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Research for development approaches in mixed crop-livestock systems of the Ethiopian highlands

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This study presents processes and success stories that emerged from Africa RISING's Research for Development project in the Ethiopian Highlands. The project has tested a combination of participatory tools at multiple levels, with systems thinking and concern for sustainable and diversified livelihoods. Bottom-up approaches guided the selection of technological interventions that could address the priority farming system challenges of the communities, leading to higher uptake levels and increased impact. Joint learning, appropriate technology selection, and the creation of an enabling environment such as the formation of farmer research groups, the establishment of innovation platforms, and capacity development for institutional and technical innovations were key to this study. The study concludes by identifying key lessons that focus more on matching innovations to community needs and geographies, systems orientation/integration of innovations, stepwise approaches to enhance the adoption of innovations, documenting farmers' capacity to modify innovations, building successful partnerships, and facilitating wider scaling of innovations for future implementation of agricultural research for development projects.

KEYWORDS

action research, systems thinking, innovations, partnership, scaling

1. Introduction

In developing countries, the demand for food-feed energy has increased because of a rapidly growing population. This situation has called for a joint effort to seek potential and impactful approaches and interventions. Sustainable intensification (SI) has been proposed as one of the strategies/approaches to meet the current needs and ensure future food-feed-energy security (Pretty and Bharucha, 2014). It is an approach using innovation to increase productivity on existing agricultural land with positive environmental and social impacts (Loos et al., 2014; Pretty and Bharucha, 2014; Donovan, 2020). SI takes into consideration the impact on overall farm productivity, profitability, stability, production and market risks, resilience, and the interests and capacity of individual farmers to adopt innovations. Sustainable intensification is not limited to environmental concerns but also includes social and economic criteria such as improved livelihoods, equity, and social capital (Loos et al., 2014; Pretty and Bharucha, 2014; Donovan, 2020).

The concept of SI has evolved and become a subject of debate, although there is agreement among wider groups of experts on its contribution to increasing productivity and improving sustainability in smallholder mixed-crop livestock systems. Various approaches/tools/frameworks have been used by different scholars to assess the performance of SI at the field level for individual technologies (Musumba et al., 2017) and at the farm-to-landscape/district level for multiple technologies (Hammond et al., 2021). The SI assessment findings on multiple crops, livestock, and NRM technologies by Hammond et al. (2021) showed more synergies than tradeoffs among SI domains.

The conventional approach to agricultural research with a linear model of technology being generated by research, transferred through agricultural technologies extension to reach farmers has been found inadequate to address the challenges facing agricultural development in sub-Saharan Africa (Ellis-Jones et al., 2017). As a result, different participatory-oriented and integrated agricultural research for development (IAR4D) approaches have received due attention in the developing world to implement SI programs, address context-specific problems of smallholder farmers, and enhance interaction and adoption of agricultural technologies. IAR4D attempts to combine conventional research approaches, the co-creation of scientific knowledge, and mechanisms of interaction with agricultural technology innovators, beneficiaries, and other actors (Zonta et al., 2021). In addition, it fosters the development of research approaches that are inclusive of all relevant actors, markets, and end users' demands, with due consideration for value chains (Adekunle and Fatunbi, 2014).

As the name implies, integration is at the heart of IAR4D. Integration is envisaged along four lines as follows: integration of stakeholder perspectives, knowledge, and actions; integration of mutual and collective learning experiences; integration of analysis, action, and change along sustainable development goals; and integration of analysis, action, and change along different socioeconomic and spatial organizations (Adekunle and Fatunbi, 2014). Integrations along these four lines are expected to lead to the integration of research and development, technological solutions with institutional and infrastructure solutions, production, and gender and social inclusion considerations (Adekunle and Fatunbi, 2014). The IAR4D works with "principles and guidelines that brings [sic] stakeholders with different background and interests to analyze agricultural challenges, develop solutions, and translate them into achievable targets" (Ngaboyisonga et al., 2017).

The study aimed to share IAR4D approaches that enabled smallholder farmers to apply SI technologies, present key findings, and share lessons learned through the implementation of the first phase (2012–2016) and the second phase (2017–2021) of the Africa RISING project in the Ethiopian Highlands and to draw implications for future project design and for the theory of agricultural development.

2. Materials and methods

2.1. Project description

Africa Research in Sustainable Intensification for the Next Generation (Africa RISING) is a program that consists of three projects, namely, West Africa (WA), East and Southern Africa (ESA), and Ethiopian Highlands projects. The program operates in six African countries and is managed by IITA, ILRI, and IFPRI. The United States Agency for International Development (USAID), as part of the U.S. government's Feed the Future initiative, has been funding the program since 2012.

Through action research and development partnerships, Africa RISING aimed to create opportunities for smallholder farmers to move out of hunger and poverty through sustainably intensified farming systems that improve food, nutrition, and income security, particularly for women and children, and conserve or enhance the natural resource base (International Livestock Research Institute, 2020). Africa RISING in the Ethiopian Highlands operated in eight research intervention kebeles (the lowest administrative units in Ethiopia) that spread across the four main highland regions (Amhara, Oromia, Tigray, and SNNP). The average number of households in the Africa RISING operational areas is ∼860. The project's first phase was implemented from 2012 to 2016. The second phase became operational in 2017 and continued until 2021. An approach based on Integrated Agricultural Research for Development (IAR4D) methods was applied both in the first and second phases of the project.

2.2. Selection of project sites

Representatives from multiple institutions, such as the donor (USAID, Washington, USA), the implementing agency in Ethiopia (ILRI), and the implementing agency for sister projects such as the West Africa project and the East and Southern Africa project, co-developed a research framework in 2012 to serve as a guideline or reference document for the operation and implementation of the Africa RISING program (International Livestock Research Institute, 2012). A set of three broad site selection criteria at the woreda (district) level was then established for the four main Ethiopian Highland regions (Amhara, Oromia, SNNPR, and Tigray). These woredas, which had more than 25% of their land area under wheat cultivation, and were located between 1,900 and 2,400 m above sea level (m.a.s.l.), participated in USAID's main Feed the Future investment for the Highlands, and the Agricultural Growth Program (AGP). Within each of these woredas, two representatives "research kebeles" were jointly selected as platforms for the IAR4D activities to be implemented by the project (Table 1).

