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Transdisciplinary knowledge co-production as a catalyst for community-led innovation: a case study of farmers' milk cooperative in Laikipia, Kenya

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Food systems must be reconfigured for them to alleviate poverty, hunger, food losses, and waste, promote healthy diets, inclusivity, resilience, and livelihood opportunities, and be environmentally sustainable. This requires a shift in production, and consumption, as well as transformative research, responsive policy, people-centered innovations, and safety nets for the most vulnerable people. Transformation of food systems also depends on a shift in science, policy, and practice to promote sustainable futures. For science to be transformative, discipline-oriented research is important, however, societal challenges are becoming more complex hence requiring more interdisciplinary research with collaboration and integration of knowledge from actors in policy and practice. Scientists must learn to first work together, and then work with non-academic actors to solve complex problems facing food systems and the society at large. This kind of research is transdisciplinary, meaning right from the framing of complex problems, data collection, analysis, and validation, non-academic actors must be actively involved in the process of knowledge co-creation to create sustainable outcomes. This study demonstrates how co-production of knowledge between academic and non-academic actors through a participatory negotiated process, can contribute to transformative development intervention. The study applies a case study of an agro-pastoral community involved in a milk value chain in Laikipia County. The transformative areas in the study were; (a) capacity development in commercial dairy farming, (b) formation of Umande farmers' Cooperative, and (c) construction of a cooler house, and installation of a milk cooling system for milk bulking, and value addition. The case study offers several lessons; (a) the role of transdisciplinarity in science, policy, and practice, (b) proper identification of stakeholders in collaborative community development initiatives, (c) the community must always be at the forefront of any development initiative for ownership and sustainability, and (d) skills development and economic empowerment are paramount for any innovation in the community. The objectives of the study were (a) participatory assessment of the local food system to identify the strengths and weaknesses, (b) assessment of perceived benefits of farmer capacity development and lessons learned, and (c) assessment of farmer perception of the benefits of milk cooling and bulking system on livelihoods. More farmer -led development initiatives are needed to improve livelihoods of actors in food systems.

KEYWORDS

knowledge co-production, food systems transformation, sustainability, innovation, Kenya

1 Introduction

The study demonstrates how knowledge co-production between academia and societal actors across different levels and sectors is an important impetus to the transformation of food systems (Schneider et al., 2022; Barth et al., 2023). Transformed food systems contribute to the reduction of hunger, and poverty, and several other sustainable development goals such as SDGs 3, 8, and 12. Knowledge co-production in transdisciplinary[1] research can be looked at as an interactive, participatory process that brings diverse actors such as scientists, practitioners, and community members together to collectively generate, integrate, and apply knowledge to address complex sustainability challenges (Bandola-Gill et al., 2022).

Co-production has emerged as an important concept in science—policy—practice nexus as societal problems become more complex and difficult to solve (Pohl et al., 2010; Metz et al., 2019; Jacobi et al., 2020b; Llanque-Zonta et al., 2023). Knowledge co-creation helps to transform food systems creating sustainable solutions to improve the welfare of actors such as farmers, traders, processors, and consumers who obtain their livelihoods from food systems activities, and value chains (Llanque-Zonta et al., 2023). This concept of knowledge co-creation has been used in various fields such as environmental sciences (Djenontin and Meadow, 2018), sustainability (Pohl et al., 2010; Polk, 2014; Schneider et al., 2022; Miller and Wyborn, 2020), public administration (Ostrom, 1996), health (Grindell et al., 2022), and science and technology (Verwoerd et al., 2023). Co-production can also be viewed as a methodology where scientists, practitioners, and community members, develop holistic solutions through a collective process to solve complex challenges (Horvath and Carpenter, 2020). Collective action[2] through knowledge, co-creation means that academic actors are agents of change working together with stakeholders to solve problems together rather than individually.

Co-production has several interrelated pathways; "step 1: defining the objectives, step 2: identifying actors to participate, co-creation activity and conditions enabling co-creation, step 3: identifying the level of co-creation that is desirable, step 4: selecting the tool and learning about it with the stakeholders, step 5: inviting stakeholders and sharing information, step 6: implementation, step 7: evaluate and adapt" (Dushkova and Kuhlicke, 2024, p. 6). In this study, the context was studied during phase one (2016–2018) of the project. The data from all work packages were then integrated and validated by the stakeholders to co-create the Food Sustainability Assessment Framework (FOODSAF, later modified to; Food Sustainability Assessment and Transformation-FOODSAT) (Rist et al., 2021; Llanque-Zonta et al., 2021). The framework has been tested in several food systems contexts in Africa and Asia to create transformative pilot projects to solve food systems challenges (Llanque-Zonta et al., 2021). In this case study, the framework was introduced to the farmers, they learned about it, assessed their food system, and diagnosed the challenges and practical solutions.

Using the theory of change (TOC) as applied in transdisciplinary research (TDR) (Deutsch et al., 2021; Claus et al., 2023), we assess how knowledge co-creation can contribute to addressing challenges facing society through a participatory process. Transdisciplinary research uses methods and expertise from different disciplines, and societal actors to solve complex problems facing society (Buizer et al., 2015; Belcher et al., 2020; Sellberg et al., 2021; Jacobi et al., 2022). The theory of change is applied in action research as a problem-solving strategy involving multi-level, multi-stakeholder, and multi-sector actors together with scientists from different disciplines to understanding the challenges, and focusing on sustainable solutions (Claus et al., 2023). Transdisciplinary research applying TOC helps to create transformative change for posterity, due to it being multi-stakeholder from production, processing, distribution, and consumption (Llanque-Zonta et al., 2021). Challenges in food systems such as food insecurity, poverty and inequality, vulnerability to shocks, biodiversity loss, land degradation, resource use conflicts, water shortages, and fragmented markets (Foran et al., 2014) are collectively tackled for livelihood enhancement and social-ecological resilience.

