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Identifying governance challenges in scaling biofortification programs and the potential of training: a case study of Uganda

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Introduction: Biofortification initiatives can significantly help reduce micronutrient deficiencies in developing countries. However, when hidden hunger affects a large segment of the population, large-scale implementation is necessary to achieve the desired results. We aimed to identify governance challenges in biofortification, and potential remedies based on a conceptual framework that considers low demand and the invisible nature of micronutrient traits in crops.

Methods: Using process net maps and quantitative methods, this paper explores how farmer training can address governance issues.

Results: Results show that, in addition to common agricultural marketing issues, sweet potato vine multipliers struggle with vine supply, value chain actors adulterate iron beans, and consumers are hesitant to pay higher prices for biofortified crops. These problems may result from information asymmetry, merit goods, collective action issues, and free riding. Furthermore, training had little impact on reducing the governance challenge arising from information asymmetry.

Discussion/conclusion: One of the key solutions was investing in subsidies to increase production and raise awareness of the importance of nutritious foods. With governance problems, there is a need to take them into consideration when planning and expanding biofortification programs.

KEYWORDS

training, biofortified crops, governance challenges, scaling, process net map

1 Introduction

Biofortified crops must be rapidly developed, adopted, and scaled to address the current micronutrient deficiency, where 17% of the world population has inadequate micronutrient intake (Beal et al., 2017). The focus of biofortification for scale-up needs to be on the adoption of biofortified crop varieties, as well as policy, institutions, and markets (Deissy et al., 2024). The literature on biofortification to date has shown potential benefits in terms of yield, micronutrient intake, and health (Funes et al., 2019; Haas et al., 2016; Finkelstein et al., 2015). Scholars in scaling innovation literature suggest that ignoring governance challenges in program implementation might hinder the widespread adoption of the innovation (Birner and Sekher, 2018).

Scaling biofortification involves expanding programs across extensive regions to maximize their impact (Wigboldus et al., 2016). In Uganda, this includes breeding iron-rich beans,

orange-fleshed sweet potatoes, and Vitamin A maize, as well as seed production, dissemination, cultivation, processing, and consumption. While considerable progress has been made in understanding how to scale agricultural innovations (Hermans et al., 2016; Schut et al., 2020; Wigboldus et al., 2016), a research gap remains concerning governance challenges specific to scaling biofortified crops. This paper examines these governance issues and suggests potential solutions. A significant challenge arises from the nature of biofortified crops as a “merit good” with an invisible micronutrient trait. Since their nutritional benefits are not visually apparent, consumer demand may remain low, leading to market failures that hinder widespread adoption. Although existing research on agricultural scaling exists, few studies have focused on how governance structures can address market and visibility barriers to accelerate biofortification initiatives (Bouis and Saltzman, 2017; Meenakshi et al., 2010; Birol et al., 2015; De Steur et al., 2017). By filling this gap, the study aims to enhance scaling strategies for biofortified crops in Uganda and similar contexts.

Governance has been defined within the context of managing common pool resources, vertical integration and business activities, as well as boards and corporate governance (Ostrom, 1990; Williamson, 2005; Doornbos, 2003). In this study, we employ the definition derived from new institutional economics, which conceptualizes governance challenges as “characteristics of formal and informal institutions that jeopardize positive development outcomes” (Burnside, 2000). When scaling biofortification projects, we identify three types of governance, namely “the market, state, and community.” Consequently, any challenges that impede the functioning of these sectors are designated as market failure, state failure, and community failure (Birner and Sekher, 2018).

Identifying solutions to governance challenges is crucial for effective policy formulation (Birner and Sekher, 2018). Studies have shown that legislation, training, and supervision are among the solutions to governance challenges (Birner and Sekher, 2018; Lubungu and Birner, 2018). The training and awareness creation may be correlated to the demand and adoption of improved crop varieties. Farmers’ awareness of seed quality in maize is linked to higher yields (Hsu and Wambugu, 2022). However, few studies have examined the role of training and awareness in farmers’ ability to identify seed quality from the physical attributes of the seed. The invisible traits of iron in beans exacerbate the problem of poor-quality seeds. HarvestPlus (2018) noted that iron bean seeds share similar attributes with other bean varieties, albeit with slight differences. Low-quality inputs, particularly fertilizers and seeds, are prevalent in developing countries, negatively impacting farmers’ productivity and income. Ashour et al. (2016) have demonstrated the impact of low-quality inputs on productivity. Fake inputs can drive good quality inputs out of the market (Akerlof, 1970).

Transaction theory has been employed to explain the existence of governance challenges within development initiatives. It suggests that economic agents choose governance arrangements that minimize the costs associated with economic transactions (Williamson, 1985). In essence, various governance structures are expected to emerge in economic exchanges to optimize cost efficiency. The extensions of this theory provide a foundational basis for analyzing governance challenges observed in studies of fresh vegetable value chains (Eaton et al., 2008), rural service delivery (Birner and Braun, 2009), and veterinary service delivery (Illukor et al., 2015). Drawing upon these studies, three governance structures applicable to large-scale biofortification may

be found, namely spot markets, modular/relational, and vertical integration. The spot market governance structure involves farmers selling to conventional buyers—typically on a daily, weekly, or monthly basis. The modular structure involves farmers organized within cooperatives, while the relational structure pertains to farmers selling to aggregators (Kwikiriza et al., 2018). Spielman and Smale (2017) found that vertical integration in the seed system involves policies that enable farmers to access improved seeds, including biofortified seeds, through seed systems that encompass breeding, production, and delivery.

Uganda’s biofortification program deserves focused attention for several compelling reasons. For one, the country has over 20 years of experience in this area, making its initiatives among the longest-standing globally. This work has been driven by a coalition of organizations, including HarvestPlus, the International Potato Center (CIP), and the National Agricultural Research Organization (NARO). These initiatives include programs such as Reaching End Users (REU), the Sweet Potato for Profit and Health Initiative (SPHI), Developing and Delivering Biofortified Crops (DDBC), and Meal for Nutrition (MENU). Secondly, the program has achieved significant progress in scaling biofortified crops, with the release of six iron-rich bean varieties and 12 Orange Fleshed Sweet Potato (OFSP) varieties, both of which are rich in essential nutrients. It is estimated that by the end of 2020, approximately 1,000,000 households were cultivating iron beans, and 1,100,000 households were growing OFSP (HarvestPlus, 2020). This corresponds to an estimated 2.0% of bean production and 3.2% of sweet potato production in 2020 being biofortified.

We hypothesize that training on the identification of biofortified crops would reduce the governance challenge arising from biofortified crop products being merit goods and the invisibility of the micronutrient traits in the products. This paper aims to explore the role of training and awareness creation in increasing demand for biofortified crops, which are considered merit goods and possess invisible traits. Our research questions are: What governance challenges can be observed in biofortified crop programs in Uganda? What are the process and influence levels of the actors in the implementation of biofortification? Does training and awareness creation address the governance challenges?

Our study contributes to the literature of institutional economics by examining the role of training and awareness in mitigating governance challenges within value chains. The literature on governance challenges appears to be particularly highlighted in livestock programs, vaccination (Lubungu and Birner, 2018), nutrition (Birner and Sekher, 2018), and innovations, as well as mechanization (Van Loon et al., 2020; Daum and Birner, 2015). Specifically, Adu-Gyamfi et al. (2017) found seed adulteration in the Ghanaian maize seed system.

The paper proceeds as follows: in Section 2.0, we present the conceptual framework and identify governance challenges based on economic theory and literature on the food value chain. We describe the methods in section 3.0, while section 4.0 presents the empirical results and discussions. Lastly, section 5.0 includes conclusions and policy recommendations.

