Impact of participatory sorghum breeding in Burkina Faso

Kirsten Vom Brocke, Clarisse Pulcherie Kondombo, Marion Guillet, Roger Kaboré, Adama Sidibé, Ludovic Temple, Gilles Trouche

Impact of participatory sorghum breeding in Burkina Faso

Kirsten vom Brocke[a, g*], Clarisse Pulcherie Kondombo[b], Marion Guillet[a,c], Roger Kaboré[d], Adama Sidibé[e], Ludovic Temple[f h], Gilles Trouche[a g]

[a]CIRAD, UMR AGAP, F-34398 Montpellier, France
[b]INERA, programme Céréales Traditionnelles, CRREA du Centre, BP 10 Koudougou, Burkina Faso
[c]IEDES, Université Paris I Panthéon-Sorbonne /CIRAD, UMR AGAP, F-34398 Montpellier, France
[d]AMSP, BP 268, Kaya, Burkina Faso
[e]UGCPA/BM, BP 74 Dedougou, Burkina Faso
[f]CIRAD, UMR INNOVATION, F-34398 Montpellier, France
[g] AGAP, Univ Montpellier, CIRAD, INRA, Montpellier SupAgro, Montpellier, France
[h] INNOVATION, Univ Montpellier, CIRAD, INRA, Montpellier SupAgro, Montpellier, France

* Corresponding author at: CIRAD, UMR AGAP, F-34398 Montpellier, France.

E-mail addresses: Kirsten.vom_brocke@cirad.fr (K. vom Brocke), clarissebk@yahoo.fr (C.P. Kondombo), guillet.marion2@gmail.com (M. Guillet), agrisahel@yahoo.fr (R. Kaboré), sidibadama@yahoo.fr (A. Sidibé), ludovic.temple@cirad.fr (L. Temple) gilles.trouche@cirad.fr (G. Trouche)

Highlights

- Timeline established with complex multidimensional, multi-stakeholder processes
- Thirty measurable indicators assessed via secondary data sources and surveys
- A collaborative experimental system established between researchers and farmers
- Outputs and outcomes are related to varieties, seed access and capacity building
- Impacts mainly on variety adoption and productivity, formal seed system, wellbeing

Declarations of interest: none.

Abstract

An *ex post* analysis of the impact of research projects related to Participatory Breeding (PB) of sorghum in Burkina Faso was carried out in 2015 and 2016 using the “Impress” method developed by CIRAD. The sorghum PB approach emerged in Burkina Faso in the late 1990s as a response to the very low adoption of improved varieties released by the conventional breeding program. This approach represents a paradigm shift from a research approach focused solely on the development of “high-yielding varieties", irrespective of the social context in which these varieties are to be used, towards the development of varieties, seed and their dissemination within a multi-stakeholder framework. The present study aims to assess the impact of the sorghum PB program and the activities related to seed production and dissemination carried out in Burkina Faso over a period of 20 years. Detailed mappings of the timeline and the actors that have been involved in the innovation process, as well as the impact pathway, have been established. The causal relationships between outputs, outcomes and impacts have been developed on the basis of 67 impact descriptors provided by research partners and beneficiaries during participatory workshops. Around thirty measurable impact indicators were assessed by means of individual or focus-group interviews and by means of secondary data sources. The three major outputs of the study were: the new improved varieties (IV) resulting from the PB actions; the mini-pack seed strategy; and the new skills acquired by the farmer organizations regarding sorghum improvement and certified seed production. The appropriation of these outputs by the farmer organizations not only brought structure to the experimentation networks, but also ensured the promotion and dissemination of the new varieties, and the establishment of a decentralized certified seed production scheme. One major positive impact was the significant increase in the use of sorghum IVs not only in the villages covered by the program but also in neighbouring areas. The expansion and performance of these new IVs has helped reduce the hunger gap while increasing the revenues of farmers involved in seed production. Furthermore, the research projects helped bring structure to the national seed sector as well as to the certified seed

market, where the farmer seed production Unions consolidated by the PB projects now play an important role in the orientation of national legislation. The experimental method of impact assessment used in this analysis explores and makes visible the complex multidimensional and multi-stakeholder processes that have helped shape technological innovation and its impact on development. Such impact assessments can also elucidate the role of research in reinforcing the individual and collective capacities needed for innovating and testing out new technologies, that is, new varieties and seed production practices according to local constraints and/ or opportunities.

Keywords: Plant breeding; Agricultural innovation systems; Participatory research; Empowerment; Impact

1. Introduction

The efficiency of breeding programs targeting staple crops produced by smallholder, resource-poor farmers in developing countries rarely goes beyond the reporting of numbers: the number of varieties released and/or the extend of yield gains achieved by these varieties in research-managed trials (Ceccarelli, 2015). Impact assessments of these types of breeding programs reveal large discrepancies between the number of formally registered varieties and the number of varieties actually adopted, grown or used by farmers. Low adoption rates for varieties improved by such research have been reported for several crops in various countries, including that for maize (Mabah Tene et al., 2013), upland rice (Virk and Witcombe, 2007), barley (Ceccarelli and Grando, 2007) and pearl millet and sorghum (Ndjeunga et al., 2015). Different studies refer to three main possible causes for the low adoption rates or outright rejection of new varieties. (1) The unsuitability of these varieties – chiefly developed to optimize the agronomic criteria of yield – in regard to the specific quality traits demanded by stakeholders in the value chain: farmers, stockbreeders, local processors, consumers and others who influence technological choice (Weltzien and Christinck, 2009). (2) The perceived inefficiency of the breeding strategy in responding to high Genotype x Crop Management interactions, which are pervasive in family farming systems (e.g. Ceccarelli, 2015). All too often, variety selection and evaluation phases are performed under optimal agronomic conditions without taking into consideration the farming context of the target farmer groups. The social reality of smallholder farmers in many developing countries is that they lack access to credit and viable markets, which thus creates an aversion to risk (Boussard, 2017; Sumberg et al., 2013). This consequently limits farmers' possibilities (credit) or willingness (risk) for modifying their environment through the application of external inputs or the replacement of their traditionally reliable varieties (Ceccarelli and Grando, 2007; vom Brocke et al., 2010). And (3) a weak research-development continuum running through the agricultural extension services, together with low-operating seed systems, act as a major drag on knowledge of new varieties and/ or access to seeds (Hoffmann et al., 2007; Almekinders et al., 2007; Smale et al., 2018)

These observations question the relation between researcher-managed variety development and that of variety innovation. Variety development is often the result of breeding processes taking place on research stations where the plant breeders (generally working with a small team of genetics and crop protection researchers) are the sole decision-makers, as detailed by Ceccarelli (2009). Varietal innovation, on the other side is defined by as an organizational scheme that allows for the interaction of stakeholders involved in a product chain within a given region (Touzard et al., 2015). Innovation in this context encompasses a process of successful and significant adoption of the variety inventions by all those involved in the agricultural and food network.

As a response to the observed failure of conventional breeding, participatory breeding (PB) was developed as a new collaborative breeding approach in Asia and Africa in the late 1980s and early 90s with the aim of creating varieties that take into account the needs and trait preferences of resource-poor farmers in subsistence farming systems (Maurya et al., 1988; Sperling et al., 1993). Compared to conventional breeding, PB programs have a wider range of goals that go beyond simply the development of new and improved varieties or productivity-related concerns. Such PB goals can include, for instance, the maintenance of agrobiodiversity or the empowerment of women and small farmers (Christinck et al., 2005). Since its introduction, PB has been widely implemented in numerous countries and in diverse social and environmental contexts (Ceccarelli et al., 2013), including organic agriculture in Europe and the USA (Lammerts van Bueren and Myers, 2012). Based on the level of participation of farmers and other stakeholders in the crop value chain, two main strategies are commonly used: Participatory Varietal Selection (PVS) and Participatory Plant Breeding (PPB). PVS encourages the participation of farmers in the identification and definition of breeding goals and in the evaluation and selection of existing varieties or advanced genetic material. PPB incorporates all the PVS goals, in addition to the involvement of farmers in the actual selection of segregating materials (Witcombe et al., 1996). PVS has proven to be effective in various African contexts, particularly for (1) the rapid identification of new varieties that perform well under the target cropping conditions and with wide acceptance among farmers, (2) the faster release and higher adoption by farmers of those varieties, and (3) being more cost-effective when compared to conventional breeding programs (Mulatu and Belete, 2001; Ceccarelli and Grando, 2007; Nkongolo et al., 2008; Tiwari et al., 2009). A number of PPB activities have been successfully carried out in Sub-Saharan Africa during the past 20 years, as documented for cotton in Benin (Lançon et al., 2004), sorghum in Mali and Burkina Faso (e.g. Boubacar et al., 2014; vom Brocke et al., 2008 and 2010), cassava in Ghana (Manu-Aduening et al., 2006), and pearl millet in Namibia (Monyo et al., 2001), among others.

Impact studies on PB programs aim to assess the overall benefits of the variety innovation, including changes in social organization (e.g. shifts in the decision-making hierarchy, empowerment of women and small farmers, skill building); increased effectiveness of reaching women and the poor; better research technologies to enhance the efficiency of overall innovation (i.e. so that improved varieties are accepted more willingly and disseminated faster); and reduced costs without lowering the cost-benefit ratios (Weltzien et al., 2008; Paris et al., 2008; Ashby, 2009; Joshi et al., 2012, Smale et al., 2018). To take as an example, Paris et al. (2008) assessed the impact of participatory rice breeding in India, focussing on variety adoption resulting from PVS activities, in particular the empowerment of women and their ability to make varietal choices and seed acquisition, and to access new seeds or adopt new crop management practices, if the women so choose to do so. Joshi et al. (2012) showed that PVS can increase the efficiency of a breeding program by significantly reducing the time for varietal testing while increasing the benefits for farmers and end-users. The authors evaluated not only the adoption rate of a new rice variety identified through PVS strategies, but also the mechanisms which led to its adoption in Nepal. Smale et al. (2018) measured the impact of adopting new improved sorghum varieties and hybrids developed through PB approaches in Mali by taking into account the well-being of rural families. Nevertheless, some authors consider that an impact assessment of such research programs raises specific conceptual and methodological challenges due to their depart from the linear sequence or “top-down” approach of research which is replaced by a continuous flow of information and interaction among many different stakeholders with evolving objectives and priorities (van de Fliert and Braun, 2002; Lilja and Dixon, 2008).

Our study aims to assess the impact of participatory breeding programs for sorghum and related activities of seed production and dissemination carried out in Burkina Faso over a period of 20 years. For this purpose, the PB program is considered as an innovation process for variety development that underpins the selection and sustainable adoption of new varieties by farmers. Specific objectives of the study were (1) to describe and characterize the innovation process and the evolution of its geographical and temporal delimitation; (2) to evaluate the impact of the innovation process on the formal seed system and the actual rate of adoption, as well as the impact on the agronomic performance of the new varieties in farmers’ production systems; (3) to see what, if any, positive effects there were on the livelihoods of the direct beneficiaries, that is, the seed producers, farmers and their families who adopted the new varieties and finally (4) to evaluate the effect of capacity-building through the sharing of knowledge between farmers and researchers.