Food systems comprise the entire range of actors and their interlinked value-adding activities including; production, aggregation, processing, distribution, consumption, and disposal of waste of food products, and the broader economic, societal, and natural environments in which they are embedded (Colonna et al., 2013; Food and Agriculture Organisation of the United Nations (FAO), 2018). The concept of a system refers to a holistic interplay of interacting subsystems in which feedback plays a key role, rather than as a simple chain of cause-effect relationships, value chain approaches, or food security thinking (Ingram, 2011; Alongi and Anese, 2021). Due to the multiple entities, processes, activities, and actors, food systems are well-positioned for transdisciplinary knowledge co-production and transformative pathways (Leeuwis et al., 2021). Food systems based on smallholders and agropastoralists have been perceived as more localized, small-scale, ecologically friendly, and culturally oriented production, distribution, and consumption systems, that are perceived to have limited environmental impacts (Feagan, 2007; Brunori et al., 2016; Wilkes et al., 2020), more sustainable due to less energy intensity, low inputs of agrochemicals, and low food miles (Edwards-Jones et al., 2008). Smallholder-based food systems also support more diverse, farm-based agroecosystem services, and have been found to be more resilient (Augstburger et al., 2018; Augstburger and Rist, 2019; Mukhovi and Jacobi, 2022). Livelihoods, incomes, food and nutrition security of farming communities, and social, environmental, and ecological benefits are also important outcomes (Berti and Mulligan, 2016; Leventon and Laudan, 2017).

Kenya's milk sector is characterized by unprocessed surplus milk that makes up a large proportion of the value chain. Farmer cooperatives have been important in Kenya's dairy sector with the oldest one being Kenya Cooperative Creameries (KCC), which until the early 1990s had a monopoly in milk processing and marketing in the country (Chege and Bula, 2015). However, after market liberalization in 1992, many private milk processors entered the market (Wanyama, 2016). Cooperatives in Kenya have been found to facilitate access to credit, especially for women farmers who are constrained by a lack of collateral (Ingutia and Sumelius, 2024). Studies have suggested that participation in cooperatives increased the price of farm produce, access to markets, credit, and improvement in income (O'Brien et al., 2013;

1 Transdisciplinary approach addresses complex societal changes through collaborations between disciplines (interdisciplinary) as well as collaboration between academic and non-academic actors.

2 A collective action is an action taken by a group in pursuit of common objectives that are difficult to address individually.

Meador et al., 2016; Zhong et al., 2018; Liu et al., 2023; Onyango et al., 2023; Ingutia and Sumelius, 2024). However, income for dairy farmers is affected by factors such as farm size, number of lactating cows, distance to market, level of education, and access to off-farm income (O'Brien et al., 2013; Onyango et al., 2023). Cooperatives should also be accompanied by non-income benefits such as social capital, promotion of innovation, and leadership participation (Meador et al., 2016; Tenzin and Natsuda, 2016; Belay, 2020).

Farmers' cooperatives are important alternative milk cooling, bulking, marketing, and innovations that enhance the livelihoods of members (Fischer and Qaim, 2012; Shi et al., 2019; Uddin et al., 2022). Farmers' cooperatives are also important avenues for increasing output, providing infrastructure for value addition, cooling, bulking, and safety measures that individual farmers may lack (Wolz and Duong, 2010; Walk and Schröder, 2014). Farmer cooperatives help to improve bargaining power through collective marketing and purchase of inputs in bulk (Mojo et al., 2017; Manirakiza et al., 2020; Muunda et al., 2023), and have the potential to transform local food systems toward more productive and resilient value chains (Amarasinghe and Bavinck, 2011; Shapiro-Garza et al., 2020). Productivity enhancement is made possible through technology use enabled by pulling resources together (Galdeano-Gómez et al., 2006). Farmer cooperatives have been observed to reduce the poverty vulnerability of members by improving income and other benefits (Shen et al., 2022; Liu et al., 2023), as well as positively impacting farmers' wellbeing (Ahmed and Mesfin, 2017). Farmers that use cooperatives to market farm produce in a global value chain, have been found to receive higher prices as compared to those using traditional channels (Wollni and Zeller, 2007). Several factors affect farmers' perception of benefits from cooperatives such as level of education, household size, farm size, farming experience, and support services received, among others (Nyawo and Olorunfemi, 2023). On the other hand, technical training of cooperative members increases the willingness to adopt green production technology (Luo et al., 2022), which is critical for mitigating climate change within food systems.

2 Materials and methods

2.1 Study context

The Umande Farmers' Cooperative Society Limited is located in Laikipia County (Figure 1). The cooperative is located in a semi-arid area receiving less than 700 mm of rainfall per annum. The members of the cooperative are smallholders keeping 2–3 cows on small land holdings ranging from 2 to 4 acres. The average milk output per farmer before the project was 2 liters per farmer during the dry season and 5 L in the wet season. The cooperative was started in 2016 and has 188 registered members who are dairy farmers in Umande Location but only 90 members were supplying milk at the time of data collection. The *ad hoc* formation of the farmers' cooperative in 2016, through the amalgamation of crop-based groups had several challenges; not well aligned with Kenya's milk regulations (Cooperative Act CAP 490), limited skills in commercial dairy farming, low purchasing power, pasture shortages, poor milk handling and hygiene, limited knowledge on good animal husbandry practices, lack of good governance practices, poor methods of milk transportation, lack of cooling facility, limited access to markets, and vulnerability to droughts.