2 Governance challenges and biofortification

The primary governance challenges in large-scale nutrition programs stem from inefficiencies in the market. The question we aim

to answer is why market institutions are ineffective in addressing the problem of hidden hunger. Market failure may lead to governance challenges due to information asymmetry and the nature of biofortified crops. Biofortified crops are nutrient-enriched crop varieties with higher micronutrient content than other crop varieties (Lockyer et al., 2018). Biofortified foods may be considered a merit good, a good that people undervalue because they do not know their future benefits. The private sector, including processors and traders, does not easily enter these types of goods markets, as there is limited demand (Birner and Sekher, 2018). Poor consumers have high time discounts; in other words, they are not willing to offer a higher premium for products whose benefits are in the future (Mann, 2003; Birner and Sekher, 2018).

Information asymmetry appears to constitute a prevalent market failure for two primary reasons: firstly, biofortified crop products, such as those enriched with nutrients, have demand that is contingent upon the availability of nutritional information (Birner and Sekher, 2018). Secondly, consumers often struggle to assess the quality of these products or verify health claims. For instance, farmers cannot verify the quality of the seeds they purchase, whereas consumers of iron-rich beans cannot readily validate the iron content (Birner and Sekher, 2018). It is recommended that governments address this market failure by incorporating minimum nutritional standards—such as iron content—as a core mandatory criterion within a comprehensive varietal release system. This system should also evaluate and promote traits that are essential for both farmers (e.g., yield, climate resilience) and consumers (e.g., preferred taste, cooking time). Such measures will ensure that new bean varieties are not only nutritious but also productive, profitable, and desirable. Simultaneously, non-governmental organizations can play a role in raising awareness and developing capacity for quality monitoring.

The community has the capacity to organize into farmer groups within the production system, facilitating the allocation of goods and services in instances where state and market mechanisms are inadequate. Nonetheless, these communities frequently encounter governance challenges attributable to free riding (Birner and Linacre, 2008). The free-rider issue in collective action arises from the inherent nature of seed saving for iron beans and vines, wherein farmers share and utilize saved seeds, thereby disincentivizing the development of community-based seed multipliers and private sector investment (Olson, 2009).

In cases of market failure, the public sector sometimes intervenes in production systems to regulate, but most of the time, it is limited in its capacity (Feder et al., 2010). One of the underlying reasons for the governance challenges faced by the state is the high transaction intensity in agricultural programs (Birner and Linacre, 2008). The involvement of many transactions and face-to-face interaction makes the transaction intense (Pritchett and Woolcock, 2004). In transaction cost economics, transaction intensity relates to transaction frequency (Williamson, 2005; Birner and Linacre, 2008). The widely dispersed production units for agricultural products are primarily located in remote, rural areas (Birner and Braun, 2009; Birner and Linacre, 2008). Due to transaction intensity, governance systems such as cooperatives that are closely linked to farmers can overcome transaction intensity challenges (Sastri and Raju, 2005; Oruko and Ndong'u, 2009).

Some of the governance challenges facing the state include procurement challenges, such as the leakage of funds and inadequate

supervision (Birner and Sekher, 2018; Lubungu and Birner, 2018). Conventionally, corruption involves demanding bribes, stealing, misusing public resources, and influence peddling (Komakech, 2019). Bribery is the most prevalent form of corruption in Uganda, accounting for up to 25% of the contract sum (Komakech, 2019). Corruption manifests in the implementation of biofortified programs through public procurement of supply vines and iron bean seeds. For example, due to bribery, suppliers are not selected based on their technical capacity (Mihály et al., 2021). The selected suppliers should have invested in the production of OFSP vines, unless they supply low-quality vines, which drives the actual vine multipliers out of business. The overall effect is the supply of poor-quality seeds that may lead to a phenomenon economists call the “lemon market” (Akerlof, 1970). Reducing corruption requires the government to implement legislation and foster a well-informed community (White, 2004).

3 Methods

We employed both qualitative and quantitative research methods to examine Uganda's governance challenges in expanding the biofortified crops program. Initially, qualitative Process Net-Map workshops with stakeholders identified key barriers to scaling, including seed adulteration. This process generated a range of potential strategies to reduce adulteration, including seed tracing, premium pricing for quality products, stricter enforcement mechanisms, and training. To transition from mapping to evidence-based action, we quantitatively assessed the effectiveness of training through field lab experiments, as it is cost-effective, empowers farmers, and promotes ethical practices, albeit with a slower impact. Combining multiple research approaches helped with understanding the problems encountered with program implementation.

3.1 Process net-map

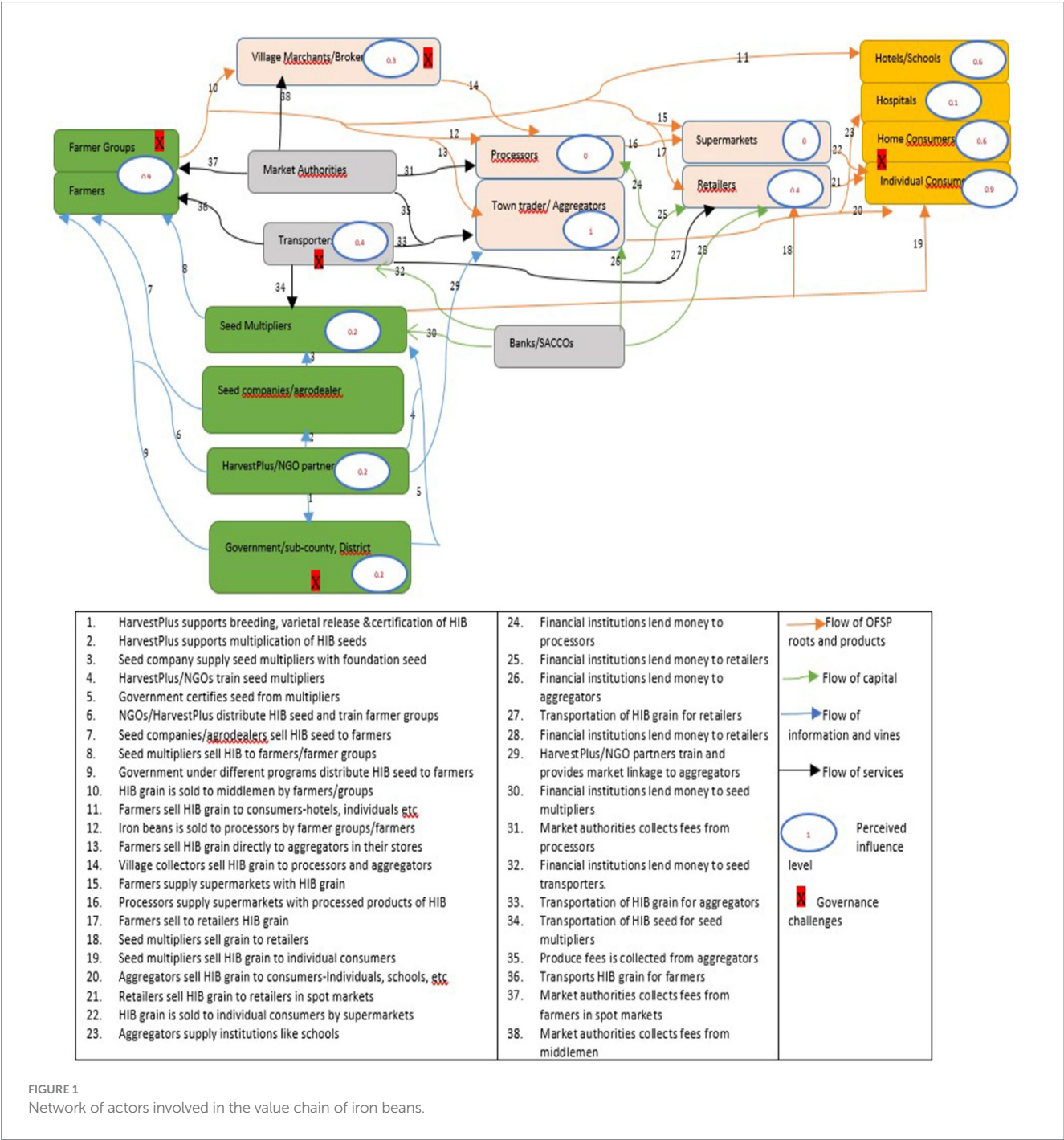
To identify governance challenges, we employed the Process Net-Map (PNM) tool, which tracks sequential processes in program implementation to identify governance failures, power concentrations, and deviations from plans (Schiffer and Hauck, 2010; Birner and Sekher, 2018). This method has been applied to analyze governance in nutrition programs, seed systems, and mechanization across Africa and Asia (Illukor et al., 2015; Adu-Gyamfi et al., 2018). We used purposive sampling to engage 63 stakeholders (32 iron bean and 31 OFSP maps) with strategic and operational roles, ensuring a multifaceted view from policy design to on-the-ground execution. The process involved four steps. First, respondents mapped actors and their linkages (including information and product flows) using sticky notes and arrows on paper. Second, they rated each actor's influence (0–8) using checker-piece “towers” and explained their ratings. Third, they identified problems and responsible actors. Fourth, they proposed solutions. Discussions were transcribed, translated, and analyzed in MAXQDA to code themes, challenges, and solutions, while descriptive statistics were generated from influence ratings.

