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ABSTRACT

Enhancing smallholder chicken production and productivity is an integral component of agricultural development strategies in sub-Saharan Africa. The African Chicken Genetic Gain (ACGG) project has been testing, identifying, and disseminating tropically adapted improved breeds (TAIBs) in Africa to improve the production and productivity of the sector. We applied a multimethod approach and integrated analysis to explore the overall feasibility of TAIBs under smallholder management conditions and documented evidence for sustained adoption. We used data from a baseline survey, on-farm experiment, cluster-randomized study, and market assessment survey to analyse the technical, economic, social, and environmental feasibility of TAIBs adoption under smallholder management conditions. The multimethod approach attests TAIBs as a sustainable technological alternative to smallholder chicken producers in the region. Most smallholder farmers prefer TAIBs to indigenous breeds, and TAIBs-based production enhance producers' consumption and income generation goals. Moreover, adopting these breeds generates higher economic gains, is socially viable, is technically feasible, and has mitigable environmental risks. However, sustained adoption requires delivery models, capacity building, marketing and financial models, and integrated risks reduction strategies. We argue that demonstrating innovations' economic, social, technical, and ecological viability and enhancing access to efficient input and output markets are vital for sustained agricultural technology adoption.

1. Introduction

Smallholder chicken production is an integral part of rural and resource-poor households' livelihoods in sub-Saharan Africa. It accounts for about 80% of the poultry flock in the region (Akinola & Essien, 2011; FAO, 2020). Smallholder chicken production contributes to income generation and food security and supplies social, cultural, and environmental values (Akinola & Essien, 2011; Wong et al., 2017). It also plays a significant role in poverty alleviation strategies, especially for resource-poor and historically neglected groups (Islam & Jabbar, 2005; Assa, 2012).

However, low input-output production systems characterize the sector. As a result, limitations in access to improved breeds, input and output markets, institutional support, and technical and financial capacity constrain the sector. Thus, improving the production and productivity of the sector requires an integrated intervention that includes improving management practices and enhancing the productivity of genotypes (Riise et al., 2005; Pym, 2013; FAO, 2014; Padhi, 2016; Wong et al., 2017).

The low productivity of existing local breeds and limited returns from improved management make

genetic interventions the primary strategy to enhance productivity. Previous research and development efforts focused on introducing commercial broilers or layers, crossbreeding commercial and local genotypes, introgression of commercial genes, and breed selection (Cheng, 2010; Pym, 2013). Historically, the introduction of exotic genetics into smallholder, intensive chicken production has not been competitive in sub-Saharan Africa due to management issues and high feed, veterinary, and energy costs (Sonaiya & Swan, 2004). While many sub-Saharan African countries have access to exotic germplasm, the birds-developed for high-input production systems in temperate regions are generally poorly adapted to these countries' low-input chicken management systems. Furthermore, most sub-Saharan African countries cannot produce the quantities of feed grain needed to support intensive chicken production. Therefore, while commercial layer or broiler lines provide high yields under ideal management conditions in temperate climates, they are not a good option for smallholder producers in the tropics (Pym, 2013).

Moreover, smallholder farmers in sub-Saharan Africa need tropically adapted, improved breeds (TAIBs) that are dual-purpose (i.e. simultaneously supply meat and eggs) using modest management conditions (Kumaresan et al., 2008; Dana et al., 2010). Dual-purpose breeds have the following benefits for smallholder production: like local breeds, they are more convenient to produce eggs and meat simultaneously (Mueller et al., 2020); they have good scavenging ability (Spencer, 2013); they are easily adaptable to diverse agro-ecosystems, and they are calm, mobile, and easy to manage at village level (McDougal, 2019). Dual-purpose breeds have lower protein requirements, and they are less susceptible to common diseases like Gumboro. Conventional and non-conventional feeds can be used without affecting their performance, making them more suitable for smallholder production. Also, these breeds have higher productivity than local breeds (Kumaresan et al., 2008; Sharma et al., 2015; Lambertz et al., 2018), which helps smallholder producers achieve their production goals (Mueller et al., 2020).

Based on the above premises and considering the potential contribution of dual-purpose breeds to smallholder producers in the tropics, ILRI has been implementing the African Chicken Genetic Gains (ACGG) project in Ethiopia, Nigeria, and Tanzania. The project aimed to avail high-producing, farmer-preferred chicken genotypes to improve the region's smallholder chicken production and productivity. To date, the project has implemented considerable research for development activities, including the following: baseline surveys; on-station and on-farm testing of TAIBs; establishment of chicken multiplication and dissemination systems; enhancing awareness on poultry products consumption (PPP); establishing innovation platforms; and marketing assessments. Moreover, in collaboration with the Agriculture to Nutrition (ATONU) project, ACGG implemented a package of nutrition-sensitive interventions in Ethiopia and Tanzania to evaluate the impact of TAIBs on households' nutritional outcomes.

Results from the on-farm testing demonstrate that the productivity of introduced strains is 200-300% (live body weight) and 150-200% (egg) higher than existing household strains. As a result, these breeds have been widely multiplied and disseminated in the three countries. However, the overall feasibility of adopting these breeds and their impacts on smallholders' livelihoods remains unknown. Therefore, we used the datasets collected from the above studies and applied a multimethod approach to examine the technical, economic, social, and environmental feasibility of adopting these breeds and identify possible interventions for sustained adoption and widespread diffusion. We believe this paper is one of the few research endeavours to holistically address the intricate process of sustained agricultural technology adoption under smallholder management conditions.

2. Theoretical background

There exist multiple technology acceptance theories, and these theories associate technology adoption with different factors and processes. Here, we provide a brief overview of several fundamental technology acceptance theories that informed the design of this study and ACGG more broadly. As an early contribution to technology adoption, Rogers (2003) theory of 'diffusion of innovation outlines several stages of adoption. These stages include understanding the technology, persuasion, decision, implementation, and continuation. The theory also stresses the negative impact of uncertainty in technology adoption and emphasizes that informing individuals on the advantage and disadvantages of the technology could reduce adverse effects. The Technology Readiness (TR) theory emphasizes the important role of technologies readiness in fulfilling households goals (Parasuraman & Colby, 2001). According to this theory,

optimistic and innovative people with less discomfort and insecurity about the technology are more likely to use it. The Task-technology Fit (TTF) theory describes the impact of technology on improving individuals' efficiency, effectiveness, and/or higher quality (Goodhue & Thompson, 1995). According to this theory, if there is a good fit between task and technology, technology utilization and impact on performance would increase. The Theory of Reasoned Action (TRA) is the other critical theory that focuses on factors that affect the individuals' attitudes (based on beliefs) towards objects and their attributes (Fishbein & Ajzen, 1975). The Technology Acceptance Model (TAM) developed by Davis (1989) explains the role of Perceived Usefulness (PU) and Perceived Ease of Use (PEU) in technology acceptance. According to this theory, the PU and PEU affect individuals' attitudes toward technology use which can be affected by external factors. Venkatesh et al. (2003) empirically evaluated eight technology acceptance models and developed and tested a Unified Theory of Acceptance and Use of Technology model (UTAUT). UTAUT identified performance expectancy (individuals' belief that the system generates gains in job performance), effort expectancy (defined as the degree of ease associated with the use), social influence (individual believe that others believe he or she should use the technology) and facilitating condition (individual believes on the existence of organizational and technical infrastructure to support) as the four predictors of users' behavioural intention. In this model, gender, age, experience, and voluntariness of use are considered as moderators.

Although most of the existing theories in technology adoption were developed in the context of the information technology industry, some of the principles are relevant to agricultural sectors. For example, Flett et al. (2004) showed that TAM could adequately explain the adoption and use of dairy farming technologies in New Zealand. Other studies have also applied similar theories in the agricultural sector (Naspetti et al., 2017; Silva et al., 2017; Ambong, 2021). These studies documented the role of perceived usefulness and relative advantage in technology adoption. Focusing on the dynamic nature of technology adoption, Ghadim and Pannell (1999) developed a conceptual framework in the agricultural sector that include skills, reducing uncertainty in profitability, farmers perception, risk and managerial preferences and other demographics as essential factors for technology adoption decision.