Apart from milk, the farmers in Umande also practice mixed farming which is largely subsistence in nature growing maize, beans, potatoes, and vegetables in addition to raising livestock (cattle, sheep, goats, and poultry) to meet multiple household needs. Some foodstuffs are sold in the local markets making up a significant portion of the local informal trade sector. Other food systems exist in the region including agro-industrial, that produce vegetables for export to European markets and provide employment opportunities for subsistence farmers in the study area. Additionally, the regional food system comprising products such as meat, wheat, and barley value chains occupies a large part of the landscape in Northwest Mt. Kenya region (Jacobi et al., 2020a; Mwangi et al., 2020; Mwangi et al., 2021). The food systems in the area (local, regional, agro-industrial) offer diverse livelihood opportunities, in addition, to sharing scarce resources of water, land, and labor (Peter et al., 2018; Mutea et al., 2019; Mwangi et al., 2020; Mwangi et al., 2021). The resources water and land are scarce in the region because of the following reasons; there is a high demand for water for irrigation by the flower farms, horticulture farms, and smallholders, high population density in the area and high demand for land by multinational companies producing flowers and vegetables for export, commercial ranches, and smallholder farming puts pressure on land resources. On the other hand, labor is very expensive and scarce in the region due to many commercial farms that are preferred employers for wages that support livelihood. This makes it difficult for smallholders to access labor cheaply when the demand on the farms is high.

2.2 Data collection

For objective one, data were collected using 50 members out of the active 90 cooperative members in 2.5-day workshops for the participatory food system assessment. The authors invited all the members of the cooperatives to participate in the workshops, however only 50 out of 90 consistently attended the 2.5-day workshops. For objectives 2 and 3, we used data from two Focus Group Discussions, in-depth interviews with five farmers, and eight key informant interviews (two officials from Laikipia County Government MOALF, two from the Ministry of Cooperatives, and Micro, Small, and Medium Enterprises Development, two staff from a local institution that participated in the knowledge co-production, and two cooperative officials). In total 70 farmers participated in the study exclusive of the Key Informants and in-depth interviews with cooperative leadership and lead farmers. During the workshops we explained the pillars and indicators of food sustainability using Swahili language which is understood by all, second, we agreed on a score of 1–5 (Table 1), and then the farmers scored each indicator through discussions and building consensus. Other activities undertaken during the workshops were sharing experiences from other farmer-led collective actions, discussions on branding of the cooperative, and resource mapping. Postdoc researchers who had been involved in the entire research project right from initiation and had adequate knowledge of the context and the framework facilitated the workshops, shared their experience from other projects in other contexts, explained the framework to the farmers using various drawings, and collected the data from other stakeholders. We applied the FOODSAF tool (Rist