Our governance study was to assess whether scaling biofortified crops involves unique challenges compared to other improved varieties, such as beans. Although the actor network—comprising researchers, seed producers, and NGOs—is similar, we expected roles

and interactions to differ based on the product attribute, such as hidden nutrition (biofortification) versus visible traits like improved varieties. Our Process Net-Map findings, involving 286 actors, confirmed the network could be divided into four functional groups (see Figures 1, 2): (1) Seed Production & Primary Production (e.g., NARO, CIP, farmers); (2) Product Development & Market Delivery (e.g., processors, aggregators); (3) Service & Capital Provision (e.g., financiers, extension services); and (4) Consumers. Importantly, the key difference is not in actor types but in governance challenges. For biofortification, a significant obstacle is establishing a value chain where the primary benefit (nutrition) cannot be visually verified. This necessitates complex coordination for identity preservation,

traceability, and consumer trust to avoid adulteration—issues that are less critical for traits like heat tolerance, which offer yield stability directly to farmers.

The study was conducted in 10 districts within HarvestPlus’s main delivery areas in Northern Uganda (Gulu, Amuru, Omoro), Eastern Uganda (Mbale, Kamuli, Bukedea, Serere, Ngora), and Western Uganda (Hoima, Kakumiro). These regions are marked by high poverty levels (MFEPD, 2023) and have seen over 10 years of HarvestPlus efforts promoting biofortified crops through market linkages, radio campaigns, and machinery distribution (HarvestPlus, 2018). Participants included national managers, district officers, seed multipliers, and farmer groups—averaging seven people per



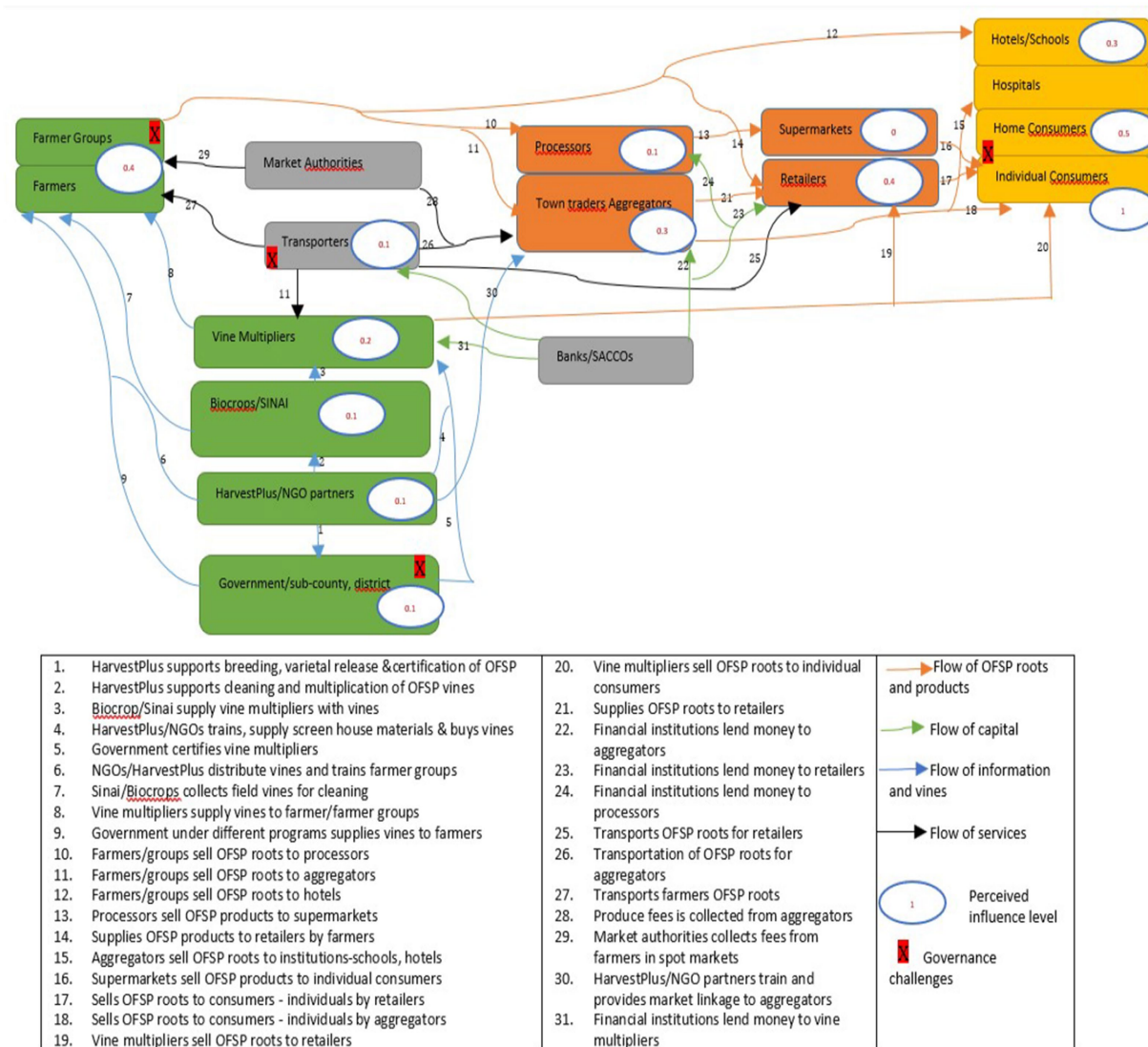


FIGURE 2
Network of actors involved in the value chain of OFSP.

map—chosen based on their availability and role. This method ensured the maps reflected real operational conditions, not just theoretical plans. It provided detailed insights into governance challenges related to biofortification's less visible aspects, such as the need for strict quality control and consumer education to maintain market integrity.

Data collection took place in two phases. The first phase occurred between January and April 2021, while the second phase took place in December 2021. The second data collection phase aimed to verify the results from the first and to collect additional information for the case study of aggregators. We recruited and trained six enumerators to collect data during Process Net-Map and in-depth interviews. All interviews were audio-recorded with the respondent's consent.

3.2 Training and identification of iron beans

We conducted a field lab experiment to evaluate the impact of providing extra training on farmers' ability to identify different iron

bean varieties. It is essential to note that all farmers involved had already received standard agronomic training from institutions such as HarvestPlus on growing iron bean varieties. Our intervention provided the treatment group with additional, specific details regarding physical features, such as seed size, color, and shape, to aid post-harvest identification—a tactic aimed at raising consumer awareness and preventing market adulteration. Field lab experiments, increasingly popular in economics for studying behavior and policy impacts (Fairbairn, 2017; Ashour et al., 2017), were perfect for this purpose as they complement randomized controlled trials and surveys. Farmers were selected from groups in six districts who had previously grown at least one of the six released iron bean varieties (e.g., Narebean 1, 2, 3 in the west; distributed by HarvestPlus, 2018), ensuring a basic level of familiarity with these varieties. Two groups per district were randomly selected, with 7–8 experienced farmers purposively chosen for each group and then randomly assigned to either the control or treatment group.

