potential for improving soil fertility and provides the best option for crop rotation'. (Researcher5C2)	Gives high nutrition
'The application of DAP [a type of fertilizer] yields good legume performance, but at a high price […]'. (Farmer3LB1)	Gives high yield
'Inoculant helps to improve soil fertility, and hence gives a high yield'. (Farmer12C2)	Gives high yield, improves soils
'The practices are perceived to yield a good harvest and easier management (like weeding), as they allow farmers to move easily through the plants'. (Expert5HB1)	Gives high yield Eases weeding
'The combination of inputs results in high grain and biomass yield, and it contributes to the yield of rotating crops by increasing soil fertility […]'. (Farmer10HB2)	Gives high yield, improves soils
'The farmers are not comfortable with the blackness [colour] of inoculant when applying it to seeds'. (Expert10C2)	Convenience
'Lower convenience of faba bean production, as compared to wheat [no mechanization service]'. (Expert5HB1)	Convenience
'Farmers say that weeding is more intensive for soybeans than it is for maize; herbicide is used with maize'. (Researcher5C2)	"
Compatibility	
'Farmers prefer to use inoculant, but they need the inoculant to be supplied in smaller packaging'. (Expert5HB1)	Package sizes do not correspond to needs
'[…] Smallholders are also concerned with the packaging and the availability of sizes that farmers can afford. For example, farmers buy DAP on the open market [informal market where smaller amounts can be obtained], as this allows them to buy what they are able to afford'. (Agro-dealer1LB2)	"
'Inoculant is inexpensive, we incur much more cost for wheat production, as compared to faba beans […]'. (Farmer6LB1)	Inexpensive to buy
Complexity	
'Row planting both for chickpeas and faba beans […] is difficult for farmers to practice'. (Researcher1R)	Difficult to practice

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Annex 1 (*continued*)

Representative quotations	Codes
'The application of inoculant is a challenge for farmers, as is the application of DAP (fertilizer source). It requires more labour [This respondent was looking for accompanying services]'. (Expert5HB1)	"
'The application of inoculant is time-consuming when planting in rows; farmers compare it to row planting with teff, which is tiresome. Sugar and water are used to get the inoculant [in powder form] to stick to the seeds, but it also sticks to your hands while planting'. (Farmer 9LB2)	"
Observability	
'[…] For chickpeas, the bio-fertilizer [inoculant] has no visible effect. Farmers are less likely to adopt bio-fertilizer [inoculant] for chickpeas in Bichena'. (Researcher2R)	Impact not visible
'[…] impact of fertilizer is marginal, with only a marginal [yield] increment as compared to seeds, so they might not convince farmers to adopt'. (Researcher2R)	Only marginal impact
'The contribution to soil fertility improvement is obvious to farmers […]'. (Reseracher5C2)	Impact visible
Uncertainty	
'[…] But there is hesitation based on concerns that the performance of the technology might not be same in the next season, due to different risk factors'. (Researcher2R)	Doubts about future performance
'[…] However, the variety [Arerti chickpeas] may be affected by boll borers [bollworms], and the seed price is high'. (Farmer3LB1)	Susceptible to pests
'[…] Farmers want to apply a smaller amount of DAP [fertilizer source], as they think it will lead to crop lodging'. (Farmer3LB1)	Fear of crop lodging
'[…] farmers say, "We do not want to apply fertilizer for chickpeas, because our land will become accustomed to it'. (Farmer4LB1)	Fear of soil deterioration
'The market is the big problem; there are no buyers, even in the local market. Farmers fear that they might not find any market for their soybean grains'. (Farmer12C2)	Fear lack of buyers

Annex 2
Representative quotations relating to adoption intention, behaviour and impact