Understanding smallholder farmers' perception of the acceptance and use of newly introduced agricultural technologies is intricate. Examining producers' perceptions is challenging due to smallholders' heterogeneous constraints, production objectives, livelihood strategies, and access to information and services, among others (Llewellyn & Brown, 2020). Sustained adoption involves multiple stages, including awareness about the technology, adoption, evaluation, and sustained adoption/dis-adoption (Weersink & Fulton, 2020). Weersink and Fulton (2020) identified the relative advantages of the technology, technology trialability, and social, cultural, and personal influences as the three critical factors that affect adoption. Norman et al. (1995) indicated that the incompatibility of policies and technologies with smallholder farmers' technical and socio-economic conditions limit the adoption and use of technologies. Therefore, comprehensive analyses of technologies' suitability for smallholder farmers are essential. Considering the unique conditions of smallholder farmers in developing countries, Norman et al. (1995) suggested adopting a farming system approach that includes evaluating the biological performance, technical feasibility, economic viability, and social acceptability of technologies before wider dissemination. Norman et al. (1995) approach can incorporate most of the concepts indicated in the technology acceptance theories briefly discussed above and can be applied under smallholder agricultural technology adoption conditions. Evidence from the above theories shows that the technical, economic, social, and environmental feasibility of technologies seems the most important consideration for sustained adoption and use. We applied this concept to examine the feasibility of adopting TAIBs at the smallholder level in sub-Saharan Africa countries context.

3. Methodology and data sources

3.1. Sampling and data generation

The ACGG project data used in this paper include a baseline survey, on-farm experiments, cluster-randomized control trials, and marketing assessments. First, we conducted the baseline survey in 2015 in Ethiopia, Nigeria, and Tanzania on 3,355 households (Ethiopia = 1258; Nigeria = 1146; Tanzania = 1151). The aim was to characterize smallholder poultry production systems in the three countries. We adopted a multistage sampling approach that included a

selection of regions, sub-national zones, districts, villages and households (Alemayehu et al., 2018).

Second, we conducted the on-farm experiment on 6,017 households (Ethiopia = 2250; Nigeria = 1964; Tanzania = 1803) in the three countries. The experiment aimed to test the adaptability and productivity of selected local African chicken strains and TAIBs in the three project countries. We tested four imported (Kuroiler, Sasso-R, Sasso, and Koekoek) strains and one improved local (Horro) strain in Ethiopia; two imported (Kuroiler, Sasso) and four improved local (Shika Brown, FUNAAB Alpha, Fulani and Noiler) strains in Nigeria; and three imported (Kuroiler, Sasso and Australorp) strains in Tanzania. The chicken strains were distributed to smallholder producers to test their performance under village management conditions.

Third, the cluster randomized control trial was conducted in Ethiopia and Tanzania from 2016 to 2018. This study was overlaid on the ACGG villages and had control and treatment arms. From each village, households in the treatment arms and control arms were selected based on inclusion criteria. Although the study had three treatment arms in the two countries (ACGG, ACGG + ATONU, Control), we considered only 2,669 observations in Ethiopia's ACGG and Control treatment arms.

Lastly, we conducted the marketing survey in Ethiopia, Nigeria, and Tanzania on 267 households (Ethiopia = 100; Nigeria = 95; Tanzania = 72) in 2019. This study also adopted multistage sampling techniques that included the selection of three representative market sheds in each country, the purposive selection of villages, and the random selection of households. The market sheds and villages were selected based on smallholder chicken production, marketing potential, and availability of different chicken breeds. In each country, we interviewed households regarding their inputs use, level of production and productivity, marketing of products, collective actions, constraints, and opportunities. For the sake of comparison and overall estimation, the local prices of inputs and outputs were converted into USD using the official exchange rate of each country during the survey (1 USD = 28.6 Ethiopian Birr; 307 Nigerian Naira; 2295 Tanzanian Shilling) (Valev, 2020).

3.2. Empirical approaches

Empirical approaches for agricultural technology adoption focus on an ex-ante examination of the potential acceptance of a new technology before its wider dissemination and the ex-post models to examine the reasons for adoption or dis-adoption of technologies (Weersink & Fulton, 2020). The ex-ante studies usually focus on farming systems-based studies and explore the profitability and acceptability of technologies and farmers' willingness to pay (Sirrine et al., 2010). The ex-post analyses mainly focus on assessing the relationship between actual adoption and producers' socio-economic, farm, and agroecological characteristics (Sirrine et al., 2010). However, the intricate nature of smallholders' agricultural technologies adoption cannot be fully explored using a single study and usually require a continuous and integrated assessment and application of various empirical methodologies. This is typically referred to as a multimethod approach (Morse, 2015) and is usually applied to understand human behavior's complex nature and answer complex research questions (Greene, 2015; Anguera et al., 2018). Multimethod approaches combine two or more research methodologies within the same study to address an overarching research objective and interrelated research questions (Hunter & Brewer, 2015; Anguera et al., 2018). We applied this approach to examine the technical, economic, social, and environmental feasibility of adopting TAIBs based production.

3.2.1. Economic feasibility

At the smallholder level, higher production and productivity do not always lead to sustainable adoption of improved technologies due to economic, social, and cultural reasons. Moreover, a higher yield obtained from technology adoption does not always guarantee higher economic and social gains (Rogers, 2003; Michler et al., 2019). Therefore, it is imperative to evaluate technologies' economic and financial feasibility before wider dissemination (FAO, 2014). The economic feasibility analysis refers to examining the economic gain obtained from adopting technologies. In this paper, the economic feasibility shows the benefit and costs of adopting TAIBs and other socio-economic contributions of adopting these breeds under smallholder farmers' management conditions. We evaluated the economic return using partial budget analysis (PBA), the most common technique in agricultural technologies adoption studies (Weersink & Fulton, 2020). PBA is used to measure the gain or loss in income during a slight or marginal change in farming practices (Brown, 1979; Soha, 2014). Since overall profitability assessment is complex due to inadequate record-keeping of households and unmeasured inputs, PBA

helps estimate the marginal benefits obtained from adopting the introduced breeds.

We based the PBA on FAO (2014) smallholder chicken production classification: extensive small-scale scavenging, extensive scavenging, semi-intensive, and small-scale intensive production systems. The classification mainly considers flock size, type of breeds, source of new chicks and feed, housing qualities, access to vaccines and market, and time allocated to management. The PBA was applied to estimate the economic gain of shifting extensive scavenging systems to TAIBs based semi-intensive production systems. The aim was to estimate the economic gains with change in breeds and management. We considered three major assumptions: change in the breed, flock size, and the modest change in management. The change in breeds represents shifting local breeds to dual-purpose TAIBs, identified by the ACGG project. Change in flock size refers to increasing the average flock size in extensive scavenging to 50 or 75 flocks. A modest change in management denotes a modest change in feeding, vaccination, and housing systems. Since most sample smallholder producers used comparable feed and vaccination for the local breeds and TAIBs, we called the change in management modest. The overall production cycle for this analysis was assumed to be 18 months.

PBA has four major sections: added income, reduced income, added cost, and reduced cost. While the added income refers to the income generated from semi-intensive production, the reduced income refers to the income from extensive scavenging (given up income due to a change in the production system). The reduced cost is the sum of the costs forgone due to a shift in production or costs associated with extensive-scavenging production. The added cost is the cost associated with semi-intensive production. The sum of added income and reduced cost would give us the total gain, and the sum of reduced income and added cost would give us the total loss. The difference between total gain and total loss gives us the Net Gain (NG) in income.

$$TG = ADIN + RDCO \qquad (1)$$

$$TL = RDIN + ADCO \qquad (2)$$

$$NG = TG - TL \qquad (3)$$

Where TG -Total gain; ADIN-Added income; RDCO-Reduced cost; TL-Total loss; RDIN-Reduced income; ADCO-Added cost; NG-Net gain in income.

