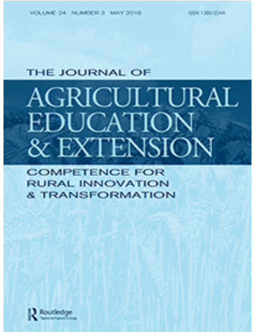

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Facilitating integrated agricultural technology development through participatory research

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ABSTRACT

Purpose: In this paper, we discuss the role of participatory research in integrated agricultural technology development using the example of a solar fruit drying project in Mozambique.

Design/methodology/approach: We engage in seven participatory exercises with groups of farmers from two farmers' associations in Inharrime district in Mozambique to identify their needs for solar fruit drying that are crucial for solar dryer technology design. We focus in the analysis on three of these exercises including a daily schedule exercise, SWOT (Strengths Weaknesses Opportunities and Threats) analysis and technology requirement exercise.

Findings: Participatory research takes a dual function for integrated agricultural technology development. First, it can help to identify the technology needs of farmers and second it can enable the exchange and creation of different sets of knowledge for agricultural technology development between multiple stakeholders.

Practical implications: Participatory research provides a tool for joint knowledge exchange and creation, which allows the identified technology requirements to be translated into practical technology design.

Theoretical implications: This paper extends the concept of integrated research to integrated agricultural technology development and shows how participatory research is a tool that enables transdisciplinarity, which presents the most desired form of integrated research.

Originality: This research is highly relevant for researchers working in an interdisciplinary environment with agricultural technology development in cross-cultural contexts. From a meta-level perspective, it provides insights for joint and integrated technology development.

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Participatory research; integrated agricultural technology development; tansdisciplinarity; solar drying; solar food; Mozambique

Introduction

Agricultural extension and education have considerable potential to improve agricultural production and thus decrease rural poverty, particularly in developing countries

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where agriculture presents a major livelihood activity for people. Despite this, extension work has only had limited success in Sub-Saharan Africa (Spielman, Ekboir, and Davis 2009). One reason for this is that traditional agricultural technology transfer models follow a linear 'top-down' approach where new technologies are generated by scientists and transferred by community and extension workers to agricultural practitioners (Miller and Cox 2006; Suvedi, Ghimire, and Kaplowitz 2017). These types of projects are not sustainable because they follow 'a one size fits all' approach and do not take context specific factors into consideration. This lack of particularity has contributed to the failure of many agricultural innovations, but also leaves room for the development of a more iterative approach that does not focus on innovations in isolation from people's socio-cultural context but rather actively involves agricultural practitioners in the process of the design, construction and implementation of new technologies.

A crucial approach for stakeholders working in the field of agricultural extension is participatory research, which actively involves relevant groups in the research process and questions common scientific approaches. It does so by allowing different sets of knowledge to be incorporated and locally relevant contextual knowledge to be jointly developed by different stakeholders.[1] Participation in agricultural extension *involves* farmers rather than treats them as *passive* recipients of knowledge (Massey et al. 2006). It captures the different and sometimes contradicting needs and preferences of scientists and the farmers (Leeuwis and Van den Ban 2004) and establishes a dialogue between these groups (Bellon 2001; Hoffmann, Probst, and Christinck 2007; McEntee 2014).

However, critics claim that evidence from participatory research is too site-specific, too costly and time intensive, which limits their transferability to other contexts (Bentley 1994; Neef 2008; Neef and Neubert 2011). As it is challenging to combine different knowledge sets of farmers and scientists effectively into agricultural technology development, collaborations between farmers and researchers have often remained superficial (Bentley 1994; Hoffmann, Probst, and Christinck 2007, 356).

In addition to these different understandings between farmers and researchers, there are also profound differences in the conceptual understanding between the researchers involved in a technology development project. Discrepancies between ontological and epistemological approaches in the natural and social sciences are a major barrier for successful integrated research (Burton, Rønningen, and Wedderburn 2008).

Previous studies in agricultural extension have tended to ignore this perspective by focusing mainly on the importance of farmers' involvement within participatory research (Franz et al. 2011; Lacy 2011; Sewell et al. 2017) but have not, however, addressed the interdisciplinary work between the researchers themselves in agricultural technology development (e.g. Hoffmann, Probst, and Christinck 2007).