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TABLE 1 Climate, soil, and crop production characteristics of the eight Africa RISING kebeles in the Ethiopian Highlands.

Region	Woreda	Kebele	Elevation range	Annual rainfall (mm)	Mean annual max temp (°C)	Mean annual min temp (°C)	Dominant soil type	Main crops	Priority issues/problems
Amhara	Basona	Goshe Bado	2,001–3,800	912–1,127	22	9	Cambisols/vertisols/lithosols	Wheat, faba bean, barley, potato	Land degradation, soil depletion, and low crop and livestock productivity
		Gudo Beret	2,500–3,800	1,128–2,228	20	6	Regosols/cambisols/lithosols		
Oromia	Sinana	Salka	2,000–2,800	950–1,000	20	6	Vertisols/fluvisols/nitisols/	Wheat, faba bean, emer wheat[b]	Wheat-dominated mono-crop system, poor human and livestock nutrition, and crop diseases
		Ilu Sanbitu	2,000–2,500	950–1,000	22	8	Vertisols		
SNNPR[a]	Lemo	Jawe	2,000–2,300	1,100–1,120	23	10	Vertisols	Wheat, faba bean, teff[c], and enset[d]	High population, feed shortage, soil acidity, and enset disease
		Upper Gana	2,000–2,500	1,120–1,170	22	10	Vertisols/nitisols/cambisols		
Tigray	Endamekoni	Emba Hazti	2,000–3,800	700–750	15	6	Cambisols/regosols/lithosols	Wheat, barley, faba bean, potato	Shortage of protein-rich fodder, few income diversification options, water scarcity, soil depletion, and low crop yields
		Tsibet	2,500–3,800	700–750	12	4	Cambisols/regosols/lithosols		

Source: Ellis-Jones et al. (2013): EIAR GIS (2015, personal communication); Authors' own expert knowledge.
[a]Southern Nations, Nationalities, and Peoples' Region.
[b]Triticum dicoccum.
[c]Eragrostis tef.
[d]Ensete ventricosum.

TABLE 2 Average annual dry biomass and nutritive value of selected forage options at the project sites in the Ethiopian Highlands observed from 2013 to 2020.

Forage types	Scientific names	Observed dry matter (t ha^{-1})	Reference yield (t ha^{-1})*	CP (% DM)	ME (MJ/kg DM)	IVOMD (%)	Observed CP yield (t ha^{-1})
Oat	*Avena sativa*	14.5	12.2	10.5	8.7	60	152.3
Vetch	*Vicia villosa*	9.6	5	18.0	10.8	67.4	172.8
Lablab	*Lablab purpureus*	5.3	6.1	16.0	8.6	63	84.8
Sweet lupin	*Lupineus albus*	3.4**	3.7	21.0	9.26	65.5	71.4
Alfalfa	*Medicago sativa*	15.3	18	22	11.4	80	336.6
Brachiaria	Brachiaria hybrids, Var Mulatto II	7.5	8.5	19	7.8	57.5	142.5
Phalaris	*Phalaris aquatica*	8.5	14	9.0	7.4	56	76.5
Fodder beet	*Beta vulgaris*	20.2	31	7.5	11	79	151.5
Desho grass	*Pennisetum pedicellatum*	8.4	10	11	7.5	62	92.4
Tree lucerne	*Chamaecytisus pamensis*	8.7	10.2	22.5	9.0	70	195.8
Faba bean—oat intercropping	*Vicia faba–Avena sativa*	5.5***	NA	10	8.5	64	55.0
Oat-vetch mixture	*Avena sativa–Vicia villosa*	15	12	15	9.5	66	225.0
Desho grass—vetch intercropping	*Pennisetum pedicellatum–Vicia villosa*	11	NA	14	9.2	65	154.0

*Reference average yields were derived from Feedipedia: https://www.feedipedia.org/ and the Tropical Forages Database: https://www.tropicalforages.info/; NA, not available.
**The number in the table refers to biomass production from sweet lupin.
***This refers to the grain yield of faba bean and biomass of oat.

2.3. Farming system diagnosis

The project coordination team involved leading researchers from CGIAR centers (ILRI, IWMI, CIAT, CIP, CIMMYT, ICRAF, ICARDA, ICRISAT, and IFPRI) and local partners to design and implement the subsequent IAR4D activities. Development agencies, such as public extension services and locally operating non-governmental organizations (NGOs) were included in the cohort of local partners at this very early stage to ensure that their priorities would be embedded within those of Africa RISING and to develop a strong sense of ownership among them. The broader Africa RISING team conducted diagnostic exercises in the selected sites using eight tools and methods (e.g., Lunt et al., 2018) to understand the farming systems and identify major challenges and opportunities. The tools/methods used were Rapid Telephone Survey (RTS), Sustainable Livelihood Asset Evaluation (SLATE), Participatory Community Analysis (PCA), IMPACTlite survey, Agro-ecological knowledge Tool (AKT5), Feed Assessment Tool (FEAST), Technology Fit (TECHfit), and Market/Value chain studies. The priority issues identified by the communities were then used as a basis for formulating a set of thematic research areas. The Africa RISING Agricultural Research for Development Team (ARAR4DT) used these themes as a framework for developing action research protocols to directly address the concerns of communities and development partners. Regular monitoring of IAR4D activities and mid- and end-term evaluation of project performances were carried out throughout the life (Phases I and II) of the project (Pound et al., 2015; Negra et al., 2020).