1.1 Background

In western Africa, sorghum (*Sorghum bicolor* [L.] Moench) and pearl millet (*Pennisetum glaucum*) are the two dominant cereal crops of the Sudanian savannah regions, where they constitute the staple foods of the rural population. With about 1.65 million hectares per year, Burkina Faso ranks fifth among the sorghum producing countries in Africa (FAOSTAT, 2016). Burkinabe farmers mainly cultivate sorghum in low-input cropping systems under a wide range of soil and climatic conditions and with diversified production goals. Until fairly recently, these farmers almost exclusively used their traditional varieties: tall, photoperiod-sensitive cultivars of the guinea race (Kondombo-Barro et al., 2008). Earlier sorghum breeding programs in this country were mainly based on photoperiod-insensitive germplasm with high yield potential, and focused on intensifying cropping systems using chemical fertilizers. These programs, however, had little success in disseminating their varieties. Subsequent studies indicated that the breeding objectives did not appropriately target the prevailing agricultural conditions of high biophysical stress, e.g. soils with low fertility and recurrent drought. Neither were these earlier programs sufficiently oriented towards the needs or preferences of the farmers themselves or other stakeholders (vom Brocke et al., 2010). In the wake of these past failures, certain breeders and leaders of farmer organizations in Burkina Faso and Mali concluded that new varietal adaptation to the prevailing conditions could only be addressed through the implementation of decentralized (*in situ*) and participatory breeding programs (Weltzien et al. 2008). After the first consultative participatory activities (i.e. PVS trials) showed favourable results in Burkina Faso in the late ’90s (Trouche et al., 2001), a multidisciplinary participatory research project on sorghum agrobiodiversity was initiated in 2002 (Trouche et al., 2004). This project paved the way for decentralised, collaborative participatory breeding activities in three administrative regions with contrasting ecological and socio-economic contexts (vom Brocke et al., 2005). The objectives of these new PPB breeding programs were to develop improved sorghum varieties adapted to the constraints of local cropping systems and farmer needs while increasing productivity and expanding the varietal portfolio through the enhancement of local genetic diversity (vom Brocke et al., 2010). They further considered how farmers' variety choices could be integrated into the seed supply chains in order to improve availability and access to farmers, i.e. by initiating farmer seed production activities (vom Brocke et al, 2014) and testing dissemination strategies, such as the mini-pack approach (Jones, 2014).

2. Material and Methods

2.1. Impact assessment method

The impact assessment of these participatory sorghum breeding programs in Burkina Faso was carried out by CIRAD (French agricultural research and international cooperation organization) within the larger framework of an initiative to test and develop a novel method for impact assessment (ImpresS). The larger initiative includes 13 different case studies dealing mostly with agricultural research in developing countries (Faure et al., 2018; Temple et al., 2018a). The ImpresS methodology draws on participatory assessment methods by involving stakeholders to elaborate impact pathways connecting outputs (products) of research processes to different impacts identified by the beneficiaries of this research (Barret et al., 2017; Temple et al., 2018b). The methodological framework makes use of three tools for understanding innovation processes: mapping of stakeholders through institutional surveys, development of timelines to identify periods of structural modifications to the stakeholder system, and construction of impact pathways to show interaction between different resources. Participatory workshops during the data collection phase and the validation phase of the ImpresS study has enabled researchers, together with the different stakeholders, to confirm and describe various indicators related to the different potential impacts. These follow-up workshops using the ImpresS methodology has helped shed light on the impact of research on varietal innovation processes over many years. In Burkina Faso, the study was conducted by a “case study team” consisting of one INERA researcher, three CIRAD researchers, and representatives of two Burkinabe farmer organizations, along with the support of the ImpresS methodological team.

2.2. Methods and tools of Information collection

Prior to the workshops, information and data was firstly gathered from literature reviews of research reports, as well as from direct exchanges with the original researcher team. This information was complemented by secondary data sources from the Burkinabe state statistical services of the Ministry of Agriculture, the national seed agency and INERA (Institut de l’Environnement et des Recherches Agricoles). The main methods of information collection, however, were participatory workshops backed up by key informant surveys and open-ended interviews carried out during the field research phase of May-August 2015. One-day participatory workshops were organized in the main towns of each target region, specifically at the headquarters of each farmer organization (FO) that has been partnering the PB program since 2002. The farmer organizations were in charge of inviting 20 participants per workshop, representing farmer unions, seed producers, input dealers, processors, development organisations, regional representatives of the Ministry of Agriculture and agricultural chamber as well as representatives of the farmer organisation. The main objectives of these workshops were to identify and discuss a list of impact descriptors. The local workshops were co-facilitated by a researcher and a farmer organization representative. They were organized in plenary sessions as well as small workgroups. Tools and exercises used during these workshops included diagramming, mapping and discussion of the timeline, the innovation actors and other participants, as well as inventorying perceived impact descriptors and their grouping/ ranking. Impact assessment tools comprised a two-phased survey, in addition to formal and semi-structured interviews. The first surveys were carried out in 2013 before the actual impact assessment study in order to quantify variety adoption rates and hectares grown with improved varieties in two of the three regions of the 2002 initiated project, the Centre-North and the Boucle du Mouhoun. Two categories of farmers took part: a sample of 30 farmers from six villages who have been collaborating in the PB programs for at least 10 years (further referred to as “PB-farmers”); and 67 other farmers from seven neighbouring villages not involved in these programs (further referred to as “non-PB farmers”). The latter were chosen as representative of the different facets of a village. The second survey consisted of semi-structured interviews conducted in 2015 designed to measure impact indicators. The interviews were held with 36 stakeholders (24 farmers from ten villages, six grain traders, six FOs, NGOs and extension agency technicians). Focus-group discussions with seven processor groups of women comprised a further assessment tool. Table 1 summarizes the different stages and methods used for information collection and impact assessment of the study.

2.3. Stages of the impact assessment report

The first stage of compiling the report involved constructing a timeline aimed at identifying key phases of the innovation process and public policies that have influenced the dissemination of new varieties: seed production and distribution laws, government interventions, and funding. The construction of the timeline was based on information of technical project reports as well as scientific publications analysed during the literature review. The bibliographical work was enhanced by exchanges within the case study team.

The second stage of the report was aimed at defining the periods of structural modification to the stakeholder system supporting innovation. This stakeholder mapping consisted of classifying all stakeholders and identifying key actors involved in the innovation process of all subsequent sorghum PB programs and seed projects carried out in Burkina Faso since 1995. Necessary information for the mapping was mainly provided by the literature review and through dialogue with the case study team, and validated during the local workshops.

The third stage describes how different resources interact within an impact pathway. The main impact pathway of this study was built upon 1) identification of cause-effect relationships between the IOOI (Input-Output-Outcome-Impact) components that emerged from the data collection process and 2) a qualitative synthesis by the actors involved during the two local workshops. This impact pathway was refined during the different phases of the study, including the field study, feedback from the case study team and the methodology experts. As a first step, a list of impact descriptors was established and discussed during the participatory workshops conducted in both regions at the beginning of the study. These impact descriptors were aggregated into impact categories, resulting in a preliminary list of potentially measurable impact indicators. Finally, a shortlist of indicators considered to be measurable within the time available for the study was selected by the research team. This impact pathway was then validated by the stakeholders during the validation workshop.

The preliminary impact assessment report comprising the timeline, stakeholder map and first impact pathway was constructed by the case study team and then reviewed, amended and confirmed via a validation workshop. The workshop brought together 21 PB stakeholders that included 13 representatives and members of the two FOs (AMSP, UGCPA), five research partners, two representatives of the agro-dealer network, and one NGO representative.

2.4. Evaluation of innovation in terms of geographical and temporal dimensions

The geographical scale of the innovation analysed comprises two distinct agro-ecological zones in Burkina Faso: the Boucle du Mouhoun region and the Sanmatenga province in the Centre-North region (Figure 1). These two regions are differentiated by their average rainfall and their agro-production systems. The Centre-North is situated in the Sahelian climatic zone (less than 700 mm of rain per year) and where the production systems are mainly based on millet, sorghum and cowpea, along with small ruminant production. The Boucle du Mouhoun region is situated in the northern Sudanian climatic zone (600-900 mm of rain per year) where production systems are more diversified and include cash crops such as cotton, maize and sesame. First consultative participatory activities (on-farm PVS trials) were initiated in 1995 in these regions (Trouche et al., 2001). Collaborative participatory breeding activities started in 2002 with the initiation of a participatory, decentralised breeding program that was still in progress in 2015 at the time of the impact assessment.

3. Results

3.1 Analysis of the timescale and stakeholders

The innovation process can be divided into three phases since its debut in 1995 (Figure 2): the initiation phase (1995-2001), the development phase with the localised implementation of the innovation (2002-2007), and the extended implementation and impact generation phase (2008-2015). The first research projects during the initiation phase saw scientific knowledge being considered in terms of genotype x context interactions through the adjustments of experimental protocols and new institutional interactions. This brought about a second phase in which a collaborative experimental and breeding system was established between the research team and the initial stakeholders, mostly farmers mobilized by the PB program. This in turn led to the creation of intermediary resources, which enabled the expansion of stakeholder networks bridging the deployment of innovation in other villages that did not take part in the initial intervention. The impact generation phase became tangible in 2008 when the appropriation of generated capacities began to first impact upon the development indicators of the stakeholders involved.

The timeline in Figure 2 visualises the specific instances when the different actors and organizations intervened, which can be characterized as stakeholders influencing the innovation process. This is mainly in relation to particular project needs, such as the state or the Ministry of Agriculture dealing with seed system issues (purchase, distribution and production). Furthermore, the timeline exposes the diverse donors (IFAD, French Embassy, FFEM, McKnight Foundation) influencing the innovation process, in addition to the extension and development structures (rural development projects and NGOs) for capacity building, seed dissemination issues or infrastructure acquisition. The three research institutions of INERA, CIRAD and ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) together with the two farmer organizations of UGCPA (*Union des groupements pour la commercialisation des produits agricoles de la boucle du Mouhoun*) and AMSP (*Association Minim Sông Pânga*) can be nominated as the key stakeholders in the innovation process due to their persistence in the timeline. Further key stakeholders with a continuous involvement include certain donors: the FFEM (French Fund for World Environment) through the project "sorghum agrobiodiversity", which was the main driver of the development and localised implementation phase; in addition to the McKnight Foundation, via three consecutive projects financed within the framework of their Collaborative Crop Research Program. Through these projects, the McKnight Foundation was involved not only in the implementation stage, but also the extended implementation and impact generation phase. Approx. 30 stakeholders/ stakeholder groups were identified by the surveys and participatory workshops for the entire innovation process period. The stakeholder mapping shown in Figure 3, summarises the different stakeholders involved in the studied innovation process during the phases of development and extended implementation, and their respective roles (key actors, influent actors or recipients of innovation).

3.2. Impact pathway of the innovation process

The development of the impact pathway of the studied innovation process was the result of an iterative work using different monitoring tools and phases. The final pathway agreed upon by the stakeholders during the validation workshop is presented in Figure 4. The four major outputs of the innovation process were: (1) the registration of eight new improved varieties (IVs) of sorghum resulting from the PB actions, as well as a higher demand and use for three former IVs; (2) the development of a seed mini-packs concept, making certified seed accessible to small producers; (3) the new knowledge and skills acquired by the farmer groups and scientists for breeding activities, variety evaluation and sorghum seed production, certification and commercialization; and (4) the training modules and technical documents.

