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Economic viability and sustainability of quality declared seed system in Tanzania

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ABSTRACT

Relative to the informal seed systems, quality declared seed (QDS) system provides higher quality seed. Thus, it offers smallholder farmers an opportunity to access seeds of new and improved varieties more conveniently and efficiently. However, various challenges limit growth of QDS production in many subscribing countries. Therefore, this study assesses economic viability and sustainability of QDS system for common bean, groundnuts and sorghum in Tanzania. We find that QDS production is profitable, with positive profit margins and a benefit-cost ratio greater than one. QDS is primarily sold at the farmgate, with <10% sold through formal outlets or shops, posing quality and traceability challenges. QDS system avails to smallholder farmers diverse and improved varieties at affordable costs and in a timely manner. Weak regulations, inadequate inspections, low producer license renewal or registration may slow gains in the QDS business. We recommend developing marketing infrastructure to integrate private sector players like grain traders and processors, and enhancing public-private partnerships for early generation seeds and certified seeds needed for QDS production. We also suggest revising and updating the QDS training curriculum to include business entrepreneurship and marketing modules and revising existing laws to support faster QDS sector growth.

1. Introduction

The role of smallholder farmers in food security and nutrition enhancement is widely documented [1,2]. Therefore, the technologies, innovations, and inputs used by smallholder farmers play a critical role in shaping food and nutrition security. While it is well established that seeds, for example, are sourced from both formal and informal systems, the informal seed sector remains the predominant source in many developing countries [3]. In a country like Tanzania, smallholder farmers rely heavily on local markets for their seed supply, with over 97% of seeds being sourced through these informal channels [4,5] while <3% of planting material comes from formal and semi-formal (referred to as Quality Declared Seeds (QDS)) seeds systems. Informal seed systems flourish for less profitable crops and for open-pollinated crops such as sorghum, common beans, and groundnuts. In contrast, informal seed purchased from local markets is growing rapidly and organically, displacing farm-saved seed as the predominant source of seed used by smallholders in Africa mainly for OPV crops [4–6]. Thus, vast quantity of planting material is provided regularly at acceptable prices by local grain traders, aggregators and grain processors, who also sell seed after recleaning superior lots of grain for sale "local seed' during the planting season [6].

Besides, grain traders provide market signals that create seed demand pull in the value chain and seed actors such as seed producers including QDS respond to the demand through increased seed production to meet the seed needs of the farmers who supply them with grains

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[6,7] . They also thrive in areas where commercial seed is either unavailable or too expensive for smallholders to purchase [8]. Seed companies consider these crops less profitable due to uncertain and fluctuating demand caused by competition from farm-saved seeds [9, 10]. They have little or no incentive to invest in additional production and sales.

Rural development initiatives have largely supported farmer seed production in sub-Sahara Africa (SSA) [11,12]. Seed producers often serve local markets or contract with development projects, government agencies, non-governmental organizations (NGOs), or commercial seed companies [13,14]. However, the extent of farmer involvement in seed production and marketing varies across countries depending on existing policies and regulatory frameworks [15,16]. In response to these dynamics, the Food and Agricultural Organization (FAO) introduced the concept of quality declared seed (QDS) in 1993 as Plant Production Paper 117 to enhance the value and marketability of seeds produced by smallholder farmers [17]. Since then, the QDS approach has been adopted by several sub-Saharan African countries such as Ethiopia, Tanzania, and Uganda. Despite its adoption in Tanzania as cost-effective, and easy way for the smallholder farmers to access improved seeds, the scale of QDS production and dissemination remains low in many countries due to limited added value for both seed producers and buyers (farmers) since sales are only legally permitted within the districts or localities [15,18]. As a result, QDS seed production remains low, accounting for only 6% of all the quality sorghum, groundnut, and common bean seed produced in the country during the 2022/23 production season, according to TOSCI database.

The QDS system has huge potential to address seed availability gaps as it shifts seed quality assurance responsibilities from the government to producers who could be individuals, small-scale enterprises, farmer groups or project-based organizations on assumption that these producers will maintain high quality standards to protect their reputation and customer trust [19]. QDS offers a more open and flexible regulatory framework compared to certified seed, making it easier for smallholder farmers to enter the seed market and increasing the supply of seed without compromising seed quality. Moreover, compared to formal seed systems, QDS offers sustainability driven by the market, decentralization of seed production to cater to regionally specific varietal preferences, possibilities of establishing linkages to formal institutions, and production of quality seed. These advantages address difficult challenges in areas experiencing high pests and diseases, humanitarian conflicts or crisis, and accelerated climate change [9,20]. Strengthening seed marketing ultimately promotes broader adoption, improved varieties produced and approved by farmers [12,21].

Production of quality seeds by smallholder farmers is challenging and may require support from technical and market intelligence experts and from public agencies providing production infrastructure, among other parties. More often, communities have been supported by NGOs to produce and sell QDS thus the enterprise can collapse when the NGOs exit. This has led to the notion that investment in QDS is unsustainable in the long term. In this study, we explore this notion with real data from QDS-producing smallholder farm households from Tanzania. The study combines in-depth interviews and qualitative approaches, such as expert elicitation opinion (EEO). The focus crops include common beans, groundnuts, and sorghum, all of which are open-pollinated crops. The objective is to assess the profitability of QDS production and identify key factors that either support or hinder the sustainability of smallholder investment in QDS.

Tanzania is among the African countries that officially recognize QDS in their policy framework. Other countries include Ethiopia, Uganda, Senegal, Niger, South Africa, Zimbabwe, Zambia, Malawi, South Sudan, and Rwanda [22,23]. In Tanzania, QDS was integrated into the National Seeds Act of 2003 [24]. These systems were further supported by seed rules, regulations, and procedures established in 2007, along with guidelines for seed production control. QDS is classified as semi-formal seed system, which is widely accepted for various crops including indigenous vegetables, pulses, and cereals [25].

The open pollinated varieties (OPVs) listed in the official national variety catalogue [26,27] can be used to produce QDS seeds while they cannot be used to produce F1 Hybrids. For instance, the production and certification of common beans, groundnut and sorghum seeds are governed by the Seed Production Act of 2003/2007 and regulated by the Tanzania Official Seed Certification Institute (TOSCI) under the Ministry of Agriculture. Small-scale farmers cultivating these and other crops produce QDS to help bridge the gap in seed availability and access. Production and marketing of QDS are decentralized and limited to specific Wards within districts where district extension officials, under the supervision of the TOSCI, oversee inspection and compliance. The inspection process is governed by the 2020 Seeds (Control of Quality Declared Seeds) regulations. It involves notifying the QDS seed producer, payment of the required fees by the producer, inspecting 10% of the registered fields in the district, sampling, and testing to ensure the seeds meet minimum quality standards [18]. However, under contractual seed production arrangement for example in Zambia and Niger, seed companies conducted inspections themselves [14]. Across the country, QDS production and marketing have largely been promoted through project-based interventions, which may obscure the true profitability and sustainability of the enterprise. Against this backdrop, the study aimed to generate data-driven insights to evaluate the profitability and sustainability of the QDS enterprise and identify factors such as overreliance on donor-supported programs that may hinder its long-term viability.

QDS producers are rational and would be motivated to undertake the investment only when it is profitable. Profitability serves as a key indicator of the viability of the enterprise and can be assessed using the gross margin approach [28,29]. In this study, gross margin analysis was used to determine the profitability of QDS production in common beans, groundnuts, and sorghum among the smallholder farmers. A key strength of this study is the use of comprehensive and systematic approaches. We combined multiple methods, starting with a literature review, followed by a survey of QDS producers, expert consultations, and qualitative in-depth interviews with stakeholders. This multi-faceted approach allows us to identify critical success factors and challenges within the QDS production system in Tanzania. Such a methodology is particularly useful in contexts where data availability is limited.

The rest of the paper is structured as follows: the next section outlines the methodology, including data sources, collection methods, and analytical approaches; Section 3 presents and discusses the results, while Section 4 provides conclusions and recommendations.

2. Data and methodology

2.1. Survey data

The study used cross-sectional data from 148 quality declared seed (QDS) producers of common bean, sorghum, and groundnut seeds across five zones in Tanzania: Central, Lake, Northern, Southern Highlands and Western, targeting the 2022/23 main cropping season in January 2024. A list of trained QDS producers in the target regions was obtained from the seed regulator, Tanzania Official Seed Certification Institute (TOSCI), and randomly selected producers from the list for interviews through research randomizer (see https://www.randomizer.org). The final sample consisted of 93 QDS producers for common beans, 28 for groundnuts, and 27 for sorghum. The interviews were conducted face-to-face using semi-structured questionnaires. The survey team collected information on farmer characteristics, QDS varieties produced, incentives for QDS production, costs and revenues, access to marketing information, sustainability of seed production, and challenges faced [30]. analyzed other information, including access to digital devices, level of digital literacy, the digital services accessed, communication channels in seed business interactions, and information-seeking

behavior of the QDS producers.