Representative quotations	Codes
Adoption intention	
'I decided to use all of the inputs because of the productivity improvement. Most farmers are also willing to buy and use the inputs'. (Farmer9LB2)	Intention to use inputs that are productive
'The Nasir common bean seed is similar to our favourite Wolaitta red, which most farmers prefer for its high yield, marketability and tasty traits. Farmers are willing to buy the improved variety, Nasir'. (Farmer9LB2)	Willingness to buy seeds that are comparable to locally known seeds
'If access is ensured, most farmers will buy inoculant'. (Farmer10HB2)	Intention to use if access guaranteed
'Most farmers plan to use improved seeds with inoculant. They think it is affordable and profitable for them'. (Expert11C2)	Intention to use inputs that are affordable/ profitable
Adoption behaviour	
'Few farmers use inoculant because of lack of promotion and availability in the local area'. (Expert3LB1)	Few farmers used
'[…] row planting and inoculant application are difficult for most farmers to adopt'. (Farmer6HB1)	"
'I used seeds from my own storage after sourcing them from research […]' (Farmer3LB1)	Use seeds from own storage
'Farmers buy and use all of the inputs disseminated'. (Expert5HB1)	Many farmers used
'My own stored common bean seeds, Hawassa Dume and Nasir, in the second place, used together with inoculant and fertilizer'. (Farmer7LB2)	Use seeds from own storage with inoculant and fertilizer
'Inoculant and fertilizer were bought and used. Last year, I bought seed [Nasir variety]* from the seed cooperative. The price of the seed is high, so farmers say, "Nasir is Nasir" and use seeds either from the open market or other sources'. (Farmer8LB2)	Use seeds from different sources with inoculant and fertilizer
'The improved common bean variety [Nasir] is used continuously, as farmers share with each other. Less fertilizer is also being used. Inoculant is not being used, as farmers are not aware of the source'. (Expert7LB2)	Use seeds from sharing with each other Inoculant not used
'Improved soybean seeds are being used by most farmers'. (Farmer11C1)	Most farmers using seeds
Adoption impacts	
'[…] the productivity [of the new faba bean variety], its high protein content and its contribution to soil fertility made me keep using it'. (Farmer2R)	Adoption has impact on productivity, food value and soil fertility
'Inoculant has increased soil fertility, and it even contributed to maize yield in the next season. The maize was deep green […] and that increased the yield'. (Farmer11C1)	Adoption has impact on productivity
'The improved faba bean seed has good market value. The monetary value of one quintal of faba bean is equivalent to 2 quintals of wheat'. (Expert5HB1)	Adoption has impact on income
'If inputs are used together, a quality harvest can be obtained. That attracts the market and results in a good income'. (Farmer12C2)	Adoption has impact on productivity and income

[…]*: added by author.

Annex 3
Representative quotations relating to awareness

Representative quotations	Codes
Awareness-Knowledge	
'Demonstrations helped to provide knowledge of seed varieties and technology performance for purposes of selection […]'. (Farmer1R)	Awareness that the technology exists
'Field days help to raise awareness amongst farmers, so that they can let others know what exists and share their views with various actors'. (Researcher1R)	"
'Demonstration trials are better for helping farmers to become aware of the technologies so that they will ask for them'. (Expert7LB2)	"
'There is not much promotion of the technologies; few farmers are aware of them'. (Agro-dealer2LB2)	"
'Lack of a proper extension service approach. […] Allow farmers to learn through proper extension services; let them decide at some point after evaluation'. (Researcher3LB2)	"
Awareness-Application	
'Adaptation [provision of small input packages for trial] helps farmers to gain practical knowledge and experience'. (Farmer2R)	Awareness of how to use the product

(continued on next page)

Annex 3 (*continued*)

Representative quotations	Codes
'Few farmers knew about inoculant. Awareness is low. It is difficult to adopt because of the challenges associated with its application'. (Farmer6HB1)	"
'Lack of proper use of the improved practices and inputs, as per the recommendations, by the farmers due to lack of sufficient knowledge'. (Expert7LB2)	"
'I prefer adaptation trials. They allow farmers to engage in practical implementation, gain practical knowledge and benefit from the harvest'. (Farmer12C2)	"
'[…] technical support is a major limitation to the use of inoculant'. (Expert11C2)	"
Awareness-Functioning	
'Farmers are not aware about the functioning of the various improved chickpea varieties'. (FGD1LB1)	Awareness of how the product functions
'Some farmers view stored seeds differently from seeds that have been freshly harvested from the Belg* season. They think that stored seeds are not that effective as those that have been harvested from Belg, so only seeds harvested from Belg are assumed to serve the real seeding functions'. (Farmer8LB2)	"
'I am aware of how inoculant improves soil fertility. Soybeans to which inoculant has been applied will stay green due to the added [fixed] nitrogen'. (Farmer11C)	"

Belg*: The short rainy season that usually begins in February and ends in late April/May in Ethiopia (Rosell, 2011).

Annex 4
Representative quotations relating to the continuity of adoption

Representative quotations	Codes
'[…] the productivity [of the new faba bean variety], its high protein content and its contribution to soil fertility made me keep using it'. (Farmer2R)	Experiences of positive impact reinforce or confirm previous decisions.
'I am still using the technologies. I already knew the benefit [yield impact]'. (Farmer11C1)	"
'[…] I heard from a friend who had used the ACOS [Agricultural Commodity Supply] variety that the variety is not affected by disease. In addition, ACOS is easy for row planting because of seed size. I therefore decided to buy and use ACOS'. (Farmer5HB1)	Positive word-of-mouth leads to dissemination
Farmers are not convinced of the yield impact of DAP, so it is difficult for them to continue to adopt'. (Expert6HB1)	Negative agronomic experiences lead to discontinuance.
'I am not using [soybean technologies after the trial] because I could not sell my soybean produce from the last season. I had to keep it at home because there was no buyer'. (Farmer13C2)	Negative economic experiences lead to discontinuance.