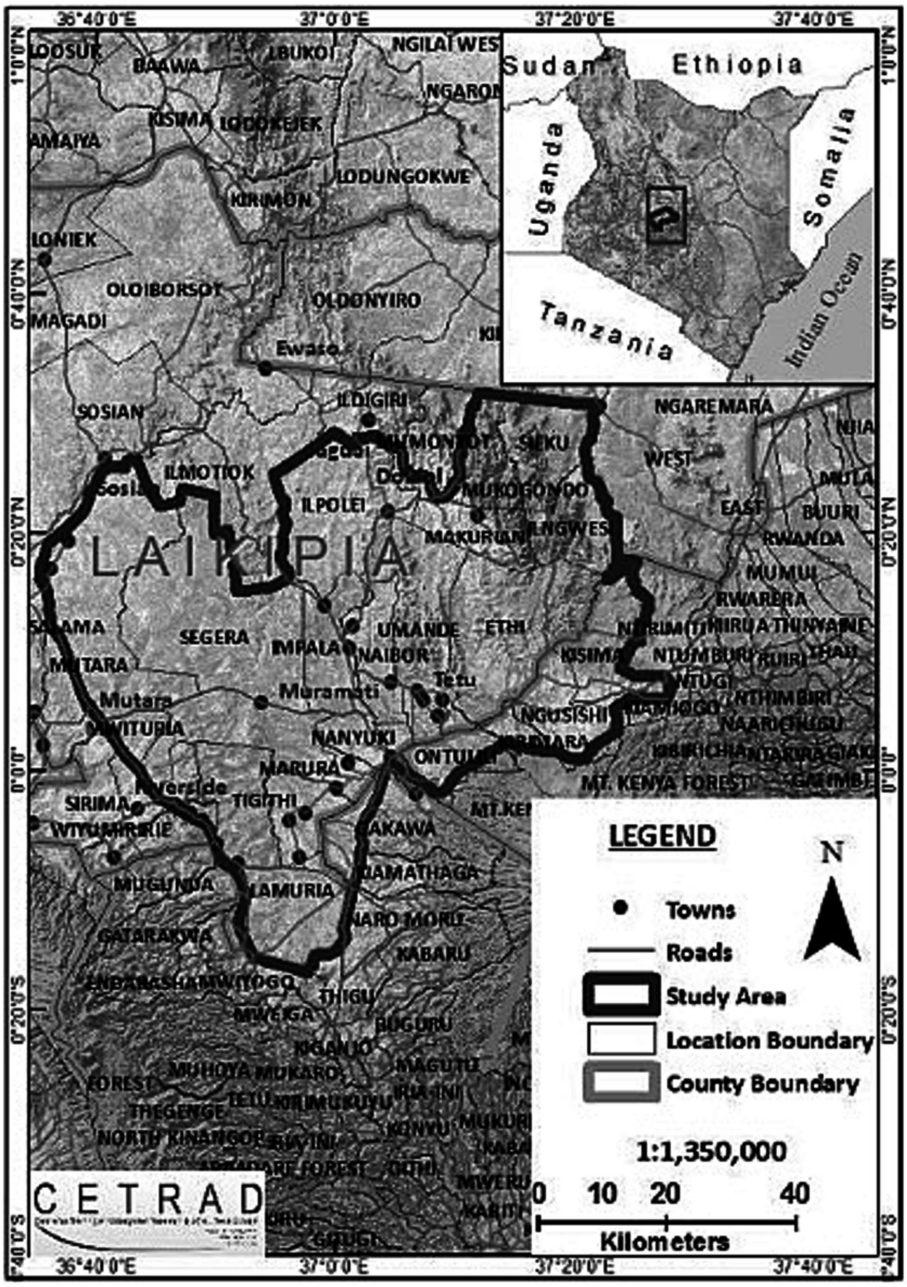

FIGURE 1
Map showing the study area (Source: Mukhovi et al., 2020b).

TABLE 1 Indicators for assessing food sustainability.

Pillars/indicators	Food security	Social-ecological resilience	Environmental performance	Right to food	Poverty and inequality
Indicators (Measurement 1–5 Very Bad to Excellent)	Household food security	Diversity	Impact on human health	Non discrimination	Sources and levels of income
	Power relations	Social-self organization	Carbon footprint	Access to information	Access to social-technological infrastructure
	Capacity of food system to store and process food	Ancestral/local knowledge	Environmental benefits of food systems landscape	Active participation	Performance of food value chains

and Jacobi, 2016; Rist et al., 2021), to assess to what extent the agropastoral food system in which the milk value chain is embedded, contributed to food security, guaranteed the right to food, supported the reduction of poverty and inequality, promoted social-ecological resilience, and protected the environmental resources (Table 1). The participatory process was made possible by the use of a 5-point Likert Scale. To enhance the consistency of the data collected, all the participants used one venue, and the facilitation was conducted by three senior researchers (two of them postdocs and one co-principal investigator) and two additional staff. A Likert scale is a psychometric scale of agreement applied in social sciences to assess respondents' opinions and attitudes about a specific subject (Göb et al., 2007; Batterton and Hale, 2017; Gaitán-Cremaschi et al., 2019; Lionello et al., 2021). The framework and scoring process had been validated in food systems in Zambia, Brazil, and Colombia and found to be useful in the diagnosis of challenges facing food systems and designing interventions through a participatory process. The facilitators for the series of workshops had experience in using the framework in other contexts.

The research was a 6-year research project that started from 2015 to 2021. The first year (2015) was used for scoping, mapping of stakeholders, identifying graduate students, and strengthening the methodology. In the first 3 years (2016–2018), empirical research was conducted to understand the food systems in the two countries Kenya and Bolivia. The second phase of the research was action-oriented (Transformative Pilot Actions using the FOODSAF) research (2019–2022). This study was conducted in the second phase, first by following all the activities to understand the process of knowledge co-creation and how it contributes to development, and secondly by conducting research at the end of activities to assess farmers' and stakeholders' opinions on benefits. The action-oriented research activities were affected by COVID-19, and hence, there was an extension of 1 year. In the second phase, the research was extended to other countries Zambia, Ghana, Brazil, and Colombia. In total, the research facilitated 15 projects (Transformative Pilot Actions) in six countries using the (FOODSAF). Apart from COVID-19, there was a severe drought that affected the study area, and hence farmers could not participate in any activities rather they were allowed to cope with the drought.

2.3 Data analysis

Content analysis was used to analyze data from workshops, FGDs, and in-depth interviews because the data were largely qualitative. The content analysis applied in this study is a naturalistic and interpretive approach and not a quantitative description that relies on reliability, validity, and generalizability (Ahuvia, 2001). This is attributed to the focus of the study which was on the process of coming up with a community-led technology intervention, the perceptions, and opinions of farmers about the benefits of the cooperative, and the milk cooler. Content analysis is used to analyze verbal, audio and video, and visual data (Kleinheksel et al., 2020). The Likert scale data were summarized into tables and then used to draw spider diagrams together with the farmers (Figure 2). The next step was to conduct a rank analysis of the strong and weak indicators to arrive at three agreed-upon indicators (including justifications), to form the next deliberations on the most sustainable intervention that would benefit the majority of the farmers. Data from FGDs and interviews were organized into themes and then ranked by building consensus together with the farmers. Content analysis has been applied in food systems research to analyze qualitative data (Lin and Mao, 2015; Béné et al., 2019).