2.2. Elicitation of expert opinions

We used the elicitation of expert opinion (EEO) method to complement survey data for assessing the sustainability of the QDS business in Tanzania. Several studies have used EEO to assess sustainability and adoption of new varieties in agricultural systems [12,31,32]. EEO as a systematic method uses repetitive and independent questioning of experts. This method is suitable for assessing sustainability of QDS in the current context as producers themselves may lack the capacity to determine its long-term viability with certainty making it necessary to involve experts in the evaluation process. We conducted EEO in two stages. In the first stage, questionnaires were emailed to 44 experts, and data were analyzed. In the second stage, a national workshop was convened on 10th December 2024 in Dodoma, Tanzania, that brought together the 44 experts with diverse background knowledge, experience and expertise in breeding, socioeconomics, seed systems and agronomy or extension services (Table 1).

These participants included agricultural experts from national and international research organizations, extension officers, seed producers, seed regulators in the country, non-governmental organizations (NGOs) staff, and grain traders. While engaging experts, we also broadened participation to include QDS producers themselves, traders who depend on QDS farmers for affordable and sustainable seed supplies, and NGOs actively supporting QDS production across several regions of the country. The discussions were moderated by an experienced external expert to avoid possible biases and/or domination by specific groups of experts. The results are presented in Table 1a in supplementary material. This approach ensured that conclusions based on interviews with QDS producers met high quality and validity standards.

Based on a synthesis of information from experts or key informants, we analyzed whether the QDS system meets the five principles of sustainable seed systems shown in Table 2. As appropriate, QDS is evaluated against farm-saved and certified seeds.

QDS producers and experts scored the three principles of sustainability - quality, quantity, and affordability on a 5-point Likert scale. Quality ratings were identified as very good to very poor. Quantity ratings were designated as very low, low, average, high, and very high. Affordability ratings were scored as very high, high, the same, low, and lower. Lastly, data from TOSCI were used to analyze the trend in the registration and renewal of QDS producers in Tanzania.

2.3. In-depth interviews

Finally, we conducted in-depth interviews with 19 QDS producers who were interviewed using the questionnaire—ten with 5–10 years' experience in QDS and nine with more than ten years' experience. This final interview aimed to gain a better understanding of what has sustained their seed business. Of the ten producers interviewed with <10 years' experience, five were individual producers, two farmer groups, and three NGOs. The nine producers with more than ten years' experience included five individual producers, three farmer groups, and one NGO. The questions for the in-depth interviews focused on: whether the producer had at one time stopped QDS production and the reasons why; how she or he considered resuming their QDS business; the main factors or pillars that have kept the business going; whether the business has been growing or not; and factors contributing to the growth.

Table 2
Concept of sustainable seed systems.

Principle	Description/Relevant Question
Quality	Is the QDS system able to supply quality seeds to farmers?
Quantity	Does the system supply enough quality seeds to meet the demand?
Diversity	Does the system provide adequate quantity and quality of diverse varieties to meet the needs of the farmers?
Accessibility	Does the system deliver the seeds in a timely manner in locations that are convenient to the farmers?
Price/ affordability	Does the system supply seeds at affordable prices?

Source: Adapted from [33,34].

2.4. Analytical approach

The study used gross margin (GM) to analyze the profitability of QDS production by the smallholder seed producers, using farm level data from the 148 QDS producers from different regions of Tanzania. Gross margin is defined as the difference between total revenue and total variable costs associated with an enterprise. The novelty of using the GM is its ability to show how much money may be reinvested in growing the business. It is a measure of the growth potential of a business which is useful for sustainability analysis. Monetary values are expressed as Tanzania shillings (TSH). The gross margin is computed as follows:

$$GM = Q_y P_y - \sum X_i P_{xi}, \quad (1)$$

where GM = gross margin; Q_y = total output of crop (kg); P_y = price per unit of output; X_i = quantity of the input used; P_{xi} = per unit price of input; $Q_y P_y$ = total revenue from the output; $\sum X_i P_{xi}$ = total variable cost. Therefore, the GM = gross total revenue (GTR) – the total variable cost (TVC), where GM = gross margin (TSH/acre), GTR = gross total revenue (TSH/acre), and TVC = total variable cost (TSH/acre). Using GM, we assessed whether QDS meets the "cost-recovery" principle of a sustainable seed system. From a business perspective, this is the most important principle of a sustainable seed system. A positive gross margin would serve as an incentive for producers to invest in QDS production, ensuring its sustainability.

The benefit-cost ratio (BCR) was calculated as also used in [35]. We analyzed survey data using STATA Software. A content analysis approach was used to analyze data from in-depth interviews and expert opinions.

Table 1
Number of experts consulted in 2024.

Experts**	Total number of experts	Breeding	Seed systems	Socio economics	Agronomy or Extension	Others (trader, seed producers)
Development Practitioners/NGOs	4	-	-	-	4	-
NARS Research Scientists	11	2	3	4	2	-
CGIAR Research Scientists/University	12	3	5	4	-	-
Seed producers (seed companies and QDS)	5	-	-	-	-	5
TOSCI	2	-	2	-	-	-
Traders	10	-	-	-	-	10
Total	44	5	10	8	6	15

** QDS-Quality Declared Seed; TOSCI- Tanzania Official Seed Certification Institute; NARS- National Agricultural Research System; CGIAR- Consultative Group on International Agricultural Research.

3. Results and discussion

3.1. Descriptive results

Survey data were collected from 148 QDS producers in Tanzania, covering three crops—common bean, groundnut, and sorghum. Table 3 shows the summary statistics of the characteristics of these seed producers organized by crop type and the producers' level of experience. Men dominate QDS production in all crops with the highest proportion in common beans (62%), sorghum (55%), and groundnuts (51%). While groundnuts have a more balanced gender representation, the overall trends suggest that men are more engaged in QDS production than women. Men may have better access to land, credit, and training opportunities, which are crucial for quality seed production. Women may be more involved in other agricultural activities rather than seed business, such as food production, particularly in rural areas where cultural norms influence economic roles [36]. Lack of tailored support for women in seed production, such as training, credit, land and financing, might contribute to their lower participation [14]. The majority of the QDS producers in our survey had been in business for less than five years (81% in beans, 69% in groundnuts, and 72% in sorghum). The high percentage of new entrants indicates that seed entrepreneurship is gaining traction, possibly due to increased awareness and policy support. For instance, initiatives of the Tanzania Agricultural Research Institute (TARI), the Tanzania Official Seed Certification Institute (TOSCI), and the Alliance of Bioversity International and the International Center for Tropical Agriculture (CIAT) to support seed production and distribution have created opportunities for individuals to engage in the seed sector. The influx of new producers shows promise for expansion.

To capitalize on the potential growth of the QDS system, new seed producers need comprehensive training and support. Our survey showed that the majority of the trained QDS producers registered to produce seeds, regardless of their experience in the business (at levels of 66% for common bean, 83% for groundnuts, and 72% for sorghum). High registration rates suggest that most QDS producers operate within formal regulatory frameworks, which are crucial for maintaining seed quality standards. The availability of registration services and

Table 3
Basic characteristics of Quality declared seed producers.

Variables	Beans			Groundnut			Sorghum		
	<5 years %	≥ 5 years %	Overall %	<5 years %	≥ 5 years %	Overall %	<5 years %	≥ 5 years %	Overall %
Sex of the QDS producer									
Female	33	61	38	58	27	49	52	25	45
Male	67	39	62	42	73	51	48	75	55
Registered to produce QDS seeds after training (%)	63	78	66	92	64	83	86	37	72
System of QDS production									
Farmer group	7	0	5	0	27	8	0	25	7
Farmer Cooperative	0	6	1	4	0	3	0	0	0
Non-governmental Organizations (NGO)	5	16	8	8	9	9	5	12	7
Grain trader (off taker)	1	0	1	0	0	0	0	0	0
Individual seed producer	87	78	85	88	64	80	95	63	86
Where producer sell the seed									
Locally (within the district)	100	100	100	100	100	100	100	100	100
Outside the district	37	44	38	25	36	28	10	12	10
Promotion of produced seed									
Communication materials (leaflets, brochures, posters)	5	0	4	0	9	3	5	25	10
Demo plots	45	72	50	38	45	40	48	25	41
Farmer field days	25	61	32	21	9	17	9	13	10
Agricultural shows	12	39	17	21	36	26	14	25	17
Mass media (radio, TVs)	1.3	0	1	0	18		0	25	7
In person gatherings	57	33	52	46	64	51	52	63	55
Traders	0	6	1	0	0	0	0	0	0
WhatsApp	12	28	15	13	0	8	5	25	10
Instagram	8	11	8	8	0	6	5	12	7
Facebook	7	22	10	13	0	9	5	12	7
M-kilimo[1]	1	11	3	8	0	5	5	0	3
Other specify	14	0	12	21	9	17	14	12	14
Distribution channel									
Direct to farmers	87	100	90	100	100.0	100	100	100	100
Seed fair	0	9	1	0	0	0	0	0	0
Contractors	25	0	21	0	0	0	0	0	0
Agro dealer	5	9	6	0	0	0	0	0	0
Agricultural shows	4	9	4	0	0	0	0	0	0
Others (e.g., traders & schools)	4	0	3	0	0	0	0	17	7
Sources of parent seed									
TARI*	66	72	67	54	73	60	48	38	45
ASA*	4	8	4	0	0	0	5	0	3
Seed company	1	11	3	4	0	3	0	0	0
Own production	1	0	1	4	9	6	0	25	7
Others specify	34	11	30	42	18	34	52	50	52
Enough knowledge for QDS production (%)	84	72	82	83	55	74	86	50	76
Able to sell all produce (%)	88	83	87	71	73	71	76	50	69
Able to meet farmers' seed demand (%)	11	11	11	21	18	20	29	38	31
Adoption of new varieties (%)	20	28	21	25	64	37	9	25	14
Number of observations (n)	**75**	**18**	**93**	**19**	**9**	**28**	**20**	**7**	**27**

* TARI-Tanzania Agricultural Research Institute; ASA-Agricultural Seed Agency; QDS - Quality declared seeds. Source: Survey.