Annex 5Representative quotations relating to actual barriers to the technology adoption decisions of smallholders

Representative quotations	Code	Barrier
'There is no supply in August, when chickpea planting is done by most farmers'. (Researcher2R)	Seeds not present on time	Availability of inputs
'Delays were created by the lengthy procedure involved in the estimation of [input] demand, the government's revision of demand and its order to make input supply. As a result, farmers did not get the inputs on time'. (Unionmanager1R)	"	"
'The timely supply of seeds is a big challenge, and it affects seed purchase. Late planting due to late supply will affect production in Boricha, due to moisture stress'. (Farmer7LB2)	"	"
'Local shortage in the supply of inoculant'. (Farmer4LB1)	Complementary inputs not present	"
'Inoculant is not used continuously, due to availability […] If other accompanying inputs are not available, farmers prefer not to use improved seeds […]'. (Expert8HB2)	"	"
'[…] lack of inoculant availability on the local market […]'. (Researcher5C2)	"	"
'[…] lack of cash sources for fertilizer purchase. Due to capacity limitations, priority is assigned to buying seeds'. (Farmer2R)	Not enough money	Purchasing power
'Medium-income farmers use seeds stored from previous seasons [own storage] or buy from other farmers who produced them in the previous season. Farmers with less financial capacity use local seeds with inoculant'. (Expert5HB1)	Adoption dependent on income	"
'Lack of credit service for NPS [fertilizer source], combined with limitations in the financial capacity of farmers'. (Expert7LB2)	"	"
'Limitations in financial capacity for the purchase of DAP [fertilizer source] and […]'. (Expert9C1)	"	"
'The high price of the variety [improved seed] when buying from the cooperative. Farmers source the variety from local market'. (Farmer4LB1)	High input price	Affordability
'The price of NPS [fertilizer source] is high; the price is usually set by the government based on the price of the previous season's unsold fertilizer in the store'. (Expert6LB2)	"	"
'Farmers intend to use DAP [fertilizer source], but the price is high, the financial capacity of farmers to buy is low, and no credit arrangements are available for inputs'. (Seedsupplier1C1)	High input price Not enough money	"
'Farmers prefer to use inoculant along with local or improved faba bean varieties, but they need the inoculant to be supplied in smaller packaging sizes. The application of inoculant is a challenge for farmers, as is the application of DAP, It requires more labour'. (Expert5HB1)	Preferred package sizes not present	"
'Common bean seed packaging in different sizes based on the financial capacity of farmers and seed quality are the factors hindering usage'. (Expert6LB2)	"	"
'Price is the first reason for not buying. Farmers found the price to be very high, which is because of the cost of seed production [within the Anno agro industry]. Packaging is another reason. Smaller packages of seeds are needed, as farmers need small amounts of seeds. To date, however, there is no packaging service at Anno'. (Seedsupplier2C2)	High input price, Preferred package sizes not present	"

Annex 6

Representative quotations relating to unexpected barriers to the technology adoption decisions of smallholders

Representative quotations	Code	Barrier
'Climate change [moisture stress] is reducing the performance of technologies, thereby affecting interest in using inputs'. (Expert1R)	Affected by moisture stress	Weather & climate
'Moisture stress, like rainfall variability, is frequent in our area, and it poses a challenge for common bean production'. (Farmer7LB2).	"	"
'Faba beans are sensitive to natural hazards, and they are easily affected by frost […]' (Coopmanager1R)	Affected by frost	"
'Faba bean gall [*Olpidium viciae*] disease and chocolate spot affect the productivity of smallholders'. (Researcher1R)	Affected by disease	Diseases & pests
'The improved chickpea seeds, Arerti, was were good from germination till flowering. It dried on stand, became yellowish in colour and seemed to mature, but the grains didn't fill. It was affected by a disease'. (Farmer5HB1)	"	"
'Chocolate spot disease in faba beans makes production more difficult'. (Expert5HB1)	"	"
'Bollworm infestation is severe for chickpeas. The pesticides were ineffective. [We] applied multiple times, and it did not even work in 2016'. (Farmer3LB1)	Affected by pests	"
'The application of inoculant is a challenge for farmers, as is the application of DAP. It requires more labour'. (Expert5HB1)	Not enough labour	Labour scarcity
'We received inoculant and improved chickpea seeds to try along with improved practices: row planting and proper weeding practices. I tried it all. But there were farmers who did not use row planting because of a shortage of land'. (Farmer1R)	Not enough land	Land scarcity
'Soybean weeding is laborious compared to maize; herbicide was used for maize, but no herbicides were accessible for soybeans. Farmers do practice spacing, but they put the rows closer than recommended, due to a shortage of land'. (Researcher5C2)	Not enough labour/ land	Labour and land scarcity
'Fluctuations in grain markets. Whenever there is grain market failure, farmers refuse to buy inputs'. (Unionmanager4LB2)	Low price	Output market functioning
'There is no local output market for soybeans like there is for maize at the village or Woreda level. If one does exist, the price is not stable'. (Farmer13C2)	No buyer	"
'I am not using [soybean technologies] because I could not sell my soybean produce from the last season. I had to keep it at home because there was no buyer'. (Farmer13C2)	"	"