The mobilisation of these outputs was driven by farmer groups with continuous support from research, leading to the key outcomes of: (1) networks and mechanisms for interaction between research and public support services (extension, seed certification, etc.), and between research and farmers (sorghum producers, seed producers); (2) the strengthening of capacities for variety testing and sorghum breeding and for the production of certified seed and its marketing according to national legislation; and (3) the establishment of a decentralised, certified seed-production system. Based on these identified outputs and outcomes, we can infer that this collaborative research led to two complementary innovation types: (1) a process innovation related to adaptation through its implementation of PB methods, including the production and distribution of seed; and (2) a product innovation such as the creation of new productive, well-adapted varieties and the production of high quality seed (certified seed).

The impact of the innovation process resulting from the described outcomes refers to crop management and production, food security, economic benefits, skill building and empowerment in varietal evaluation and seed production, improved quality seed production, variety adoption, as well as seed commercialisation and dissemination. According to the applied methodology, these are considered as first-level impacts (Tables 2 and 3). Secondary impacts are represented by out-scaling and up-scaling of the innovations, which is mainly related to the diversification and increased dissemination of IVs, agricultural extension activities and the strengthening of the formal seed sector at the regional and national level (Table 4).

3.3. Impact on agronomic performance and other benefits from new varieties – farmers' perceptions and researchers' data

According to farmer interviews, new IVs derived from the PB program show higher grain yield and improved earliness when compared to traditional or old improved varieties: *"Today there is sorghum available to eat and also to sell"* – a cereal producer from Dawaka. The new IVs were also believed to be favoured by farmers on the basis of their grain and fodder quality, as well as apparent resistance to striga (Table 2). Increased yield from new IVs released between 2004 and 2014 is confirmed by secondary data from on-farm advanced yield trials carried out by research and FOs in the target regions between 2004 and 2016. For the Centre-North region, these data indicate positive average yield gains of up to 400 kg ha^{-1} for much of the test-year periods compared to the farmers' traditional variety (local check) (Figure 5). Yield gains tended to be more stable for the new IV Sariaso 16 (average of +30%) than for Sariaso 15 (average of +5%). The new IV Sariaso 18 showed an average yield gain of 318 kg/ha (+ 57%) across 18 on-farm tests in comparison to the local check. Gain in earliness by the IVs was mentioned by all sorghum producers who were interviewed. This is confirmed by research data from studies in the Boucle de Mouhoun region (average of 5 to 10 days, vom Brocke et al., 2014), where farmers opted for varieties with shorter cycles that could provide better yield security than the longer-cycle varieties previously cultivated in this region. Improved earliness is further validated by the individual interviews: "*Even if you don't get rain, you can produce* *sufficiently to be able to buy something"* – female farmer in Lekuy; and, *"If you sow IVs early, even before your food grain stock finishes, harvesting is already possible; the children nowadays don't know hunger"* – a cereal producer in Lekuy. No research data is available to confirm the farmers' perception of the increased resistance to striga brought about by the new IVs. Few negative impacts have been identified, such as an increase in the use of insecticide products for seed storage and a possible reduction in varietal diversity in some villages covered by the projects.

Interestingly, farmers pointed out that the use of new IVs has further helped to improve food security by reducing the hunger gap period (inter-seasonal food shortage) in terms of both duration and intensity. All of the farmers interviewed in the non-PB villages believe that the food situation has improved since the use of IVs and 43% of the farmers in the PB villages even consider that the hunger gap has disappeared (Table 3). Farmers who have adopted IVs, including the FO leaders, consider that the use of IVs has contributed to reducing the hunger gap in two ways: an earlier harvest reduces the food shortage period while increased yields make the food stock last longer. For example, the following was expressed by a cereal producer from Lekuy (Mouhoun): "*Nowadays, there is no hunger anymore from the beginning of September*." Another farmer from Barakey added, "*Since using IVs, I do not feel anymore the hunger period*".

3.4 Impact on livelihood for direct beneficiaries

The adoption of IVs has furthermore increased small producers' incomes through the sale of production surplus. This was mentioned by at least half of the PB farmers interviewed (Table 3). Even though no formal evaluation of income gains from IV seed production has been carried out, PB farmers who became seed producers through the projects' actions have indicated that this activity has been highly profitable for them. Improvements of living conditions derived from this new income source include building a house with a tin roof, buying a motorcycle or livestock capitalization, as stated by the cereal producers from different PB villages: "*Growing IVs has improved living conditions of the villagers, now I manage to pay school fees for four primary school children, nine in college and one university student and I was able to buy a motorcycle"* – a cereal and seed producer from Kéra. Seed producers from Zikiémé and Lekuy villages likewise confirmed an increase in their incomes: "I *could buy a motorcycle and a cart"* and *"I bought a motorcycle, some goats and I built a house with a tin roof".*

3.5. Impact of adopting the new varieties and professionalization of local FOs in formal seed production and marketing

One striking first-level impact is a significant increase in the use of IVs in the project's intervention sites. Assessing five consecutive years, the 2013 survey found that more than 70% of the sorghum area was planted with IVs in PB villages and 20% for non-PB villages (Figure 6). Even though these numbers are from a survey using restricted sampling (i.e. limited number of farmers chosen by farmer organizations for their participation in the survey), they nonetheless point to an increased adoption of IVs in the villages directly involved in the PB activities, as well as in neighbouring villages. The different research projects have also contributed significantly to the innovation process by empowering and making more professional the farmers' unions in their activities with certified seed production and marketing, not only with sorghum but also now with other crops. One example is the deployment of the mini-pack strategy. This involves the sale of small seed packs, in general 100 to 200 g, with treated seed along with variety passport information on local markets, input shops or info from the village farmers. The UGCPA sold 3700 packs between 2010 and 2015 (data not shown), whereas the AMSP farmer organisation disseminated more than 17000 different types of seed-packs following different commercialisation strategies (Table 5). An increased proficiency in formal seed production since the implementation phase of the innovation is reflected in a 22-fold increase in production and sale of certified sorghum seed by the UGCPA farmers from 2006 to 2012 (Figure 7) and a 6-fold increase for AMSP (Table 2). Further, as revealed by the stakeholder mapping, the farmer organizations amplified their network by establishing collaborations and extending their seed markets, and also by collaborating with significant NGOs or agro-dealers, thereby limiting the dependency on government purchase (Figure 9). The network also includes some Malian farmer unions, to which the UGCPA farmer organization sold 500kg foundation seed of three varieties in 2011 (Table 4) .The increased proficiency thus contributed to an extension of area for IVs developed in Burkina Faso, identified as a second-level impact (Table 4)

3.6. Effects on the formal seed system at a national level

Whereas an increase in varietal diversity of IVs is a direct effect of the increased number of IVs registered and of their genetic origin, the cause-effect relationships for impacts on the seed system are more complex. The Impact pathway confirms that the innovation has produced knowledge and enhanced technical skills which have led to the creation and institutionalisation of seed producer unions and regional and national networks. The resulting first-level impacts on local seed production and marketing as illustrated by the case of UGCPA (Figure 7) positively affected the national seed sector and the extension of the area where IVs are used (Table 4). For example, foundation seed of the IV Kapelga, a guinea variety without grain pigmentation (tan plant colour), promoted by seed producers of both farmer organizations, has been sold by INERA to more than ten out 13 regions of Burkina Faso (Table 4). The highest quantities were sold to the Centre-Sud, Centre and Boucle du Mouhoun regions, with respectively 47%, 20% and 7% of total quantities sold (data not shown). Data on the production of certified seed in Burkina Faso provided by the National Seed Service (SNS) indicate considerable increases in seed production from 2007 to 2013 (Figure 8). A further effect of the professionalization of the farmer seed producer unions (revealed during the validation workshop and not included in the impact pathway) is that the innovation has significantly influenced certain guidelines for national and regional seed legislation. Table 4 describes how several members of the seed producers unions, some of whom have been sorghum PB farmers since the first *sorghum* *agrobiodiversity* project, contributed to drafting the 2006 seed regulations in the role of representatives of the seed producers.

3.7. Capacity-building facilitated through knowledge-sharing and learning between farmers and researchers

The study shows that the research activity for participatory plant breeding has structured a complex 'capacity-building' process, as identified in the outcomes. A core change due to the innovation was the newfound capacity of producers to appropriate the knowledge needed for making new varietal choices based on local constraints of the various agroecosystems, social conditions of production, or food and non-food uses for the crop. Apart from the training courses, participatory variety evaluations and selection activities/ trials, other vital tools for increasing the use of new IVs were the demonstration plots and the decentralised seed production and distribution, both of which became an integral part of the innovation process.

4. Discussion about the dynamics and impacts created by the innovation

4.1. How this impact study helped to better understand the innovation process

The methodological approach used in this study allows us to identify technological out-scaling processes generated by the sorghum PB activities in Burkina Faso. In the literature these effects are identified as impacts on development that cannot be captured by quantitative evaluation methods (De Janvry et al., 2011). Our study identified two main effects. The first focuses on the mechanisms behind the dissemination of innovation in areas not targeted by the initial research activity. Since 2012, individual and collective skills generated by research activities (seed production guides and training modules) adapted to local conditions by other stakeholders (FOs, NGOs, other research projects) has led to the emergence of associations (unions) of farmer seed producers. The adoption rate of new varieties further increased when seed production and/or dissemination were up-scaled to areas not directly targeted by the research projects. This expansion, which is a second-level impact, probably helps to explain the veritable explosion in seed production from 140 tons in 2007 to more than 2000 tons of improved seed by 2013 at the national level. This methodological framework, however, does not allow for the quantification of causality, only helping to explain its existence. The second out-scaling effect is linked to the strengthening of capacities to innovate. Thanks to the involvement of the farmer unions in regard to seed production and quality standards for certified seed production, collaborative relationships emerged in the sorghum value chain between various stakeholders. Such relationships formed the basis for building new confidence in the form of new rules and learning processes, which are acknowledged as necessary capacities for innovation. These intangible capacities were subsequently harnessed by stakeholders for the adoption of other innovations not targeted by the initial research activity. Although difficult to measure, these capacities are nevertheless identifiable and recognizable. The presented sorghum PB activities deal with knowledge, a collaborative breeding strategy, a network for variety testing and the initiation of standard sorghum seed production, which was then redistributed across other agricultural sectors, such as cowpea and pearl millet (Kaboré et al., 2010).

4.2. Knowledge-sharing over time between farmers, researchers and FO leaders is the determinant for capacity-building

Exchange networks structured by a participatory approach require the research activity to create formal as well as informal interactions (focus group, surveys, training vs connections between various farmer organizations and NGOs). This two-way feedback system enhances the effectiveness of the actions for the various stakeholders. With regard to the sorghum PB activities and the farmers, such interactions can create the required capacities for better managing variety trials and evaluations, and analysing the effects of technical decisions and the results achieved. Several authors have identified participatory approaches – such as innovative platforms, local agricultural research committees (CIAL), farmer field schools (FFS), and PVS activities – as important aspects of farmer empowerment, which leads to an overall positive impact on agricultural technology development (Humphries et al., 2012; Classen et al., 2008; Friis-Hansen, 2008). For example, participatory variety selection initiatives for rice in India have been described as an efficient tool for empowering women farmers and for strengthening their capacities for managing variety trials and making decisions on new varieties (Paris et al., 2008). Such exchange networks also enable farmers to discuss advantages and disadvantages with stakeholders outside of the rural communities, as illustrated by our aforementioned example of farmers and FO representatives influencing seed legislation in Burkina Faso. Jones et al. (2014), who analysed the outcomes and processes of PB in western Africa including the Mouhoun region of this study, concluded that the empowering relationships among farmers generated by the PB process could provide the foundation for a shift towards more autonomy over decisions made in agricultural production systems in the region. This is in agreement with Friis-Hansen (2008), who concluded that empowered farmer groups are the basis for establishing higher-level farming organizations that could represent small-farmer interests at local and national levels.