[1] M-Kilimo is a strategic initiative aimed at leveraging the near-ubiquity of mobile phones to transform agricultural practices. Farmers can access a wealth of services including market information; real-time updates on commodity prices; buyer demand; direct buyer connections; agricultural advice; expert tips; and best practices to improve yields and productivity. https://exts.kilimo.go.tz/.

regulatory enforcement could drive this trend, ensuring that new and existing producers comply with certification requirements [37]. Groundnut producers registered at the highest rates (83%), possibly indicating better organization or stronger incentives for compliance in this crop compared to beans and sorghum. However, it is also important to note that not every trained potential QDS producer eventually registers to produce. Others fail to join the production, which could justify the need to train higher numbers because not everyone trained eventually takes up the business.

The most common QDS production system was that of individual producers (85% in beans, 80% in groundnuts, and 86% in sorghum). A few producers, however, produced QDS as groups or under NGO-supported initiatives. This trend could be because individual producers have full control over their production processes, from seed selection to marketing, allowing them to make independent business decisions [38].Operating individually allows producers to retain all profits from their seed sales and adapt their production to market demands without group constraints. Furthermore, in some areas there are fewer farmer cooperatives or associations that support QDS production, leading more farmers to operate independently. While the rules require that QDS producers sell within their districts, 37% of common bean producers, 29% of groundnut producers, and 10% of sorghum producers sold some QDS beyond the district. This highlights the complexities and challenges in enforcing QDS regulations. Limited access to quality seeds in a location may drive cross-district trade, encouraging producers to sell beyond their jurisdictions. It is possible that, at some point, producers find better prices and larger markets outside their districts, motivating them to bypass regulations. Details are available in Table1a supplementary material.

The producers used different approaches to promote their products, such as public gatherings and demonstration plots. This was true for all producers surveyed, regardless of their experience in QDS production. Public gatherings provide a platform for direct engagement with seed producers, farmers and other stakeholders, which create awareness of the benefits of QDS, delivering information on seed availability and addressing farmer concerns in real time. While the demonstration plots are particularly useful in seed marketing—because they allow farmers to see and compare seed performance in real field conditions, they also build trust and credibility, encouraging technology adoption [39]. A few producers used social media applications to promote their products, indicating a potential gap in the adoption of digital marketing [40]. Majority of the QDS producers sourced their parent seed (basic seed) from TARI, and that they had sufficient knowledge for QDS production. Over 87% of common beans producers, 74% of groundnuts and 69% of sorghum producers sold all the QDS seeds produced, failing to completely satisfy market demands. Although QDS seeds can be produced using Certified seed from seed companies, QDS producers preferred to use EGS primarily the basic type sourced from TARI. The reliance on TARI for sourcing parent seeds is indicative of the institutional support that QDS producers receive, which is crucial for ensuring seed quality. TARI—the primary government body responsible for research and production of early generation seed (EGS)—ensuring that the seed supplied to QDS producers meets high-quality standards. This is vital for the integrity of the QDS system and for ensuring that farmers receive seeds that are reliable for planting. However, it would be impactful if TARI could supply early generation seeds (EGS) to other seed companies for multiplication. This would guarantee production and supply of enough certified seeds to meet the growing demand from QDS producers. In Tanzania, EGS include breeder (pre-basic) and foundation (basic) seeds [40].

Evidently, current producers cannot satisfy the enormous QDS market. About 90% of the common bean producers, 80% of the groundnut producers, and 70% of the sorghum producers said that they were unable to satisfy the demand for their QDS. The inability to meet market demand shows that the QDS sector is experiencing strong demand from farmers and stakeholders who recognize the value of quality seeds. Farmers are more likely to adopt high-quality seeds when they understand the benefits, including higher yield potential, better disease and pest resistance, and improved market value [41]. The growing preference for improved, high-yielding and disease-tolerant varieties has contributed to the increased demand for quality seeds. Policies aimed at improving agricultural productivity and food security, such as those promoting access to certified seeds, could be driving the demand for QDS. The main buyers of QDS were the farmers. All groundnut and sorghum QDS producers (100%) and 90% of common bean QDS producers sold their seeds directly to farmers whereas 21% of them also marketed their seeds through contractors.

With respect to the adoption of new varieties (<10 years old), our survey found that the QDS producers are hesitant in adopting new varieties. About 80% of common bean producers, 63% of groundnut producers, and 86% of sorghum producers said that they were not producing new varieties (Table 3). QDS producers may be sticking with old varieties because they are established in the market and may not require investment in promotional campaigns. This underscores the need for collaborations and partnerships in the promotion of the new varieties because it would be challenging for the QDS producers to do this on their own. Table 4 shows the main varieties developed by QDS producers. Calima Uyole, Selian 13, and JESCA were the three most popular bean varieties. For groundnuts, Naliendele 2016, Mnanje, and Mangaka were the most popular varieties. For sorghum, Macia and Naco Mtama 1 were the most popular varieties.

Despite recommendations that farmers adopt newer crop varieties, QDS producers in developing countries often continue to grow varieties that are over 10 years old [42] . For example, old common bean varieties included Jesca (28 years old), Lyamungo 90 (35 years old), and Uyole

Table 4
Varieties of sorghum, common beans and groundnuts cultivated by smallholders in Tanzania.

Variety	Year of Release	Variety Age	Experience (% of QDS producers)		% of QDS producers (n = 148)
			<5 years' experience (n = 114)	≥5 years' experience (n = 34)	
Beans					
Calima Uyole	2011	14	30	0	23
JESCA	1997	28	13	22	15
Kipapi/TARI Bean 8	2024	1	1		8
Lyamungo 90	1990	35	0	22	5
Selian 13	2018	7	13	33	18
Selian 14	2018	7	7	0	5
Selian 15	2018	7	3	0	3
Uyole 03	2003	22	10	0	8
Uyole 18	2018	7	0	11	3
Uyole 19	2018	7	3	0	3
Uyole 96	1996	29	7	0	5
Njano Uyole	2008	17	3	11	5
Groundnuts					
Mangaka	2009	16	10	19	15
Mnanje	2009	16	20	25	23
Nachi 2015	2015	10	10	6	8
Naliendele 2016	2018	7	50	38	42
Narinut 2015	2015	10	0	6	4
Pendo	1998	27	10	6	8
Sorghum					
Macia	1998	27	50	43	44
Naco Mtama 1	2008	17	50	14	22
Pato	1977	48	0	14	11
Tegemeo	1995	30	0	14	11
Wahi	2002	23	0	14	11

Source: Survey, TARI (2024); Ndimbo et al., (2022); Daudi et al., (2022).

03, and Uyole 96 (22 and 29 years old, respectively). Old sorghum varieties included Pato (48 years old), Macia (27 years old), Tegemeo (30 years old), and Wahi (23 years old). The groundnut variety Pendo is 27 years old.

Overall, 50% of the QDS producers introduced new varieties into their portfolio, with >53% of them being bean farmers. Producers highlighted mainly market-related factors that would make them introduce a new crop variety into their QDS production portfolio (Fig. 1). The results show that the QDS producers target the market. Thus, varieties with high demand are the most preferred. Related to high demand are high prices. Other important considerations include ease of production, tolerance to pests and diseases, and resilience to climate change. Thus, when these considerations change, QDS producers are more likely to change varieties.

The key drivers that motivate QDS producers to increase investment in production such as introducing new varieties into their portfolios and expanding area under cultivation are presented in Fig. 2. For all the crops surveyed, availability of EGS and building the capacity of QDS producers were the most important interventions that would accelerate the adoption of new varieties. Other important interventions suggested by QDS producers were varietal promotional campaigns and favorable policy changes. Production of EGS, which includes breeder and foundation seeds, is essential for producing high-quality QDS. Many QDS producers struggle to access EGS due to high costs, limited supply and weak distribution networks. Public research institutions produce limited EGS, while private sector involvement is minimal, leading to frequent shortages. To curb this scenario, there is a need to strengthen public-private partnerships (PPPs) that improve the production and distribution of EGS, and certified seeds for QDS producers [7]. Stakeholders should encourage contract farming models where QDS producers' partner with research institutions or seed companies. This model could provide a consistent seed supply, decentralizing EGS production to ensure better accessibility at regional levels.