In this paper, we aim to show how participatory research can facilitate integrated technology development (here understood as the active collaboration between researchers from different disciplines and farmers). We will illustrate this by (i) investigating farmers' needs in the case of developing a new solar fruit drying technology with farmers in rural Mozambique and (ii) discussing how these needs can be embedded into integrated technology development.

Participation for integrated agricultural technology development

Participation

'Participation' is a loose term that lacks a specific definition (Mikkelsen 2005). In general, we can differentiate between participation as a means of improving development activities and participation as an end in itself (ibid). In the first understanding, participation captures mainly making the development process more effective and sustainable by involving the end-users. Participation as an end in itself ensures people's influence on their own situation (empowerment) (Narayanasamy 2009). Other researchers have made this division even more detailed by dividing participation into seven different stages that include different levels of involvement/agency of the end-users ranging from passive participation to self-mobilization (Pretty et al. 1995, 61; Narayanasamy 2009). However, recently developed new frameworks critically question these linear typologies of participatory research (Neef and Neubert 2011). Current definitions of participation do not view participants as beneficiaries of new technologies but as stakeholders and customers. Thus, end-users are ascribed a higher level of involvement and participation, which becomes a partnership that aims to empower people to take their own decisions.

Participatory research allows for the integration of community's indigenous values and beliefs (Kindon, Pain, and Kesby 2009). It enables farmers and researchers to collaborate on joint technology development and build a platform for direct contact, which is considered to be a prerequisite for successful technology development (Hoffmann, Probst, and Christinck 2007). Thus, participatory research challenges the dominance and power of researchers by giving more power to stakeholders to direct the research (Brockington and Sullivan 2003, 60). Researchers as outsiders of a community take the role of catalysts and facilitators instead of extractors of information (Chambers 1991). By following a participatory approach, they do not impose their own views on people but take a step back to learn and listen (Chambers 1997) and to generate new knowledge from the farmers' perspectives (Beazley and Ennew 2012).

Participatory research emerged as an attempt to move social research from an abstract, detached science conducted by outsiders to an emancipatory form of research where poor and marginalized people become actively involved in creating just, peaceful and democratic societies (Jordan 2009). However, participatory research has become increasingly interesting to NGOs, international development agencies and consultants over the years. Critics argue that participatory research is being re-contextualized by these groups into a neoliberal governmental framework that makes use of quasi-participatory methodologies that are contrary to the bottom-up democratic origin of participatory research (ibid., 22).

In addition, participatory research demands high levels of interdisciplinarity between researchers. That can be challenging if researchers with different systems of knowledge work together on a common research problem. As Kindon, Pain, and Kesby (2009, 93) state 'it requires an epistemological and practical shift in how we do research, how we relate to our participants, and what we think of as knowledge'. Within participatory research, knowledge follows an ontology that sees people as dynamic agents and allows for different forms of knowledge production rather than validating only academic knowledge (Kindon, Pain, and Kesby 2007, 13). When focusing on technology development, in order to guarantee the success of an agricultural research project, a fruitful interactive collaboration between all stakeholders with their different sets of knowledge systems is thus required, where knowledge is not only exchanged but also jointly and equally created.

Integrated agricultural technology development

We use the term integrated agricultural technology development to describe the desired final outcome: the joint development of an integrated solar drying technology that Mozambican farmers will adopt for long-term use. We define integrated research as 'a collective noun to refer to all categories of sustainability research involving integrated multiple disciplines' (Stock and Burton 2011, 1091). We can distinguish between three different forms of integrated research, including multidisciplinary, interdisciplinary and transdisciplinary research. These differ in their levels of knowledge exchange and creation, their focus on real world problems, and their involvement of different stakeholders. Multidisciplinary research represents the least integrative form while transdisciplinary research represents the highest integration that also includes non-academics in the research process (Aagaard-Hansen 2007; Stock and Burton 2011; Kirk-Lawlor and Allred 2017). Transdisciplinary research is the most desirable formof collaboration but also the most difficult to achieve. In terms of agriculture, many researchers lack the experience of working with farmers and vice versa. In addition, both groups tend to follow different worldviews, goals, roles and motivations (Sewell et al. 2017, 315). By involving researchers and farmers in the research process, we aspire in our research project towards a transdisciplinary form of integrated research.