On the research side, exchange networks set up by participatory research have led to a better understanding of certain obstacles to the innovation process, leading to a reformulation of the primary scientific questions. The rejection of certain variety types and the preference patterns of farmers in the Boucle du Mouhoun region, for instance, can now be partly explained by the farmers' perception of climate change, in addition to their local processing and consumption habits, and the ability or inability of the variety to fit in with low-input production conditions (vom Brocke et al., 2014). This localized knowledge reinforces the researchers' awareness and capacity to adapt their technical offer and/ or strategies to the specialised needs of the local agroecosystem or production chain. As for the public institutions involved in technical extension, such exchange networks enable valuable discussion and the conditions in which rural communities can choose to accept or reject exogenous technology.

4.3. Impact of the innovation on the adoption rate of new varieties and strengthening of the formal seed sector

The applied methodology makes it possible to identify the different types of impact indicators concerning the adoption process, as observed by the stakeholders in the intervention zone of phases 2 and 3 of the innovation process.

Regarding variety adoption and dissemination, our assessment study elicited significant rises in the use of IVs as well as a large dissemination of some IVs throughout the country. High adoption rates of IVs developed through PB approaches have been reported by other previous studies (Monyo et al., 2001; Witcombe and Yadavendra, 2014; Joshi et al., 2014). In our case, the applied evaluation method revealed that adoption was especially high in the PB villages-sites of the research projects compared to nearby villages. However, the estimates for neighbouring villages are still markedly higher than the national average, which has been reported to be as low as 3% for new sorghum varieties (Walker et al., 2014). A close correlation between the involvement of rural actors in participatory research actions and the effectiveness of the local agricultural production system has also been highlighted by different studies. In assessing the effect of participatory development research (farmer-field schools) on the empowerment or wellbeing of farmers in Uganda, Friis-Hansen (2008) found that a significantly higher percentage of farmers who were members of the FFS groups adopted and used improved techniques compared to the non-members. An impact study across several west African countries carried out by Christinck et al. (2014) suggests that adoption and utilization of new IVs is 25-50% in the villages where farmers participate in the participatory breeding and seed production activities, 5-15% in clusters of neighbouring villages, and 2-10% countrywide (percentages based on farmer estimates). Along with the increased use of IVs, farmers also identified an increased use of chemical fertilizers and pesticides. This association of IVs and chemical inputs is probably due to the fact that researchers recommended chemical and organic fertilizers in their protocols for variety testing. On the one hand, a rise in pesticides and chemical fertilizers indicates increased investment in agricultural intensification, motivated by a short term potential economic gain. On the other hand, increased use of chemical inputs, especially pesticides, could prove costly over the long term, including damage to the environment, human health and sustainability (not initially looked at, as argued by Wilson and Tisdell, 2001). Resulting externalities from the increased use of chemical inputs and pesticides thus confirm the negative nature of this impact.

Our impact assessment in Burkina Faso indicates that the mini-pack approach played a major role in promoting and facilitating access to seed, as well as the general dissemination of new IVs. According to Jones (2014), the mini-pack strategy responds to the contextual constraints of adopting new improved varieties. These constraints include low rates of available cash and high-opportunity costs for trying something new. The in-depth analysis of the seed system carried out by Jones (2014), who covered one of our intervention areas (Mouhoun region), further indicates a ‘secondary’ seed spread via gifts and bartering. This seed diffusion, from the original buyers/ testers to relatives and neighbours, apparently occurs at a much broader scale than the other two aforementioned pathways. Similarly, Witcombe and Yadavendra (2014) have reported high secondary spread of a rice variety in India, bred for local adaptation and based on farmer preferences.

4.4. Impact of innovation on living conditions of resource-poor farmers in target areas

The findings make it possible to qualify the impact on socio-economic living conditions through the common indicators of income growth, food security and well-being, e.g. reducing the hunger gap, buying motorcycles or housing improvements. The farmer perception of an increased availability of sorghum grain is indeed backed up by the scientific data on the performance of the new improved varieties Sariaso 15 – 18 (vom Brocke et al., 2014). Several previous studies also show that participatory development actions, such as FFS initiatives or CIALs groups, significantly improve the wellbeing of farmers participating in such programs (e.g. Friies-Hansen, 2008; Classen et al., 2008; Humphries et al., 2012). However, the method applied in the present study is not intended to quantify these impacts. In fact, these indicators frequently result from a cluster of macro-economic variables linked to various determinants in the form of international markets, public policies or local initiatives. The assessment of these variables requires another methodological framework. In a context of limited social science resources, as is the case in Burkina Faso, the view is that the impact evaluation process must be prioritized by the endogenous research, which is more likely to reference and understand the construction of the development impacts (Faure et al., 2018), albeit not in the exogenous design for quantifying the impacts without being able to understand the underlying mechanisms. Therefore, the present study applied a methodological approach defined by Faure et al (2018), that is, a participative collection of descriptors of changes in the form of perception which are characterized by quantitative or qualitative indicators through *ad hoc* surveys, interviews, focus groups and secondary data. Similar tools were employed in the 'Most Significant Change' (MSC) technique used by Christinck et al. (2014) for impact assessment, i.e. documenting statements or 'stories' of impact from discussions with farmer groups. Friis-Hansen (2008) applied a methodological framework which seeks to understand the dynamics and interactions between the intervention and the beneficiaries (rather than the effects or impact of an intervention on the recipients) via a range of anthropological fieldwork techniques and household questionnaires. In this study, indicators were based on farmers' own perception of well-being using a ranking methodology (Ravnborg, 1999). Smale et al. (2018) collected field data in order to measure the impact of adopting improved seed or improved hybrids on farming families in Mali, using an ordered logit model and a multivalued treatment effects model. The authors found that the effect of growing improved varieties is positive on the expenditure share of other cereals, and concluded that earnings from additional sales might be utilized to purchase other food items. Interviewed farmers in our study confirm these assumptions, claiming that their income has increased thanks to the sale of surplus sorghum production that can be traced back to those IVs first introduced through PB programs. The sustainability of this effect is assumed by the fact that these impacts are not only based on direct financial support, but on capacity building that facilitates seed production marketing, dissemination and networking with large and well established organizations (AGRODIA network) and NGOs (GRET, FERT) not directly involved in the project, all of which has promoted the use of IVs far beyond the initial target areas.

5. Conclusion

In this innovation process the following factors had a major influence: the *Sorghum Agrobiodiversity* project, which was the starting point for the innovation development phase; the continuity and coherence of the projects that followed on from 2006; the support and trust of certain donors over an extended period of time (in particular the McKnight Foundation); the effective, long-term cooperation between the three research organizations involved; and the stability and vision of the two partnering farmer organisations. The impact analysis method tested here enabled us to explore and better understand the multi-dimensional, multi-stakeholder structure behind the innovation processes and their overall impact on development in Burkina Faso. The impact assessment has also helped shed light on the role of research as a key player in the strengthening of individual and collective capacities to innovate within a participatory context. The initial research work on sorghum PB initiated in the late 1990s was the catalyst for a complex process of capacity-building evolving over some twenty years and continuing today. A key shift in the innovation model was first signalled by Burkinabe farmers who were the first to acquire the knowledge necessary for rationalizing their varietal choices based on their own local environmental constraints, social conditions and alimentary needs. Since then, these farmers have exercised significant leverage in the use of and regulating of new sorghum varieties within an increasingly decentralized seed production system, which itself is a major outcome of the innovation process.

Acknowledgment

We are grateful for the participation and contributions of farmers from Burkinabè villages of in the Boucle du Mouhoun and Sanmatenga regions. We also thank the National Seed Service (SNS) in Ouagadougou and the regional offices of the Ministry of Agricultural and Water Development (DRAHRH) for providing data and their contribution to workshops and surveys, as well as the various actors who accepted to share their knowledge for this study. We further thank Mr. A. McGowan for the English editing of the draft manuscript. The impact study would not have been possible without the support of funding from CIRAD.

References

Almekinders, C.J.M., Thiele, G., Danial, D.L., 2007. Can cultivars from participatory plant breeding improve seed provision to small-scale farmers? Euphytica 153, 363–372. https://doi.org/10.1007/s10681-006-9201-9

Ashby J.A., 2009. The impact of participatory plant breeding. In: Plant breeding and farmer participation. Ceccarelli, S., Guimarães, E.P., Weltzien, E. (Eds.). FAO, Rome, pp. 649–671.

Barret, D., Blundo-Canto, G., Dabat, M.-H., Devaux-Spatarakis, A., Faure, G., Hainzelin, E., Mathe, S., Temple, L., Toillier, A., Triomphe, B., Vall, E., 2017. Guide méthodologique ImpresS: Évaluation *ex post* des impacts de la recherche agronomique dans les pays du Sud. Montpellier, France : CIRAD, 96 p. ISBN 978-2-87614-731-7 https://doi.org/10.19182/agritrop/00005

Boussard, JM., 2018. Food Challenges in Africa. In : Temple, L., Compaore Sawadogo, E.M.F. (Eds.), Innovation Processes in Agro-Ecological Transitions in the Developing Countries. Collection ISTE, Série Innovation in Engineering and Technology, pp. 141-169, ISBN: 9781786302724 - http://iste.co.uk/book.php?id=1333

Boubacar, A., A. Daou, E. Weltzien, B. Dakouo, B. Sogoba, O. Niangaly, S.B. Coulibaly H. Moussa Maiga, B. Koné, H. Maiga, G. TRouche, K. vom Brocke (2014). Mise en œuvre de nouvelles stratégies de sélection du sorgho pour les régions marginales et à forte contrainte climatique du Mali. Agronomie, Environnement & Sociétés. Vol 4, n° 2.

Ceccarelli, S., Grando, S., 2007. Decentralized-participatory plant breeding: an example of demand driven research. Euphytica 155, 349–360. https://doi.org/10.1007/s10681-006-9336-8

Ceccarelli S., 2009. Selection methods Part 1: Organizational aspects of a plant breeding programme. In: Plant breeding and farmer participation. Ceccarelli, S., Guimarães, E.P., Weltzien E. (Eds.) FAO, Rome, pp. 195–222.

Ceccarelli, S., Al Yassin, A., Goldringer, I., Mendes Moreira, P., Chable, V., 2013. Analysis of major Participatory Plant Breeding worldwide https://prodinra.inra.fr/ft?id=A3E52EA1-0BF8-40E7-8A78-2BBBC5FF912B.

Ceccarelli S., 2015. Efficiency of Plant Breeding. Crop Sci. 55, 87–97. https://doi.org/10.2135/cropsci2014.02.0158

Christinck, A., Diarra, M. and Hornber, G., 2014. Innovations In Seed Systems: Lessons from the CCRP Funded Project "Sustaining Farmer-Managed Seed Initiatives in Mali, Niger, and Burkina Faso", The McKnight Foundation, Minneapolis. https://www.ccrp.org.