Improved breed adoption usually involves an added cost for variable and fixed inputs. To buy these inputs, farmers need more funds from financial institutions or to use their savings. Whatever the source, the invested added funds should generate a modest financial return, which refers to financial feasibility. At the smallholder producers' level, it is the principal constraint for technology adoption. Although financial feasibility can be assessed through various approaches, we used the marginal rate of return (MRR) or the rate of return in our analysis. It measures the net return from the added capital invested in shifting from local breed production to TAIBs-based production. MRR can be represented as follows:

$$MRR = \frac{\Delta NB}{\Delta TC} \qquad (4)$$

$$\Delta TC = TC_D - TC_L \qquad (5)$$

$$\Delta NB = NB_D - NB_L \qquad (6)$$

The change in net benefit (ΔNB) or marginal benefit is the difference between net benefit generated from semi-intensive production (NB_D) to the net benefit generated from extensive scavenging system (NB_L). Similarly, the change in cost ΔTC or marginal cost refers to change in cost, which is the difference between total cost used in the semi-intensive production (TC_D) and extensive scavenging production (TC_L).

Risks and uncertainties in agricultural production and marketing activities are inherent, and there is a need to consider the critical risk factors in economic, financial, and technical analysis. Various empirical studies using the diffusion of innovation theory have documented the roles of risk and uncertainty in adopting profitable technologies (Rogers, 2003; Foster & Rosenzweig, 2010; Mukasa, 2018; Mao et al., 2019). These studies show the significant role of minimum risk for sustained adoption of profitable technologies. The main risks associated with poultry production may relate to production, price, institutions and policies, human health, and the environment (Komarek et al., 2020). However, production risk, which may refer to the loss of birds and decreased productivity, is the most important and affects technology adoption decisions significantly (Ogada et al., 2010; Komarek et al., 2020). Here, we conducted a sensitivity analysis of the estimated

PBA indicators to examine the production and marketing risks.

3.2.2. Social feasibility
Economic feasibility alone is not a sufficient condition for sustained adoption of agricultural production practices, and there is a need to address the social feasibility of technologies (Rietveld et al., 2021). Social feasibility refers to the overall acceptance of the technology by the households and community. It examines the acceptability of the technology by different household members and community members and its potential contribution to food and nutritional security. The role of social acceptance of technology in successful technology diffusion and adoption is also reflected by the theory of UTAUT(Venkatesh et al., 2003). Empirical evidence also shows that smallholder producers have additional objectives other than profit maximizations (Llewellyn & Brown, 2020). The non-separable household economic models indicate that we cannot separate smallholders' production and consumption decisions due to market imperfections and transaction costs (Janvry & Sadouleti, 2006). This interdependence is highly likely under smallholder poultry production due to the significant role of poultry products in households' consumption and income generation. Higher interdependence suggests the vital role of generating technologies that maximize consumption and income generation goals.

We used household preference for introduced breeds and the estimated impact of TAIBs adoption on consumption and products sale as social feasibility indicators. During the on-farm experiment, producers evaluated breeds' adaptability, performance, and likability at various stages. This evaluation involved four steps: identifying important chicken characteristics, ranking the introduced and indigenous chicken characteristics, ranking the likability of the flock, and overall flock preference. During this evaluation, producers used body size, growth rate, supplementary feed requirement, scavenging ability, egg numbers, egg size, plumage colour, and survivability as criteria. Based on the above quality attributes, farmers ranked their preferred flock. We linked farmers' preference indicators with production objective data generated from the baseline survey. Aligned with Rogers (2003) theory of 'diffusion innovation,' farmers' preference demonstrated how the experiment supports farmers' understanding of the technology and its usefulness. Furthermore, this shows the perceived usefulness and ease of using the

technology, an important concept in TAM technology adoption theory (Davis, 1989).

We estimated the impact of TAIBs-based production on households' chicken meat and egg consumption and volumes of eggs and live bird sales. Then, we used these data to examine if adopting TAIBs contributes to maximizing households' production goals. For this purpose, we applied a Difference-in-Difference (DID) econometric approach using the ATONU data. The DID approach compares the outcome variables' double difference between the ACGG project participants and control areas. However, to balance the treatment and control arms at the baseline, the two groups were matched using household-level covariates, which are correlated with smallholder chicken producers' production and consumption decisions (Krauss, 2018). According to Villa (2016), the general equation for DID with observable covariate is as follows:

$$\begin{aligned} DID = \{&E(Y_{it=1}|D_{it=1}=1,\ Z_i=1,\ X_i)\\ &- E(Y_{it=1}|D_{it=1}=0,\ Z_i=0,\ X_i)\}\\ &-\{\{E(Y_{it=0}|D_{it=0}=0,\ Z_i=1,\ X_i)\\ &- E(Y_{it=0}|D_{it=0}=0,\ Z_i=0,\ X_i)\}\} \end{aligned} \quad (7)$$

Where Y_{it} is the outcome variable, t = 0 is the baseline, t = 1 is the follow up, $Z_i = 1$ is the treatment group, $Z_i = 0$ is the control group, and X_i are observed covariates.

In addition to including the control variables, we incorporated Kernel propensity score-weight to match the control and treatment observation according to their propensity score (Heckman et al., 1997). We also restricted the estimation to the common support of the estimated propensity score to increase the internal validity (Villa, 2016). Thus, the DID estimate with kernel propensity score-matching can be specified as follows:

$$\begin{aligned} DID = \{&E(Y_{it=1}|D_{it=1}=1,\ Z_i=1)\\ &-w_i\ \times\ E(Y_{it=1}|D_{it=1}=0,\ Z_i=0,\ X_i)\}\\ &-\{\{E(Y_{it=0}|D_{it=0}=0,\ Z_i=1,\ X_i)\\ &-w_i\ \times\ E(Y_{it=0}|D_{it=0}=0,\ Z_i=0,\ X_i)\}\} \end{aligned} \quad (8)$$

We applied the linear regression model to implement the above kernel-propensity-score matching weights as indicated in the following basic framework (Villa, 2016).

$$\begin{aligned} Y_{igt} = \beta_0 +\ &\beta_1 \times (\ Treated)_i +\ \beta_2 \times (Period)_i\\ &+ \beta_3 \times (Treated)_i \times (Period)_i + \underset{igt}{\cup} + \varepsilon_{igt} \quad (9) \end{aligned}$$

Where Y_{igt} is the outcome indicator for production, consumption, and sale of group 'g' poultry products at period 't.' *Treated* is a binary variable for treatment indicator (1 = ACGG) and (0 = Control); *Period* is a binary variable for period indicator (0 = *Baseline*) and (1 = *End line*); $\cup_{igt}$ is individual-level factors that vary across groups and over time; and ε_{igt} represents the random error. A positive and notable change in the estimated difference between baseline and end-line suggests TAIBs help maximize smallholder producers' production goals.

3.2.3. Technical feasibility

The technical feasibility of agricultural technologies is a vital aspect of sustained adoption. It refers to the availability of all the allied inputs associated with the core innovation and ease of undertaking the production activities at smallholder management conditions (Norman et al., 1995). Smallholders cannot sustainably adopt agricultural technologies if they are not easily doable. Technical feasibility analyses mainly focus on the levels of technical responses than testing hypotheses of significant difference (Norman et al., 1995). It evaluates the technical requirement to adopt the technology, producers' required skills and technical capability, and availability and access to the needed resources. The analysis helps identify if additional resources are required or if producers can use existing resources differently. In this paper, we generated indicators that include chick delivery systems, access to inputs, and availability of skills and knowledge from the baseline, the on-farm testing, and the marketing assessment data.