Annex 7

Representative quotations relating to anticipated barriers to the technology-adoption decisions of smallholders

Representative quotations	Code	Barrier
'[…] farmers didn't get the inputs in a timely manner. Afterwards, they had no trust that the inputs would be supplied in time to use them continuously'. (Unionmanger1R)	Inputs may not be present on time	Availability of inputs
'Not sure of the continued supply of seeds, inoculant and herbicides for weeds, thus contributing to low scale of production. What if N2Africa and Bako Agricultural Research Centre are not supporting inputs? Soybean production is occurring primarily because of the urging and support from the project. Most farmers say the same thing'. (Farmer13C2)	May not find complementary inputs	"
'Farmers think that they will be constrained by labour for growing faba beans; they say that human labour is needed for weeding, harvesting and threshing, as there are no mechanization services'. (Expert5HB1)	May not find enough labour	Labour scarcity
'[…] there will be competition for the available labour between various farm activities and the children's schooling'. (Farmer9LB2)	"	"
'Smallholders expect a lack of supply of herbicides for protection against weeds and combine harvesting for faba beans. This is important for faba bean production, as people have become accustomed to convenience with practices associated with wheat production, which is fully mechanized. Wheat mono-cropping is a challenge by now'. (Farmer6HB1)	May not find spraying and mechanization services	"
'I will not use chickpea technologies this year because of land shortage. I allot land for sorghum and teff. I am considering using it next year for rotation'. (Farmer1R)	May not find enough land	Land scarcity
'Future use will be constrained by moisture stress (leading to reduced performance of technologies), the financial capacity of farmers to purchase DAP, and the amount of labour required by improved farm practices'. (Expert1R)	May be affected by moisture stress, lack of money and labour	Weather & climate, purchasing power, labour scarcity
'[…] It [inoculant] has a long application process, and sugar is needed in order to apply the inoculant to the seeds, and we may not be able to afford it'. (Farmer5HB1)	May not have enough money	Purchasing power
'Above all, if the onset of the rainy season is late, I prefer not to use the technology'. (Farmer2R)	May be affected by moisture stress	Weather & climate
'Risk of rainfall variability, which could obscure the effect of the inoculant, so that farmers do not demand it'. (Coopmanager3LB2)	"	"
'Improved chickpea seeds—the Arerti variety—provide high yield and are preferred at the market. […] However, the variety may be affected by boll borers [bollworms] […]'. (Farmer3LB1)	May be affected by pests	Diseases & pests
'Farmers usually complain about the market for their produce, even before they have produced anything'. (Agro-dealer1LB2)	Buyer may not be present	Output market functioning
'First, because they fear risk due to lack of a market for grain, farmers do not produce grains. In addition, soybean diseases like leaf blight and African boll worm—or *kishkish*, as we call it—are local factors that increase the risk of using the technologies. Limitations in the financial capacity for purchasing DAP and labour for row planting are other constraints. Labour is an issue, as all farm practices are performed at similar calendar to that of soybean production'. (Expert9C1)	Buyer may not present May be affected by diseases May not have enough money May not have enough labour	Output market functioning, Diseases & pests, Purchasing power, Labour scarcity
'The market is the big problem; there are no buyers, even in the local market. Farmers fear that they might not find any market for their soybean grains […]'. (Farmer12C2)	"	Output market functioning
'Grain market problems. We are not sure if farmers will continue to grow soybeans next year if they did not sell what they produced this year'. (Seedsupplier2C2)	"	"

Data availability

Data will be made available on request.

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