The experiment involved preparing 22 samples (each 100 g) of iron beans and comparable non-iron varieties, all of which were placed in transparent polythene bags. For Narobeans 1–3, two non-biofortified varieties were included per type; for Narobebean 4, only one was included. To ensure that physical traits are attributable to varietal genetics and not influenced by agronomic or environmental factors, the seed samples used in the experiment were sourced from certified suppliers to represent standard phenotypic expressions of each variety. The treatment group was trained on iron bean features —such as grain coat color and size —mimicking information from radios, extension workers, or peers. In contrast, the control group received no such training. Farmers then tried to identify the samples, with their responses recorded as correct or incorrect after about an hour. A total of 85 farmers (72% women, aligning with NGO efforts to target women for food security crops) participated, providing 340 observations. Random assignment resulted in 42 control and 43 treatment farmers, although initial differences in age, land size, and market distance existed (see Table 1). The results showed a modest impact, with 46% of control and 50% of treatment farmers correctly identifying the iron beans.

To evaluate the impact of training provision on outcomes, we employed a correlated random effects model (Equation 1). This model accounts for bias from unobservable covariates and permits the use of constant group-level factors (Wooldridge, 2013; Jeffrey et al., 2019). It controls for socioeconomic, institutional, and regional variables, including prior experience with specific varieties. This deliberate design choice aims to test supplemental training in real-world conditions, where farmers already possess some agronomic knowledge. Such an approach helps determine whether additional training can improve results within actual agricultural constraints and if targeted training can boost outcomes following standard extension services.

$$y_{it} = \alpha + \beta x_{it} + \gamma \bar{x}_i + r_i + \mu_{it} \quad (1)$$

where y_{it} is the correct or false identification of iron beans by farmer i and variety t , x_{it} is a vector of independent variables, including training, r_i is the uncorrelated error term with x_{it} and μ_{it} is the idiosyncratic error term.

TABLE 1 Number of process net-maps conducted.

Stakeholder category	Iron beans	Orange fleshed sweet potatoes	Approach
Aggregators	4	4	PNM
Retailers	6	6	PNM
Farmer groups	11	10	PNM
Processors	1	3	PNM
Seed multipliers	3	4	PNM
NGO partners	3	3	PNM
Schools	1	1	PNM
Total	29	31	

PNM is Process Net Map.

4 Results

This section presents the findings of the Process Net-Maps and field lab experiment. First, we present results from aggregated Process Net Maps from various actors. Next, the governance challenges associated with scaling biofortified foods are discussed. In the field lab experiment, we present the results of the effect of information provision on the correct identification of iron beans.

4.1 The process net map

To elucidate the governance challenges in implementing biofortification, we began by mapping the key actors. Results from the Process Net-Maps indicated that actors involved in scaling biofortified crop programs could be grouped into four major categories based on their roles, as shown in Figures 1, 2. The first category of actors is involved in seed production, delivery, and primary production. These include the National Agricultural Research Organization (NARO), the International Potato Center (CIP), HarvestPlus, partner NGOs, government agencies, seed companies, seed multipliers, farmer groups, and individual farmers. The second group of actors is involved in product development and delivery from farmers to consumers. Examples include village collectors, processors, aggregators, supermarkets, and retailers. They provide a market for farmers' produce, add value, and make biofortified products available to consumers. The third group, coded gray, provides services and capital. The last group of actors is consumers, ranging from individuals to institutions, coded beige.

The food value chain of iron beans and OFSP begins with seed production, as this study highlights, due to the vital role seed multipliers play in supplying clean planting material. Farmers make various decisions in acquiring planting material, allocating land between biofortified crops and non-biofortified crops, preparing the land, planting, and utilizing the produce. With the help of HarvestPlus and partners, farmers acquire the necessary skills for biofortified crop production through group platforms, radios, and television. The Process Net-Map discussion indicated that farmers sell their iron bean grain and OFSP roots to individual consumers, aggregators, processors, retailers, schools, and hotels (arrows 10, 11, 12, 14 for OFSP). The presence of village collectors in iron beans differentiates it from the OFSP value chain (arrows 10, 11, 12, 13, 15, 17). Though the spot market governance structure, where market authorities collect fees, seems familiar, HarvestPlus and its partners have developed modular and relational governance systems (arrow 29 for iron beans and 30 for OFSP). In modular governance, farmers are organized in groups to add value to OFSP by processing roots into flour. Another important relationship in scaling the biofortified crops program is between aggregators and farmers. Transporters' banks, village-level savings and loan associations provide transportation services and capital in the food value chain.

Comparing the Process Net-Maps for the OFSP and iron beans revealed that respondents had identified similar types of actors and their roles. Similar studies on governance challenges have shown convergence among participants on the roles of actors and governance challenges but differ in their perceived influence levels (Birner and Sekher, 2010; Ilukor et al., 2015; Adu-Gyamfi et al., 2017). The variation in the number of actors, roles of actors, and governance

challenges between iron beans and the OFSP program implementation may be due to the nature of the crop. One key difference is that OFSP roots are perishable, while iron beans can be stored for an extended period. Secondly, the results showed that OFSP processors are in rural study districts under the modular governance system. In contrast, the iron beans processing plant is situated in Kampala, the capital city. The extent and role of supermarkets and institutional buyers, such as schools and aggregators, were similar for iron beans and OFSP. However, few supermarkets are yet involved in selling iron beans and OFSP food products.

4.2 Influence levels of the actors

Our analysis of actor influence, presented in Table 2, highlights key players and governance challenges affecting the scaling of biofortified crops. We developed a normalized, weighted influence score (ranging from 0 to 1) that considers both perceived importance and the frequency of actor mentions in Process Net-Map discussions, as infrequent mentions with high ratings could skew the results. Respondents identified consumers as the most influential actors, as they created market demand. Households that consume their own produce formed a significant group, with influence scores of 0.6 for iron beans and 0.5 for OFSP, aligning with other studies that noted “most household production is for own consumption” (HarvestPlus, 2018). Market consumers and schools appeared as up-and-coming channels for market-led scaling—schools offering nutritional benefits for children and providing stable market links for farmers.

Supermarkets and processors were seen as the least influential, probably because there are few processed biofortified products available in formal markets. This contrasts with studies showing the importance of supermarket contracts for vegetable farmers in Kenya (Ogutu et al., 2020). Aggregators were highly influential for iron beans (score 1.0) but less so for perishable OFSP (score 0.3), demonstrating how product traits influence actor roles. Seed system actors (such as NARO, seed companies, HarvestPlus) received unexpectedly low scores (0.1 for HarvestPlus), despite their key supply functions. This indicates a disconnect between their development contributions and their perceived influence in the value chain. It appears that while these actors promote initial adoption through breeding and awareness

efforts, their influence seems to decline once products enter the commercial market.

4.3 Governance challenges in the scaling of biofortified crops

In Section 2.0 of this paper, the conceptual framework outlines various factors that may lead to governance challenges in scaling biofortified crops. Using a field study, we present empirical results on governance challenges in Table 3 based on content analysis during the process of net maps. We limit the governance challenges to vine multipliers, aggregators, processors, and retailers, as shown in Figures 1, 2, to stay within the scope of the study.