3.2.4. Environmental feasibility

Technological change is usually associated with a shift in resource use and management along the value chain, affecting production efficiency and environmental performances (Pelletier et al., 2018). A recent scoping review on sustained adoption of agricultural technologies shows the need to adopt an integrated approach that addresses both short-term priorities, such as profitability, while simultaneously working towards long-term environmental outcomes (Piñeiro et al., 2020). Poultry production has various ecological impacts, including resources depletion, human toxicity, biodiversity loss, and others (Bengtsson & Seddon, 2013; McClelland et al., 2018). Mitigating the adverse environmental impacts of improved livestock production, including chicken, is an important research and development concern (Ruviaro et al.,

2016; Rojas-Downing et al., 2017; Paul et al., 2020). Hence evaluating possible positive and negative environmental impacts of adopting introduced breed would have various long and short-term benefits. In this paper, we considered manure management, use of kitchen waste, biodiversity losses, and some qualitative evidence as potential indicators of environmental feasibility. We integrated indicators from the baseline survey, on-farm experiment, and marketing assessment surveys to generate evidence on the environmental feasibility.

4. Results and discussion

4.1. Economic feasibility

We ran a PBA to estimate the gain in income by shifting local breeds based extensive production to TAIBs based semi-intensive production. The overall results suggest that moving from the most widely used extensive production system to a semi-intensive production system would generate adequate income under village management conditions (Figure 1). The positive net change in income suggests the contribution of the TAIBs either by increasing yields or reducing the cost of production, or both. Based on the 50-flock size scenario, the estimated average gain is about USD 820.9, 968.4, and 809.7 per 18 months in Ethiopia, Nigeria, and Tanzania. This is a net increase in income from shifting extensive production to TAIBs based semi-intensive production. When the flock size increases to 75 birds, 50 layers and 25 cockerels, the overall gain increases to USD 1515.9, 1500.7, and 1639.1 per 18 months in Ethiopia, Nigeria, and Tanzania.

The observed variation in the estimated gains in income among the three countries could be associated with variability in the productivity of breeds and differences in input costs and price of outputs. The added gain in income looks significant under village management conditions, and this change is sensitive to change in flock size, as shown by the two flock size scenarios. The estimated net gain in income demonstrates TAIBs based production is profitable under village management conditions. This income gain could serve as an incentive for the smallholder farmers to continue adopting the introduced breeds. Aligned with the PBA, producers reported higher income from the adoption of these breeds during the on-farm experiment and marketing assessment survey. Other empirical studies have also
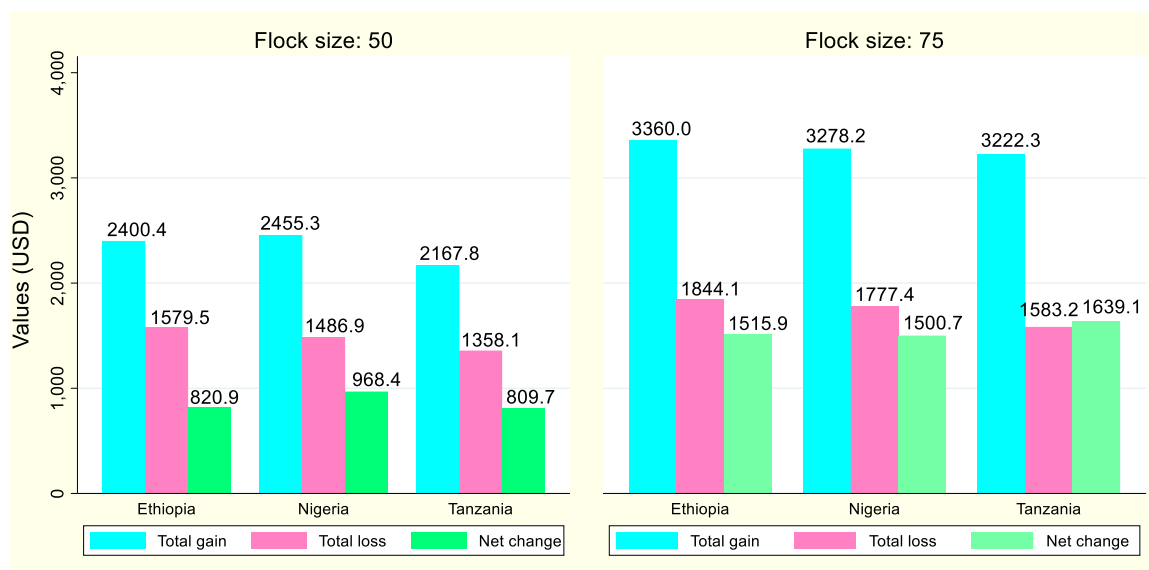
Figure 1. Summary of the partial budget analysis results.

documented the importance of considering profitability instead of solely an increase in yields for sustainable agricultural technology adoption (Michler et al., 2019; Zoll et al., 2019).

4.1.1. Financial viability

Economic feasibility alone does not guarantee sustained adoption of TAIBs due to the opportunity cost of added invested finance. Therefore, it is vital to ascertain the financial feasibility of the additional expenses invested in the production system. The additional investment cost must generate a modest return equivalent to the expected return from other agricultural or non-agricultural activities. This analysis helps to evaluate the viability of investing in TAIBs breeds vis-à-vis the existing financial condition, operating performance, and the expected return and risks. We used the marginal rate of return (MRR) as an indicator to assess the finical feasibility of shifting traditional extensive scavenging systems to TAIBs based semi-intensive production systems described above. Accordingly, the estimated average rate of return for a unit of added investment in the three countries is about 284% (Figure 2). This rate shows that a dollar invested in TAIBs based on semi-intensive production would generate 2.84 dollars as a management and operating capital return in 18 months. When we disaggregate MRR by country, the returns in Nigeria and Tanzania are higher than those in Ethiopia due to lower input costs and higher productivity changes.

Here, we explain the viability of the estimated MRR using Ethiopia as a specific example. In Ethiopia, microfinance and cooperatives usually lend money to farmers with an annual interest rate of 15%. Assuming 18 months or 1.5 years of production duration, the cost of this capital would be 22.5% (15% +7.5%). If a farmer assumes a socially acceptable rate of return for management and other overheads are 100%, the overall expected financial return would be 122.5%. The estimated MRR, 168%, is 45.5% higher than the anticipated rate of return. This illustrates that investing in TAIBs based production generates better financial returns than expected from similar activities. If there is access, smallholder producers can borrow money from financial institutions to adopt these breeds.

4.1.2. Sensitivity of estimated economic gains

We conducted a sensitivity analysis to account for the production and marketing risks associated with TAIBs adoption. This analysis considers uncertain parameters and significantly impacts adoption outcomes (Finger & Schmid, 2008). We evaluated the sensitivity of the estimated income gains from TAIBs based production against a decrease in egg productivity/production and loss of chicken. We applied this in the 50-flock size PBA conducted above. Three scenarios—5, 10, and 15% losses of output (eggs & live birds)—were considered and compared with the reference category (RF), the estimated value under the extensive production condition. The results highlight TAIBs based
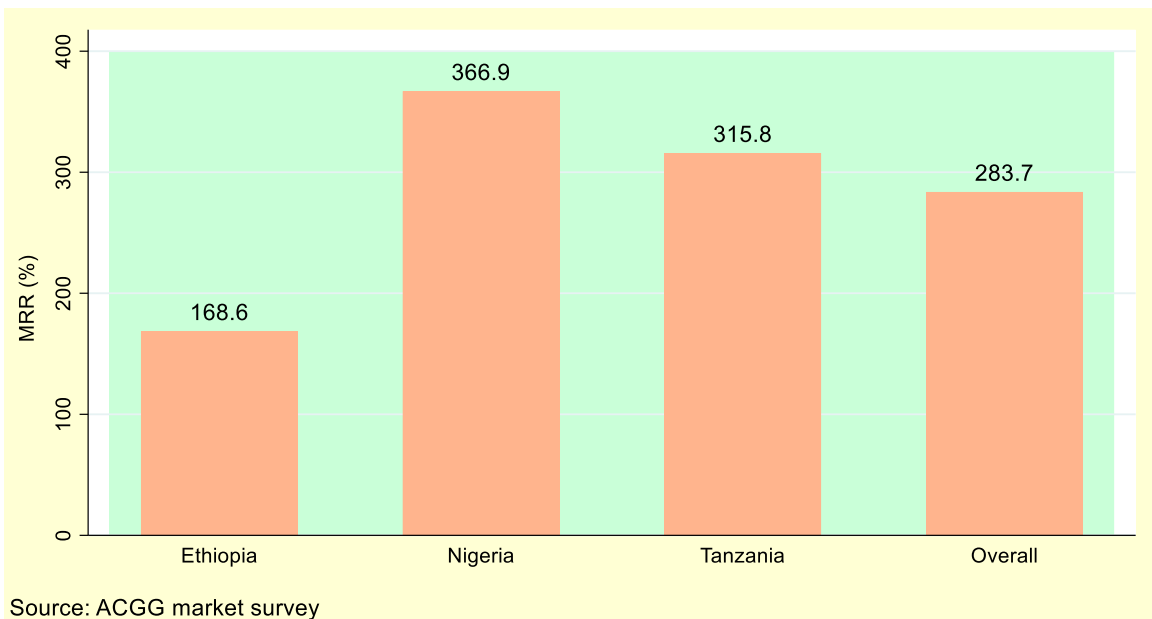
Source: ACGG market survey