Solar food project Mozambique

The solar food project takes place in Inharrime district in Inhambane province in Mozambique. Although there is enough food grown to satisfy the needs of the population in Mozambique, many still go hungry because a massive amount of production is lost due to underdeveloped primary processing and storage facilities. Fruits ripen in a very short period, and what cannot be eaten, spoils rapidly and never reaches the end-consumers. Post-harvest losses in Mozambique are estimated to be 25%–40% and much of the fruit is never even collected because of a short ripening season (USDA 2011). That estimate includes Inhambane province, which has the highest tangerine production in Mozambique. Inharrime district within the province is the production leader, with local authorities estimating annual production at about 25,000 tons of citrus fruit (Governo do distrito de Inharrime 2012).

In this context, the development of a preservation technology suitable for smallholder famers becomes very relevant. It is important to have a simple, small-scale fruit processing technology that can preserve fruit in a safe and cost-effective way close to the point of harvest when plentiful, so it can be consumed at a later time when it is no longer fresh. Existing small-scale dehydration methods for drying include *oven drying*; wood, charcoal or diesel burning evaporators; *osmotic dehydration*; and *solar drying*. Oven driers require an expensive energy source (i.e. electricity or gas) and contribute to CO_2 emissions. Wood, charcoal or diesel burning evaporators also contribute to the release of CO_2

and have a time and/or economic burden. Solar drying seems preferable since it uses a free, renewable energy source. Open-air sun drying of food is a preservation method already applied in rural Mozambique, but it also has significant limitations. It is not suitable for preserving juicy fruits because (1) it is difficult to handle large open trays of liquid and (2) juices/purées dried in open trays attract dust, insects and pests and are therefore easily contaminated by microorganisms and toxins (VijayaVenkataRaman, Iniyan, and Goic 2012). Hence, a drying technology is needed that overcomes these limitations. One potential solution presents sealed bags made of a food grade breathable membrane: they can be used to contain and concentrate fruit juices/purées using solar irradiation and ambient air (Phinney et al. 2015).

Thus, the main purpose of the solar food project is to investigate, adapt and combine solar collector technology that produces solar heat with newly developed membrane pouches for drying and thus preserving and utilizing fruits that would otherwise spoil. The membrane pouch and an example of a solar drying collector are illustrated in Figure 1. If the membrane bags are combined with an adequate solar dryer, there is potential to improve food safety as a result of higher temperatures, decrease the drying time, increase productivity, improve vitamin retention through temperature control and protect the final product from external contamination such as dust and insects. The development of a small-scale solar dryer could help Mozambican farmers to prevent citrus fruit spoilage by producing jam and juice that can be either sold at the local market or consumed by the farmers themselves.