2.4. Clustering of farming system constraints and identification of thematic areas

The constraints identified at the project sites covered different socioeconomic, biophysical, and climatic dimensions. The most important constraints identified included climate variability, low crop yields ($< 1\,t\ ha^{-1}$), soil fertility depletion, erosion, poor drainage, high prices and poor access to fertilizer, crop pests, weeds and diseases, postharvest losses (30%—40%), lack of improved farm implements, acute shortage of animal feed, poor access to veterinary drugs and animal health services, seasonal water scarcity, poor household nutrition, shortage of wood for fuel, and weak links to markets (Ellis-Jones et al., 2013). Experiences from other IAR4D projects, such as the African Highlands Initiative (German et al., 2012), were reviewed to understand how they developed frameworks for integrated research thematic areas and protocols. Accordingly, the ARAR4DT then clustered constraints and identified seven key thematic areas based on (i) feed and forage development, (ii) field crop varietal selection and management, (iii) integration of high-value

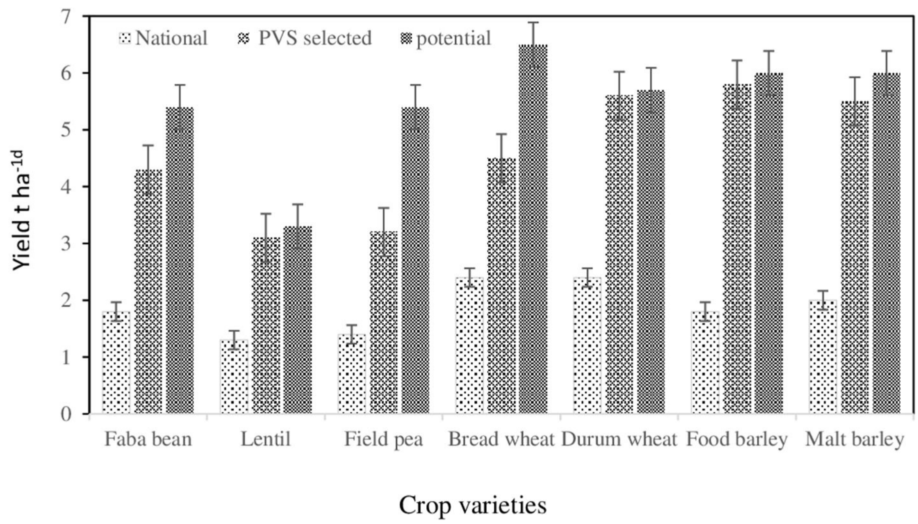

FIGURE 1
Potential, participatory varietal selection (PVS) and national average yield difference in the Ethiopian highlands.

products into mixed farming systems, (iv) improved land and water management for sustainability, (v) improving the efficiency of mixed farming systems through more effective crop-livestock integration, (vi) cross-cutting issues and opportunities (markets, gender, and nutrition), and (vii) knowledge management, sharing, and capacity development. The ARAR4DT then designed 17 primary action-oriented research interventions that addressed one or more of the seven identified themes (Lunt et al., 2018). Aspects of pest and disease management were addressed under the theme of field crop varietal selection and management.

2.5. Identification and validation of SI technologies

A menu of SI technologies and their performance requirements was presented to communities to engage them in on-farm research initiatives. Africa RISING encouraged the elective engagement of participating farmers, including women and youth, in the SI technologies to ensure context-specific and demand-driven focus. Farmers who were interested in participating in one or more SI technologies and who could allocate suitable parcels of land for on-farm research were identified and registered during the community consultation meetings. Farmers who were interested in participating in the different SI technologies were grouped into farmer research groups (FRGs). The CGIAR centers, Africa RISING site coordinators, local partners, and farmers established different on-farm action research experimental plots in 2013 and continued the research thereafter. The number of farmers that directly engaged in crop varietal selection, feed and forage options, and natural resource management was over 2,183. Biophysical/biological and socioeconomic data that matched each of the SI technologies were collected. Review and planning workshops were organized regularly to evaluate research results and plan for follow-up experimentation.

2.6. Demonstration of best SI technologies

Different SI technologies were demonstrated within and outside the Africa RISING research kebeles to encourage user adoption. Validated SI technologies were demonstrated using three approaches.

- Model farmers—These are farmers who have participated in the validation of different SI technologies and have successfully managed them. Most of these farmers have benefited from SI technologies and have shown interest in allocating more land and resources to maintain and expand these technologies on their farms. These model farmers are visited by neighboring farming communities and other farmers from different localities, and they serve as one of SI technology demonstration sites to promote wider adoption.
- Farmer training centers (FTCs)—FTCs have been established by the Ethiopian government in different kebeles to demonstrate technologies and equip farmers with essential farming knowledge and skills. In the context of the Africa RISING project, the existing FTCs have been useful niches to establish research for development activities and evaluate various crop, livestock, and natural resource management technologies. In addition, they have played significant roles in multiplying forage and improving crop varieties.
- Contracted land—SI technology demonstrations on mother-baby plots (crop and forage varieties) were established on contracted land in different Africa RISING project research kebeles. These plots consist of different SI technologies. Farmers visited during field days and other events to observe the use of SI technologies on mother-baby plots.

TABLE 3 Uptake and adoption rates of various technologies promoted by the Africa RISING program.

Site (Woreda)		Basona Worena	Endamehonei	Lemo	Sinana
Number of surveys		148	213	254	164
PVS	Number trialed	111	144	116	133
	% continued using	79	84	77	87
	% doubled use	43	48	13	32
Seed supply	Number trialed	24	18	26	29
	% continued using	92	67	54	62
	% doubled use	21	44	0	17
Cultivated forage	Number trialed	66	95	122	48
	% continued using	65	74	87	40
	% doubled use	41	37	7	15
Fruit trees	Number trialed	35	64	102	19
	% continued using	43	95	94	68
	% doubled use	23	28	6	0
Soil testing	Number trialed	34	49	1	6
	% continued using	97	94	0	50
	% doubled use	9	4	0	33
Water pumps	Number trialed	0	5	8	0
	% continued using	NA	100	50	NA
	% doubled use	NA	0	0	NA

Source: a household survey conducted in 2018 in Africa RISING sites in the Ethiopian Highlands.
The number of households that trialed each technology is reported and can be compared to the total number of households surveyed in each community. The proportions of those who continued to use the technology at a similar rate and the proportions of those who continued to use the technology at an increased rate (doubled use or more) are also reported.
PVS, participatory variety selection; NA, not available.

Model farmers, FTCs, and contracted land technology demonstration approaches contributed to the utilization of SI technologies in many ways. First, they enabled farmers to visit and observe the performance and benefits of the SI technologies because of their proximity to villagers. Second, the model farmers generated more interest and increased their willingness to practice the SI technologies as a result of sharing their successes. Third, they served as a means for the quick transfer of knowledge and information that improved the utilization of SI technologies. In most cases, farmers became convinced when they heard from those who had become successful by adopting/practicing SI technologies.