3.2. Profitability of QDS production

To understand the profitability of QDS production enterprises, three crops were considered: common beans, groundnuts, and sorghum. Table 5 summarizes the results of the analysis of QDS farmer enterprises. The costs and revenues arising from one acre of land under QDS production were examined. Results show that land rental and purchase of basic or certified seeds constitute the largest expenses in QDS bean production, accounting for approximately 30% of the total cost. The cost of renting production land is a major factor in determining the overall expense of QDS production. Renting land can be costly if producers are in areas where land is scarce or in high demand. This cost can be even higher if the land rental price is seasonal. Threshing, winnowing, sorting, and bagging follows as the second highest cost component.

For QDS production of groundnuts and sorghum, threshing, winnowing, sorting, weighing and bagging constitute the highest cost, accounting for approximately 30% of the total cost for groundnuts and 32% for sorghum. This is followed by the cost of purchasing basic seeds for groundnuts and inspection fees for sorghum. Overall, the total variable costs were TSH 849,100 (USD 333) for common beans, TSH 1178,000 (USD 461.5) for groundnuts and TSH 1048,500 (USD 410.7) for sorghum.

The revenue analysis indicates that producers earned a gross income of TSH 2508,390 per acre for common beans, TSH 2774,600 (USD1,087) for groundnuts, and TSH 2970,425 (USD 1163.8) for sorghum. All three categories of producers achieved positive returns on their investments. However, sorghum producers recorded the highest gross margin at TSH 1921,925 (USD 752.9), followed by common bean producers at TSH 1659,290 (USD 650), and groundnut producers at TSH 1596,600 (USD 625). Although the direct comparison of the margins made by QDS producers to those made by producers of cereals was not made, it is evident that the QDS producers use basic seeds from regulated seed sources, TARI being the main source of EGS. Such seeds are improved and likely to be better suited for the changing climate, pests, and diseases. Thus, it is plausible to assume that producers of QDS get better returns on their investment than their counterparts who produce recycled seeds [43,44].

All the three crop QDS enterprises surveyed yielded benefit-cost ratios greater than one. They all promise positive profit margins and profitable investments. However, in comparative terms, investment in production of bean QDS is the most profitable, followed by investment in sorghum. Thus, other factors being equal, a QDS producer would be more inclined towards beans than either sorghum or groundnuts. Although this paper did not collect data to compare the observed profitability levels of QDS with grain production, studies elsewhere have observed that the net return from seed production could be as high as 22 times that of grain production for a crop like rice and sesame [45] and 44% higher groundnuts [46].

If profitable, what limits QDS development? In-depth discussion with more experienced QDS producers showed that production is indeed profitable given the high market demand and the relatively high prices of QDS compared to normal grain. However, several obstacles impede faster development of the QDS sub-sector (Table 6). The dominant challenges are inadequate supply of EGS and certified seeds, inadequate market information, shortage of entrepreneurial skills among the QDS producers, policy restrictions regarding market boundaries, size of land per farmer producing QDS, and shortage of capital to invest in QDS production. Additionally, most farmers are unaware of the benefits of new varieties, such as higher yields, disease resistance, high nutritional content in terms of iron and zinc, and drought tolerance [47]. Lack of extension services and farmer training programs could be a major barrier to adoption.

The production and supply of EGS are often inadequate, making it difficult for seed producers to access foundation seeds for multiplication [6,12]. Furthermore, farmers often grow what the market demands. If consumers or traders prefer old varieties due to other qualities such as taste, cooking qualities, or cultural significance, farmers may hesitate to adopt new or improved varieties. Traders and processors plays an important role in seed systems as they provide market signals to farmers about the type of grains demanded thus creating seed demand pull in the entire value chain where seed producers of early generation seeds, certified and QDS respond to the demand by supplying quality seeds to the farmers [6,7,48]. Additionally, smallholder farmers make liberal use of local markets or traders for seeds in normal times and in stress periods [5] with local markets proving to be more important for farmers' getting seed than emergency seed aid itself [49]. This helps in reducing the cost of transportation, making QDS business more attractive.

3.3. Sustainability of QDS system

3.3.1. Is the QDS system sustainable?

First, positive profit margins and benefit-cost ratios greater than one quantitatively show that QDS production is sustainable as its economic benefits to producers are larger than costs (Table 5). In this section, qualitative responses to the five evaluation questions for sustainability are presented.

Eq 1. ***Does the QDS production system supply quality seeds to farmers?***

The results show that the QDS quality was largely good compared to farm-saved seeds (Fig. 3). These results are consistent with those that reported that latent Ralstonia solanacearum (Rs) infection was higher in home-saved or local seed (21%) than QDS seeds (9%) of potato in Ethiopia [50] and common bean seeds from trained seed producers were free from bacterial and fungal pathogens [51].

Ninety-six percent of the key informants and experts listed in Table 2 indicated that the seed quality of common beans ranged from acceptable to very good, with 27% rating it as acceptable, 64% as good, and 5% as

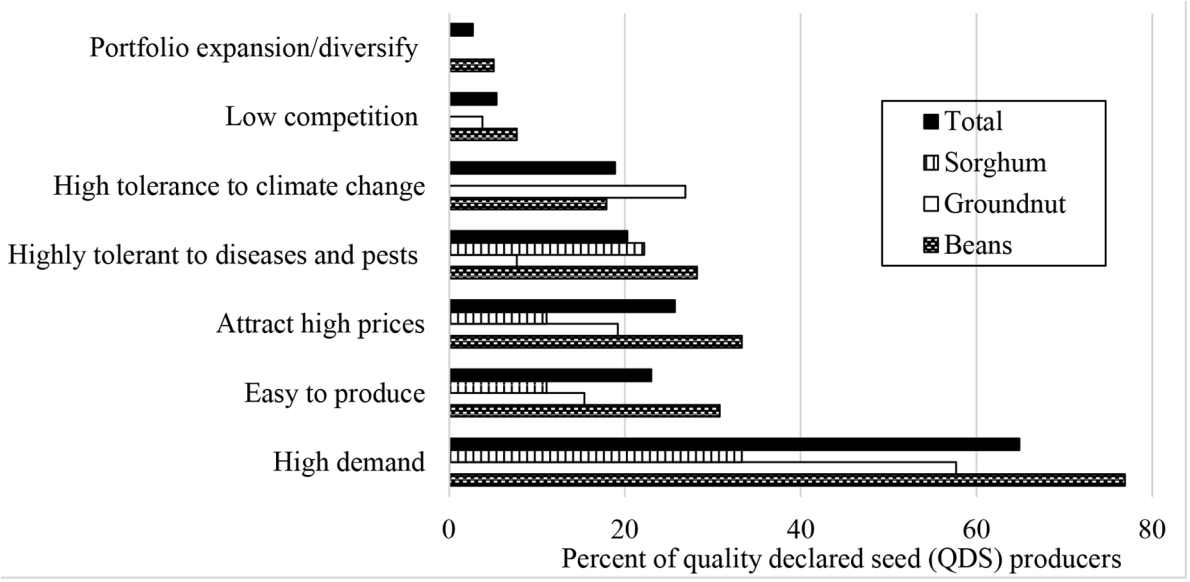

Fig. 1. Reasons for introducing a new variety into QDS production portfolio.
Total (n = 74); Sorghum (n = 9); Groundnut (n = 26); Beans (n = 39): Source: Survey

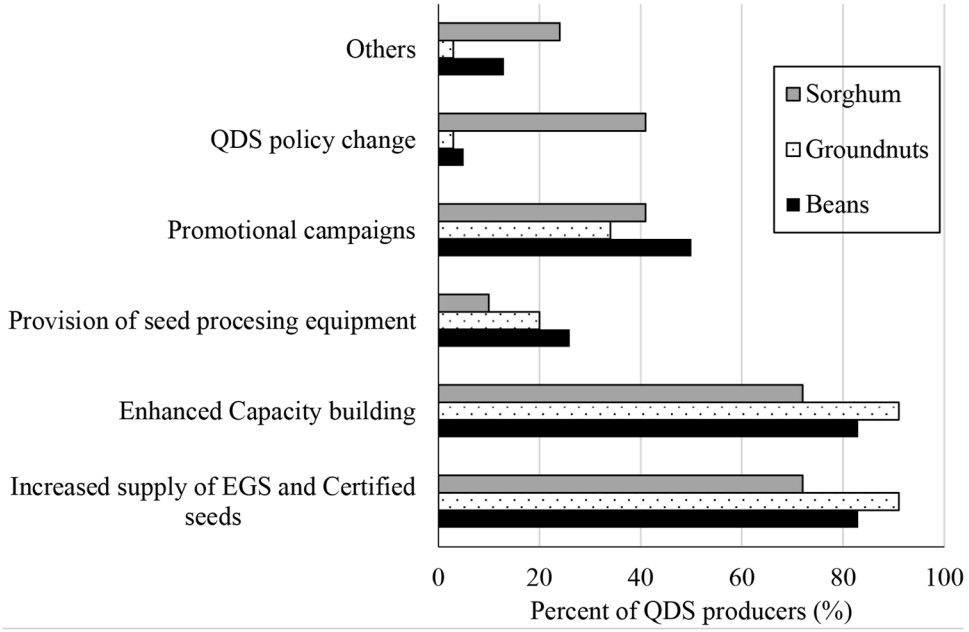

Fig. 2. Drivers for increased investment in quality declared seed (QDS) production.
* Sorghum (n = 27); Groundnut (n = 28); Beans (n = 93). Source: Survey

very good. About 4% of the key informants, however, felt that the quality of QDS was very poor. It is, therefore, important to find out what the reservations with the quality of QDS could be. The quality of groundnuts produced was either good or very good, as indicated by 80% and 20% of the key informants, respectively. For sorghum, 33% of the respondents rated the quality of the seeds as being acceptable while 67% rated the quality as being good.