Weltzien, E., 2005. Research on priority setting with farmers. In: Christinck, A., Eva Weltzien, E., Hoffmann, V. (Eds.), Setting Breeding Objectives and Developing Seed Systems with Farmers. A Handbook for Practical Use in Participatory Plant Breeding Projects. Margraf Publishers, Scientific Books, Weikersheim, Germany , 188 p.

Classen, L., Humphries, S., Fitzsimons, J., Kaaria, S., 2008. Opening participatory spaces for the most marginal : learning from collective actions in the Honduran hillsides. World Development 36, 2402–2420. https://doi.org/10.1016/j.worlddev.2008.04.007

De Janvry, A., Dustan, A., and Sadoulet, E., 2011. Recent Advances in Impact Analysis Methods for Ex-post Impact Assessments of Agricultural Technology: Options for the CGIAR. Berkeley: University of California. 36 p.

Faure, G., Barret, D., Blundo-Canto, G., Dabat, M.-H., Devaux-Spatarakis, A., Le Guerroué, J.-L., Marquié, C., Mathé, S., Temple, L., Toillier, A., Triomphe, B., Hainzelin, E., 2018. How different agricultural research models contribute to impacts: Evidence from 13 case studies in developing countries, Agric. Syst. 165, 128–136. https://doi.org/10.1016/j.agsy.2018.06.002

Friis-Hansen, E., 2008. Impact assessment of farmer institutional development and agricultural change: Soroti district, Uganda. Development in Practice 18 (4-5), 506–523. https://doi.org/10.1080/09614520802181236

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

Humphries, S., Classen, L., Jiménez, J., Sierra, F., Gallardo, O., Gómez, M., 2012. Opening Cracks for the Transgression of Social Boundaries: An Evaluation of the Gender Impacts of Farmer Research Teams in Honduras. World Development 40 (10), 2078–2095. https://doi.org/10.1016/j.worlddev.2012.05.008

Jones, K., 2014. Emerging seed markets, substantive seed economies and integrated seed systems in West Africa: A mixed method analysis. PhD thesis in Rural Sociology and International Agriculture and Development. Department of Agricultural Economics, Sociology, and Education. The Pennsylvania State University. Available at https://etda.libraries.psu.edu/paper/21110/21030 ,

Jones, K., Glenna, L.L., Weltzien, E., 2014. Assessing participatory processes and outcomes in agricultural research for development from participants' perspectives. J. Rural Stud. 35, 91–100. https://doi.org/10.1016/j.jrurstud.2014.04.010

Joshi, K.D., Devkotab, K.P., Harris, D., Khanal, N.P., Paudyal, B., Sapkota, A., Witcombe, J.R., 2012. Participatory research approaches rapidly improve household food security in Nepal and identify policy changes required for institutionalization. Field Crops Res. 131, 40–48. https://doi.org/10.1016/j.fcr.2012.03.001

Joshi, K.D., Khanal, D., Harris, D., Khanal, N.N., Sapkota, A., Khadka, K., Neupane, R.K., Joshi, M., Witcombe, J.R., 2014. Regulatory reform of seed systems: Benefits and impacts from a mungbean case study in Nepal. Field Crops Res. 158, 15–23. https://doi.org/10.1016/j.fcr.2013.12.011

Kondombo-Barro, C.P., vom Brocke, K., Chantereau, J., Sagnard, F., Zongo, J.D., 2008. Variabilité phénotypique des sorghos locaux de deux régions du Burkina Faso: la Boucle du Mouhoun et le Centre-Ouest. Cahiers Agricult. 17, 107–113. https://doi.org/10.1684/agr.2008.0175

Kabore, R., Dabat, M-H., vom Brocke, K., 2010. Coordination et durabilité des nouvelles formes de production semencière vivrière au Burkina Faso. Seiny-Boukar, L. and Boumard, P. (Eds.), Savanes africaines en développement : innover pour durer, Apr 2009, Garoua, Cameroun. Cirad, 8 p.

Lançon, J., Lewicki, S., Djaboutou, M., Chaume, J., Sekloka, J., and Farmer-Breeders: Assogba L., Takpara D., Orou Moussé B. I., 2004. Decentralized and participatory cotton breeding in Benin: farmer-breeders' results are promising. Exp. Agric. 40, 419–431. https://doi.org/10.1017/S0014479704002078

Lammerts van Bueren, E.T. and Myers, J.R, 2012. Organic Crop breeding. Wiley-Blackwell. 282 p.

Lilja L. and Dixon J., 2008. Responding to the challenges of impact assessment of participatory research and gender analysis. Expl. Agric., 44, 3–19. https://doi.org/10.1017/S0014479707005972

Mabah Tene, G.-L., Havard, M., Temple, L., 2013. Déterminants socio-économiques et institutionnels de l'adoption agricole sur le maïs à l'Ouest Cameroun. Tropicultura 31 (2), 137–142.

Manu-Aduening, J.A., Lamboll, R.I., Ampong Mensah, G., Lamptey, J.N., Moses, E., Dankyi, A.A., Gibson, R.W., 2006. Development of superior cassava cultivars in Ghana by farmers and scientists: the process adopted, outcomes and contributions and changed roles of different stakeholders. Euphytica 150, 47–61. https://doi.org/10.1007/s10681-006-9091-x

Maurya, D.M., Bottrall, A., Farrington, J., 1988. Improved livelihoods, genetic diversity and farmer participation: a strategy for rice breeding in rainfed areas of India. Exp. Agric. 24, 311–320. https://doi.org/10.1017/S0014479700016161

Monyo, E. S., Ipinge, S. A., Heinrich, G. M., Chinhema, E., 2001. Participatory breeding: Does it make a difference. Lessons from Namibian Pearl Millet Farmers. In: Lilja N., Ashby J. and Sperling L. (Eds.), Assessing the impact of participatory research and gender analysis. Participatory Research and Gender Analysis (PRGA), Program Coordination Office; International Center for Tropical Agriculture (CIAT), Cali, CO. 294 p.

Mulatu, E., and Belete, K., 2001. Participatory varietal selection in lowland sorghum in eastern Ethiopia: impact on adoption and genetic diversity. Exp. Agric. 37, 211–229. https://doi.org/10.1017/S0014479701002034

Ndjeunga, J., Mausch, K., Simtowe, F., 2015. Assessing the effectiveness of agricultural R&D for groundnut, pearl millet, pigeonpea, and sorghum in West and Central Africa and East and Southern Africa. In: Walker, T.S., Alwang, J. (Eds.), Crop Improvement, Adoption, and Impact of Improved Varieties in Food Crops in Sub-Saharan Africa. CABI, Wallingford, UK.

Nkongolo, K.K., Chinthu, L., Malusi, M., Vokhiwa, Z., 2008. Participatory variety selection and characterization of sorghum (*Sorghum bicolor* (L.) Moench) elite accessions from Malawian gene pool using farmer and breeder knowledge. Afr. J. Agric. Res 3, 273–283.

Paris, T.R., Singh, A., Cueno, A.D., Singh, V.N., 2008. Assessing the impact of participatory research in rice breeding on women farmers: a case study in Eastern Uttar Pradesh, India. Exp. Agric. 44, 97–112. https://doi.org/10.1017/S0014479707005923

Ravnborg, H.M., 1999. Developing regional poverty profiles based on local perceptions. CIAT publications no. 291, 56 p.

Smale, M., Assima, A., Kergna, A., Thériault, V., Weltzien, E., 2018. Farm family effects of adopting improved and hybrid sorghum seed in the Sudan Savanna of West Africa. Food Policy 74, 162–171. https://doi.org/10.1016/j.foodpol.2018.01.001

Sperling, L., Loevinsohn, M.E., Ntabomvuras, B., 1993. Rethinking the farmer’s role in plant breeding: local bean experts and on station selection in Rwanda. Exp. Agric. 29, 509–419. https://doi.org/10.1017/S0014479700021219

Sumberg, J., Thompson, J., Woodhouse, P., 2013. Why Agronomy in the Developing World Has Become Contentious. Agric. Human Values. 30, 71–83. https://doi.org/10.1007/s10460-012-9376-8

Temple, L., Gaunand, A., Trouche, G., Vall, E., 2018a. Évaluer les impacts des recherches en agriculture sur la société et les écosystèmes : outils, méthodes, études de cas. Cahiers Agricult. 27, 34002. https://doi.org/10.1051/cagri/2018022.

Temple L., Barret D., Blundo Canto G., Dabat MH., Devaux-Spatarakis A., Faure G., Hainzelin E., Mathé S., Toillier A., Triomphe B., 2018b. Assessing Impacts of Agricultural Research for Development: a systemic model focusing on outcomes. Research Evaluation, 27, 157–170. https://doi.org/10.1093/reseval/rvy005

Tiwari, T.P., Virk, D.S., Sinclair, F.L., 2009. Rapid gains in yield and adoption of new maize varieties for complex hillside environments through farmer participation. I. Improving options through participatory varietal selection (PVS). Field Crops Res. 111, 137–143. https://doi.org/10.1016/j.fcr.2008.11.008

Touzard, J.-M., Temple, L., Faure, G., Triomphe, B., 2015. Innovation systems and knowledge communities in the agriculture and agrifood sector. J. Innov. Econ. Manag. 2 (17), 117–142. https://doi.org/ 10.3917/inno.043.0013

Trouche, G., Da, S., Pale, G., Sohoro, A., Ouedraogo, O., Den Gosso, G., 2001. Evaluation participative de nouvelles variétés de sorgho au Burkina. In : Hocdé, H., Lançon, J. and Trouche G. (Eds.), La sélection participative : impliquer les utilisateurs dans l'amélioration des plantes. Proceedings of a MICAP/CIRAD workshop held in Montpellier, France, 5-6 September 2001. CIRAD Montpellier, France, pp. 36-55.