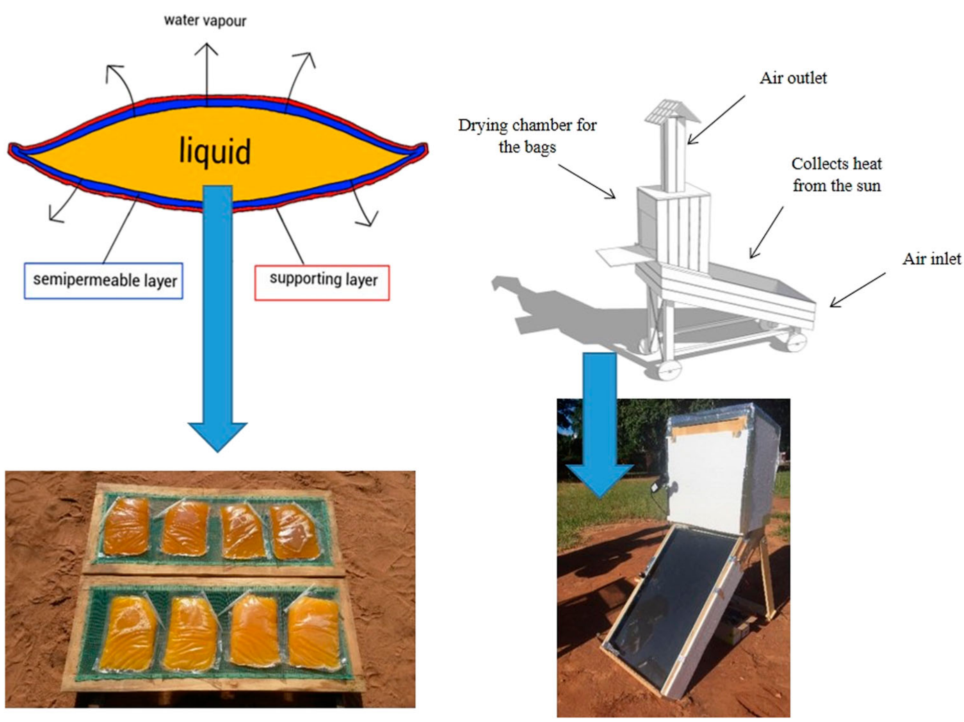

Figure 1. Membrane pouch and solar collector.

The project involves five international researchers with backgrounds in food technology, theoretical physics, civil engineering and social sciences. Each researcher provides crucial expertize for an integrated technology development process as illustrated in Figure 2. In addition, two professor-level food technologists are involved to provide theoretical guidance. On a short-term basis, technical master's students are also affiliated with the project.

Methods field setting

The solar food research project is a three-year-long project that includes three different phases of joint technology development ranging from (1) identifying farmers' needs for technology development, (2) testing of prototypes, followed by (3) revising prototypes and final testing and implementation. A key feature of the project for integrated research is that all five researchers work jointly in the field during these three stages. In addition, one of the food technologists is a local Mozambican researcher who continues the testing of the first prototypes with the farmers between Phase 2 and 3. This paper is based on the first phase of fieldwork (Phase 1), which took place 2–25 April 2016 in Inharrime district with two agricultural associations.

The connection to the two agricultural associations was established during a previous project on cassava processing that started in 2007. The purpose of the project was to evaluate traditional cassava processing methods that were, at that time, still being done manually. During the fieldwork, farmers expressed their need for drying citrus fruits, which led to a new project investigating the use of membrane pouches. The two food scientists travelled to Inharrime in 2015 to investigate citrus fruit production and existing fruit processing methods. Their visit formed the basis for this project (Figure 3).

The prior fieldwork showed that famers are already sun drying different food products (e.g. peanuts and cassava) as way to increase their shelf life. They wish to increase preservation of citrus fruits. However, citrus fruits have different food characteristics and cannot be dried openly. They require a technology that can reduce their water content to increase their shelf life, and solar energy seems to be a suitable source of energy for doing so.

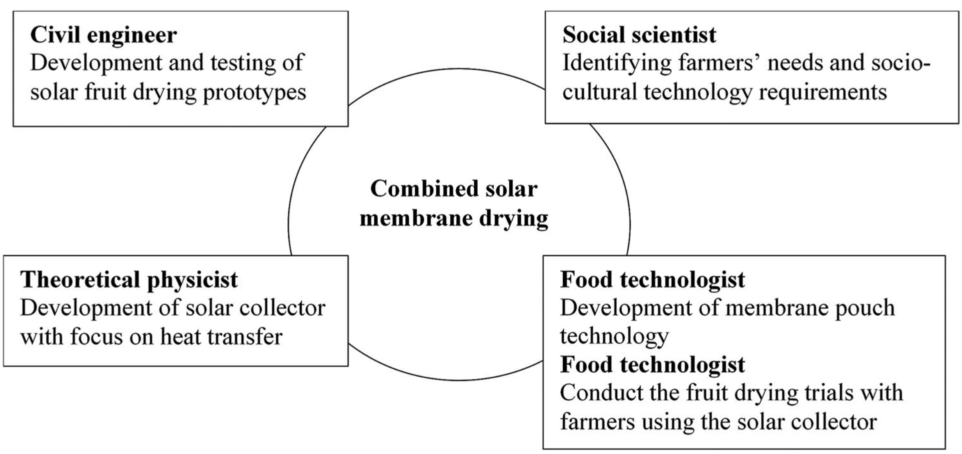

Figure 2. Research background and roles in the project.