4.3.1 Problems in the supply of OFSP vines by multipliers

The problem with the supply of vines was mentioned by 35% of participants in the process net map discussions. The governance challenge mentioned was corruption in the procurement of vines to be given to farmers as subsidies. Government and NGO procurements of vines are the most significant single-source sales for vine multipliers, as they involve large quantities procured at premium prices. Respondents noted that governments and NGOs procure, on average, 500 bags of vines at 40,000 Ugandan shillings, compared with a bag at 5,000 Ugandan shillings by individual farmers. Farmers have less incentive to buy vines because of free riding, where farmers save and share common vines (HarvestPlus, 2018). Government and NGO procurements of OFSP vines are motivated by the economic benefits of the projects, specifically the reduction of micronutrient deficiencies. The large quantities of vine procurements are subject to abuse by district or subcounty technical people. By design, the vine multiplier applies to a supply contract, with the application processed through a standard contracting procedure. One participant stated that “technical people in the district charged with ensuring the quality of planting material delay verification of our supplies so that we can pay kickbacks”. The power to demand a kickback payment is derived from the recipient’s authority to provide a signature required in the release of funds process. Birner and Sekher (2018) identified actors who sign for funds in government offices to be involved in corruption.

TABLE 2 Descriptive statistics of farmers participating in the field lab experiment.

Variable	Treatment (n = 43)	Control (n = 42)	Difference
Identification (% of correct identification of iron beans)	50	46	
Household size	8.00	6.64	1.54**
Age of farmer (years)	44.21	36.93	7.28***
Distance to the nearest output market (Km)	2.39	2.36	0.03
Distance to the nearest agrodealer (Km)	2.43	2.46	0.04
Sex of the farmer (1 = female, 0 = otherwise)	0.64	0.53	0.11
Land (ha)	1.39	1.89	0.50*
Log Income	14.61	14.85	0.25
Credit (1 = received credit, 0 = otherwise)	0.28	0.18	0.11
Extension service (1 = extension, 0 = otherwise)	0.46	0.39	0.07
Total livestock units	1.78	1.21	0.57

TABLE 3 Perceived influence levels of different actors in the biofortified food value chain.

Actor	Iron bean				Orange sweet potatoes			
	Mean	Min	Max	Range	Mean	Min	Max	Range
Individual consumers	0.94	3.00	8.00	5.00	1.00	3.00	8.00	5.00
Household consumers	0.63	8.00	8.00	0.00	0.48	6.00	8.00	2.00
Hospitals					0.08	5.00	7.00	2.00
Hotels	0.57	5.00	8.00	3.00	0.30	1.00	6.00	5.00
Schools	0.61	2.00	8.00	6.00	0.43	4.00	8.00	4.00
Transporters	0.40	3.00	8.00	5.00	0.02	4.00	4.00	0.00
SACCO/Banks	0.11	2.00	6.00	4.00	0.02	1.00	6.00	5.00
Supermarkets	0.01	1.00	5.00	4.00	0.01	0.01	0.00	0.00
Aggregators	1.00	2.00	8.00	6.00	0.30	5.00	6.00	1.00
Regional Market traders	0.20	5.00	5.00	0.00	0.16	8.00	8.00	0.00
Small-scale retailers	0.53	3.00	8.00	5.00	0.35	3.00	7.00	4.00
Processors	0.01	0.00	0.00	0.00	0.15	6.00	6.00	0.00
Village Merchants/brokers	0.26	3.00	7.00	4.00				
Farmer Groups	0.29	7.00	8.00	1.00	0.17	2.50	8.00	5.50
Seed company/Vine multipliers					0.14	6.00	8.00	2.00
HarvestPlus	0.20	6.00	8.00	2.00	0.11	7.00	8.00	1.00
National Agricultural Research Organization	0.11	8.00	8.00	0.00	0.10	6.00	8.00	2.00
NGO partners (VEDCO/WV/HOCADEO)	0.10	6.00	8.00	2.00	0.10	4.00	8.00	4.00
Fellow farmers	0.85	2.00	8.00	6.00	0.64	2.00	8.00	6.00
Integrated Seed System Development	0.07	5.00	6.00	1.00				
Biocrops/Sinai					0.07	6.00	8.00	2.00
International Potato Center (CIP)					0.11	7.00	8.00	1.00
Governments at subcounty	0.01	1.00	5.00	4.00	0.10	4.00	8.00	4.00

Source: Own calculations based on process net map: The mean presented in the table is normalized by subtracting the mean from each actor from the grand mean and dividing it by the standard deviation. SACCO is a savings and loan association. VEDCO, WV, and HOCADEO were local NGOs implementing a scaling program.

4.3.2 Maintaining the quality of biofortified products

Biofortified crops face quality challenges due to the product's nature and trader behavior. This may be due to market failure resulting from information asymmetry and weak enforcement of policies. The invisible micronutrient trait in biofortified beans, such as Narobean 3, makes it difficult to distinguish from conventional varieties, leading to confusion and potential mixing by profit-driven traders. For example, Narobean 3 is nearly identical to other yellow beans. Government standards, like East Africa's old bean standard (1919), are largely ignored, with traders relying solely on visual assessment. Without proper enforcement, traders lack incentives to adhere to quality standards in the bean value chain. Traders often mix beans to maximize profits, as sorting increases costs and reduces margins. In the OFSP value chain, the practice of farmers harvesting "piece by piece" may suggest that roots are not harvested at an appropriate time, thereby reducing their shelf life during marketing.

Addressing quality governance challenges requires demand creation. Many non-governmental organizations (NGOs) and community-based organizations (CBOs) run awareness campaigns, but their effectiveness is not evaluated. A coordinated, strategic approach, possibly led by public agencies, is needed to create a strong, conscious consumer demand that supports a quality-driven

value chain. The premium for biofortified crops should be viewed not as a consumer surcharge but as a public investment in preventative health. This can be achieved through subsidizing production and consumption, which stimulates the market, makes nutritious food more accessible, and transfers costs to the public sector, resulting in long-term savings in healthcare and productivity.

4.3.3 Unwillingness to pay a premium price for biofortified crop products

The results suggest that consumers may be less willing to pay extra for OFSP roots and iron beans, despite their perceived importance. One retailer mentioned, "*We mix the OFSP with yellow sweet potatoes so that we can sell them as my customers pay the same price for both yellow and orange*". Several reasons might explain this market failure. First, as noted in section 2.0, biofortified crop products are considered merit goods whose long-term nutritional benefits are often undervalued, especially by low-income households with high time preferences. Second, many consumers lack awareness of the health benefits associated with biofortified crops. Quantitative studies using both stated and revealed preferences generally show that consumers are willing to pay a premium for these products (Oparinde et al., 2016; Bocher et al., 2019; Ongudi et al., 2017). For example, Ongudi et al. (2017) applied a contingent valuation method to assess willingness to

pay for pearl millet in Kenya, revealing an average premium of 42% above the current market price for finger millet varieties. Similarly, a study on yellow cassava in Nigeria found that consumers are willing to pay more for the yellow cassava variety (Oparinde et al., 2016). All these studies focus on consumers who mainly influence pricing decisions within the value chain (Breidert et al., 2006).

4.3.4 Problems in the modular governance system

Commercializing biofortified crops, such as the Orange-Fleshed Sweet Potato (OFSP), is hindered by systemic issues in the value chain's modular governance, primarily due to the poor management of shared processing equipment. The inability to process and add value locally directly reduces farmers' incomes, shortens product shelf life, and hampers the development of a resilient biofortified supply chain. The problem of modular governance includes a low supply of OFSP roots and ineffective machinery management. A low supply of OFSP results in significant economic inefficiency, as processing equipment operates at only a fraction of its capacity. As Varian (2014) notes, when machinery operates at this suboptimal level, marginal costs exceed the product price, rendering operations financially unviable.

Managing machines in a processing plant for farmer groups is marked by a collective action problem where individual farmers rely on drying services without contributing to maintenance or security; a principal-agent problem where machine operators, who are not adequately supervised or incentivized by farmer groups, lack motivation to maintain the equipment properly; and a significant human capital gap due to a shortage of skilled operators. These governance issues hinder smallholders from earning higher margins through processing, forcing them to sell low-value raw produce and limiting investment and productivity.