Figure 2. Marginal rate of return (MRR) for shifting extensive scavenging to semi-intensive production (50 birds).

production remains competitive and generates a positive net income gain in the three countries (Figure 3). This suggests the robustness of adopting TAIBs during unexpected production risks and their potential contribution as a risk-minimizing strategy at village management conditions.

Price fluctuations in inputs and outputs are a significant challenge to smallholder chicken production. We
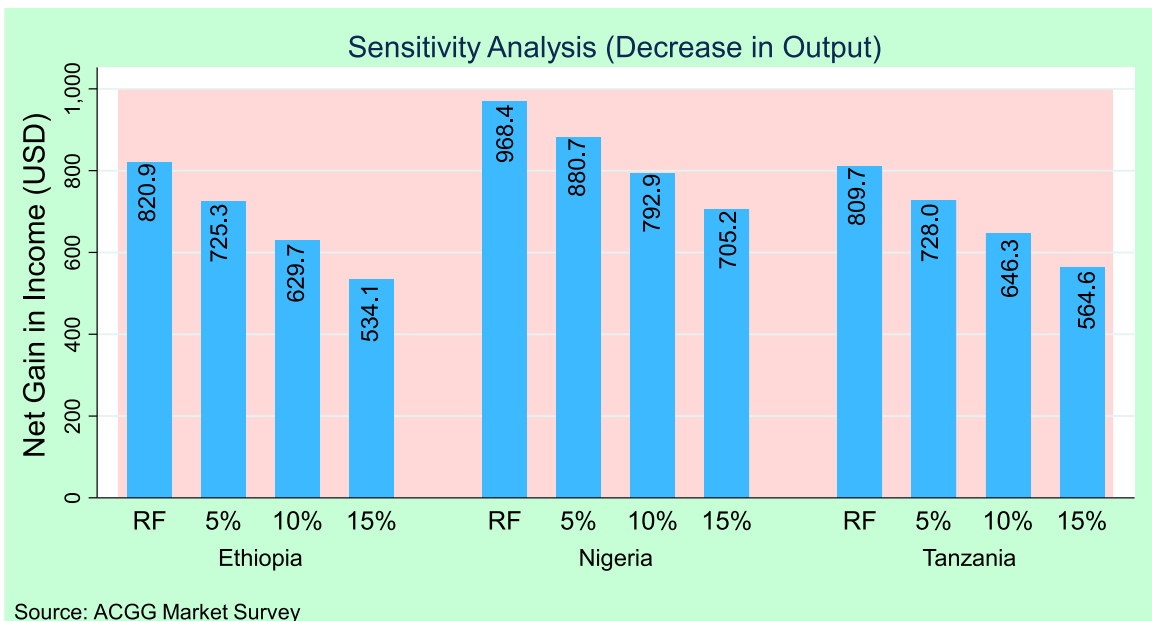

Source: ACGG Market Survey

Figure 3. Sensitivity of change in net income due to a decrease in production.
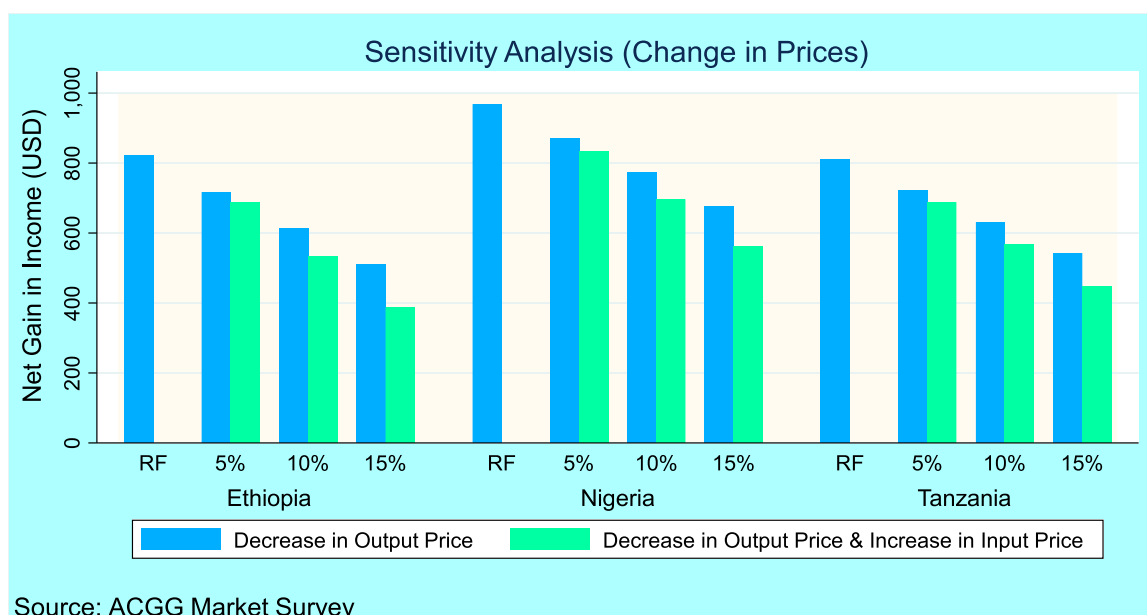
Figure 4. Sensitivity of Change in net income due to Change in Price.

examined the effects of a decrease in the price of outputs and a steady increase in the price of inputs on the estimated net gains in income. Like the production risk, we considered the 50-birds flock scenario used in the PBA. We considered two different scenarios: a decrease in price-output only and a simultaneous decrease in the price of outputs and an increase in input prices. The following three prices change situations were assumed: 5, 10, and 15%. For instance, a 5% change represents a decrease in output prices by 5% and an increase in input prices by 5%. In the three change scenarios, the net gain in income is positive and significant (Figure 4). Although observing both an increase in input price and a decrease in output price is unlikely, the estimated gains in income remain positive. This demonstrates TAIBs based production could generate positive income during unexpected price shocks, which could be an excellent incentive for farmers to adopt the breeds continuously.

4.1.3. Market access

Sustainable adoption of improved technologies could not be achieved without access to better markets. Data generated from the marketing assessment survey indicate that 92.0, 91.6, and 90.3% of the smallholder producers participated in poultry products marketing in Ethiopia, Nigeria, and Tanzania. Higher market participation suggests the importance of access to output markets for sustained adoption. We asked smallholder producers to explain the main marketing challenges they experienced in the previous 12 months. Accordingly, low product price, price fluctuation and unorganized market structure were the three principal challenges reported. The low market price or price fluctuation was reported by 42.0, 20.0, and 50% of the sample respondents in Ethiopia, Nigeria, and Tanzania. Most of the sample respondents indicated the prices of eggs and live birds are low. They associated this with limited buyers and the seasonality of demand in the local markets. While the proportions of respondents raising marketing constraints range from 20-50%, we hypothesize that this constraint will intensify as production and productivity increase.