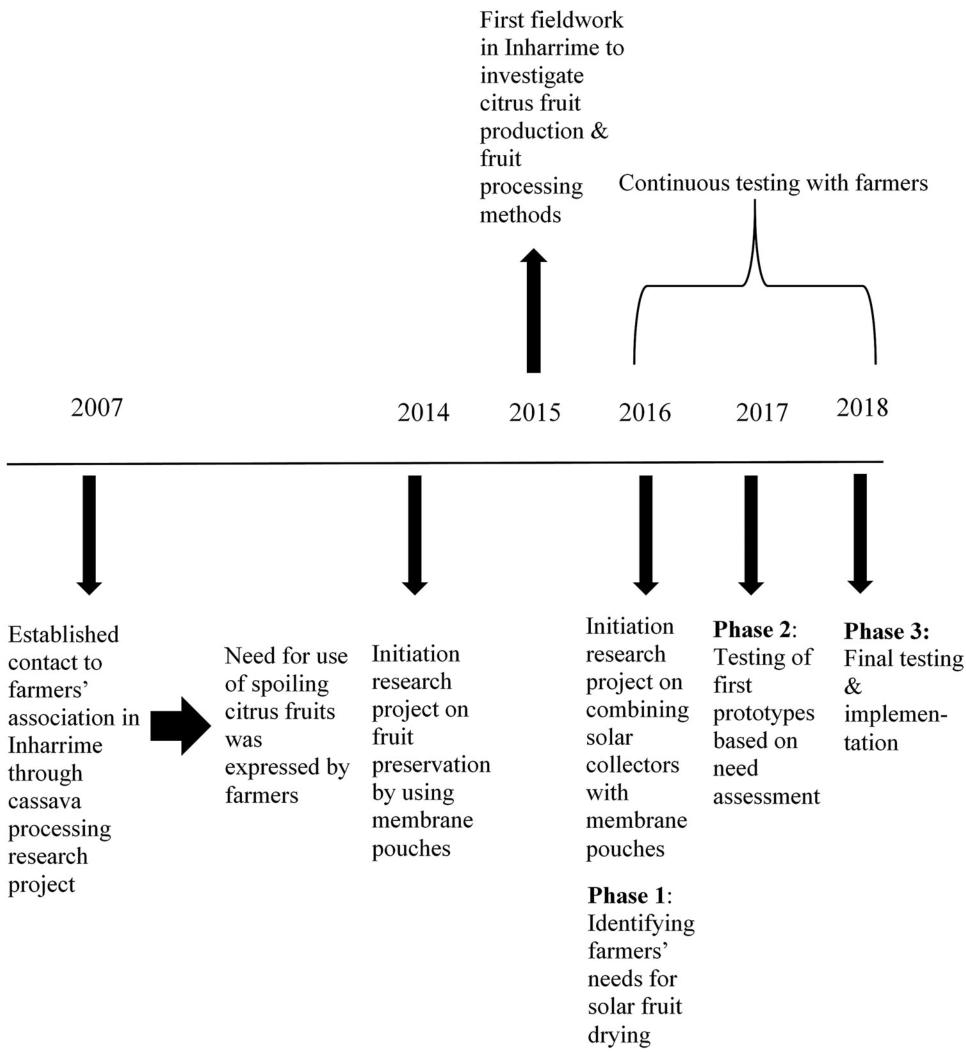

Figure 3. Project development time line.

As participation is a key feature in the project, prior to the fieldwork, the two agricultural associations were informed about the research project and members could voluntarily sign up to take part in the fieldwork. The dates and times for conducting the participatory exercises were arranged with the farmers to ensure that they would not interfere too much with their normal workday, which could lead to significant time, labour and consequently financial constraints for them (Hauser et al. 2016). The meetings were normally scheduled in the morning and finished after lunch time. We also assisted the farmers in some of the agricultural tasks for team building and creating an informal atmosphere.

An important issue that presented the baseline for a valid and reliable data collection in our project was the consideration of gender relations and unequal power relations between men and women. Gender divisions in agriculture are particularly visible in African societies. They concern the division of tasks, crop growing and value of time (Doss 1999). They also address educational levels. Women generally have less education than men in Mozambique (UNDP 2016), particularly in rural areas. The women interviewed in our group had not completed primary school and mainly spoke the local language (Chopi) whereas men could also speak the official language (Portuguese). Hence, it is important to talk to both men and women because they might have access to different resources, knowledge and information and bear different workloads and responsibilities that would be crucial for sustainable technology implementation (Bellon 2001; Mikkelsen 2005). They might also have conflicting interests (Mikkelsen 2005). Thus, we divided the participants into two groups, men and women, in order to create a free environment for both genders to share their experiences with us and to identify the different perceptions on the feasibility of solar drying.