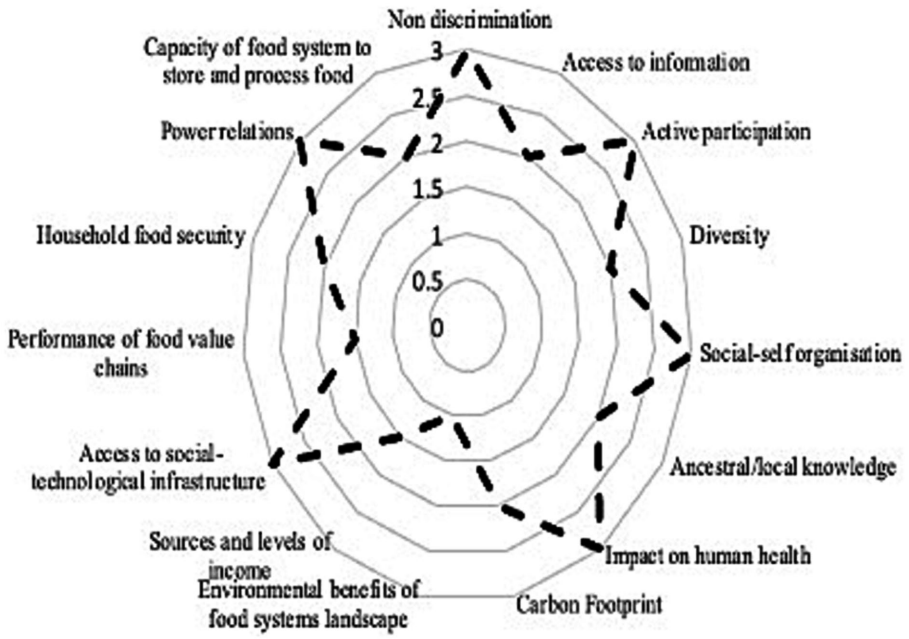

FIGURE 2
Assessment of the strength and weakness of the food system.

3 Results

3.1 Participatory assessment of the food system and problem diagnosis

During the workshops, the farmers participated in the assessment of their food system to identify the strong and weak links. The weakest links in the food system formed the basis of the negotiation of the collective action. The outcome of the assessment showed that the strongest indicator under the food security pillar was power relations with a score of (3). The cooperative members applied mechanisms to manage power within the food system and there were limited power imbalances among the actors. During discussions, one of the members said that '*they are all equal as subsistence farmers*' meaning there were no power differences among actors in the food system. Household food security and the capacity of the food system to store and process food were given a score of (2) meaning fair/satisfactory. The reasons given were that the area is semi-arid hence during droughts they experience food shortages and some households receive relief food. The farmers have limited access to post-harvest management technologies, making food storage and processing at a household level a challenge.

The right-to-food pillar had the highest score for active participation and non-discrimination (3), while the lowest score was access to information (2). The reasons given for the high score were the perceived high level of social-self organization that led to the formation of the cooperative and limited discrimination within the community. However, they perceived that they did not have adequate information about the food they ate from outside. Information from the government to farmers was also limited due to less contact with extension personnel. The poverty and inequality pillar had strengths access to social-technological infrastructure (3), mainly because they are close to passable roads to transport farm produce to the markets; however, the roads were impassable during the wet seasons making transportation of perishable farm produce difficult. The indicator sources and levels of income and performance of the value chain both scored (1.5) attributed to limited direct access to markets. The majority of the smallholder farmers use middlemen who buy farm produce at low prices and sell the same at high prices in neighboring towns due to farmers' limited access to transportation means, muddy roads during rainy seasons, as well as farmers having small quantities of farm produce during some seasons. However, large-scale farmers (horticulture, wheat, and livestock for meat) from the same region access markets directly. This means that the middlemen obtain a higher share of the profit than smallholder farmers (Mwangi et al., 2020). The government can incentivize middlemen by improving infrastructure so that the savings on the cost of transport can benefit farmers.

The strongest indicator under the environmental performance pillar was the health impacts of the food system (3). The farmers perceived their food to be of good quality as compared to people living in cities because their food is "*natural*." The farmers believed that the quality of their environment was not as modified as urban areas—they had some natural plants and animals. However, the carbon footprint indicator had a score of (2), attributed to increased deforestation and limited efforts to restore degraded areas. The environmental benefits of the food system landscape scored (1), meaning very bad (Figure 2). The horticulture, wheat, and flower farms near the community were perceived to be responsible for the heavy use of agrochemicals some of which 'contaminated' the environment, especially water and air. However, there is increasing use of agrochemicals in smallholder agriculture (Jacobi et al., 2019a). For the social-ecological resilience pillar, the indicator social-self organization received the highest score of (3-good) attributed to the ability of farmers to form several groups which were then merged to form a milk cooperative. Social self-organization among smallholders is an important means of overcoming challenges within the food system- challenges that are difficult to tackle at the individual level (Mukhovi et al., 2020a). However, diversity and use of local knowledge both received a score of 2 (fair) because the farmers viewed their farms to be less diverse, used few local seed varieties, and dairy cows were mainly crossbreeds.

3.2 Negotiation for the collective action

The three indicators with the lowest scores were the basis of negotiation for the collective action. These were the environmental benefits of the food system landscape (1), sources and levels of income, (1.5), and performance of the value chain both scored (1.5) (Table 2). After great reflection and negotiation, the farmers prioritized the indicators by building consensus. The performance of the value chain was ranked the highest and hence formed the basis of further deliberations with more stakeholders to initiate a development intervention. Farmers indicated their hard work to produce; however, the farm produce fetched low profit, attributing this to selling through brokers/middlemen. Middlemen play a critical role in the marketing of farm produce in the global south (Abebe et al., 2016; Nguyen Viet and Nguyen Anh, 2021).