Trouche, G., Vaksmann, M., Reyniers, F., Touré, A., Konaté, A., Weltzien, E., Sautier, D., De Raïssac, M. 2004. Agrobiodiversity preservation of sorghum *in situ* in Mali and Burkina Faso through participatory improvment of local ecotypes. In: Sperling L., Lançon J. and Loosvelt, M. (Eds.), Participatory plant breeding and participatory plant genetic resource enhancement: an Africa-wide exchange of experiences. Proceedings of a workshop held on M'bé, Ivory Coast, May 7- 10, 2001, pp. 367-377.

van de Fliert, E. and Braun, A. R., 2002. Conceptualizing integrative, farmer participatory research for sustainable agriculture: From opportunities to impact. Agric. Human Values 19**,** 25–38. https://doi.org/10.1023/A:1015081030682

Virk, D.S., Witcombe, J.R., 2007. Trade-offs between on-farm varietal diversity and highly client-oriented breeding - a case study of upland rice in India. Genet. Resour. Crop Evol. 54, 823–835. https://doi.org/10.1007/s10722-006-9158-5

vom Brocke, K., Taonda, J.-B., Barro-Kondombo, C., Sorgho, M.-C., Somé, L., 2005. Un partenariat pour la sélection du sorgho au Burkina Faso: Cas du projet "Préservationde l'agrobiodiversité au Mali et au Burkina Faso". In: Lançon, J., Weltzien, E., Floquet, A. (Eds.) Gestion du Partenariat dans les Projets de Sélection Participative. Proc. Workshop. Cotonou, Benin, March 14–18, pp. 23–31.

vom Brocke, K., Trouche, G., Zongo, S., Abdramane, B., Barro Kondombo, C.P., Weltzien, E., Chantereau, J., 2008. Création et amélioration de populations de sorgho à base large avec les agriculteurs au Burkina Faso. Cahiers Agricult. 17, 146—153. https://doi.org/10.1684/agr.2008.0174

vom Brocke, K., Trouche, G., Weltzien, E., Barro Kondombo, C.P., Gozé, E., Chantereau, J., 2010. Participatory variety development for sorghum in Burkina Faso: farmers' selection and farmers' criteria. Field Crops Res. 119, 183–194. https://doi.org/10.1016/j.fcr.2010.07.005

vom Brocke, K., Trouche, G., Weltzien, E., Kondombo-Barro C.P., Sidibe, A., Zougmoré, R., Gozé, E., 2014. Helping farmers adapt to climate and cropping system change through increased access to sorghum genetic resources adapted to prevalent sorghum cropping systems in Burkina Faso. Exp. Agric. 50, 284—305. https://doi.org/10.1017/S0014479713000616

Walker, T., Alene, A., Ndjeunga, J., Labarta, R., Yigezu, Y., Diagne, A., Andrade, R., Muthoni Andriatsitohaina, R., De Groote, H., Mausch, K., Yirga, C., Simtowe, F., Katungi, E., Jogo, W., Jaleta, M., Pandey, S., 2014. Measuring the Effectiveness of Crop Improvement Research in Sub-Saharan Africa from the Perspectives of Varietal Output, Adoption, and Change: 20 Crops, 30 Countries, and

1150 Cultivars in Farmers' Fields. Report of the Standing Panel on Impact Assessment (SPIA), CGIAR Independent Science and Partnership Council (ISPC) Secretariat: Rome, Italy, 83p.

Weltzien, E., vom Brocke, K., Touré, A., Rattunde, F., Chantereau, J., 2008. Revue et tendances pour la recherche en selection articipative en Afrique de l'Ouest. Cahiers Agricult. 17, 165–171. https://doi.org/10.1684/agr.2008.0193

Weltzien, E. and Christinck, A., 2009. Methodologies for priority setting. In: Ceccarelli S. , Guimaraes E.P. and Weltzien E. (Eds.), Plant breeding and farmer participation, FAO, Roma. 76–105.

Wilson, C., Tisdell, C., 2001. Why farmers continue to use pesticides despite environmental, health and sustainability costs. Ecological Economics 39, 449–462. https://doi.org/10.1016/S0921-8009(01)00238-5

Witcombe, J.R., Joshi, A., Joshi, K.D., Sthapit, B.R., 1996. Farmer participatory crop improvement, I: Varietal selection and breeding, methods and their impact on biodiversity. Exp. Agric. 32, 443–460. https://doi.org/10.1017/S0014479700001526

Witcombe, J.R., Yadavendra, J.P., 2014. How much evidence is needed before client-oriented breeding (COB) is institutionalised? Evidence from rice and maize in India. Field Crops Res. 167, 143–152.

Table 1

Summary of methods used during the different stages of the impact study, sources of information and actions

Stages	Method	Periods	Participants/sources	Action
Information collection	**Literature review**	May 2015	project reports, internet search, annual reports of farmer organisations	Establishment of preliminary timeline and stakeholder map (identification of influent and key actors) Collection of Impact indicators
	Exploitation of Secondary data sources	June 2015	Statistical service of Ministry of Agriculture; national seed service, INERA, farmer organizations, thesis and research reports	Indicators for on seed production and dissemination, variety performance, Collection of Impact indicators
Impact assessment	**Participatory workshops at FO headquarters :** • Local stakeholder workshops • Validation workshop	Local workshops : 12 May 2015 (BM) 19 May 2015 (CN) Validation workshop : 04 February 2016	Local workshops: 20 (BM) and 21 (CN) members of the FO, input traders and extension service representatives Validation workshop: 21 stakeholders from farmer organisations and research	Local workshops : Completion of timeline, collection and classification of impact descriptors, Validation workshop : Finalization and collective validation of outputs, outcomes and impact indicators (impact pathway)
	Field surveys: • Individual Semi-structured interviews • Focus groups	Oct – Nov 2013 (BM+CN) 15-19 June 2015 (BM) 22-26 June 2015 (CN)	2013 – A total of 100 structured interviews: 30 interviews in 6 PB villages 70 in 7 non-PB villages 2015 - A total of 35 semi structured interviews in 12 villages : 25 farmers, 5 input traders, 4 institutional agents A total of 7 focus groups with 23 female processors, mostly beer producers	Data and information to support identification and documentation of selected impact indicators : 2013 - Qualitative and quantitative data on variety adoption rates 2015 - Qualitative data on impact of PB activities

Table 2
Production-related 1st level impacts, indicators and their measurements

Impact	Indicators selected	Impact measurements
Increased use of improved varieties	Change in number of producers purchasing certified seed	22-fold increase from 2006 to 2012 for UGCPA producers (Fig. 7)
	% of areas sown with IVs in villages covered by PPB programmes	71% compared to less than 3% for the country as a whole (Fig. 6)
	% of areas sown with IVs in neighbouring villages	20% compared to less than 3% for entire country. (Fig. 6)
Increased production efficiency of IVs compared to LVs	Yield gain of IVs compared to LVs	Only two farmers can quantify these gains (yield gains of 1.3 and 0.6 t ha^{-1} compared to LVs); research data indicate that yield gains range from +4% to +57% (Fig.5)
	Earliness of IVs compared to LVs	Farmer interviewees confirm earlier maturity of IVs; research data indicate an average gain in earliness of 5-10 days (e.g. vom Brocke et al. 2014)
	Striga resistance of IVs compared to LVs	Farmers' opinions expressed during regional workshops
Increased proficiency amongst FOs in high quality seed production & marketing	Change in the volumes of certified seed produced	AMSP: 6-fold increase from 2008 to 2012
	Change in strategy of producers' unions: less dependent on state seed procurement	Description of strategies applied by UGCPA and two AMSP unions (e.g. mini-pack sale, collaboration with NGOs and Malian FOs)
	Change in seed units most commonly purchased	Increase in minimum and average seed units purchased by producers. From a minimum of 1kg in the beginning of seed commercialisation up to 15kg in 2015 according to UGCPA.
Increased chemical fertilizer use	Change in chemical input purchases	50% of producers from PPB villages say that they use a higher quantity of chemical inputs for the production of IVs, but only 20% of producers from non-PPB villages
Increased use of pesticides	Change in insecticide treatments used for improved seed storage	UGCPA officials confirm the use of insecticides to treat stores and seed backs

Table 3.

Livelihood-related, 1st level impacts, indicators and their measurements

Impact	Indicators selected	Impact measurements
Alleviate hunger gap	Producers' perception of a reduction in the duration and/or intensity of the hunger gap	100% of producers interviewed in non-PB villages say that the food situation has improved with the use of IVs
		43% of producers from PB villages say that the hunger gap has disappeared
Increased income	Cereal producers' perception of an increase in their income linked to surplus sales	50% of producers from PB villages indicate increased surplus production for sale thanks to IVs while 100% of the same producers claim that their income has increased with both the use of IVs and participation in the PPB projects
	Seed producers' perception of an increase in their income linked to IV seed production	Consensus that seed production activities are profitable
		Farmers interviewed in PB villages mentioned building a house with a tin roof (28% of citations), purchase of a motorcycle (28%), livestock (14%), bicycle (7%) or a cart/ wagon (7%)

Table 4. List of 2nd level impacts, indicators and their measurements

Impact	Indicators	Impact measurements
Increase in sorghum varietal diversity	Number of IVs developed from ‘lost’ or abandoned landraces	Two varieties: Gnossiconi and Flagnon
	Number of varieties from PPB registered in 2014	Eight varieties from PPB programmes registered in the national catalogue (30% of total sorghum varieties by 2014)
	Regional destinations of foundation seed sales by INERA-Saria	In 2014, IVs from PPB were used in at least 11 regions and 17 provinces in the country (source: scientific and technical service of INERA Saria)
Extension of area for improved varieties	Sales of foundation seed in neighbouring countries	UGCPA sells seed to a farmer union (UACT) in the Tominian zone in Mali (source: UGCPA, seed production report 2011-2012)
	Seed sales/ input network: wholesalers’ association	AGRODIA distributes certified sorghum seed in all provinces of the country
Consolidation and structuring of certified seed sector at the national level	Change in national production of certified sorghum seed	From 26.3 t in 2001 to 2 933 t in 2014: multiplier > 100 (source: National seed department-SNS, Ministry of Agriculture and water development)
	Change in production of foundation seed	From 4.7 t in 2001 to 33.5 t in 2014: multiplier = 7 (source: National seed department-SNS, Ministry of Agriculture and water development
	Change in quantities of sorghum seed redistributed by government programs	20-fold increase between 2010 and 2013 (source: FAO/MAFAP-SAPAA, 2014 http://www.fao.org/3/a-i4516f.pdf)
	Change in proportion of improved sorghum seed/ total cereal seed distributed by the government	From 1% in 2010 to 19% in 2013: multiplier = 19 (source: FAO/MAFAP-SAPAA, 2014, http://www.fao.org/3/a-i4516f.pdf)
	Change in number of seed training courses provided (SNS, INERA, CIRAD) since 2001	At least 3 training courses per year during 2003-08; a minimum of 120 producers trained per year (source: SNS + INERA)
Increase in income or activity for sorghum processors	Processors’ perception of increase in their activity due to use of IVs	Non-measurable impact as processors interviewed know little about IVs and could not answer this question
Agricultural extension conducted by FOs in intervention areas	Change in approach and of stakeholders involved in agricultural extension	State services have insufficient means and human resources. FOs, NGOs and their members carry out a significant part of this extension work.
Effect on seed legislation	producers and FO officials involved in sorghum PPB influenced national and regional seed legislation	Producers contributed to drafting the 2006 seed regulation (as union representatives) and influenced the conditions for applying the 3ha rule as the minimum area for sorghum seed fields. ECOWAS seed regulation was significantly influenced by Burkina Faso legislation.

Table 5.