Other aspects of seed quality include whether seeds are free from seed-borne diseases and pest infections. Producers need seeds that are clean, free from weed seeds and other materials, and whole (not broken, not peeled off, and not damaged). Seeds should be of uniform size and have germination rates of about 80% or higher.

Several factors could account for the observed quality of the seeds produced under the QDS system. Most notably, majority of producers interviewed reported having sufficient knowledge for QDS production – including 82% of bean producers, 74% of groundnut producers and 76% of sorghum producers. Moreover, all these producers have at least 3 years of experience in QDS production. They sourced basic seed from authentic sources. In addition, 94% of bean QDS producers, 66% of the groundnut QDS producers, and 74% of sorghum QDS producers confirmed that their farms were regularly inspected by the regulator. Over 85% of QDS producers confirmed that they received feedback from their farmer clients. These factors must have ensured that the seeds produced were of recommended quality. Furthermore, the majority of the QDS producers stored their produce for 3 months, which may have limited quality deterioration.

Discussions with sector experts indicated that for continued QDS quality assurance, legal and licensed QDS market outlets would be

Table 5
Gross margin analysis for quality declared seed (QDS) production.

Average Cost of production (TSH/ Acre) **	Crops		
	Common Beans	Groundnuts	Sorghum
Seed purchased (certified or basic)	100,000	140,000	10,500
Land preparation (ploughing)	60,000	70,000	70,000
Labor for planting	50,000	20,000	20,000
Planting fertilizers	10,000	70,000	70,000
Agrochemicals (for crop protection)	45,000	68,000	68,000
Labor for agrochemical application	44,000	10,000	10,000
Weeding	60,000	20,000	20,000
Harvesting (including transport)	54,000	30,000	30,000
Threshing, winnowing, sorting, bagging	84,500	335,000	335,000
Polypropylene sheet	6000	25,000	25,000
Polypropylene Bags-100kgs	5600	30,000	30,000
Weighing and bagging-100kgs	10,000	10,000	10,000
Transport to market	60,000	60,000	60,000
Preservation during storage	10,000	45,000	45,000
Cost of inspection /inspection fee	120,000	120,000	120,000
Other costs specify (land renting)	100,000	100,000	100,000
Other costs, specify (clearing farm)	30,000	25,000	25,000
Total	**849,100**	**1178,000**	**1048,500**
Average Harvest & Sales per acre			
Total harvest (kg)	880	750	1800
Yield (kg/acre)	880	600	1125
Quantity sold as seed (kg)	770	500	900
Price/kg (TSH)	3250	5000	3000
Quantity sold as grain (kg)	-	100	300
Price/kg sold as grain (TSH)	-	2500	500
Quantity lost postharvest (kg)	-	90	525
Quantity used for other purposes (kg)	-	60	75
Revenue from sale of seeds (TSH)	2502,500	2500,000	2700,000
Revenue from sale as grain (TSH)	-	250,000	150,000
Value used for other purposes (TSH)	-	15,000	112,500
Other specify-Post harvest loss (kg)	110	-	-
Total value of QDS harvested (TSH)	**2508,390**	**2774,600**	**2970,425**
Gross Margin	**1659,290**	**1596,600**	**1921,925**
Benefit-Cost Ratio (BCR)	3.0	2.4	2.8

** Notes: Exchange rate: 1 USD=TSH 2552.38; TSH =Tanzania Shillings. Source: Survey.

Table 6
Challenges faced by surveyed quality declared seed (QDS) producers.

Challenges	Crops (%)		
	Common Beans	Groundnuts	Sorghum
Limited access to early generation seed (EGS) and certified seeds	42	40	38
Weak producers' capacity (e.g. limited entrepreneurial skills, infrastructure, financial capital etc.)	30	26	21
Climate change	29	34	35
Poor business environment (e.g. limited market and variety information)	12	14	10
Others (e.g. mismatch between seed demand time)	16	9	17
QDS policy regulations	2	0	0
Plant Variety Protection Act not favoring QDS producers	9	0	0
High incidence of fake seeds	2	3	0
Number of observations (n)	93	28	27

Source: Survey.

essential. Such outlets would ensure that desirable seed transportation, packaging, and storage processes are implemented. These procedures would also make it possible to trace the seeds to the different producers and enforce strict adherence to quality standards.

Eq 2. ***Does QDS supply enough quality seeds to meet farmer demands?***

Seed producers rated demand for QDS as high to very high. Notably, 91% of respondents said that producers were unable to meet the demand for bean QDS, while 60% reported a similar challenge for groundnut seeds. For sorghum seed, all key informants agreed that QDS producers could not fully satisfy the demand. Despite these supply gaps at the local level, some QDS producers extended their sales beyond their immediate communities, reaching buyers from other districts and regions.

While QDS producers are currently unable to fully meet the growing demand for seeds, it is encouraging to see an increase in the land area under QDS production. TARI, CIAT, TOSCI, local government authorities in collaboration with Accelerated Variety Turnover for Open-Pollinated Crops (ACCELERATE), Tropical Legumes I-III and Accelerated Varietal Improvement and Seed Delivery of Legumes and Dryland Cereals in Africa (AVISA)[1] projects drove this positive trend by raising awareness and promoting production of early generation seeds (EGS), certified and QDS seeds [7,38,52]. Development partners have also made deliberate investments in promoting QDS production. Additionally, development partners have made strategic investments to expand QDS production, complementing the formal seed system in Tanzania. To ensure the long-term sustainability of the QDS system, building farmer capacity is essential. Strengthening their skills and knowledge will help reduce reliance on short-term project-based support, creating a more resilient and self-sufficient seed production system.

Eq 3. ***Does the QDS system offer varieties to meet the diverse needs of farmers?***

QDS producers cultivate a range of seed types, with certain varieties being more common among those surveyed. For common beans the most widely produced varieties were CALIMA UYOLE (23%), Selian 13 (18%), and JESCA (15%). Among groundnut producers the predominant varieties included Naliendele 2016 (42%), Mnanje (23%), and Mangaka (15%). For sorghum the most cultivated varieties were Macia (44%) and Naco Mtama 1 (22%) (further details can be found in Table 4). Despite continuous release of new open pollinated varieties of sorghum, common beans and groundnuts in the last decade, those new varieties (Table 7) are not adopted by seed producers. The dominance of a few varieties per crop suggests that seed producers focus on market demand. QDS producers have a variety of options to choose from to serve the varying needs of the market, to mitigate the risks associated with erratic weather conditions, and to cope with changing plot-level conditions. Over the past decade, 27 improved varieties of common beans, 10 of groundnuts, and 9 of sorghum have been developed and released in Tanzania (Table 7. This diversification is important in ensuring that farmer preferences are met by QDS suppliers. Unfortunately, diversification could limit QDS supply if insufficient quantities of each variety can be produced. Despite this, QDS producers are always willing to adopt new varieties so long as market signals indicate that they will be able to sell large quantities to farmers at better prices.

Thus, to address this, the availability of EGS for newly released varieties should be assessed to ensure consistent and sufficient production. Strengthening promotion and farmer awareness campaigns can help to expand the adoption of improved varieties that offer better yields, climate and disease resistance.

Eq 4. ***Does QDS system deliver seeds in a timely manner and in locations convenient to the farmers?***

Expert discussions highlighted QDS production as a reliable way to improve seed accessibility and replace older varieties. Cultivating old

[1] Details on AVISA project can be found at https://www.cimmyt.org/projects/avisa-transition-investment/ while ACCELERATE at https://alliancebioversityciat.org/projects/accelerate and Tropical legumes I-III at https://tropicallegumeshub.com/

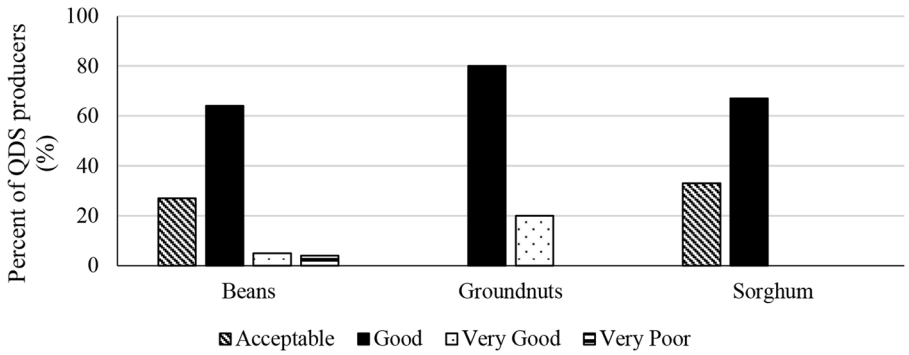

Fig. 3. Rating the quality of seed produced by quality declared seed producers.
Source: Survey

Table 7
Varieties of common beans, groundnuts, and sorghum developed and released in Tanzania.