In response, aggregators have adopted approaches to overcome supply. These include providing seed subsidies, forming relationships with farmers, and investing in storage facilities. As one aggregator said, "I give some farmers iron bean seed that I obtain from seed companies on credit and then buy the grain from the farmers after harvest." This informal contracting helps lower per-unit costs through large transaction volumes, a trend supported by HarvestPlus (2020), which reports that 20% of aggregators use such informal agreements. Nonetheless, evidence suggests that transitioning from informal to formal contracts may yield even greater benefits. Research by Bellemare (2018), Arouna and Michler (2019), and others demonstrates that formal contracts can further reduce transaction and transportation costs, thereby boosting efficiency and resilience across the value chain.

4.4 Training and invisibility of the iron trait

This study examined the impact of training on physical traits on farmers' ability to identify iron bean varieties, employing a correlated random-effects model. This approach was selected to account for potential random variation across bean varieties that could be correlated with other factors, potentially biasing the results from a standard probit model. As shown in Table 4, the probit model gave larger coefficients, indicating a positive selection bias that the correlated random effects model adjusts for.

The main finding was that the specific training—focused on seed size, color, and shape—did not significantly impact the likelihood of correct identification. This null result suggests that, for experienced farmers, additional visual training was not enough. This aligns with documented challenges in visually distinguishing iron beans (noted in Section 2 and by Omari et al., 2019), likely because farmers were already familiar with the crops, which limits the measurable impact of additional information. Descriptive analysis confirmed this difficulty, with correct identification rates close in both the control group (46%) and the treatment group (50%). This supports the conclusion that the training was not a decisive factor in the outcome (Table 5).

Instead, the analysis showed that institutional factors and farmer location had a greater influence on successful identification (World Bank, 2012). Farmers with extension access were less likely to correctly identify iron beans, possibly because the training they received emphasized agronomy, marketing, and nutrition more than physical identification. Farmers with access to credit were more likely to correctly identify iron beans. Farmers further from agro dealers were less successful in identification (Sheahan et al., 2017). Farmers in the western and eastern regions performed better, likely because HarvestPlus distributed more varieties there, thereby increasing familiarity (Spielman and Smale, 2017).

4.5 Awareness, subsidies and demand for biofortified food crops

Analysis of process net maps and discussions indicated that boosting demand for biofortified foods, such as iron beans and Orange-Fleshed Sweet Potato (OFSP), relies mainly on two key interventions. These include increasing consumer awareness and offering subsidies for planting materials. Effective awareness campaigns involve disseminating information about the nutritional benefits of biofortified crops through multiple channels, including radio, community groups, and social media. This is vital because

TABLE 4 Governance challenges in biofortification program implementation.

Governance challenge	Specific problem description	Frequency (n = 63)
1. Lack of demand	Unwillingness to pay a premium price for biofortified crop products	44%
2. Invisibility of the trait	Maintaining the good quality and identity of biofortified products (e.g., preventing mixing or quality decline)	13%
3. Inefficient coordination (Modular System)	Problems in the modular governance system (e.g., coordination failures)	21%
3. Leakage of funds (Supply Chain)	Problems in the supply of OFSP vines by multipliers (e.g., delays, shortages, misallocation of resources)	35%

Source: Own calculation based on process net map.

TABLE 5 Correlated random effects model for the effect of training on the identification of iron beans.

Variable	The correlated random effects model	Probit model
Training (1 = Yes)	0.092 (0.073)	0.261 (0.209)
Narobean 1 (1 = Narobean 1)	0.071 (0.085)	0.207 (0.246)
Narobean 2 (1 = Narobean 2)	0.018 (0.085)	0.052 (0.243)
Narobean 3 (1 = Narobean 3)	0.179** (0.085)	0.526** (0.254)
Age of farmer (years)	−0.003 (0.003)	−0.009 (0.009)
Household size	−0.011 (0.011)	−0.034 (0.032)
Sex of the farmer (1 = Female)	−0.048 (0.072)	−0.151 (0.215)
Education of the farmer (1 = primary, 0 = otherwise)	0.022 (0.135)	0.024 (0.395)
Education of the farmer (1 = secondary, 0 = otherwise)	0.149 (0.149)	0.466 (0.431)
Total livestock units	−0.012 (0.021)	−0.042 (0.062)
Extension service (1 = Yes)	−0.173* (0.088)	−0.494* (0.260)
Credit (1 = Yes)	0.185* (0.105)	0.602* (0.311)
Log Income	−0.037 (0.056)	−0.119 (0.155)
Land (ha)	0.013 (0.029)	0.061 (0.089)
Distance to the nearest agrodealer (Km)	0.095*** (0.045)	0.287** (0.139)
Distance to the nearest output market (Km)	−0.027 (0.043)	−0.069 (0.132)
Distance to the nearest all-weather road (Km)	−0.047 (0.052)	−0.149 (0.154)
Location-Kamuli	0.227* (0.127)	0.690* (0.386)
Location-Kakumiro	0.366*** (0.101)	1.121** (0.307)
Constant	0.927 (0.822)	1.329 (2.269)
N	340	340
Wald chi2	−137 (0.000)	37.23 (0.000)
R-squared		0.1501

Source: Own calculation. The figures in brackets represent the standard errors, and *, **, *** denote 10, 5, and 1% significance levels, respectively. AIC is the Akaike Information Criterion, and N is the number of observations.

information directly influences consumer perception and their willingness to pay (WTP). As [Rizwan et al. \(2022\)](#) demonstrated, awareness of nutritional benefits significantly raises WTP for biofortified wheat, with knowledge serving as a crucial demand driver. When consumers are informed, market dynamics of demand and supply operate more efficiently, resulting in prices that accurately reflect the perceived value of nutritious products. While awareness drives demand, subsidies tackle supply-side barriers, especially for farmers. The high initial costs of adopting new planting materials are well-known obstacles to the adoption of improved agricultural technologies ([Moyo et al., 2023](#); [Spielman and Smale, 2017](#)). Subsidies reduce this financial hurdle, promoting wider cultivation and boosting the market availability of biofortified crops. This greater supply is vital to meet the demand sparked by awareness efforts, ensuring that biofortified foods are accessible at reasonable prices.

5 Conclusion

This study examined governance challenges in Uganda's efforts to scale up biofortification and evaluated the impact of training on farmers' ability to identify iron-rich beans. Several key governance

challenges were identified along the value chain. On the supply side, government distribution of Orange-Fleshed Sweet Potato (OFSP) vines faced issues with fund leakage, which allowed uncertified suppliers to provide low-quality vines. Vine multiplication is asset-specific and demands substantial investment in training, screen houses, and irrigation for high-quality seed production. On the demand and marketing side, consumers' willingness to pay more for biofortified crops was low, mainly due to information asymmetries. This was worsened by opportunistic behaviors, such as aggregators adulterating iron bean grains with non-biofortified varieties. Additionally, farmer groups and other collective institutions aimed at lowering transaction costs often failed internally due to governance issues, such as free riding and poor management of shared machinery. The study also revealed that training on physical features was insufficient to significantly enhance farmers' ability to distinguish between iron-rich and regular beans, highlighting a significant gap in knowledge transfer.

We established that value chain actors adulterate iron beans because of invisible traits and mix OFSP with other varieties. Subsidies on iron bean and OFSP planting material through government and NGO programs may be viable for addressing this governance challenge. This is because subsidies would increase production of iron beans and OFSP, saturating the market ([Sibande et al., 2017](#)). With an optimal supply of

iron beans and OFSP in the market, consumers have a high probability of purchasing iron beans and OFSP. The feasibility of subsidies relies on implementing transparent, digitally managed subsidy programs, alongside complementary strategies, such as awareness campaigns and certification processes, to generate a synergistic effect, rather than relying solely on a single policy instrument.