There is strong seasonality in poultry products marketing in the three countries. Live bird marketing is significantly higher in the religious holiday seasons than in other seasons. Unlike Tanzania, many smallholder producers in Ethiopia and Nigeria sold live birds within a few months (Figure 5). For instance, more than 80% of the households in Ethiopia sold live birds during holiday seasons in January, April, and September. Similarly, about 60% of the households in Nigeria sold live birds in December, April, and November. Although the distribution of selling months in Tanzania is more expansive than in the other two
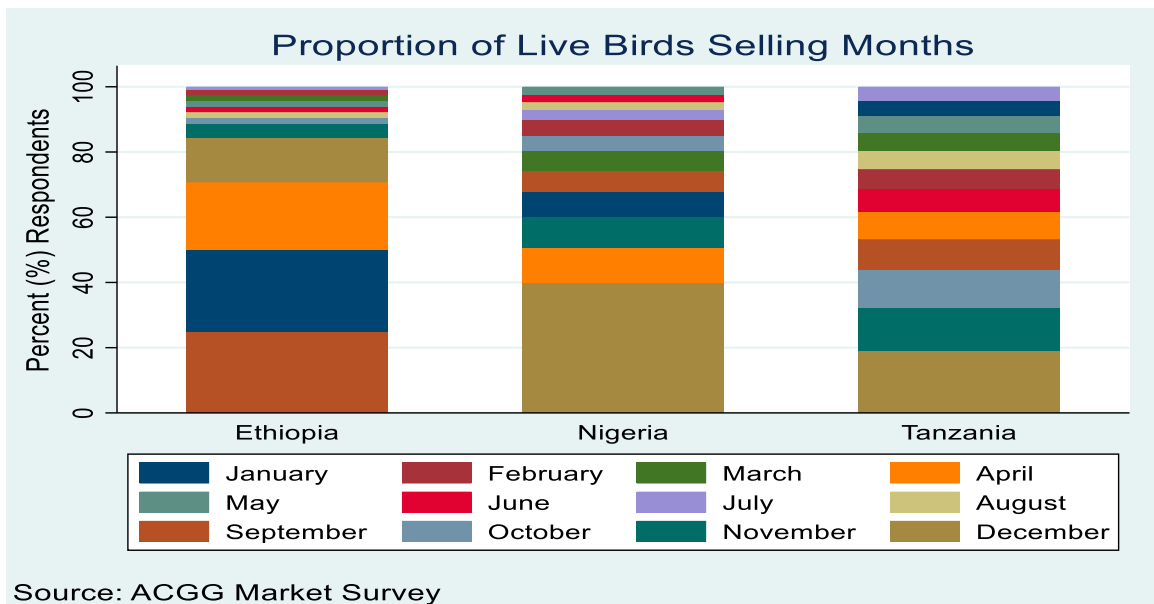
Figure 5. Reported selling months of live birds in Ethiopia, Nigeria, and Tanzania.

countries, more households sold live birds in December, November, and October. As a result, the price of live birds is generally higher during the above seasons than others. For example, in Ethiopia, during the fasting season, local demand for live birds and eggs is significantly lower, resulting in a decrease in selling prices. The seasonality of poultry product marketing in the three countries has substantial policy implications, which will become increasingly important as production and productivity increase.

Since income generation is a vital production goal, and thus, increased productivity without access to a better market leads to unsustained adoption. Therefore, policies that aim to increase current levels of production and productivity must integrate improved marketing strategies. Empirical research suggests linking smallholder farmers to better market opportunities as a key development strategy to enhance sustained agricultural production in developing countries (Yadav et al., 2021). Policy options for sustainable marketing strategies may include developing the value chain, collective marketing, contract farming, and improving the informal markets through various strategies (MacDonald et al., 2004; Mao et al., 2019). For instance, farmers could be organized into associations to access buyers in the central markets. Also, contract farming based on predefined quality attributes and marketing agreements between producers and other value chain actors could be another option (FAO, 2013).

4.2. Social feasibility

4.2.1. Farmer's preference for tAiBs
We asked farmers to indicate their preference for the introduced breeds over their existing household breeds during the on-farm experiment. Below, we summarize their responses disaggregated by the sex of the family member identified as actively engaging in chicken production activity (i.e. householder). The majority of the producers (83.17%) preferred the introduced TAIBs over existing household breeds in the three countries (Table 1). Only 7.17% preferred the existing breeds over the introduced TAIBs, and the remaining 9.66% preferred both introduced and existing breeds. The higher preference for introduced breeds across diverse agro-ecosystems and management regimes suggests the breeds' adaptability and suitability in the three countries. Unlike Ethiopia and Tanzania, the chi-square test for the association between breed preference and the householders' sex shows a significant association in Nigeria and the overall sample.

We also asked sample respondents to indicate significant reasons associated with their preferences. The main reasons for TAIBs preference are fast growth and larger body size, good overall performance, a higher number of eggs and larger egg size, and adaptability and survival (Table 2). Fast growth maximizes producers' returns and consumption utility. Some producers

Table 1. Farmers' breed preference in the three countries by the sex of the family member identified as actively engaging in chicken production activity (i.e. householder).

Country	Breed Type	Male (N = 1053)	Female (N = 649)	Total	Pearson chi^2
Ethiopia	Introduced	80.25	81.51	80.73	2.4
	Existing	5.13	6.16	5.52	
	Both	14.62	12.33	13.75	
Nigeria		Male (N = 383)	Female (N = 791)	Total (N = 1174)	6.47**
	Introduced	76.24	78.00	77.43	
	Existing	11.49	14.03	13.2	
	Both	12.27	7.96	9.37	
Tanzania		Male (N = 339)	Female (N = 967)	Total (N = 1306)	3.53
	Introduced	89.97	92.04	91.5	
	Existing	5.6	3.31	3.91	
	Both	4.42	4.65	4.59	
Overall		Male (N = 1775)	Female (N = 2407)	Total (N = 4182)	22.92***
	Introduced	81.24	84.59	83.17	
	Existing	6.59	7.6	7.17	
	Both	12.17	7.81	9.66	

Inference: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

also indicated plumage colour and scavenging ability as reasons for preferences. The major reasons for selecting indigenous breeds are adaptability or survival, scavenging ability, and lower feed cost. These are the inherent attributes of local breeds in most developing countries. Although they are few, some have also indicated fast growth and larger body size and a higher number of eggs and larger egg size as the reasons for their preference for indigenous breeds.

4.2.2. Fulfilling farmers production goals
Empirical research highlights the critical role of considering smallholder farmers' production objectives or demands in predicting agricultural technology adoption (Verkaart et al. 2019; Llewellyn and Brown 2020). As a result, we generated evidence on producers' main production goals from the baseline survey. In turn, we examined if the introduced breeds have fulfilled farmers' expectations using the randomized control trial data. Of the total respondents, 87.8 and 92.2% reported home consumption and income generation as their primary production

goals (Table 3). Unlike in Nigeria and Tanzania, most Ethiopian producers said keeping chickens more for income generation than consumption. Moreover, a higher proportion of producers in Ethiopia tend to be involved in egg consumption and selling than producers in Nigeria and Tanzania. The preference data also reflects these differences. A higher proportion of producers reported egg size and egg number as a reason for preferring the introduced breeds in Ethiopia than in Nigeria and Tanzania. Conversely, since live chicken sales and meat consumption are producers' primary goals in Nigeria and Tanzania, compared to Ethiopia, a higher proportion of producers considered fast growth and body size as a criterion for breed preference. Interestingly, the baseline and on-farm experiments demonstrate the contributions of TAIBs in fulfilling their production objectives.

Based on the above evidence, we applied a DID model using a subset of ATONU data in Ethiopia to quantify the effects of adopting TAIBs on households' consumption and income generation outcomes. This

Table 2. Reasons for farmers' breed preference in Ethiopia (ET), Nigeria (NG), and Tanzania (TZ).