2.7. Exploration of different options for seed multiplication of crop and forage varieties

Access to improved crop and forage seeds is a challenge for farmers in many parts of Ethiopia. Compared to crop seed suppliers, forage seed suppliers are very few, and their capacity to supply adequate seed is limited. Cooperatives, unions, model farmers, NGOs, local universities, and research centers were identified as potential partners to multiply crop and forage seeds in different Africa RISING sites. These partners initially received starter-improved crop and forage seeds for multiplication and later used the seeds to distribute to large numbers of farmers on a seed-revolving system arrangement. Farmers who received improved crop and forage seed were expected to either return equivalent amounts of seed or pay cash for their cost. The Africa RISING project supported informal seed multiplication by employing capacity development initiatives, like the provision of training, organizing field visits, and producing and delivering informal seed multiplication guidelines. The quality of seed received from revolving seed arrangements was carefully monitored by site coordinators and experts from local partners.

2.8. Facilitation of a broader scaling of SI technologies

Africa RISING worked with a wide range of partners during the first phase of its action research and the second phase of scaling up. The following steps were taken to develop and maintain partnerships and to facilitate the scaling of SI technologies.

- Validated SI technologies ready for scaling were identified;
- Information on validated SI technologies was packaged into fact sheets;
- Contact with potential development scaling partners was established to share research findings and requirements for the SI technologies;

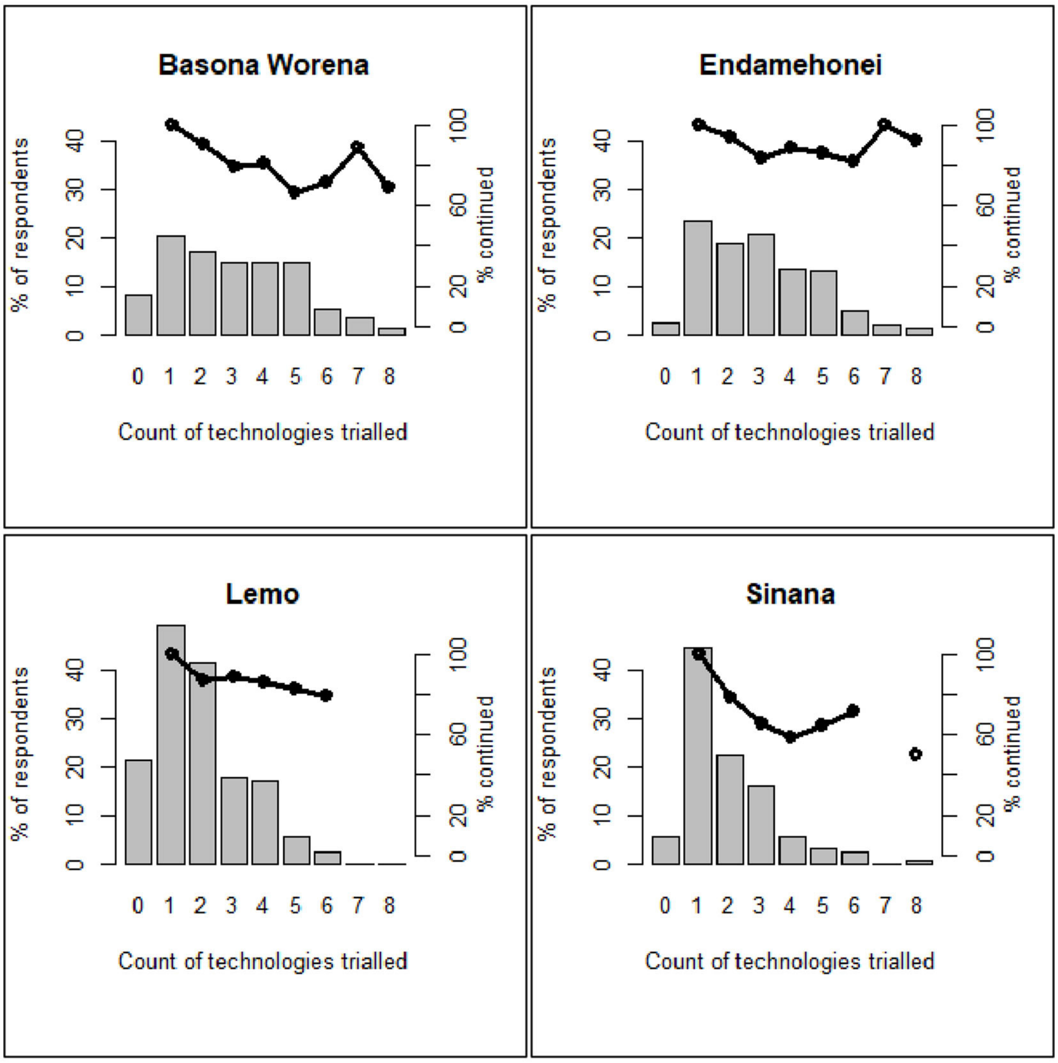

FIGURE 2
The bar charts show the number of technologies trialed by households, and the line chart on the secondary vertical axis shows the average percentage of technologies which were continued to be used by households after the year 2018. The four plots each represent one of the four study sites (woredas).

- A template to collect information on the capacity of each of the development partners to scale SI technologies was developed;
- Contacts were identified at the site level to facilitate communication, supervision, data collection, and evaluation;
- Training was provided to experts, development agents, and farmers on scalable SI technologies;
- Starter seeds of improved crop and forage varieties were purchased and provided to cooperatives, unions, model farmers, extension—FTCs (farmer training centers), NGOs, and local universities for multiplication and distribution to farmers on a revolving seed arrangement.
- Seeds of different improved crop and forage varieties and multiplication approaches were tested to recommend the best model for the extension system at the respective project sites.
- Exchange visits and training were organized for development partners to accelerate the scaling up of Africa RISING through the validated crop, livestock, and natural resource management innovations.