This study has some limitations that we have discussed. First, although our assessment of governance challenges was innovative in including the seed system and value chain for both iron beans and OFSP, it is still a developing area in Uganda. Due to inherent state and market failures, our case study was unable to fully explore key scaling factors, such as public sector governance, leadership, and evidence-based learning, within the seed policy framework. Second, the lab-in-the-field experiment design imposes certain constraints. The small sample size reduces the statistical power and limits the ability to generalize our findings, making them localized. Additionally, the sampling method only involved existing iron bean farmers, which may have introduced selection bias by including participants with prior knowledge of the topic. Therefore, these results should be seen as a validation of our methodological tools and a test of initial hypotheses rather than definitive results.

These limitations highlight directions for future research. Although this study concentrated on downstream value chain governance, future work should examine upstream governance systems in seed systems, which are vital for scaling. The field experiment can be enhanced by increasing the sample size through random selection and exploring other certifications and tracing that were not feasible due to budget and scope constraints in this study. Using RCTs or quasi-experimental designs, as recommended by Hörner et al. (2019), would be an important subsequent step.

Developing a biofortified crop depends on widespread adoption by smallholder farmers and continued consumption by rural households. As Bouis and Saltzman (2017) highlight, farmers are the key link in the chain, supported by evidence that country programs strategically focus on them to reach larger scales and impactful outcomes (HarvestPlus, 2022). Consequently, enhancing governance to connect farmers to dependable markets and quality inputs is a vital research and policy challenge.

Data availability statement

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

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.

References

Adu-Gyamfi, P., Agyare, W. A., and Kadyampakeni, D. M. (2017). Seed adulteration and quality control in the Ghana maize seed system. *J. Crop Improv.* 31, 245–262. doi: 10.1080/15427528.2017.1289713

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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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- Akerlof, G. A. (1970). The market for "lemons": quality uncertainty and the market mechanism. *Q. J. Econ.* 84, 488–500. doi: 10.2307/1879431
- Arouna, A., and Michler, J. D. (2019). Addressing micronutrient deficiencies through biofortification: a review of evidence. Rome: International Food Policy Research Institute.
- Ashour, M., Billings, L., Gilligan, D., Hoel, J. B., and Karachiwalla, N. (2016). Do beliefs about agricultural inputs counterfeiting correspond with actual rates of counterfeiting? Evidence from Uganda. Rome: International food policy research institute.
- Ashour, M., Billings, L., Gilligan, D. O., Hoel, J. B., and Karachiwalla, N. I. (2017). Do beliefs about agricultural inputs counterfeiting correspond with actual rates of counterfeiting? Evidence from Uganda. *J. Dev. Stud.* 53, 1909–1926. doi: 10.1080/00220388.2016.1251587
- Beal, T., Massiot, E., Arsenault, J. E., Smith, M. R., and Hijmans, R. J. (2017). Global trends in dietary micronutrient supplies and estimated prevalence of inadequate intakes. *PLoS One* 12:e0175554. doi: 10.1371/journal.pone.0175554
- Bellemare, M. F. (2018). Contract farming: opportunity costs and trade-offs. *Agric. Econ.* 49, 279–288. doi: 10.1111/agec.12415
- Birner, R., and Braun, J. V. (2009). "Decentralisation and public service provision—a framework for pro-poor institutional design" in Does decentralisation enhance service delivery and poverty reduction? eds. A. Ehtisham and B. Giorgio (United Kingdom: Edward Elgar Publishing).
- Birner, R., and Linacre, N. (2008). Regional biotechnology regulations: design options and implications for good governance. Rome: International Food Policy Research Institute.
- Birner, R., and Sekher, M. (2010). The role of governance in implementing large-scale nutrition programs: A framework for analysis. Rome: International Food Policy Research Institute.
- Birner, R., and Sekher, M. (2018). "The devil is in the details: understanding the governance challenges of implementing nutrition-specific programs on a large scale" in Hidden hunger: strategies to improve nutrition quality. eds. H. K. Biesalski and R. Birner (Germany: Karger).
- Birol, E., Meenakshi, J. V., Oparinde, A., Perez, S., and Tomlins, K. (2015). Developing country consumers' acceptance of biofortified foods: a synthesis. *Food Secur.* 7, 555–568. doi: 10.1007/s12571-015-0464-7
- Bocher, T., Sindi, K., Muzhingi, T., Nshimiymana, J. C., Nzamwita, M., and Low, J. (2019). Investigating consumer preferences and willingness to pay for orange-fleshed sweet potato (OFSP) juice in Rwanda. *Agriculture* 4, 227–236. doi: 10.3390/agriculture9010027
- Bouis, H. E., and Saltzman, A. (2017). Improving nutrition through biofortification: a review of evidence from HarvestPlus, 2003 through 2016. *Glob. Food Secur.* 12, 49–58. doi: 10.1016/j.gfs.2017.01.009
- Breidert, C., Hahsler, M., and Reutterer, T. (2006). A review of methods for measuring willingness-to-pay. *Innov. Mark.* 2, 8–32.
- Burnside, A. (2000). Agricultural extension and food security. Rome: Food and Agriculture Organization of the United Nations.
- Daum, T., and Birner, R. (2015). Agricultural mechanisation in Africa: a political economy perspective. Bonn: University of Bonn.
- De Steur, H., Wesana, J., Blancquaert, D., Van Der Straeten, D., and Gellynck, X. (2017). Methods matter: a meta-regression on the determinants of willingness-to-pay studies on biofortified foods. *Ann. N. Y. Acad. Sci.* 1390, 34–46. doi: 10.1111/nyas.13277
- Deissy, M. J., Martínez-Barón, D., and Loboguerrero, A. M. (2024). Policy and institutional frameworks for the adoption of biofortified crops: a systematic review. *Glob. Food Secur.* 40:100739. doi: 10.1016/j.gfs.2024.100739
- Doornbos, M. (2003). Good governance: the metamorphosis of a metaphor. *J. Int. Aff.* 57, 2–17.
- Eaton, D. J. F., Meijerink, G. W., and Bijman, J. (2008). Understanding institutional arrangements: Fresh fruit and vegetable value chains in East Africa. Wageningen: Wageningen University & Research.
- Fairbairn, A. M. (2017). Are they lemons? Unobservable quality, information, and mineral fertiliser demand. Illinois: University of Illinois.
- Feder, G., Anderson, J. R., Birner, R., and Deininger, K. (2010). Promises and realities of community-based agricultural extension. Rome: International Food Policy Research Institute.
- Finkelstein, J. L., Mehta, S., Udipi, S. A., Ghugre, P. S., Luna, S. V., Wenger, M. J., et al. (2015). A randomized trial of iron-biofortified pearl millet in school children in India. *J. Nutr.* 145, 1576–1581. doi: 10.3945/jn.114.208009
- Funes, I., Montero-Castro, J. C., and Grum, M. (2019). Impact of biofortified crops on nutritional and health outcomes: a systematic review and meta-analysis. *Ann. N. Y. Acad. Sci.* 1446, 5–22. doi: 10.1111/nyas.14112
- Haas, J. D., Luna, S. V., Lung'aho, M. G., Wenger, M. J., Murray-Kolb, L. E., Beebe, S., et al. (2016). Consuming iron biofortified beans increases iron status in Rwandan women after 128 days in a randomised controlled feeding trial. *J. Nutr.* 146, 1586–1592. doi: 10.3945/jn.115.224741
- HarvestPlus (2018). Annual report 2018: Building resilience, improving livelihoods. Washington, DC: HarvestPlus.
- HarvestPlus (2020). Responding to crisis, building resilience: HarvestPlus 2020 annual report. Washington, DC: HarvestPlus.
- HarvestPlus (2022). 2022 Annual Report: scaling biofortified seeds and foods. Washington, DC: HarvestPlus.
- Hermans, F., van der Hoeven, D., and van der Meulen, H. (2016). Scaling strategies for agricultural innovations. Wageningen: Wageningen University & Research.
- Hörner, D., Bouguen, A., Frölich, M., and Wollni, M. (2019). The effects of decentralised and video-based extension on the adoption of integrated soil fertility management—Experimental evidence from Ethiopia. Cambridge: National Bureau of Economic Research.
- Hsu, E., and Wambugu, A. (2022). Can informed buyers improve the quality of goods? Experimental evidence from crop seeds. London: Wiley.
- Illukor, J., Mashisia, S., and Okello, J. J. (2015). The impact of agricultural extension services on technology adoption: evidence from Uganda. *World Dev.* 75, 1–12.
- Ilukor, J., Birner, R., Rwamigisa, P. B., and Nantima, N. (2015). The provision of veterinary services: who are the influential actors and what are the governance challenges? A case study of Uganda. *Exp. Agric.* 51, 408–434. doi: 10.1017/S0014479714000465
- Jeffrey, M., D'souza, A., Tjernström, E., Verkaart, S., and Mausch, K. (2019). Money matters: the role of yields and profits in agricultural technology adoption. *Am. J. Agric. Econ.* 101, 710–731. doi: 10.1093/ajae/aay050
- Komakech, R. A. (2019). Corruption in public procurement in Uganda: What can be done? In Proceedings of the 2nd international conference on governance and service delivery in developing economies. Uganda Management Institute: Uganda
- Kwikiriza, K., Mugisha, J., Karantininis, K., and Kledal, P. R. (2018). Influence of transaction costs and governance in the marketing of organic pineapples from Uganda. *J. Sustain. Develop.* 11, 194–211. doi: 10.5539/jsd.v11n3p194
- Lockyer, S., White, A., and Buttriss, J. L. (2018). Biofortified crops for tackling micronutrient deficiencies—what impact are these having in developing countries, and could they be of relevance within Europe? *Nutr. Bull.* 43, 319–357. doi: 10.1111/nbu.12347
- Lubungu, M., and Birner, R. (2018). Using a process net map to analyse governance challenges: a case study of livestock vaccination campaigns in Zambia. *Prev. Vet. Med.* 156, 91–101. doi: 10.1016/j.prevetmed.2018.05.003
- Mann, S. (2003). Why organic food in Germany is a merit good. *Food Policy* 28, 459–469. doi: 10.1016/j.foodpol.2003.10.001
- Meenakshi, J. V., Johnson, N. L., Manyong, V. M., DeGroote, H., Javelosa, J., Yanggen, D. R., et al. (2010). How cost-effective is biofortification in combating micronutrient malnutrition? An ex-ante assessment. *World Dev.* 38, 64–75. doi: 10.1016/j.worlddev.2009.03.014
- MFEPD (2023). Poverty status report 2021: Jobs, informality, and poverty in Uganda: Insights on performance before and during COVID-19. Uganda: Ministry of Finance, Planning and Economic Development.
- Mihály, F., Adam, I., and Nikulina, O. (2021). Study on the cost of corruption in Uganda. Uganda: Inspectorate of Government.
- Moyo, T., Groot, J. C. J., and van Ittersum, M. K. (2023). The role of systems thinking in scaling agricultural innovations. *Agric. Syst.* 204:103558.
- Ogutu, S. O., Ochieng, D. O., and Qaim, M. (2020). Supermarket contracts and smallholder farmers: implications for income and multidimensional poverty. *Food Policy* 95:101940. doi: 10.1016/j.foodpol.2020.101940
- Olson, M. (2009). The logic of collective action. Cambridge: Harvard University Press.
- Omari, R., Essegbey, G. O., and Frempong, G. (2019). Can farmers distinguish between biofortified and conventional varieties? A case study of iron-rich beans in Ghana. *Food Nutr. Bull.* 40, 488–499. doi: 10.1177/0379572119877342
- Ongudi, S. O., Ngigi, M. W., and Kimurto, P. K. (2017). Determinants of consumers' choice and willingness to pay for biofortified pearl millet in Kenya. *East Afr. Agric. For. J.* 82, 175–187. doi: 10.1080/00128325.2017.1330272
- Oparinde, A., Banerji, A., Birol, E., and Ilona, P. (2016). Information and consumer willingness to pay for biofortified yellow cassava: evidence from experimental auctions in Nigeria. *Agric. Econ.* 47, 215–233. doi: 10.1111/agec.12243
- Oruko, L., and Nduong'u, L. (2009). "An analysis of animal healthcare service delivery in Kenya" in Institutional economics perspectives on African agricultural development. eds. J. F. Kirsten, A. R. Dorward, C. Poulton and N. Vink (Rome: International Food Policy Research Institute), 257–272.
- Ostrom, E. (1990). Governing the commons: The evolution of institutions for collective action. Cambridge: Cambridge University Press.
- Pritchett, L., and Woolcock, M. (2004). Solutions when the solution is the problem: arraying the disarray in development. *World Dev.* 32, 191–212. doi: 10.1016/j.worlddev.2003.08.009
- Rizwan, M., Abbas, A., Xu, H., Ahmed, U. I., Qing, P., He, P., et al. (2022). Role of nutrition information in acceptance and willingness to pay for biofortified cereal food: implications for better health and sustainable diet. *Nutrients* 14:3352. doi: 10.3390/nu14163352