Beans				Groundnuts		Sorghum	
Variety	Year of Release	Variety	Year of Release	Varie	Year of Release	Variety	Year of Release
Kabanima	1979	Uyole 16	2016	Nyota 1983	1983	Serena	1960
Uyole 84	1984	Uyole 17	2018	Johari 1985	1985	PATO	1977
Lyamungo 85	1985	Uyole 18	2018	Pendo 1998	1998	TEGEMEO	1995
Lyamungo 90	1990	Selian 09	2018	Sawia 1998	1998	MACIA	1998
Uyole 90	1990	Selian 10	2018	Mnanje 2009	2009	WAHI	2002
Selian 94	1994	Selian 11	2018	Naliendele 2009	2009	HAKIKA	2002
Uyole 94	1994	Selian 12	2018	Mangaka 2009	2009	Sila	2008
Uyole 96	1996	Selian 13	2018	Nachingwea 2009	2009	NACO Mtama 1	2008
JESCA	1997	Selian 14	2018	Masasi 2009	2009	PAC 537	2014
Selian 97	1997	Selian 15	2018	Nachi 2015	2015	PAC 501	2014
Uyole 98	1998	TARIBEAN 1	2021	Kuchele 2015	2015	PAC 537	2014
Wanja	2002	TARIBEAN 2	2021	Narinut 2015	2015	Rakodzi	2019
Uyole 03	2003	TARIBEAN 3	2021	Naliendele 2016	2018	SC Shaku	2019
Uyole 04	2004	TARIBEAN 4	2021	Tanzanut 2016	2016	Shirikule	2019
Bilfa Uyole	2004	TARIBEAN 5	2021	Mtwaranut 2016	2018	Vumba	2019
Selian 05	2006	TARIBEAN 6	2024	TARIKA 1	2024	TARI SOR 1	2021
Selian 06	2007	TARIBEAN 7	2024	TARIKA 2	2024	TARI SOR 2	2021
Cheupe	2007	TARIBEAN 8	2024	Shinje	2019	NACO SH1	2013
Njano Uyole	2008	TARIBEAN 9	2024	SC Orion	2019	NACO SH2	2013
Calima Uyole	2011	TARIBEAN 10	2024	Red Mwitunde	1976	TARISOR 3	2025
Pesa	2006	TARIBEAN 11	2024			TARISOR 4	2025
Urafiki (Msafiri)	2007					TARISOR 5	2025
Nyeupe Uyole	2016	Kikatiti	2024			TARISOR 6	2025
SUABRL9	2021	Kware	2019				
SUABRL4	2021	Rojo	1997				
SUA Kalima	2021	Ilomba	1990				
SAKILA20	2021	Mshindi	2006				
Sc Bounty	2019						

Sources: TARI (2024); Ndimbo et al., (2022); Daudi et al., (2022); TOSCI Data base (2025).

and obsolete varieties farmers the desired benefits that they could get from using new or improved varieties [42]. Since QDS producers operate within the local farming communities, they play a crucial role in raising awareness about new or improved varieties, including their benefits, market potentials, agroecological suitability and recommended farming practices. This localized approach should enhance the adoption of superior varieties among farmers. Additionally, farmers' proximity to QDS producers allows them to access seeds conveniently and cost-efficiently, eliminating transportation expenses and other transaction costs. Notably, over 70% of the key informants confirmed farmers can obtain seeds as needed without significant delays.

Eq 5. ***Does the QDS system offer seeds to farmers at affordable prices?***

Key informants (82%) indicated QDS is more affordable compared to certified seeds of the same varieties. For instance, common beans cost TSH 3216 (USD 1.26) per kilogram versus TSH 4500 (USD 1.74) for certified seed (40% difference). Groundnut QDS costs TSH 5000 (USD 1.93) compared to TSH 7000 (USD 2.71) for certified seed (also 40% higher). Sorghum QDS costs TSH 3000 (USD 1.16) per kilogram, while certified seed costs TSH 4000 (USD 1.55), a 33% difference. This price disparity shows how QDS offers a more affordable alternative for farmers, particularly in regions where cost is a major barrier to seed access. The lower cost of QDS could potentially enable small-scale farmers to afford high-quality seeds, thus improving crop productivity and enhancing food security. Additionally, the cost-effectiveness of QDS is likely to encourage wider adoption, especially in low-income farming communities where affordability plays a critical role in decision-making. However, while QDS is more affordable, its availability and other quality factors should also be monitored to ensure that farmers are still receiving reliable seed quality despite the lower cost. Key informants emphasized that QDS remains affordable given the economic conditions of farmers in the production areas. Additionally, since QDS is locally available, farmers can save on transportation costs that would otherwise be incurred when sourcing certified seeds from distant locations.

3.3.2. Drivers of sustainability of the QDS system

Although QDS was formalized in 2003, the regulatory body TOSCI initially focused on training QDS producers and issuing certificates to enable them to produce seeds. In 2020, TOSCI began systematically tracking production. They introduced a requirement for seed producers to register after training and have their farms inspected before producing seeds. We examined the QDS production trend from 2020 to 2024 to assess the sustainability of the system among registered farmers who are legally authorized to produce QDS. Registration of the fields to produce QDS is low at 31% of all the trained QDS producers (Table 8). A significant number of registered producers failed to renew their licenses, with 98% failing to renew their registration or licenses between 2019 −2024 (Table 8) despite registration being free. This indicates that, after receiving training, majority of farmers choose to produce QDS without registering or obtaining licenses from the seed regulatory authority. The failure to register after training or to renew registration may be attributed to several factors, including limited awareness, difficulties navigating online registration systems that are not user-friendly for all producers, and restricted access to regulatory authorities, who are often located far away and are not easily reachable. Additionally, QDS producers cited other challenges that may also contribute to low renewal of registration or licenses include limited producer capacity such as weak entrepreneurial skills, inadequate infrastructure, and insufficient financial capital as well as the impacts of climate change, and an unfavorable business environment (Table 6). As a result, the regulator lacks accurate data on the actual volumes of QDS produced nationwide, which may pose challenges in ensuring quality control and proper seed supply planning. This situation does not necessarily indicate the unsustainability of the QDS system itself, but rather highlights weaknesses in the regulatory process responsible for ensuring that producers renew their licenses. To address this challenge, TOSCI can be equipped to authorize private third parties to conduct field inspections and seed testing as recognized in the Seeds Act 2003 and Regulations 2007 and regional seed initiatives, coupled with development of clear guidelines and inspector training programs [53].

QDS producers stop production: While the QDS system aligns with the characteristics of sustainable seed systems, in-depth discussion with more experienced QDS producers revealed that even the most seasoned producers may have occasionally had to pause production. Only a few producers have consistently remained active in the business. The reasons for these periodic interruptions include those provided in Table 6 above. Specifically, producers may lack foundation seed or certified seeds for sorghum, common beans, and groundnuts (e.g. [6,10,12]. Producers may also pause production due to erratic weather and the high cost of inputs. Other reasons hindering continuity and/or expansion of QDS systems include end of supportive projects run by NGOs that push them to register their fields for production, restrictions on the kind of plots that may be used for QDS production, and shortage of land, especially for producers who depend on rented land and limited business skills of QDS producers and inadequate training curriculum for QDS training module (Table 1a-suppementary material provide details). One of the QDS producers explained: "*Land access and security pose a challenge as many producers are renting land. This makes it difficult to secure larger plots of land, ultimately hindering management and production efficiency*". High costs arising from TOSCI packaging and labeling requirements and certification could be another hindrance. One QDS producer said: "*The cost of QDS production is high, especially TOSCI certification. Previously a project subsidized our production but that came to an end. Many of us stopped production as a result but I hope to resume next season when I secure funds and in partnership with NAFCO Farms, which will facilitate TOSCI visits.*"

QDS producers continue to produce: Despite the challenges facing QDS production—particularly the low rates of registration and license renewal, even though the process is free—production has continued to increase steadily and gradually. This progress has been driven by several factors. Promotional campaigns and demonstrated high yields increased demand for quality seed [9,12]. NGOs and national and international research organizations supported and trained QDS producers, reducing some of their costs [12]. QDS production showed higher profitability compared to grain production [10,29,47]. Newly released improved varieties addressing biotic and abiotic stress provided resilience to climate change and emerging pests and diseases. In the last 10 years, 32 new varieties (22 bean varieties, 8 groundnut varieties and 2 sorghum varieties) have been released by the National Agricultural Research System in Tanzania (Table 7). These variety releases demonstrate that the system could be sustainable. Farmers could comply with the recommendation that varieties grown should not be >10 years old, except for certain unique situations in developing countries [42].