The negotiation for the collective action was achieved by several meetings between local institutions and cooperative officials, and later by members of the cooperative. Building trust was not a challenge due to the long relationship between local institutions and the community. Engagement with stakeholders' right from the beginning of the research was important to understand their interests and perspectives. The reasons why the farmers prioritized improving the performance of the milk value chain were; that it has a higher multiplier effect on household income, 95% of the farmers in the area have a dairy cow, and the milk cooling system would promote direct market access (Table 2). Apart from the improvement of the performance of the milk value chain, the farmers required training on dairy farming, value addition, table banking,[3] and cooperative governance. The Ministry officials conducted a training needs assessment and launched a tailor-made comprehensive training together with County government staff from the Ministry of Agriculture, Livestock and Fisheries (MOALF), and Ministry of Cooperatives, and Micro, Small and Medium Enterprises Development.

3 Table banking is an informal savings and credit mechanisms for women where group members meet occasionally, put their savings, loan repayment, and contributions on the table, and then proceed to borrow immediately as long-term or short-term loans as per the interest requirements.

TABLE 2 Lowest scored indicators and justification.

Indicator	Score	Rank	Justification
Environmental benefits of the food system landscape	1	3	• The environment is better than cities because the natural environment is less modified as compared to cities • The biggest challenge faced is pollution by agrochemicals from big companies, and deforestation • The food system landscapes is diverse, intercropping is practiced • The landscape still has biodiversity
Sources and levels of income	1.5	2	• Selling directly to customers will improve household income • Only one processor buys milk from the farmers, the cooperative will expand market
Performance of the value chain	1.5	1	• Poor performance of the value chain due to middlemen • Farmers work very hard on the farm but they get less share of profit due to poor access to market • Improvement of the performance of the value chain will have a multiplier effect on income, livelihoods, and resilience against droughts • At Least each farmer has 1–2 cows hence improving the value chain for milk will benefit majority of farmers • Milk bulking, cooling, and value addition enhances access to existing markets and new ones

3.3 Types and benefits of capacity development

One of the solutions the farmers identified was capacity development on dairy farming and cooperative governance, value addition, milk handling and safety, and best practices in dairy animal husbandry. This was undertaken by strong collaboration with the MOALF at the county level. The ministry identified personnel in the livestock sector and extension staff who conducted a series of practical training sessions for dairy farmers. In total, 200 farmers attended the tailor-made training sessions. The topics covered were; pasture and fodder establishment, dairy cattle feeding, pasture, and agribusiness, group dynamics and cooperative formation, livestock waste management, disease control, breed upgrading, fodder utilization and conservation, silage preparation, market linkages, cooperative governance, quality milk production and milk handling, milk value addition, and resource mobilization, and table banking as well as building social capital. Additional training was on trainers of trainers (TOT) where farmers learned how to be trainers of other farmers for the sustainability of farmer-to-farmer capacity building in the future. One of the farmers donated a section of his land for the establishment of a fodder farm for demonstration purposes. The farmers were trained on different types of fodder and how to establish them.

During this study, we visited several farmers and observed the establishment of Rhode grass (*Chloris gayana*), lucerne (*Medicago sativa*), yellow maize (*Zea mays* L.), mangels (*Beta vulgaris*), Sudan grass, Brachiaria, green leaf desmodium (*Desmodium intortum (Mill.) Urb*), Napier grass, and fodder trees (Marley berry and tree lucerne), which they use to make silage or feed directly to dairy cows. This has contributed to improved feeding and therefore improved milk yield per cow from approximately 3–5.5 L per day (*Interview with a female cooperative member who is a retired extension officer*). As a result of the training, the number of farmers that supply milk to nearby factories increased from approx. 30–71 (*key informant interview*). Demonstration farms have proven to be an effective way of social learning by farmers (Ingram et al., 2018;Sutherland and Marchand, 2021; Mukhovi et al., 2020b). The farmers interviewed indicated that as a result of the capacity development, milk production had increased from 180 L to approx. 500–600 L per day due to improved feeding and increased production per cow as a result of improved breeding made possible by artificial insemination (AI), and the purchase of improved bulls *(interview with one of the founding members of the cooperative)*. Zebu breeds in the region include Sahiwal and Boran, while other semen for AI comes from imported breeds such as Charolais, Simmental, and Hereford. Livestock Breeding Regulations of 2023, established Kenya Livestock Breeding Bureau, provides guidelines on animal genetic resources, AI, livestock and livestock inputs, breed society, breeding standards, embryo transfer, experts, genetic materials, importation of animals or genetic material, indigenous livestock breeding, pastoralists, and service providers among other provisions (Government of Kenya, 2023).

Prior to the training, milk quality and safety were poor due to poor handling and hygiene. This resulted in a daily milk rejection of 50 L by the sole buyer. However, after training, the amount of milk rejected was reduced significantly due to improved hygiene and safety as a result of transporting using stainless steel milk churns instead of plastic jericans and improved handling (*Interview with one of the officials*). Testing of milk quality for somatic cell count to determine subclinical mastitis and quality of milk was done at the factory and other milk cooling plants in the region where the farmers sold their milk. By the time of writing this study, there were several gaps; the machine for milk quality testing to improve safety standards, value addition, employment of experts to support the operation of the cooling machine, and other physical and social infrastructure. However, Zhou and Jin (2009) observed that improvement in food safety standards depends on the size of the cooperative, farmer perceptions and attitudes toward standards, expected market, and anticipated benefits and costs involved. Improved quality of milk is also associated with increased prices. In addition, the cooperative received two motorcycles, one from the Kenya Dairy Board and a second one from a former Member of Parliament to facilitate the transportation of milk safely.