- Sastry, N., and Raju, S. (2005). Animal health workers in Andhra Pradesh: service delivery, supplies, support & supervision. Kenya: International Livestock Research Institute.
- Schiffer, E., and Hauck, J. (2010). Net-map: collecting social network data and facilitating network learning through participatory influence network mapping. *Field Methods* 22, 231–249. doi: 10.1177/1525822X10374798
- Schut, M., Leeuwis, C., and Thiele, G. (2020). Science of scaling: understanding and guiding the scaling of innovation for societal outcomes. *Agric. Syst.* 184:102908. doi: 10.1016/j.agsy.2020.102908
- Sheahan, M., Barrett, C. B., and Goldvale, C. (2017). The impact of agricultural policy on food security and nutrition. *Nat. Sustain.* 1, 25–32.
- Sibande, L., Bailey, A., and Davidova, S. (2017). The impact of farm input subsidies on maize marketing in Malawi. *Food Policy* 69, 190–206. doi: 10.1016/j.foodpol.2017.04.007
- Spielman, D. J., and Smale, M. (2017). Policy options to accelerate variety change among smallholder farmers in South Asia and Sub-Saharan Africa. Washington, DC: IFPRI.
- Van Loon, J., Woltering, L., Krupnik, T. J., Baudron, F., Boa, M., and Govaerts, B. (2020). Scaling agricultural mechanisation services in smallholder farming systems: case studies from sub-Saharan Africa, South Asia, and Latin America. *Agric. Syst.* 180:102792. doi: 10.1016/j.agsy.2020.102792
- Varian, H. R. (2014). Intermediate microeconomics: A modern approach. New York: W. W. Norton & Company.
- White, G. (2004). Civil society, democratization and development: conceptual and strategic perspectives. New York: W. W. Norton & Company.
- Wigboldus, S., Klerkx, L., Leeuwis, C., Schut, M., and van der Hoek, R. (2016). Scaling principles and the role of intermediaries in agricultural innovation systems. *NJAS* 78, 1–11.
- Williamson, O. E. (1985). The economic institutions of capitalism. Washington, DC: Free Press.
- Williamson, O. E. (2005). The economics of governance. *Am. Econ. Rev.* 95, 1–18. doi: 10.1257/000282805774669880
- Wooldridge, J. M. (2013). Introductory econometrics: a modern approach. Boston: Cengage Learning.
- World Bank (2012). Agricultural innovation systems: an investment sourcebook. Washington, DC: The World Bank.