4. Conclusion

Wide access to improved seeds is important for inclusive agricultural transformation. Typically, there are formal and informal seed systems. While the formal seed system provides certified seeds, the informal system is dominated by seeds whose quality is unknown. However, the formal seed system is often unreachable, charging high prices, which limit access to high quality seeds. Quality declared seed (QDS), which lies between the formal and the informal seed systems, has been viewed as a possible avenue for bridging the gap—ensuring that farmers obtain seeds of assured quality at affordable prices. This study sought to investigate the economic viability and sustainability of the QDS seed system, using data collected from QDS producers themselves and expert elicitation from seed value chain actors. The study found that:

a) The QDS seed system is profitable, yielding positive profit margins and benefit-cost ratios (BCR) greater than one, indicating that QDS production is potentially sustainable as the benefits outweigh the costs.
b) The QDS seed system—being characterized by high quality seeds, diverse varieties, increasing production and supply, timely and convenient delivery of seeds to farmers, and more affordable prices—can enhance sustainable distribution and promotion of improved varieties, especially of open pollinated varieties. The QDS system can drive regular use of quality planting materials in marginalized areas.

Table 8
QDS producer training, registration to produce seeds, renewals of registration or license.

Details	2019	2020	2021	2022	2023	2024	2025	Total
Number of QDS producer trained	888	391	120	586	681	953	888	4507
Registration to produce QDS	787	82	123	43	317	55	0	1407
No. due for registration renewal	-	-	787	82	123	43	317	1352
Cumulative due for renewal	-	-	787	869	992	1035	1352	1352
Renewed registration/license	-	-	0	0	24	0	0	24
Not renewing registration	-	-	787	869	968	1011	1328	1328
Not renewing registration/license (%)	-	-	100	100	98	98	98	98
Overall registration rate (%)								31

Data Source: TOSCI (2024).

c) QDS production is highly dependent on the external support provided by humanitarian and non-governmental organizations (NGOs).
d) The QDS producers who have sustainably produced seeds for >10 years are driven and motivated by profits from the business, quality seeds that are adaptable to climate change, and support from public and private sectors that often create markets for the seeds through donor funded programs. The potential loss of these motivations poses a risk to the sustainability of the system. Hence, there is need for sustained effort from public and private commercial sectors to support variety promotion and outreach, working collaboratively with QDS producers.
e) The QDS regulatory and certification system is relatively weak, with limited reach to all the QDS producers in the country. Consequently, producers produce QDS without registration, frequently abandon their QDS production, or continue to produce without renewing registration.
f) QDS is mainly sold at the farmgate. <10% of the sales are made through formal outlets or shops, posing a challenge of ensuring quality of seeds and traceability.
g) Trained producers often abandon QDS systems due to several challenges, including shortage of EGS and certified seeds from TARI and licensed companies (which they prefer over other sources), erratic weather that can result in total crop failure, high input costs such as fertilizers and pesticides, and the discontinuation of supportive projects. Moreover, the high costs of QDS production driven by packaging, labeling requirements, and certification from regulatory bodies, contribute to their decision to exit the sector.

However, the sub-sector faces challenges such as the inadequate supply of EGS, inadequate market information, the shortage of entrepreneurial skills among producers, restrictive policies, shortage of capital, and the need for prolonged storage. The policy implications of these findings include:

a) Efforts should be made to enhance the supply of EGS for sorghum, common beans, and groundnuts, which could be achieved through partnerships between the national agricultural research system (e.g. TARI), the Agricultural Seed Agency (ASA), and seed companies. Under public-private partnerships (PPPs), the National Research Institute in charge of EGS production could sub-contract the seed companies to produce EGS through variety licensing, which transfers the ownership of a particular variety to the seed company in question. In this case, the seed company would manage the production of EGS for a particular variety. This system should allow pre-ordering of EGS. Alternatively, TARI could scale up EGS production during the off-season through irrigation.
b) Stakeholders should develop QDS marketing infrastructure and market information systems. They should encourage QDS producers to operate formal outlets or shops to sell the seeds, enhancing farmers' trust in QDS. Secondly, instead of supporting QDS through NGOs, linking them with the private sector would enhance sustainability of the system [6,54]. Additionally, the regulator needs to develop suitable guidelines for compliance with rules and traceability, without increasing the cost of QDS.
c) Authorities should review and revise existing laws and regulations to allow faster development of the sub-sector. For example, laws capping the land per farmer under QDS production to 5 acres could be relaxed, enabling QDS producers to enjoy economies of scale. This should be coupled with efforts to increase awareness of laws and regulations among the actors.
d) Stakeholders should review and revise the QDS training curriculum to include business entrepreneurship and marketing skills, as it currently focuses solely on seed production. This enhancement will significantly improve the capacity-building programs for QDS producers, equipping them with a broader and valuable skill set for sustainable production and impact. Improved training will help to increase registration to produce QDS, encourage renewal of licenses and motivate producers to sustainably invest in QDS businesses.

5. Future research needs

This paper has examined the economic viability and sustainability of Quality Declared Seed (QDS) production as a business, drawing on data collected from QDS producers and industry experts. For future research, it is essential to incorporate the perspectives of grain farmers who are the primary customers of QDS producers across diverse geographic, political, and policy contexts. Their insights on seed quality and the long-term sustainability of the QDS enterprise are critical to draw more robust and evidence-based conclusions about the overall viability and sustainability of the QDS business model. Additionally, this study included QDS producers from five regions, however, the results cannot be generalized at the national level as the sample size is not representative of all the QDS producers in the country. Thus, future research should employ a larger, more representative sample that also encompasses producers who attempted the QDS production but failed.

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CRediT authorship contribution statement

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Declaration of competing interest

The authors declare they have no conflict of interest.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.sftr.2026.101848.

Data availability

Data will be made available on request.

References

[1] T. Tscharntke, et al., Global food security, biodiversity conservation and the future of agricultural intensification, Biol. Conserv. 151 (1) (2012) 53–59, https://doi.org/10.1016/j.biocon.2012.01.068.

[2] FAO, The State of food insecurity in the world 2013. The Multiple Dimensions of Food Security, FAO, Rome, 2013.

[3] K. Kusena, R. Wynberg, C. Mujaju, Do smallholder farmer-led seed systems have the capacity to supply good-quality, fungal-free sorghum seed? Agric. Food Secur. 6 (1) (2017) 52, https://doi.org/10.1186/s40066-017-0131-7.

[4] S. McGuire, L. Sperling, Seed systems smallholder farmers use, Food Secur. 8 (1) (Feb. 2016) 179–195, https://doi.org/10.1007/s12571-015-0528-8.

[5] L. Sperling, P. Gallagher, S. McGuire, J. March, N. Templer, Informal seed traders: the backbone of seed business and african smallholder seed supply, Sustainability (Switzerland) 12 (17) (Sep. 2020), https://doi.org/10.3390/su12177074.

[6] J. Ochieng, et al., Accelerated varietal turnover for open-pollinated crops (beans, sorghum, groundnuts) in Tanzania – seed sector stakeholders' landscaping, Baseline Rep. (2023). Accessed: May 13, 2025. [Online]. Available, https://hdl.handle.net/10568/137495.

[7] J. Ochieng, et al., Seeds of change: enhancing availability and adoption of new sorghum, groundnut, and bean varieties in Tanzania, Accessed: May 13, 2025. [Online]. Available, https://hdl.handle.net/10568/148912, Jun. 31, 2024.

[8] A. Mastenbroek, G. Otim, B.R. Ntare, Institutionalizing quality declared seed in Uganda, Agronomy 11 (8) (2021), https://doi.org/10.3390/agronomy11081475.

[9] S. David, Farmer seed enterprises: a sustainable approach to seed delivery, Agric. Human. Values. 21 (4) (2004) 387–397, https://doi.org/10.1007/s10460-004-1247-5.

[10] Mugisha, Johnny, R.N. Proscovia, Bangizi Robert, Namwanje Diana, and Mutambira Bosco, "Access to quality seed in Uganda: the contribution of farmers' Local seed businesses to the seed sector.," Kampala, Uganda, 2022.

[11] L. Sperling, B. Dey, and D. Leege, *New models for legume seed business: resilience, nutrition and reaching farmers at the last mile MEETING REPORT*. 2022.

[12] M.K. Kansiime, et al., Assessing sustainability factors of farmer seed production: a case of the Good Seed Initiative project in Tanzania, in: Agric Food Secur, 10, 2021, p. 15, https://doi.org/10.1186/s40066-021-00289-7.

[13] SDC, "Seed value chain demand study for open pollinated variety maize, legumes, and small grains in Zambia and Zimbabwe. Berne: Switzerland.," 2021.

[14] B. Dey, et al., Strengths and weaknesses of organized crop seed production by smallholder farmers: a five-country case study, Outlook. Agric. 51 (3) (Jul. 2022) 359–371, https://doi.org/10.1177/00307270221115454.

[15] D.J. Bram, M. Gigi, M. Andrew, G.I. Normita, A. Alejandro, V. Bert, Seed laws: bottlenecks and opportunities for participatory plant breeding, Farmers and Plant Breeding (277-293). Routledge: eBook ISBN: 9780429507335, Farm. Plant Breed. (2019) 277–293.

[16] K. Kuhlmann, B. Dey, Using regulatory flexibility to address market informality in seed systems: a global study, Agronomy 11 (2) (2021), https://doi.org/10.3390/agronomy11020377.