Attribute	Introduced				Existing			
	ET	NG	TZ	Overall	ET	NG	TZ	Overall
Adaptability and survival	16.9	18.5	12.0	15.7	65.0	54.9	55.7	59.8
Eggs number and Size	25.8	13.5	15.3	19.3	11.5	2.3	2.6	6.7
Fast growth/body size	50.7	74.1	73.2	63.9	10.9	7.5	9.6	9.4
Overall performance/ contribution	31.1	14.6	27.7	25.7	5.0	7.5	5.2	6.0
Scavenging and feed Use	10.5	3.2	4.8	6.8	13.8	39.8	40.0	27.6
Plumage and attractiveness	9.5	6.7	7.1	8.0	1.2	1.1	0.0	1.0
Others	0.9	0.6	1.2	0.9	1.8	3.0	3.5	2.5
Sample size	1680	1023	1268	3989	340	266	115	721

Table 3. Chicken production objective of smallholder producers in Ethiopia, Nigeria, and Tanzania.

Objective	Ethiopia (N = 1253)	Nigeria (N = 1124)	Tanzania (N = 1148)	Total (N = 3525)
Chicken sale	80.2	84.3	91.2	85.1
Eggs sale	76.3	2.7	22.8	35.4
Chicken consumption	35.8	91.2	94.9	72.7
Eggs consumption	60.6	15.2	56.5	44.8
Ceremonies	23.8	46.4	1.5	23.7
Gift	0.1	28.6	0.7	9.4
Cock fighting	0.0	1.2	0.2	0.4
Others	1.0	3.5	1.7	2.0
Consumption	76.5	91.8	96.7	87.8
Income generation	97.3	84.6	94.3	92.3

analysis considers the ACGG on-farm experiment participants as the treatment group and similar households with local breeds as the control group. Results show that households in the treatment group had higher sales and consumption of eggs than households in the control groups. Producers in the treatment group produced about 8.0 more eggs per/week than producers in the control group, and selling and consumption of eggs increased by 5 and 3 eggs/week, respectively (Table 4). Similarly, chicken sales in 12 months increased by 3 in the treatment group than the control group. Estimated parameters from the DID model suggest the statistically significant impact of TAIBs adoption on the selected outcomes. This confirms the potential role of adopting TAIBs to maximize smallholder farmers' joint production and consumption goals. Empirical research in developing countries has documented the vital role of enhancing household food security and income for sustained agricultural production (Lee 2005). Other researchers have also examined the role of considering farmers' priorities, such as subsistence and profit, in technology adoption (Kuehne et al. 2017; Llewellyn and Brown 2020).

4.3. Technical feasibility

4.3.1. Integrated chicks' delivery

Unlike local breeds, commercial TAIBs have limited ability to reproduce themselves, and sustainable supply of replacement stock is the main challenge at a smallholder level production. Therefore, developing a well-organized and integrated chick delivery system that links smallholder producers to commercial hatcheries is essential. One of the strategic interventions promoted by ACGG was establishing public-private partnerships (PPPs) that facilitate the continual supply of replacement stocks to smallholder producers. The partnership focused on multiplying farmers' preferred TAIBs, raising chicks to 45 days, and delivering the chicks to smallholder producers. This partnership included Agricultural offices (public sector), commercial hatcheries (private companies), and small-scale entrepreneurs (mother units). Each actor had specific roles. This partnership enhanced the sustainable supply of chicks and helped raise vigorous and healthy chicks with lower mortality under smallholder management conditions. Lessons learned from the three countries indicate that such a public-private partnership can achieve a sustained supply of chicks. Other researchers have examined the role of public-private partnership for the sustained supply of agricultural technologies (Simtowe et al. 2021).

4.3.2. Access to feed

Poultry feed is usually cited as the major constraint for semi-intensive or intensive-based production at the smallholder level (Roothaert et al. 2011, Wong et al. 2017). Unlike local breeds based production, TAIBs based production needs a better supply of feeds. Some farmers have also indicated that these breeds have a higher feed demand for better production and productivity. However, their scavenging ability and lower protein requirement minimize the

Table 4. Impact of TAIBs adoption on consumption and sale of poultry products in Ethiopia.

Type of Product	All households					
	Before (T-C)		After (T-C)		Diff-in-Diff	
	Diff	t	Diff	t	Value	t
Eggs produced/week	−3.35	−2.25**	4.65	2.83***	8.01	4.63***
Egg sold/week	−2.66	−2.45**	1.93	1.87*	4.58	3.73***
Egg consumed/week	−0.37	−0.83	2.08	3.15***	2.45	4.37**
Chicken sold/year	−1.15	−1.41	1.19	1.86*	2.84	2.21**
Chicken consumed/year	0.12	0.25	0.26	0.57	0.14	0.19

Inference: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$; T = Treatment; C = Control
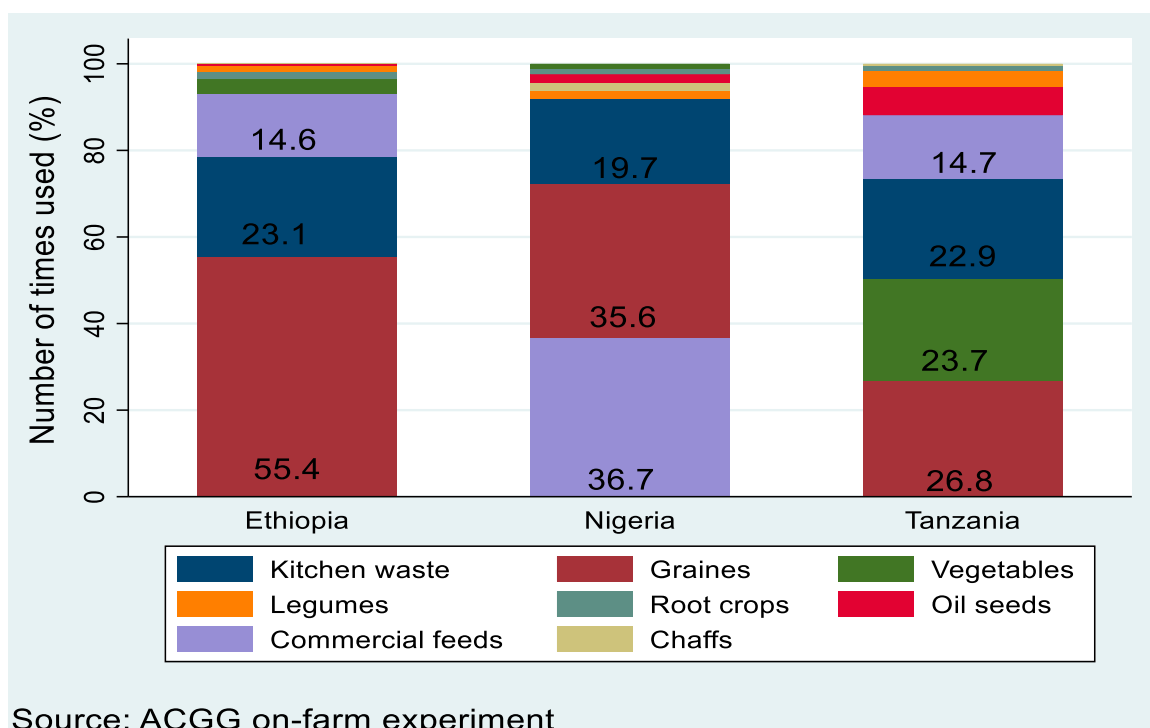
Figure 6. Frequency of different feeds used by producers who preferred introduced breeds.

expected cost of feed supplied to these breeds and create opportunities to use locally available feeds in rural areas. We asked producers to list the type of feeds used for TAIBs and indigenous breeds during the on-farm experiment and disaggregated the responses by breed preference. Results show that producers who preferred TAIBs used diverse locally available feeds (Figure 6). Grains, kitchen waste, and commercial feeds are the three most often used feed types in the three countries. Contrasting Nigeria, smallholder producers in Ethiopia and Tanzania used grains and kitchen waste more frequently than commercial feeds. Managing these breeds with locally available grains and household wastes indicates their suitability for smallholder production in the tropics.