Mini-pack approach of the AMSP farmer organization: Distribution year, number and type of seed packs distributed, including sales and dissemination points

Year	No. packets	Crops [b]	Type	dissemination strategy
2010	815	s+m	mini-packs	9 points of sale: 4 FO member in villages, 5 input shops
2011	3277 740	s m	mini-packs	17 points of sale: 12 FO-members in village, 5 input shops
2012	2576 2175 1500	s m c	mini-packs	30 points of sale: 10 FO members in villages, 18 input shops, 2 agricultural fares
2013	4550 75	s m	1kg bags	2 input-shops, 1kg/pack
2014	*na*[a]	s+m	1kg bags	16 input shops
2015	90 36	s m	intensification kits (seed + fertilizer)	FO headquarter
	350	s+m	mini-packs	FO-agents
2016	280	s+m	intensification kits	Input shops of AGRODIA network
	800	s+m	mini-packs	FO-agents

[a] information not available

[b] Crops included into the mini-pack distribution : sorghum (s), millet (m) and cowpea (c)

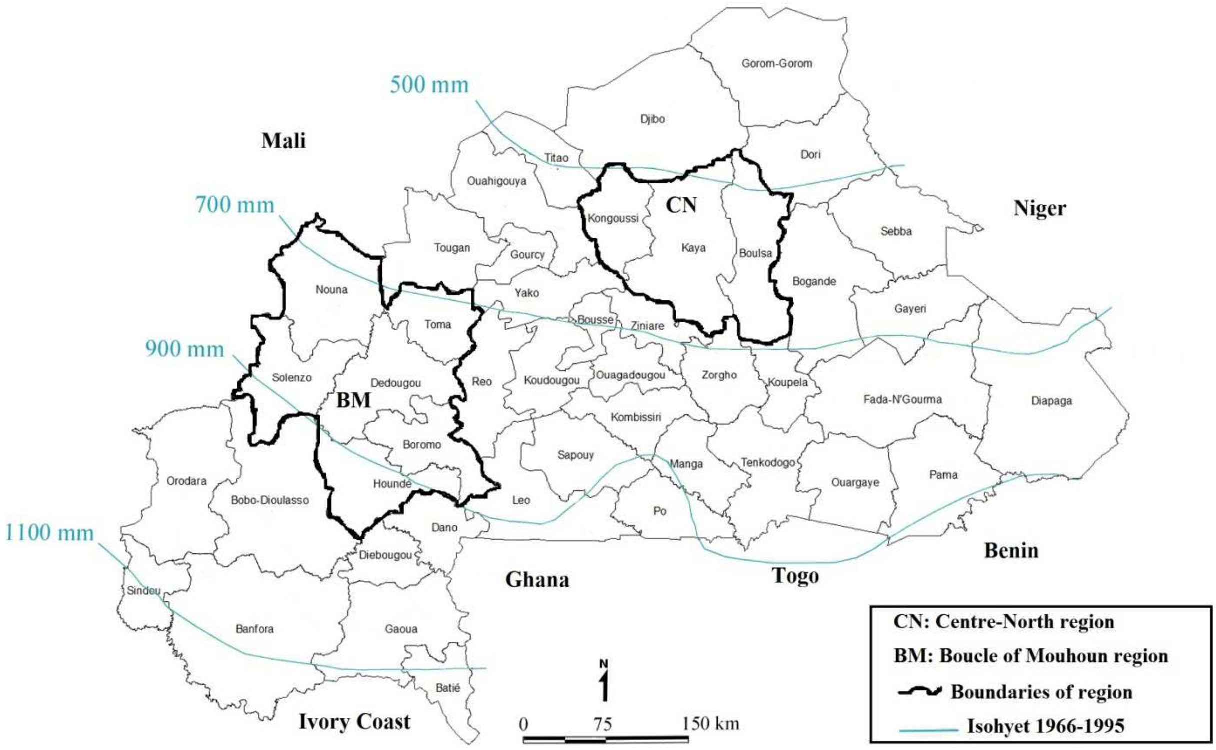

Fig.1. Geographical location of the two regions considered for the impact assessment in Burkina Faso.

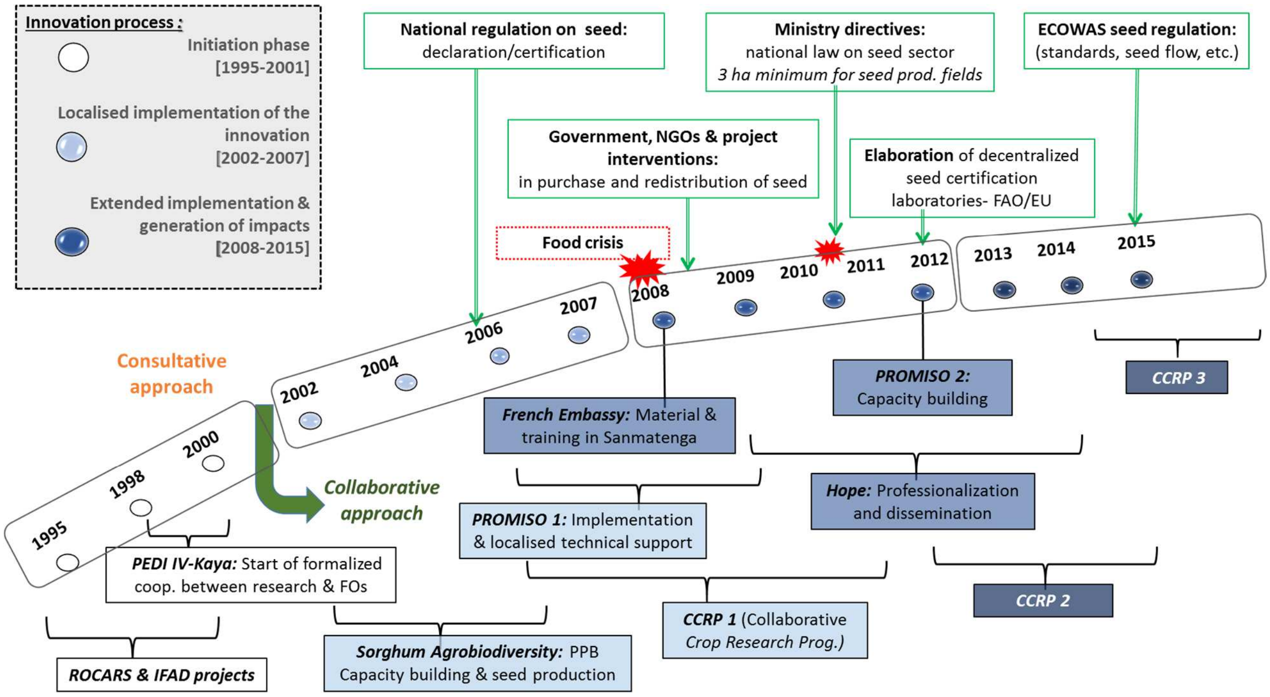

Fig. 2. Timeline of innovation process with projects and external factors that influenced the innovation process

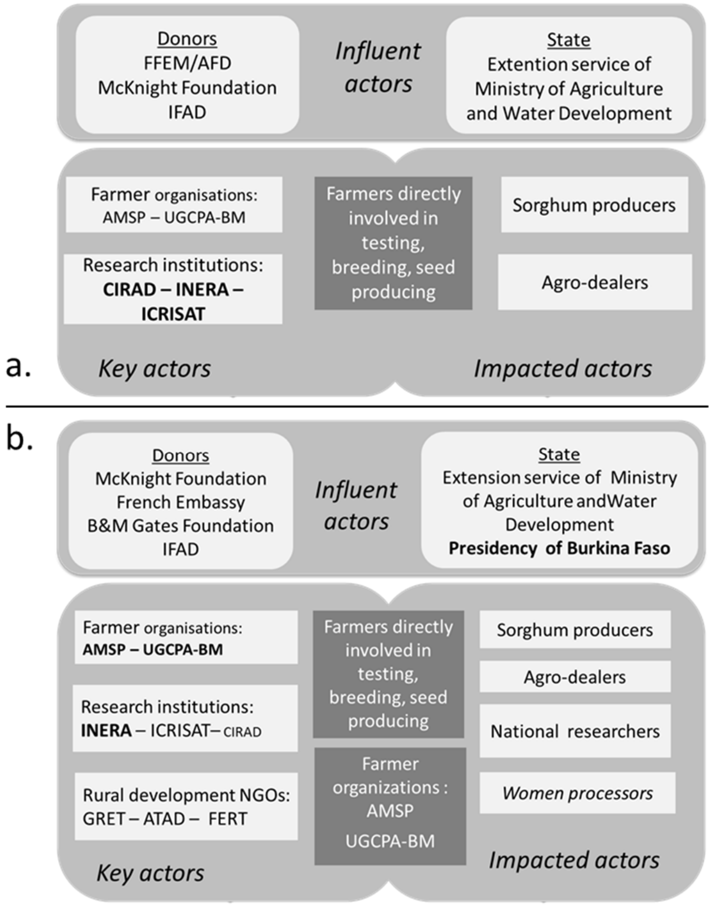

Fig. 3. Mapping of stakeholders involved in the innovation process regarding participatory sorghum breeding and seed projects carried out in Burkina Faso during the phases of development (**a**.) and extension (**b**.) of this innovation. Actors names printed in bold are key stakeholders.

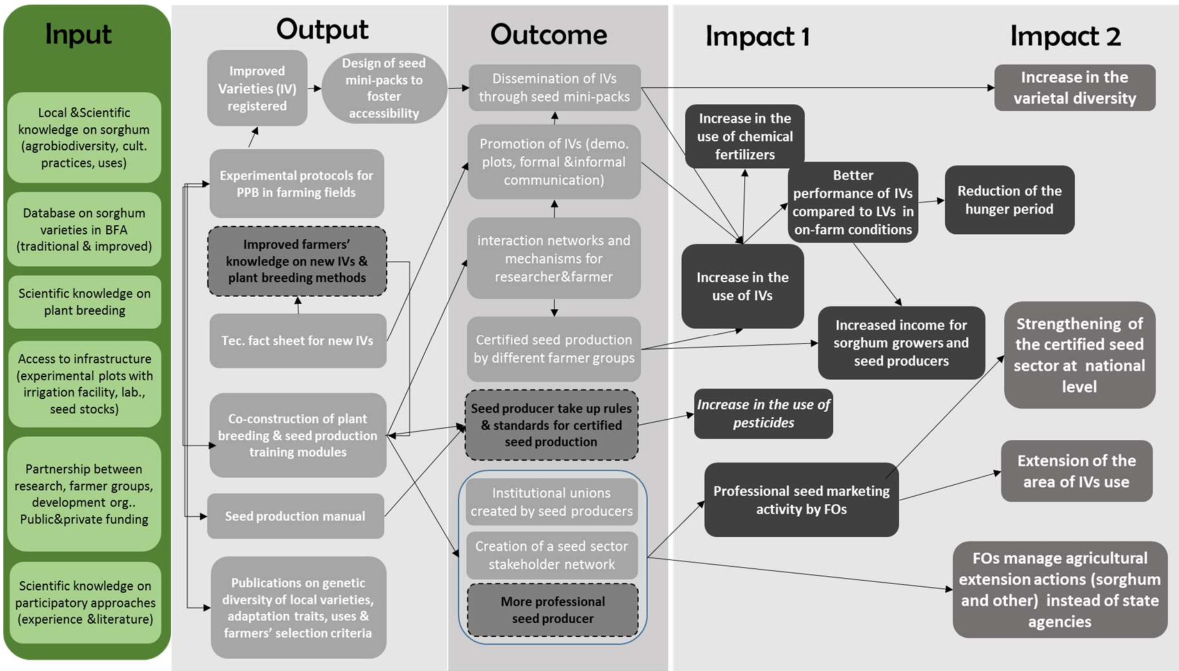

Fig. 4. The impact pathway of the innovation process resulting from the PB program. Dark cases with dotted framing signifies situation of learning; italics signify negative impacts

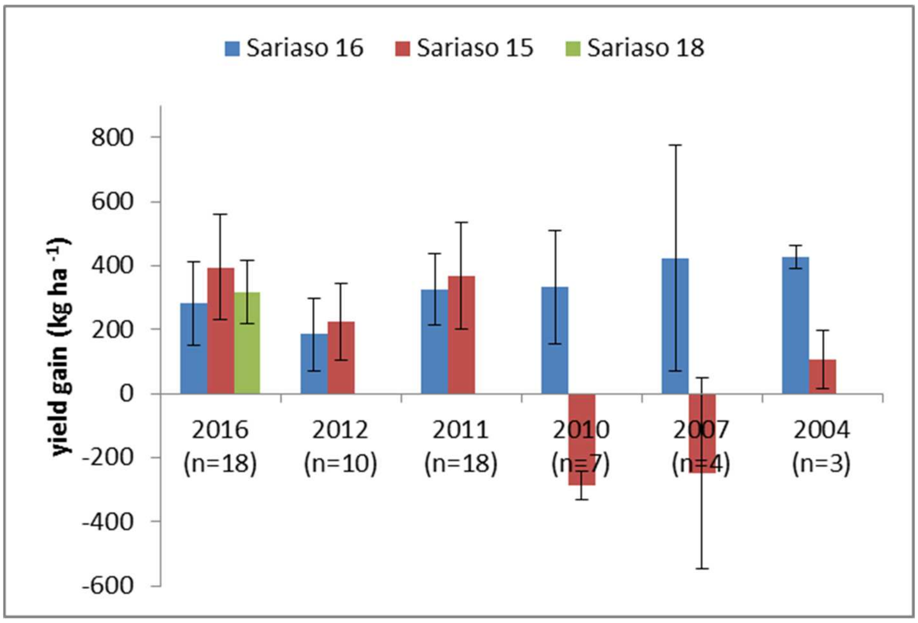

Fig. 5. Average yield gains and standard errors in kg ha^{-1} of new improved varieties derived from PPB compared to the local landrace variety tested in on-farm trials during six years in the Center-North and Center West regions of Burkina Faso; n refers to the number of trials within a year.