3.4 Farmers' perceptions of the benefits of the cooperative and cooling system

One of the challenges farmers experienced was the marketing of their milk. The second component of the intervention was to construct a cooler house, install a milk cooling system, and establish a transportation system to reduce the middlemen challenge and hence increase the income for farmers (Figure 3). Collaboration with local

FIGURE 3
Milk cooling system.

leaders and county and National governments from the initiation of the project contributed to successful resource mobilization that made the intervention successful. The County government provided land on which the cooler house was constructed, the national government bought the cooling system worth KES. 6M. A local research and training institution—the Centre for Training and Integrated Research in ASAL Development (CETRAD) supported the construction of the cooler house together with the farmers while the community provided labor and locally available materials. The financial resources for the capacity development, construction of cooler house, and purchase of milk cooling and bulking system came from multiple stakeholders; the funder (Swiss National Science Foundation), CETRAD, national government, County government, and the community. Facilitation for other components of the project such as milk transportation and ablution block came from a member of parliament at the time and a Member of County Assembly (MCA).

It was clear from the cooperative members that the livelihood of farmers had improved since the cooperative was formed and they foresee more benefits accruing from the milk cooling system. The farmers never used to sell evening milk;[4] however, with the cooling system and the infrastructure that will be put in place, this will be achieved. Evening milk is a challenge to many smallholders and has been identified as a major reason for the formation of farmers' cooperatives and milk-bulking systems in Kenya (Foster, 2015). The challenges of evening milk are limited access to markets, lack of storage, and limited infrastructure. Sell of evening milk had the potential to increase household income and expansion of the market. Improvement of household income has a positive outcome on expenditure on children's education, food and nutrition, health, and poverty reduction (Cooper and Stewart, 2021).

Milk cooling systems enable farmers to refrigerate evening milk which would otherwise go to waste and also improve milk safety standards hence improving the competitiveness of the cooperative (Foster, 2015; Rojas et al., 2018). Farmers have access to income monthly with extra income generated from other farming activities (poultry and crop farming). Farm performance had a chance of improving as a result of cooperative membership (Verhofstadt and Maertens, 2014) as farmers reinvest income in different dairy and other farm enterprises with the potential to improve the economic and environmental sustainability of the farms (Candemir et al., 2021). Members of the cooperative were also accessing credit and advances to meet emergency household needs. Access to credit by smallholder farmers is a challenge in Kenya as a result of a lack of collateral. This is even worse for women farmers who are constrained by gender rules in African culture (Mukhovi et al., 2020b). Farmers prefer credit from informal sources due to the lack of collateral to obtain from formal institutions (Ullah et al., 2020).

4 Discussion

The cooperative movement in Kenya has largely been successful and has contributed significantly to the livelihoods of smallholder farmers (Meador et al., 2016). Among the benefits that have been observed in Kenya are increased income (Onyango et al., 2023), social capital and improved livelihoods (Kustepeli et al., 2023), and improved local governance (Mukhovi et al., 2020b). One of the limiting factors to increasing productivity among smallholder is access to credit. Cooperatives breach this gap by allowing farmers to save and access credit, among other services provided to the farmers (Kehinde et al., 2021). Other benefits of cooperatives are; a gradual increase in assets, higher yields, a decrease in transportation costs, and increased use of

4 Marketing of evening milk in Kenya is a challenge due to limited access to storage facilities, poor infrastructure inhibiting access to cooling and processing companies, and KDB regulations that prohibit the sale of raw milk.

inputs (Blekking et al., 2021). Capacity building has been supported as a key intervention for food system transformation (Alanya et al., 2021). Building the capacity of farmers in dairy farming and governance of the cooperative is critical in ensuring sustainability (Tassew and Seifu, 2009; Marsden et al., 2018; Leeuwis et al., 2021; Alanya et al., 2021). While capacity building, governance, savings, and credit are important in sustaining a young cooperative, the sustainability of any intervention requires continuous monitoring by policy enforcers to guarantee safety.

Creating innovations in food systems based on livestock has a higher impact due to the subsector's important role in poverty alleviation especially in marginal areas (Millar and Photakoun, 2008; World Bank, 2022). Livestock production is an important source of income, capital assets, draught power, organic fertilizers, and food and nutrition security (Dolberg, 2001). However, the livestock value chain is characterized by unorganized supply chains and fragmented infrastructure where the smooth flow of livestock products from the producer to the customers is still a big challenge (Pingali et al., 2019). Inefficient supply chains coupled with limited innovation, fodder scarcity, poor breeds, poor access to markets, limited skills in improved animal husbandry, and poor infrastructure, reduce the competitiveness of livestock enterprises, negatively affecting the livelihoods of herders and farmers (International Livestock Research Institute (ILRI), 2008; Larbi et al., 2010; Ashley et al., 2018; Lovemore et al., 2019). Other challenges include; low levels of innovation, limited social learning, fragmented markets, limited collective action, limited support from the government, and limited resource mobilization (Ayele et al., 2012: Ainembabazi and Mugisha, 2014; Andersson and D'Souza, 2014; Mwangi et al., 2020). Contractual agreements between producers and processors are also limited contributing to low profits due to operating individually and on a small scale (Pacheco et al., 2018). In addition, direct market linkages by livestock farmers are limited due to small quantities of milk, and sometimes domination of the marketing by middlemen (Abebe et al., 2016). A cordial relationship and mutual benefits between producers and middlemen may also exist (Fischer and Qaim, 2012; Abebe et al., 2016: Van Nguyen et al., 2022).