However, continuous feed supply is mandatory to achieve the highest productivity potential of breeds. During the marketing assessment, 44, 19.5, and 17% of the smallholder producers reported limited access to feed as the primary constraint in Ethiopia, Nigeria, and Tanzania. Furthermore, we predict that this challenge will be worse if farmers increase their flock size due to the ever-increasing cost of commercial feeds, inadequate supply in the rural areas, and limited

capacity of producers to formulate feeds from locally available inputs. Hence, building the ability of producers to formulate feeds from locally available inputs will be the primary option for a sustained solution. This includes using crops not used for human consumption, forages, crops with low production costs, industry by-products, household food wastes, and other non-conventional feeds (Mwesigwa et al. 2016; Tufarelli et al. 2018; Chia et al. 2019). Addressing factors that trigger an increase in the price of commercial feeds or feed ingredients through reducing production and marketing costs and lifting or reducing import tariffs can be the other solution.

4.3.3. Availability of required skill and support system

Empirical studies also indicate that human capital, such as farmers' experience in production, plays a significant role in the early adoption and sustained use of agricultural technologies (Ainembabazi and Mugisha 2014; Ntshangase et al. 2018; Hoang-Khac et al. 2021). Farmers' knowledge and skill in production and marketing activities have a significant role in the sustained adoption of agricultural technologies. The required skills and knowledge availability could

Table 5. Farmers' technical skill indicators during the baseline survey.

Skill Indicators	Ethiopia	Nigeria	Tanzania	Total
Experience (Av. years)	13.3	16.3	8.4	12.7
Experience in exotic breeds production (%)	45.6	45.5	14.6	34.7
Exercised breed selection (%)	84.4	40.3	60.1	62.4
Exercised culling (%)	56.4	48.8	53.4	53.0
Provide water in a container (%)	98.3	88.6	96.9	94.7
Provide supplementary feeds (%)	94.4	88.8	93.9	92.5

be measured using different indicators such as farming experience and experience in improved production practices (Table 5). For instance, smallholder producers in the three countries have an average of 12.7 years of experience in chicken production and management activities. About half of the producers in Ethiopia and Nigeria have experience in managing exotic chicken. Farmers' experience in breed selection and culling is also the other technical skill that would enhance the sustained adoption of TAIBs.

Although most smallholder farmers have adequate experience in chicken management, sustained adoption of improved breeds still requires further knowledge and training. During the baseline assessment, only 10.6% (10.9% Ethiopia, 2.4% Nigeria, 18.3% Tanzania) of the total respondents had reported receiving extension and training services in the previous 12 months. This shows existing gaps in extension and training services at the smallholder production level. Integrated and innovative extension approaches like videos, mobile phones, peer-to-peer learning, and other digital extension systems can be considered possible options to deliver training and advisory services (Gandhi et al. 2009; Naika et al. 2021; Silvestri et al. 2021).

4.4. Environmental feasibility

Environmental risks in traditional extensive chicken production are marginal due to a limited concentration of manure and the use of scavengeable feed sources. However, TAIBs based semi-intensive production may lead to a higher concentration of waste as the chickens may be confined in a house or cage for certain hours in the day and throughout the night. We examine this from the feed sources and manure management indicators generated from the baseline survey and on-farm experiment. The proportion of smallholder farmers that collected manure during the baseline survey was 5.2%, and this proportion increased to 76% during the on-farm experiment (Table 6). Similarly, the proportion of producers who practised house cleaning was higher during the on-farm experiment than the baseline. This could be associated with the higher number of birds kept and higher feed consumption in TAIBs based production. Higher concentrations of waste may have positive and negative impacts on the environment and human health. For instance, some producers in Tanzania and Nigeria reported a bad smell emitted from chicken manure as a potential risk for human health in the village. Conversely, higher manure production can significantly enhance crop and livestock productions when used as an agricultural input. Some producers reported using manure to fertilize homestead lands for crop production and as an ingredient for livestock and fishery feeds. This suggests the need for integrating improved manure management strategies with TAIBs based production to reduce risks and enhance sustained adoption.

A higher level of kitchen waste use is the other environmental benefit in TAIBs based production. Overall, during the baseline, the proportion of households who used kitchen waste as chicken feed was 26.4%, and this figure increased to 60.1% during the on-farm experiment. This shows the ability of TAIBs to convert household wastes to useable eggs and meat, contributing to mitigating climate change. Other researchers have also examined the contribution of improved feeding to mitigating the adverse effect of climate change on livestock production (Rojas-Downing et al. 2017).

The other important environmental issue raised by researchers, development practitioners, and

Table 6. Households manure management and kitchen waste use in Ethiopia, Nigeria, and Tanzania.

Country	Collect manure		Clean house		Use kitchen waste		Sample	
	Baseline	On-farm	Baseline	On-farm	Baseline	On-farm	Baseline	On-farm
Ethiopia	4.7	84.8	71.2	97.4	12.3	49.4	1,253	1,948
Nigeria	4.4	53.5	72.2	98.1	45.6	52.9	1,124	1,426
Tanzania	6.4	84.1	85.7	97.3	23.1	79.6	1,148	1,603
Overall	5.2	76.0	76.2	97.6	26.4	60.1	3,525	4,977

policymakers in TAIBs based production is a concern for losing the genetic diversity of indigenous chicken breeds during broader adoption and dissemination. This issue could be a genuine concern. For instance, we have observed that some villages with a continuous supply of chicks have started replacing the indigenous breeds with TAIBs. We suggest that this should be examined in research efforts in the future.

5. Conclusion

Theories on the adoption and use of agricultural technologies in the context of developing countries have remained underdeveloped. As a result, existing evidence on the adoption and diffusion of agricultural technologies mainly focuses on partly associating adoption decisions with various household, farm, institutional and environmental factors. However, the adoption and diffusion of agricultural technologies is an intricate process that involves considering multiple dimensions and the trade-offs therein. We used empirical evidence from the ACGG project that introduced TAIBs in sub-Sharan Africa, specifically in Ethiopia, Nigeria, and Tanzania. Evidence generated using the multimethod approach demonstrates that tropically adapted dual-purpose improved chicken breeds based production is suitable for smallholder chicken production in developing countries. We identified vital technical, economic, social, and environmental indicators that show the feasibility of adopting these breeds and possible implications for sustained adoption and broader diffusion in developing countries. These include establishing integrated innovations and other input delivery systems; aligning technologies with existing resources and production practices; demonstrating the profitability and financial viability of technologies under farmers' management conditions; integrating farmers' preferences and addressing their multiple production goals; and minimizing production, marketing, and environmental risks. Agricultural research and development efforts need to consider developing context-specific and system-appropriate technologies and institutional innovations to deliver technologies. In addition, proposed technologies should pass through comprehensive evaluations that consider factors beyond increasing yields to ascertain their multidimensional feasibility under farmers' management conditions.

Data availability statement

The datasets used for this study can be found in the International Livestock Research Institute (ILRI) dataset portal: https://data.ilri.org/portal/dataset?organization=ilri.

Authors' contribution

M.Y.B.: conceptualization, methodology, formal analysis, writing-original draft, incorporate co-authors comments and reviews, design and implementation market survey; J.E.B.: project design and administration, funding acquisition, design and implementation of the baseline survey and on-farm experiment, drafting data collection tools, reviewing and editing the draft; T.A.: draft the baseline data collection tools, supervise data collection, and data curation. W.E.: supervise on-farm and market assessment data collection, and review the draft; K.G.: coordinate the implementation of ATONU project in Ethiopia and data curation in market assessment survey; T.Y.: data curation in market assessment survey; F.G.K.: data collection tool preparation and survey design, leading the on-farm experiment, and review and edit the draft; T.D.: ACGG and ATONU project conceptualization, project proposal development, funding acquisition, project supervision, and drafting data collection

tools. All authors discussed the results and commented on the manuscript.

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