[17] FAO, Quality Declared Seed System: FAO Plant Production and Protection Paper 185. Anonymous, Rome: Food and Agriculture Organization of the United Nations (2006), Apr. 2006, p. 243, https://doi.org/10.1017/S0014479706314901. $40.00. ISBN 92-5-105510-6.

[18] URT, Seeds (Control of Quality Declared Seeds) Regulations, 2020, United Republic of Tanzania (URT), Dodoma, 2020.

[19] D.J. Spielman, A. Kennedy, Towards better metrics and policymaking for seed system development: insights from Asia's seed industry, Agric. Syst. 147 (2016) 111–122, https://doi.org/10.1016/j.agsy.2016.05.015.

[20] J.M. Mondo, N. Adrien B, A. Rodrigue B, M. Henri M, B. Chance, M. R, Civava, Seed delivery system in northeastern Democratic Republic of Congo: characteristics, stakeholders mapping and challenges towards building a well-functioning seed system under humanitarian and security crises, Int. J. Agric. Sustain. 22 (1) (2024) 2335128, https://doi.org/10.1080/14735903.2024.2335128.

[21] FAO, "Impact of implementation of seed legislation on diversity of plant genetic resources for food and agriculture.," 2021.

[22] B. Douthwaite, Development of a Cassava Seed Certification System in Rwanda: Evaluation of CGIAR Contributions to a Policy Outcome Trajectory, International Potato Center, Lima, Peru, 2020.

[23] S. Herpers, R.S. Vodouhe, M. Halewood, B. de Jonge, The support for farmer-led seed systems in African seed laws, ISSD Africa (2017). Accessed: May 13, 2025. [Online]. Available, https://hdl.handle.net/10568/81545.

[24] URT, "Seed Act, 2003. United Republic of Tanzania," 2003.

[25] R. Vernooy, Options for national governments to support smallholder farmer seed systems: the cases of Kenya, Tanzania, and Uganda, Hivos (2017). Accessed: May 13, 2025. [Online]. Available, https://hdl.handle.net/10568/80762.

[26] H. Siringo, G. Lukurugu, A. Bujiku, P. Binagwa, R. Kasuga, Var. Cat. Groundnuts (Arachis Hypogaea) Tanz. (2022).

[27] M. Ndimbo, N. Shida, J. Mbiu, J. Kilango, M. Madata, P. Binagwa, R. Kasuga, Variety Catalogue of Common Beans (Phaseolus Vulgaris) in Tanzania (1) (2022).

[28] R. Fani, D. Choumbou, I.U. Odoemenem, N. Oben, Gross margin analysis and constraints faced by small scale rice producers in the West region of Cameroon, J. Biol. Agric. Healthc. 5 (2015) 108–112. Online]. Available, https://api.semanticscholar.org/CorpusID:54528546.

[29] H. Mvungi, et al., Profitability analysis of traditional African vegetable seeds production in Kenya, J. Med. Act. Plants 9 (4) (2020), https://doi.org/10.7275/08eb-nv32.

[30] R. Chima, et al., State of digitalization of seed companies and quality declared seed producers in Tanzania, Accessed: May 13, 2025. [Online]. Available, https://hdl.handle.net/10568/174218, Apr. 05, 2025.

[31] F. Pashaei Kamali, J.A.R. Borges, M.P.M. Meuwissen, I.J.M. de Boer, A.G.J.M. Oude Lansink, Sustainability assessment of agricultural systems: the validity of expert opinion and robustness of a multi-criteria analysis, Agric. Syst. 157 (2017) 118–128, https://doi.org/10.1016/j.agsy.2017.07.013.

[32] J. Ochieng, P. Schreinemachers, M. Ogada, F.F. Dinssa, W. Barnos, H. Mndiga, Adoption of improved amaranth varieties and good agricultural practices in East Africa, Land. Use Policy. 83 (2019) 187–194, https://doi.org/10.1016/j.landusepol.2019.02.002.

[33] J. Devra, S.-P. Ricardo, C.-S. José Luis, H. Toby (Eds.), Seed Systems and Crop Genetic Diversity On-Farm Proceedings of a Workshop, International Plant Genetic Resources Institute, Pucallpa, Peru, 2005. *16–20 September 2003Rome, Italy*.

[34] FAO, "Seed Systems. Available at (16 July 2025)," Jul. 2025.

[35] J. Ochieng, et al., Economic viability of scaling improved bean technologies in Burundi and Zimbabwe, Food Energy Secur. 14 (1) (Jan. 2025) e70056, https://doi.org/10.1002/fes3.70056.

[36] Africa Seeds, Gender and the Seed Sector, African Seed Sector Development Organization, Abidjan, Côte d'Ivoire, 2022. Accessed: May 13, 2025. [Online]. Available, https://www.africa-seeds.org/en/why-seeds/gender-and-the-seed-sector/.

[37] B. Granqvist, "Is Quality declared seed production an effective and sustainable way to address seed and food security in Africa. Technical Centre for Agricultural and Rural Co-operation (CTA): Wageningen, The Netherlands," 2009.

[38] A.A. Hatibu, E. Akpo, G.A. Lukurugu, J. Nzunda, P. Okori, C.O. Ojiewo, Upscaling groundnut seed production and delivery through long-term public–Private and Development organization partnerships: experiences from Tanzania, Agriculture 13 (1) (2022) 79, https://doi.org/10.3390/agriculture13010079.

[39] H. Sseguya, et al., The impact of demonstration plots on improved agricultural input purchase in Tanzania: implications for policy and practice, PLoS. One 16 (1) (Jan. 2021) e0243896, https://doi.org/10.1371/journal.pone.0243896.

[40] E. Akpo, M. Geoffrey, L. Gerald Alex, O. Hellen, O. Chris O, R, Varshney, Legume seed production for sustainable seed supply and crop productivity: case of groundnut in Tanzania and Uganda, J. Crop. Improv. 34 (4) (2020) 518–539, https://doi.org/10.1080/15427528.2020.1740368.

[41] A. Mbatia, Levelling the playing field: seed access for farmers. https://farmingfirst.org/2022/09/levelling-the-playing-field-seed-access-for-farmers/, 2022.

[42] R.P. Singh, A.D. Chintagunta, D.K. Agarwal, R.S. Kureel, S.P.J. Kumar, Varietal replacement rate: prospects and challenges for global food security, Glob. Food Sec. 25 (2020) 100324, https://doi.org/10.1016/j.gfs.2019.100324.

[43] J. Ndossi, et al., Delineating investment opportunities for stakeholders in sorghum seed systems: a logit model perspective, Agric. Food Secur. 10 (1) (2021) 43, https://doi.org/10.1186/s40066-021-00306-9.

[44] A. El Naim, M. Maruod, E. Breima, E. Elkhidir, Impact of improved seeds on small farmers productivity, income and livelihood in Umruwaba locality of North Kordofan, Sudan, Int. J. Agric. For. 3 (2013) 203–208, https://doi.org/10.5923/j.ijaf.20130306.01.

[45] C.J. Adong, "Markets for Quality Seed in Northern Uganda: skilling local seed businesses to successfully sell their seed.," Uganda, Brief, 2015.

[46] G. Pal, C. Radhika, K.U. Bhaskar, H. Ram, S.R. Prasad, A study on comparative economics of grain and seed production of groundnut in Karnataka, India, J. Exp. Agric. Int. 14 (5) (2016) 1–9.

[47] N.E. Lyimo, Drivers of quality declared seed use in Tanzania: evidence from Kilombero District, Int. J. Agric. Ext. Rural Dev. Stud. 7 (1) (2020) 44–54.

[48] L. Sperling, C.J.M. Almekinders, Informal commercial seed systems: leave, suppress or support them? Sustainability. 15 (18) (2023) 14008 https://doi.org/10.3390/su151814008.

[49] L. Sperling, H.D. Cooper, T. Remington, Moving towards more effective seed aid, J. Dev. Stud. 44 (4) (2008) 586–612, https://doi.org/10.1080/00220380801980954.

[50] L. Tessema, W. Negash, R. Kakuhenzire, G. Belay, E. Seid, M. Enyew, Seed health trade-offs in adopting quality declared seed in potato farming systems, Crop. Sci. 64 (3) (2024) 1340–1348, https://doi.org/10.1002/csc2.21025.

[51] R.J. Claude, M. Dickinson, S. Mayes, T. Assefa, Seed-health assessment of different bean Seed grades and sources from Ethiopia using molecular tools, J. New Seeds 10 (4) (2009) 293–310, https://doi.org/10.1080/15228860903336734.

[52] R.K. Varshney, C. Ojiewo, E. Monyo, A decade of Tropical Legumes projects: development and adoption of improved varieties, creation of market-demand to benefit smallholder farmers and empowerment of national programmes in sub-

Saharan Africa and South Asia, Plant Breed. 138 (4) (2019) 379–388, https://doi.org/10.1111/pbr.12744.
[53] AGRA, "A legal guide to strengthen Tanzania's seed and input markets.," 2016.
[54] A. Mwakatwila, et al., Enhancing trader seed delivery models for sorghum and groundnuts: the case of Tanzania's Kibaigwa Flour Supplies Ltd, Accessed: May 13, 2025. [Online]. Available, https://hdl.handle.net/10568/149221, 2024.