2.9. Enabling conditions applied during the research and scaling process

2.9.1. Formation of research groups

At the four research sites, eight FRGs related to SI technologies were established and named accordingly (Mekonnen et al., 2017). Each FRG consists of 25–30 male and female farmers representing a range of social groups. The FRGs were established based on farmers' common interests and technology choices and were key in enhancing cross-learning and increasing the overall efficiency of innovations. Experiences from elsewhere, such as the International Institute of Tropical Agriculture (2003),

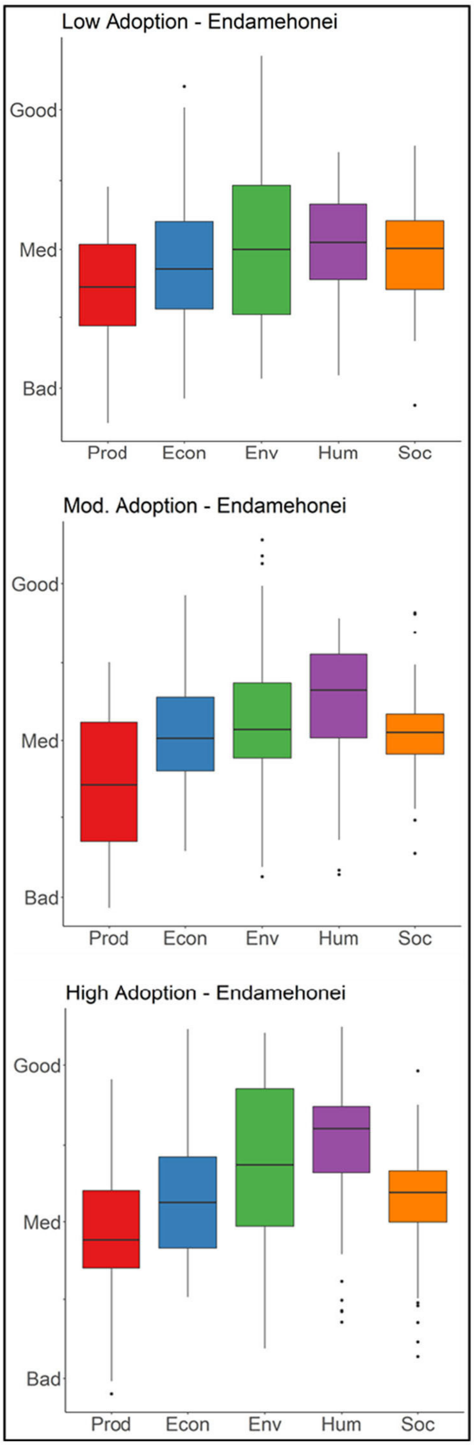

FIGURE 3
Summary of 28 indicators relating to the domains of sustainable intensification: agricultural productivity, economics, environment, human welfare, and society. Indicator scores were re-scaled according to locally thresholds. The three panels differentiate households according to the number of SI technologies they adopted, where low adoption entailed zero or one technology, moderate adoption entailed two technologies, and high adoption entailed three or more technologies. Differences between the study sites (woredas) were great, and so the results shown here are for Endamehoni.

show that FRGs are increasingly becoming the vehicle through which farmers pursue broader concerns, initiate new activities, organize collective action, and expand links with external organizations.

2.9.2. Establishment of innovation platforms

The ARAR4DT established four strategic innovation platforms (IPs) at the woreda level and eight operational innovation platforms (IPs) at the kebele level. An innovation platform is a stakeholder forum established to facilitate interaction and learning among stakeholders, often selected from a commodity chain or system, to engage in the participatory diagnosis of problems, joint exploration of opportunities, and investigation of solutions, leading to the promotion of innovation along a targeted value chain (Homann-Kee et al., 2013). The strategic IPs were established through the engagement of local decision-makers, public extension service providers, NGOs, universities, local research centers, market dealers, farmer representatives from the two Africa RISING research kebeles, breweries, development programs, community-based organizations (CBOs), and agro-food processors. Participating stakeholders were targeted to create good synergies for joint action research and to increase their capacity to contribute to SI issues specific to the local context.

The kebele operational IPs consisted of the kebele administrators, development agents, and farmers participating in the project's research for development activities. The role of these IPs was to coordinate research for development activities, identify challenges and opportunities for agricultural innovation or development, encourage interactions between the public, private, NGOs, and CBOs, and arrange and coordinate field days, evaluations, and training (Ellis-Jones et al., 2013).

The smooth and regular operation of innovation platforms requires resources and commitment. Innovation platforms can be established for a certain purpose in the short or long term. The Africa RISING Innovation Platforms had focal points composed of different local actors/partners. The focal points/partners were responsible for leading the platforms. Meetings were organized on a rotating basis in different institutions, such as extension offices, local universities, research centers, and district and zonal administration bureaus. Local partners in the different Africa RISING sites have already recognized the importance of the platforms and have used them for planning, communication, and cross-learning purposes.

A number of farmer research groups (FRGs) were formed within the operational IPs and clustered around specific research themes (e.g., feeds and forages), as a channel to link the IPs to the households participating in the action research.

2.9.3. Capacity development

Africa RISING promoted capacity building for human resource development and strengthening of local partner organizations in various ways, all designed to respond to demand from local partners and to create an enabling environment for knowledge exchange and innovation. These included the following:

- Co-designing of the research agenda for the season;
- Mid-season and end-of-season field days to demonstrate research interventions and provide feedback regarding the suitability and performance of technologies;
- Exchange visits for cross-learning and sharing of knowledge and information;
- Short-term training to familiarize project partners with the use of survey tools, research approaches, functioning of innovation platforms, operation of improved technologies and management practices, and simulation modeling;
- Placement of MSc and Ph.D. students to undertake field research as part of their studies;
- Workshops to develop and review research plans, co-develop research ideas, and share project research results and information;
- Multiple communication and learning channels, such as websites and learning events, to inform, engage with, and influence a wide audience;
- Workshops to produce briefs, journal articles, and other products;
- Field monitoring by the Africa RISING project coordination team to increase the awareness and participation of site-level partners regarding the Africa RISING research activities;
- Use of site and assistant site coordinators to run action research activities and strengthen communication and linkages between local and CGIAR partners;
- Provision of research infrastructure facilities to facilitate the generation of research evidence, implement the action research protocols, and demonstrate commitment to partners;
- Organizing feedback loops to improve research design and outcome pathways.