Participatory methods applied in the field

During the first fieldwork in Phase 1, we conducted seven different participatory exercises with the farmers to identify key factors relevant for the development and design of solar dryer prototypes. Some of the exercises were discussed purely at a group level and some others at an individual level where individual preferences were relevant. Table 1 presents an overview of all exercises, indicating the date when they were conducted, the level (individual vs. group), and their purpose with regards to the development of solar fruit dryers. The number of farmers in the groups varied from day to day with six to ten participants in each group discussion.

The analysis below focuses on exercises 1, 2 and 6, which addressed technical as well as socio-economic and cultural factors.

Daily schedule

A ranking exercise where tasks with the highest amount of time are represented with the largest amount of cowpeas. We divided the day into 12 h (6 am to 6 pm) to cover the activities during day light, which is also the time when the solar dryer would be in use. The farmers were provided with 12 seeds, which they had to place for two different daily scenarios—harvest season (especially the time when the tangerines are ready (between April and August) and a normal day.

Table 1. Overview of the conducted participatory exercises.

Date	Exercise ID	Exercise	Purpose	Level
07.04	1	Daily schedule	To get an overview of daily activities and possible available time for solar fruit drying.	Group
08.04	2	SWOT Analysis	To identify internal and external factors that are (un)favourable for solar fruit drying.	Group
11.04 13.04	3	Transect walks	To understand life and livelihoods of farmers for solar fruit drying.	Individually
12.04	4	Difficulty assessment of solar fruit drying process	Ranking and scoring to find out which steps in the solar fruit drying process the farmers consider most difficult.	Individually
12.04	5	Assessment of division of labour in the solar fruit drying process	To identify shared responsibilities in the solar fruit drying process.	Individually
14.04	6	Technology requirements	Ranking and scoring of different technology requirements by the farmers.	Group
11.04–19.04	7	Photo voice	To get an overview of farmers' daily lives in their own perspective.	Individually

SWOT

The groups were individually consulted about the strengths, weaknesses, opportunities and threats of solar fruit drying to identify the challenges for the design and development of solar drying.

Technology requirement ranking

We chose a half-open half-closed approach where we presented the farmers with cards that included different factors of technology constraints that were identified from the literature. These included (1) *affordability:* in terms of low initial costs of solar dryers (Abur, Dan-Dakouta, and Egbo 2014) and financial gains compared to conventional open sun drying (Purohit, Kumar, and Kandpal 2006). (2) *Maintenance* of solar dryers (Weiss and Buchinger, n.d.); (3) *Ease of use* (Bremm-Gehards 1991); (4) *Theft* of solar equipment (Azimoh et al. 2015) and (5) *Sustainability*, which was defined as the long-term use of solar dryers that includes the three pillars of sustainability: economic, social and environmental sustainability (Barkemeyer et al. 2014).

In addition, we included some empty cards where we provided the participants with the opportunity to include other factors that they perceive as important but that were not considered in the original study design.

Results

The results from the three participatory exercises are summarized in Tables 2 and 3. Overall, the SWOT and technology requirement exercise showed that there is a high need for easy maintenance that can be done by the farmers locally. This does not allow for large scale, complex drying technologies where the failure of one technical part could easily lead to a full breakdown of the technology. Besides technical aspects, the farmers emphasized logistical/infrastructural challenges concerning the transport of tangerines, access to containers and time constraints (particularly by women), and concerns related to juicing and the collection of tangerines.

Table 2. Results of the daily schedule and technology requirement exercises.

Exercise	Female group	Male group
Daily schedule	Very limited time. During the intense farming season their work day is longer than 12 h. Express a high interest in fruit drying but lack considerable time to do this. They do not want to use the time when they produce cassava since their income depends on it.	Much more time available and do not express time concerns. High interest in learning solar fruit drying.
Technology requirement	Maintenance has been difficult in the past. Difficult to find someone with the necessary skills to make repairs. Buying spare parts is expensive. Price or affordability: Women emphasized the price for maintenance services rather than the purchase price itself. They wish for supervision and training on the use of a solar fruit dryer for as many members as possible so that the business would not be interrupted in case of individual sickness. The solar dried products should quickly create an additional income.	They want to be trained in maintenance. Use of local materials. They suggested the use of commonly available corrugated iron sheet material frequently used for roof covers. Plastic glass. Affordability: They want a quick return on their investment. To avoid any financial risk, they would like to start at a small production level and then evaluate before continuing. Manual juice making seems time consuming. Problems with the drying process being outdoors because of sudden unexpected rain, especially during the rainy season. They want a system that withstands rain or is easy to carry in and out of the main storage building.