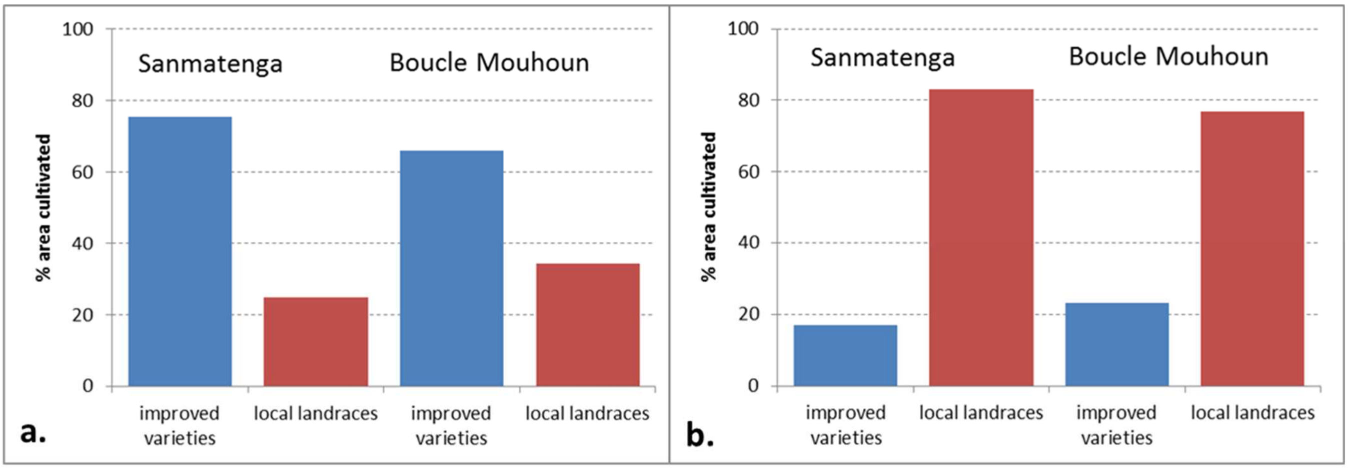

Fig. 6. Level of adoption of improved sorghum varieties (IVs) in village sites of the PB programs (**a.**) and neighbouring non-PB villages (**b.**) in two regions in Burkina Faso in 2013. Adoption rates are represented by the percentage of sorghum area planted with IVs during five consecutive years, according to farmer interviewed carried out in 2013.

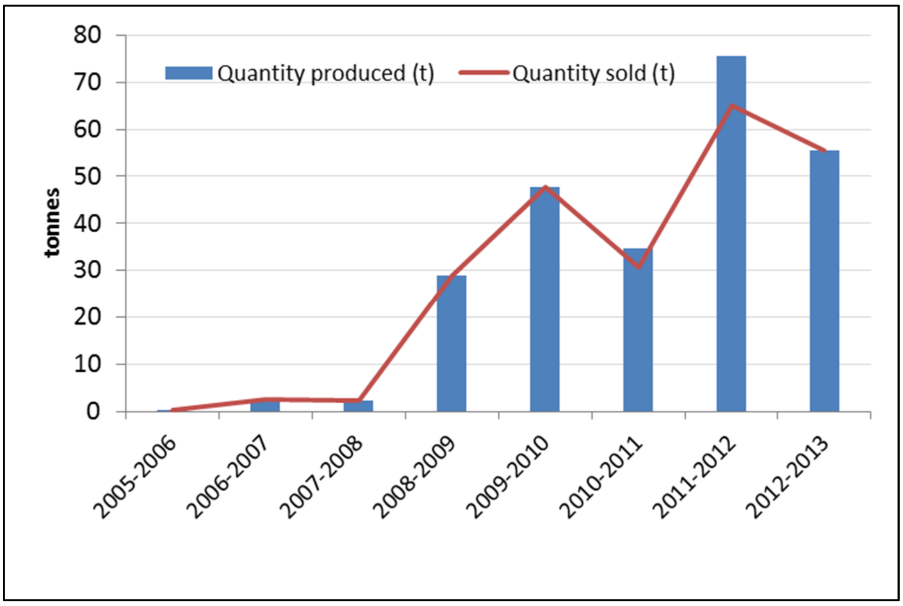

Fig. 7. Evolution of certified seed quantities (tonnes) produced and sold by the UGCPA farmer organisation from 2005 to 2013.

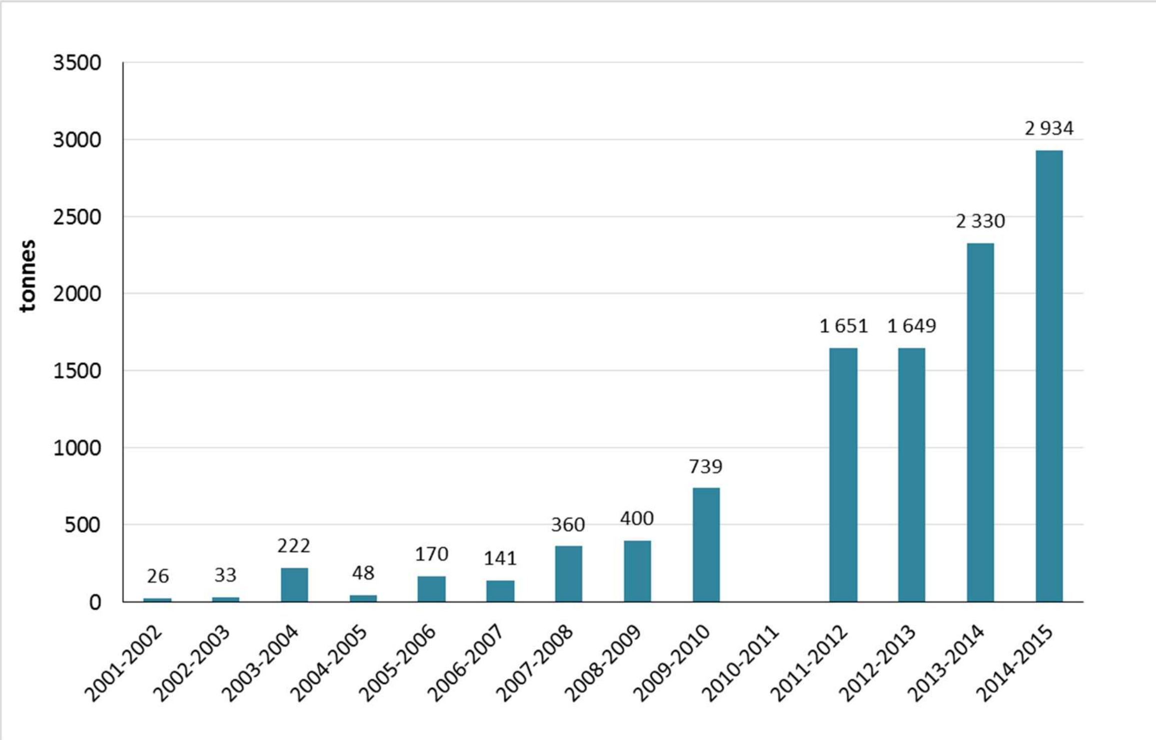

Fig. 8. Evolution of certified seed production (tonnes) in Burkina Faso from 2001 to 2015. Data provided by the National Seed Service (SNS) of the Ministry of Agriculture and Water Development in Burkina Faso.

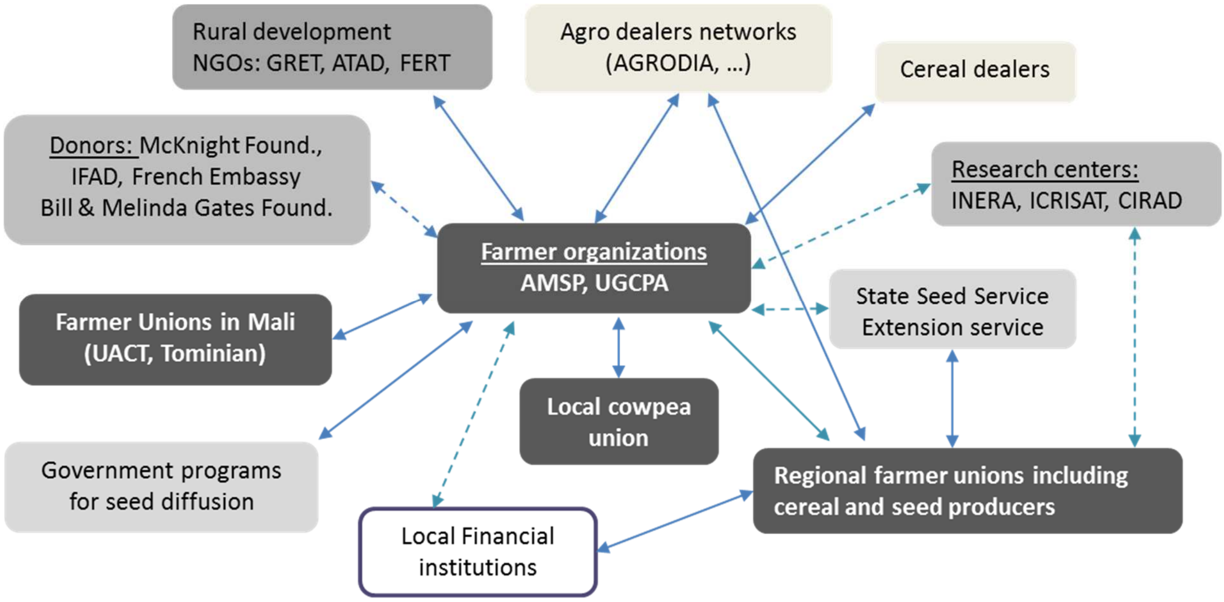

Fig. 9. Farmer organisation interactions during the innovation implementation phase, based on the literature and secondary data. Unbroken lines represent commercial interactions.