3. Results

3.1. Biomass production, nutritional value, and effect of forage supplementation on livestock performance

Cultivated forages and fodder trees validated under farmers' management conditions in sole and mixed/intercropped arrangements at the Africa RISING project sites included oat-vetch mixture, sweet lupin, alfalfa, fodder beet, desho grass, lablab, brachiaria, phalaris, vetch-desho grass mixture, faba bean-forage intercrop, and tree lucerne (Table 2). The productivity of the cultivated forage and fodder tree options and their nutritional values varied from site to site because of climatic, edaphic, and management factors. The average biomass yield (t DM ha^{-1}) and the nutritive value obtained across the Africa RISING sites under farmers' fields and management conditions are indicated in Table 2. Most of the forage and fodder trees evaluated in the Africa RISING project sites have high herbage biomass yields with good nutritional quality (Mekonnen et al., 2021). Validating this type of forage and fodder tree species is very important given the current feed supply and quality constraints in the highlands of Ethiopia. For lactating cows, milk yield increased by more than 50% when their diet was supplemented with 2 kg dry matter of oat-vetch mixture per day. In fattening sheep, supplementation with 300–400 g/day of tree lucerne hay feed increased daily body weight gain by 70 g.

3.2. Yield of field crop varieties

The Africa RISING project has introduced different varieties of cereals, legumes, oilseeds, and tuber crops and validated them through participatory varietal selection (PVS) approaches with farmers. PVS has been shown to increase crop yields compared to conventional approaches. For instance, improved potato varieties introduced by the project and validated through PVS were high yielding (32–53 vs. 2–8 t ha^{-1}), early maturing (98 vs. 120 days), and tolerant to late blight (International Livestock Research Institute, 2017). The yield of cereal and legume varieties obtained through PVS was also higher than the national average crop yields (Figure 1). PVS and other research activities were closely followed at different stages of research that included selection, application of proper agronomic practices, and postharvest techniques, which fostered yield increases in PVS as compared to conventional production systems.

3.3. High-value fruit trees

Africa RISING accessed grafted seedlings of five improved avocado varieties (Ettinger, Fuerte, Hass, Nabal, and Reed) and validated the performance of the varieties with farmers in its operational areas. The improved avocado varieties are productive and able to bear fruit within 2–3 years period. They are also short, thus making harvesting very easy. Survival rates for avocado varieties in Africa RISING sites were found to be 90%—100%. Fruit yield varied among the five varieties. The mean yield for Ettinger, Fuerte, Hass, and Reed was 45 kg per tree, while it was approximately 90 kg per tree for Nabal (Mokria et al., 2022).

3.4. Soil fertility management

The research was conducted on crop responses to combinations of multiple macronutrients and micronutrients such as NPSK, NPSB, and NPS in wheat-based cropping systems. It was possible to identify soil-specific best fertilizer blends and rates for wheat in the eight targets Africa RISING research kebeles. The new recommendations boosted yields by two to three times, even in previously "non-responsive" soils, and included N-P-K plus sulfur, zinc, and boron. As a result of the research on the targeting of micronutrients in fertilizers, a new national initiative has been catalyzed to deliver these innovations nationwide (Amede et al., 2022).

3.5. Small-scale mechanization

Different small-scale mechanization technologies for land preparation and planting, harvesting, post-harvest processing, and micro-irrigation have been tested and promoted on smallholder farms in the four Africa RISING operational regions of Ethiopia. These mechanization technologies, powered by low-horsepower two-wheel tractors (2 WT), include plowing, planting, harvesting, threshing, shelling, water pumping, and transport services. The following are examples of research results from the small-scale mechanization work:

(a) Maize and wheat productivity gains of 16%−44% and 10%−25%, respectively, have been documented on farms using 2 WT technologies compared to conventional *Maresha*-based practices (International Livestock Research Institute, 2020);
(b) Two-wheel tractor-driven harvesting of crops such as wheat saved time and increased gross margins by 55%−89% for farmers who received harvesting services as compared to those who used traditional (human labor) methods;
(c) Service providers of 2 WT generated income from maize shelling and wheat and barley threshing. For example, service providers generated US$9,180.89 and US$5,959.85 through wheat threshing and maize shelling services, respectively, during the January–April 2020 dry season.

3.6. Soil and water management

Implementation of integrated soil and water conservation (SWC) practices at the landscape scale reduced sediment yield by 74%. Runoff and soil loss were reduced by an average of 27 and 37%, respectively, due to SWC practices at the plot level (Yaekob et al., 2020). Improved water lifting technologies increased farmers' ability to irrigate high-value crops and improved household nutrition. Irrigated fodder biomass increased by 14% dry weight when farmers were guided in their irrigation practices by the wetting front detectors at the Lemo Africa RISING site.

3.7. Adoption of technologies and enabling conditions

Data collected from a survey in 2018 on the number of households that tried each intervention, and then the number of households that kept using those interventions are presented in Table 3. Interventions had a high rate of uptake. Although there was variation across study sites and between the technologies, ∼80% of farmers continued to use the interventions they trialed, and ∼30% doubled the extent to which they used them. A decline in technology use after the project support is withdrawn is possible, but these uptake and continuation rates are likely to represent a critical mass for longer-term retention. Most commonly, households tried one or two technologies, but approximately one-third of the study population trialed three or more technologies. Continuation rates for households trialing more technologies remained high (Figure 2).

To explore possible reasons for the relatively high technology uptake rate, a regression model was built using variables for the study site, household assets (land, livestock, and income), household head education, and enabling conditions influenced by the Africa RISING project. The variables used to describe enabling conditions were the number and quality of training sessions attended, the number of support groups joined, the reasons given for the selection of technologies, and the number of peers with whom good practices were shared. The indicators of enabling conditions were all found to have a positive relationship with the number of technologies, significant at the p-level of <0.001. The study site also had a major effect on adoption, with the number of technologies remaining significantly lower in Sinana as compared to the other locations (which may be related to the more cereal-focused agricultural system). Interestingly, household wealth had a smaller effect, with only livestock ownership having a significant influence on technology continuation and a non-linear relationship with the land area as implied by the model findings.