Table 3. Results of the SWOT analysis.

Exercise	Female group	Male group
SWOT Strength	They already drink and buy juice concentrate. Lot of fruit spoilage.	Knowledge is there for processing crops (e.g. cassava, cowpea) that might be applied for drying fruits as well.
SWOT Weakness	Complex, many preparation steps. Hand-made juicing allows only for small quantities. They lack containers for juice and water. They do not want to peel tangerines by hand. Challenges of transport of tangerines to the agricultural association.	Maintenance of the solar dryer. Lack of funding to buy equipment including membrane pouches. Transport and harvest of tangerines. No access to motorized vehicles and bad road conditions. The harvest and peeling of tangerines manually is very time consuming.
SWOT Opportunities	There is a market for selling jam and juice. People already buy their cassava bread at the market and it is known to be the best one in the region.	Market is there; people prefer natural juice over fruit concentrates and would prefer locally produced products over imported. Fruit products could provide an additional income.
SWOT Threats	Affordability of the products. A previous cassava drying project failed. The dryer did not work properly and was difficult to fix because they were not taught.	Distance to workshop to fix things. Lack of water, which is needed for jam/juice production. No electricity and problem of firewood availability for producing jam or juice on a fire.

Embedding the results from participatory research in integrated technology development

The results from the participatory exercises provide fruitful guidelines for the design of the first prototypes. Figure 4 shows how the previously presented results from the participatory methods can be translated into technology implications for the development of solar drying prototypes.

Development of solar collector

The original idea was to use wood as the main material source for the solar collector. However, since easy maintenance is a key parameter for the farmers, we decided to use corrugated iron sheets instead due to termites and the wood requiring treatment to withstand harsh weather conditions (high temperatures and high humidity). In addition, the design of the dryer has to be optimized to avoid transporting the solar dryer in and out at sunset and sunrise and additionally during rainfall. Furthermore, the use of glass should be avoided since it would require special care and if the glass breaks it would be difficult to get a replacement with the exact same dimensions. In order to make the system more affordable more locally available materials have to be applied such as plastic glass and corrugated iron sheets. Furthermore, the amount of thermal insulation needs to be reduced since it is not easily accessible in the area. It is preferable to increase the size of the solar dryer instead since space is not a problem.

The biggest challenge is the membrane pouches, since they are a brand-new technology. However, the exercises with the farmers provide more insights on the further bag development. The farmers stated that they would like to re-use the pouches as many times as possible to reduce costs and if feasible, produce the pouches on-site. In this way, they would avoid paying higher prices for the pouches at the local market and also be less dependent on suppliers who would bring the pouches to the rural areas. In addition to concerns regarding the solar collector and the membrane pouches, the farmers expressed