Collective action helps in solving multiple challenges of productivity, market access, and household income (Markelova et al., 2009; Fischer and Qaim, 2012; Llanque-Zonta et al., 2021). Farmer groups have also been identified as an important catalyst for innovation that can increase adaptive capacity against risks, enhance social learning and social capital (Kopytko, 2018; Jacobi et al., 2019b; Hulke and Revilla Diez, 2020), and build social-ecological resilience (Mukhovi et al., 2020a). Increased productivity, improvement in incomes and food security, and poverty reduction are also important outcomes of collective action (Markelova and Mwangi, 2010; Shumeta and D'Haese, 2018). However, institutional arrangements are important for the sustainability of collective marketing for smallholders (Shiferaw et al., 2009; Markelova and Mwangi, 2010). Incentives for increased participation of farmers in groups are crucial in maximizing the benefits of collective action to members (Fischer and Qaim, 2014; Qu et al., 2020; Das and Singh, 2024).

Transdisciplinary research projects are intended to transform policy and practice, due to them being intentional in working together with policymakers and communities right from the initial stages (Roux et al., 2017; Jacobi et al., 2020b). However, not all transdisciplinary research creates meaningful change in society due to various reasons; time constraints, difficulties in managing the expectations of the stakeholders, preoccupation with deliverables, and researchers not understanding the local context (Llanque-Zonta et al., 2023). Transdisciplinary research's impact on policy is also critical, however, this is often challenging to achieve in the short term (Roux et al., 2017; Maas et al., 2022; Jacobi et al., 2020b; Llanque-Zonta et al., 2023). Some scholars have also observed a tendency of transdisciplinary research to be dominated/led by scientists from the global north (Schmidt and Neuburger, 2017; Boampong et al., 2024), who often drive the research agenda and sometimes may not have adequate time and resources to invest into understanding rooted challenges in the global south. Power relations in north–south collaborations may also affect the outcome of transdisciplinary research in the global south (Schmidt and Neuburger, 2017). Decolonizing transdisciplinary science has therefore been looked at as one of the pathways to bringing balance between the global north and south (Chilisa, 2017; Llanque-Zonta et al., 2023).

5 Conclusion

This research has demonstrated how context-specific innovations can be achieved through transdisciplinary research where knowledge is co-created for change in society. The case study has shown that transformative knowledge co-creation for development must first start with understanding the context, in this regard, the food systems in which the innovation is embedded. Failure to understand the context may create innovations that are not owned by the community and that are unsustainable. In-depth empirical evidence compared with farmers' knowledge and perspectives of their context can support the accurate diagnosis of the root challenges and the design of collective action that benefits the majority. Ownership and sustainability of the innovation can also be made possible by a participatory process where the farmers define the objectives and desired development outcomes. Collaboration with stakeholders such as county line ministries guaranteed the bolstering of the innovation to a more self-sustaining farmers' cooperative in the future. Despite its strengths, transdisciplinary research has been criticized for having several limitations; deals with complex deeply rooted challenges, involves less robust processes, limited quality controls, and inability to reproduce results in different contexts (Bunders et al., 2015).

Capacity development of cooperative members was a settling factor for sustainability due to its determining force in sustaining milk productivity. Mobilization of membership, expansion of the herd of individual farmers, and ensuring high productivity per dairy cow are urgent to make the cooperative competitive. Although the farmers and stakeholders achieved some milestones in the initiation and implementation of the innovation, the sustainability of the collective action will depend on the line ministry's commitment to nurturing the project, private–public partnership, and commitment of the founding members to remain steadfast in providing leadership and safeguards for the project. Incentives for more farmer-led innovations are necessary in different contexts to overcome challenges that are impossible to deal with individually.

Priority areas for upscaling and improvement include; (a) establishment of cold chains for milk collection and processing for smallholders to reduce post-harvest losses, (b) diversification of

markets to sustain increased productivity resulting from capacity development, and milk bulking, (c) extended farmer-to-farmer learning through exchange visits to well-established farmers' cooperatives, (d) increased government support to smallholder farmers' cooperatives through cheaper loans, donations, access to extension services, and physical and social infrastructure, (e) rigorous campaigns to increase cooperative membership, (f) engagement of experts and purchase of equipment for milk quality testing, value addition, and other related infrastructure, and (g) further expansion of the transportation means for efficient milk delivery. Future research should test hypotheses on the impact of the cooperative and milk bulking on the socioeconomic wellbeing of farmers by comparing conditions before and after as well as comparing cooperative members and non-members.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/supplementary material.

Ethics statement

Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

SM: Conceptualization, Funding acquisition, Methodology, Writing – original draft, Writing – review & editing. BK: Conceptualization, Funding acquisition, Methodology, Project administration, Validation, Writing – review & editing. JM: Investigation, Validation, Writing – review & editing. GW: Investigation, Validation, Writing – review & editing.

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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.

Publisher's note

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