3.8. Stakeholder engagement

As a project working at the boundary between research and development, Africa RISING took an approach that engaged multiple stakeholders. The processes of engagement led to a number of results/outcomes that are both hard to measure and essential for creating the enabling environment for SI to occur. The main mode of engagement was through innovation platforms (IPs), supplemented by communication and capacity-building activities. The IPs played different roles, including the following:

- Setting research agendas: In Basona woreda, for example, during a strategic IP establishment meeting, IP members requested a focus on watershed development issues as land degradation posed a major problem in their district;
- A feedback mechanism for researchers: In Endamehoni woreda, for example, during the second strategic IP meeting, members suggested reducing the number of varieties for participatory varietal selection and focusing on just a few potential ones. Such feedback was essential for the researchers to adjust their research approach and process and maintain a response-demand-led approach;
- Partnership development for scaling: In the Lemo district, for example, during the second strategic IP meeting, scalable technologies, namely micro dose fertilizers, water lifting technologies for irrigation, potato feeds, and livestock feeds, were presented. IP members from the CG centers, regional research institutes, and a local university agreed to provide technical capacity building for community organizations. The district agricultural office and local NGOs committed themselves to mobilize resources for and empowering farmers. Africa RISING agreed to provide starter seeds and some other material provisions. The report given during the subsequent IP meeting showed that, as a result, members took

their decision-making further and committed themselves to continuing the activities during the next planting season.

3.9. Scaling and sustainability

The Africa RISING project's 2015 mid-term evaluation report noted that the action research conducted at the four research sites and the innovation platforms built around them were the nuclei for scaling out and scaling up innovations (Pound et al., 2015). Hence, the initial research phase and associated spontaneous scaling activities enabled a well-developed niche innovation system for Africa RISING-validated technologies. Long-term and evidence-based relationships, complemented by the trust of a wide range of local actors, paved the way for a subsequent, more deliberate scaling initiative in the second phase (Pound et al., 2015). For example, in one of the intervention sites, in the Tigray region, the district and zonal experts were involved in site selection, mid- and end-season evaluation of wheat, and participatory varietal selection of faba bean and potato. The new varieties and their management practices led to an enormous productivity gain (58, 47, and 88% for faba bean, bread wheat, and potato, respectively) as compared to the local, and even regional, standards. When the district experts observed these results, they returned to their office and documented all the innovations so that they could be used as benchmarks for production to be embedded in their future planning. These officials also went on to share these plans with the regional Bureau of Agriculture, using the documented evidence. This resulted in the recognition of the achievements by the regional government, which used the district experience as a benchmark for the regional expansion of wheat and potato production.

In line with its commitment to promoting SI, Africa RISING commissioned an assessment to better understand the balance between production and sustainability outcomes of the project. In a 2018 household survey, 28 indicators were collected in relation to five domains of sustainable intensification: agricultural production, economic, environmental, human welfare, and social. These indicators were rescaled and are presented in Figure 3 (which shows results for the Endamehoni district only). In general, households that utilized more technologies showed improved agricultural production and either improvements or at least no negative impacts in the other domains.

3.10. Wider scaling of SI technologies

In its second phase (2017–2021) Africa RISING set a target of reaching 0.7 million households with the project-validated SI technologies. Over the past 5 years (2017, 2018, 2019, 2020, and 2021), the project has managed to reach and benefit, through its validated SI technologies, nearly 0.4 million households (Figure 4). The Africa RISING project reached and benefited farmers with its validated SI technologies through direct researchers'

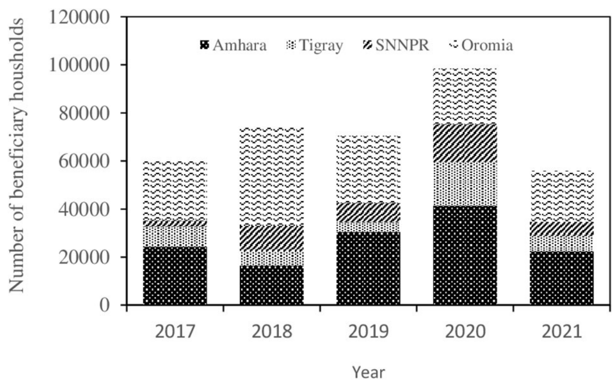

FIGURE 4
Beneficiaries of farm households from feed and forage interventions from 2017 to 2021 in the Ethiopian highlands.

engagement, development partnerships, and spillover scaling models/approaches.

4. Discussion/lessons

4.1. System orientations

A system is defined as a set of interrelated components working together for a common goal (Carlsson et al., 2002). It includes human and non-human actors, their market and non-market relationships, and the functional attributes of the actors and their relationships. A technological innovation system includes the various functions that must be performed by multiple institutional and economic structures to generate and disseminate a technology (Markard and Truffer, 2008). The system orientation of IAR4D requires that problems and solutions need to be co-investigated. Hence, joint learning through collaborative analyses of situations, collective action, and subsequent reflection are peculiar characteristics of IAR4D (Schut et al., 2016). IAR4D recognizes and engages actors and institutions at multiple levels of a technology's value chain (Nyikahadzoi et al., 2012; Adekunle and Fatunbi, 2014; Lunt et al., 2018).

Africa RISING farmers adopted and implemented different innovations based on their interests, capacities, and priorities. A systematic understanding of the interactions, synergies, and tradeoffs of the innovations at the farm/household level and beyond is useful for a complete evaluation of innovations. Research on interactions, synergies, and tradeoffs of the innovations implemented by each of the Africa RISING farmers requires skill and time. It also requires a willingness on the part of the CGIAR centers and local partners to jointly develop protocols and generate research evidence. The CGIAR centers are structured around commodity research foci such as dryland crops, root crops, livestock, water, trees, and natural resource management (NRM). This commodity focus is sometimes a challenge to bring them all together and study integrated innovations that would address interlinked system constraints. The Africa RISING project has considered landscape management as one of the core approaches to integrate crop-livestock-natural resource management and interlinked interventions.