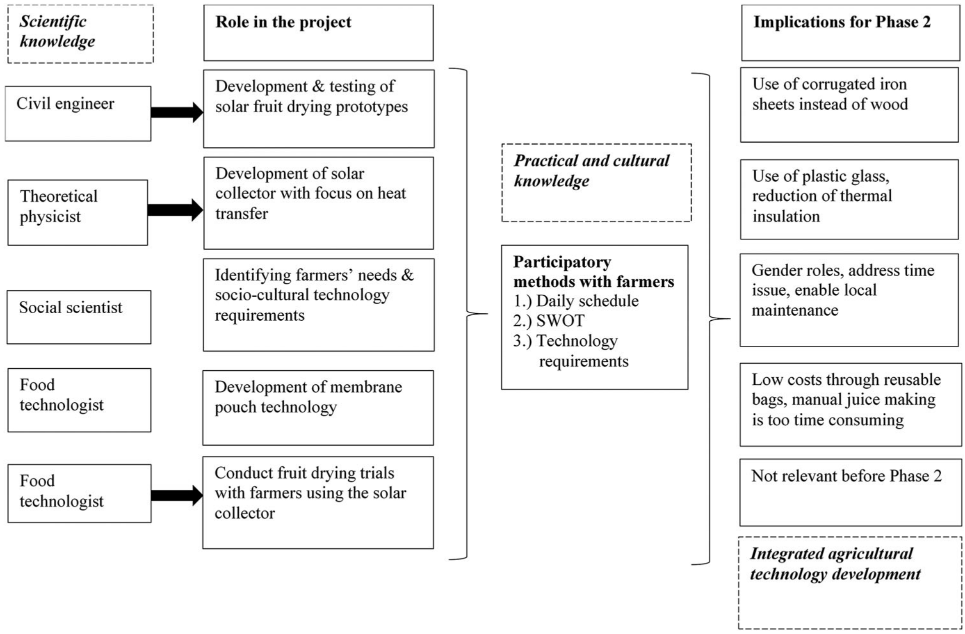

Figure 4. Translating results from participatory research to technology design.

concerns with the manual juice making process—which is perceived as too time consuming.

Based on these implications, the researchers will design one to two prototypes and test them first in the university laboratory and then in Inharrime. After the joint fieldwork to assess the use and functioning of the prototypes in the second phase, the prototypes will remain in the field where the farmers will continuously test them, in order to provide a feedback loop. This enables the farmers to engage with their own ideas for the design of solar dryers (Bentley 2006) and to facilitate farmer-to farmer learning, which is crucial to adopting new agricultural technologies (Gwandu et al. 2014). During this time, the local Mozambican researcher in the team will assist the farmers.

Our findings indicate that engaging all relevant societal groups in participatory research presents a suitable approach for facilitating integrated agricultural technology development. Participatory research empowers the farmers to become part of the technology development. It identifies farmers' cultural and practical knowledge sets that are essential for technology design and implementation. However, only an active engagement of all researchers with their disciplinary scientific knowledge makes it possible to translate the farmers' requirements into technology design.

Furthermore, by including the different sets of knowledge and all stakeholders in the work, participatory research facilitates collegial interactions between researchers and farmers that are considered to enhance innovation (Pant 2012). In addition, it enables team members to develop a cohesive team culture, which is an important prerequisite for successful intercultural research team work (Kirk-Lawlor and Allred 2017, 668).

The research group consists of researchers who were at first not very familiar with each other and each other's methods . Undertaking the participatory research as a joint group did not only help the to identify farmers' needs and technology requirements for solar drying, but it also offered informal interactions for all the participants that turned out to be a fruitful team building exercise and a platform for developing mutual trust (Kirk-Lawlor and Allred 2017).

For the engineers and natural scientists in the project, the active involvement in the participatory research led to the crossing of epistemological boundaries, since it was a new experience and different to conventional laboratory work that takes place in a social vacuum. Working with farmers was fuzzier than research tasks that can be measured with 'objective parameters'. However, in every experiment there are also factors they cannot control: systematic and random errors. Engineers and natural scientists are commonly faced with the problem of trying to understand and manage the systematic and random errors in their experiments. The social context appears as 'disturbing' but in comparison to traditional laboratory experiments, it needs to be treated as a part of the experiment and not an error in itself. Natural scientists normally try to control the context as a disturbing factor while in qualitative social science research, the context becomes a research area on its own (Aagaard-Hansen 2007).

By being actively included in the fieldwork, the engineers and natural scientists stepped out of their ontological and epistemological framework that follows a positivistic objective worldview and entered a more social constructivist understanding of reality.

Conclusion

In this paper, we discussed the role of participatory research for integrated agricultural technology development in a solar fruit drying project in Mozambique. We argued that an active participation of all stakeholders including farmers, and all researchers with their various knowledge sets and roles in participatory research is crucial for project success.

We conclude that participatory research as a tool for integrated agricultural technology development that captures the participation of all stakeholders in research projects provides a framework that can facilitate joint knowledge exchange and creation. Farmers' technology needs are identified translated into practical technology design undertaken by the natural and social scientists. Furthermore, it contributes to team building between all participants and enables the crossing of epistemological boundaries which is a key prerequisite for the success of integrated agricultural technology development.

Note

1. We divide here between three different sets of knowledge that include cultural, practical and scientific knowledge. Farmers hold important cultural and practical knowledge for technology development while scientists follow scientific knowledge frameworks based on a positivistic or social constructivist approach.

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