4.2. Targeting/matching technologies

The capacities, preferences, and priorities of farmers to adopt agricultural technologies vary across and within regions, sites, and villages. External factors such as climate, edaphic conditions, policies, and institutions also matter in determining what type of technologies to adopt, when, where, and how much or how many of them to adopt. In this regard, working with typology groups was found useful. A typology groups the farms into relatively similar clusters. This can help to identify suitable farms to target innovations, allow tailoring of technologies to best-fit farm types (niches), scale up the effects of innovations, select farms to work within projects, scale-out innovations, explain trends and farmer "behavior," and verify the impact of interventions for different farm types (Alvare et al., 2014). Targeting or matching technologies to the different farm types speeds up technology uptake and paves the way for impact. The Africa RISING experience in the Ethiopian Highlands shows the possibilities of constructing farm types (farm typologies) in two ways, namely, ex-ante vs. ex-post, depending on circumstances. For instance, the shortage of protein-rich animal feed was the farmers' priority problem in the Ethiopian Highlands. Several farmers in the Africa RISING operational areas planted fodder trees such as tree lucerne (*Chamaecytisus palmensis*) and used them as supplementary feed for dairy cows and small ruminants. To facilitate further scaling of tree lucerne, we clustered farmers after the implementation of the fodder tree intervention and identified three major farm types along with their adoption characteristics for this technology. The farm types include resource-rich, middle-class, and resource-poor households (Mekonnen et al., 2017).

4.3. Technology adoption

The involvement of multiple actors with differentiated capacities and interests requires that IAR4D projects develop the capacities of all involved and develop effective communication and knowledge management systems. Notably, capacity gaps need to be defined by each actor, and capacity building needs to be executed with the right expertise (Nyikahadzoi et al., 2012; Adekunle et al., 2013). During capacity building, it is also necessary to consider developing capacities to work together in partnership and use innovation platforms for a transformational common good (ISPC 2016). Realizing the benefits of integrating SI interventions at the household scale has been a mantra for Africa RISING projects during its first phase. In practice, we have learned that the integration of SI interventions does not happen concurrently. Farmers prefer to test one or two technologies at a time to assess their workability and the benefits that they derive from them. Once they become confident with a limited number of technologies, they often proceed further down the intensification pathway by adopting further complementary interventions. This stepwise approach to SI appears to be the reality for many farmers. Our experience also taught us the importance of understanding the types of capacity building (practical training and demonstration) that the local communities need to navigate around blockages and speed up the wider scaling of innovations.

4.4. Farmers' innovation

The Africa RISING action research approach enhanced farmers' capacities to test and modify technologies according to their needs and circumstances. For example, the project introduced and demonstrated a livestock feed trough technology prototype in different sites. This feed-trough technology enabled farmers to reduce feed wastage and labor demand for feeding by over 30 and 20%, respectively. Farmers at the different project sites modified the feed trough technology in several ways. Some farmers constructed two sides (one side for cows and the other side for sheep/calves), and others constructed only one side (for cows or sheep). Some used iron sheets for shading, and others constructed the feed trough under trees. Some farmers who own more livestock constructed large feed troughs, while those with few livestock constructed feed troughs that can feed 2–4 livestock species. In another example, Africa RISING farmers in the SNNP region learned to graft avocados to increase their access to improved avocado varieties introduced by the project. All these examples show farmers' innovativeness and the need to tap into this potential in research for development practices.

4.5. Partnerships

Partnerships are key to bringing about the desired impacts. Africa RISING has been working with CGIAR centers, local universities, federal and regional research institutions, NGOs, private entrepreneurs, government extension, and farmers since 2012. All these institutions have their own working styles/approaches, priorities, and financial requirements. It is sometimes challenging to harmonize the conflicting interests of all the partners and bring them on board to achieve plans and targets. Partners' engagement in monthly meetings, planning and review meetings, annual learning events, field days, cross-site visits, and other capacity-building schemes fosters partnership, narrows communication gaps and helps to build strong relationships and create positive working environments. Our IPs and other structures for multi-stakeholder engagement have played an important role in making our partnerships successful (Lema et al., 2021). Some local decision-makers in the Africa RISING operational areas have continued using the innovation platform to periodically meet and discuss the development agendas for their respective districts and zones.

4.6. Wider scaling of SI innovations

Wider scaling of Africa RISING-validated technologies became evident through the creation of development partnership approaches. The Africa RISING project identified potential development partners that can allocate resources and time to widely scale SI innovations and benefit smallholder farmers. Government extension is a major development partner that has been widely scaling Africa RISING project validated SI innovations. The extension system can pick up validated

SI innovations and be widely scaled to many areas as the innovations align with their priority areas and development strategies. The Africa RISING project organized different capacity development events to familiarize the development partners with the SI innovations. However, capacity development alone would not be sufficient for the development partners to widely scale innovations. Backstopping development partners with some financial resources to purchase inaccessible inputs such as seeds/planting material for some improved forage and crop varieties is necessary to continue the wider scaling efforts (Gebreyes et al., 2021). It is important to see what limits the scaling of innovations to a large number of farmers, prioritize the gaps, and address them in a way that does not create dependency.

5. Conclusion

The first and second phases of the Africa RISING project in the Ethiopian Highlands explicitly used the IAR4D approach to guide their work. The approach used the four pillars to guide the process of translating the global Feed the Future initiative into locally relevant and usable research. As a result, several positive results were achieved. Africa RISING technologies were used as a basis for regional-level benchmarks in crop production because of their outstanding performance. Farmers who participated in community seed multiplication were able to sustain their production. Moreover, communities that were able to produce enough for their families and generate more income changed the attitude of farmers and encouraged them to produce improved animal forage, identify soil-specific fertilizer blends and rates for wheat production and reduce soil loss through integrated soil and water conservation practices. The research for the development experience also generated some key lessons. First, in system research, where farmers may be provided with a package of technologies, they tend to adopt them incrementally, with each step adding more value to their farm enterprise. It was also observed that farmers transition from being mere adopters of technologies to co-generators and innovators. Second, while joint assessment of problems is essential, the Africa RISING experience showed the need to take this one step further and conduct a joint assessment in clusters based on farmer typology assessment. This helps to better target technological solutions. Third, partnership in IAR4D requires the management of complex partnerships with strong facilitation skills needed to meet the various interests of different actors in innovation platforms. Fourth, broader scaling of SI technologies reaches and benefits smallholder farmers better through development partnership approaches. Finally, there is a need for strong documentation skills as capturing success stories and failures get complicated with time.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

The first draft of the manuscript was written by KM, MG, JH, and PT. Edited and reviewed by MB, SK, LT, GA, RY, AG, MT, KS, AA, and AW. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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