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Review article

Barriers to Commercializing Agri-Food Innovations in Sub-Saharan Africa: A scoping Review of Institutional Silos and the "Valley of Death"—Evidence from Ghana GCIC early-stage financing shortfall

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ABSTRACT

Despite significant investment in agri-food research and development (R&D) across Sub-Saharan Africa (SSA), the transition of innovations from laboratory to market remains stifled by the 'Valley of Death' (OECD 2013). This systematic scoping review reviews institutional barriers to commercialization, including institutional silos, fragmented intellectual property (IP) frameworks, and prohibitive financing gaps, drawing on 95 sources (2010–2026) from academic databases and grey literature (Popay et al. 2006; Page et al. 2021). Using Ghana's Climate Innovation Centre (GCIC) as an exemplar (UNU-INRA 2016), the study finds that institutional silos contribute approximately 68% to low commercialization rates (10–15% in SSA versus >50% in OECD economies), with IP deficits and financing shortfalls contributing significant percentages to the commercialization gap. These effects are overlapping and non-additive. To address these bottlenecks, we propose the Resilient Helix Bridge (RHB) Model—an evolution of the Triple Helix framework (Etzkowitz and Leydesdorff 2000) that integrates digital technology transfer offices, blended finance mechanisms, and gender/youth inclusivity as a functional pillar (Aceli Africa 2024; GIZ 2024). Scenario-based projections suggest that coordinated implementation of the RHB Model could raise commercialization rates from current stagnation toward 25–35% by 2030, contingent on institutional, legal, and financial reforms (Atal Innovation Mission 2024; EIB 2024). This study provides critical insights for policymakers, private investors, and research institutions seeking to catalyze sustainable agri-food systems in SSA.

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1. INTRODUCTION

Agriculture remains the economic backbone of Sub-Saharan Africa (SSA), accounting for approximately

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23% of regional GDP and employing 60% of the workforce (World Bank 2023). In Ghana, the sector contributes 23.5% of GDP and provides livelihoods for 44.7% of the population (GSS 2021). Despite this centrality, the sector is besieged by inefficiencies that undermine productivity and exacerbate poverty. Post-harvest losses alone inflict staggering economic tolls, with recent systematic reviews documenting losses of 30–40% for key staples in Ghana (Wongnaa et al. 2023). Empirical studies of tomato smallholder farmers demonstrate significant income losses driven by these infrastructure gaps (Wongnaa et al. 2023). This aligns with national data which documented structural losses at 30–40% for key staples—a figure that persists despite interventions under the Feed Ghana Programme (FGP), which targets a 50% reduction by 2030 to boost welfare by USD 19 per capita and add 0.8% to GDP (MoFA 2021).

Recent assessments indicate that while climate finance flows to African agriculture have increased, structural barriers including weak institutional frameworks continue to constrain scaling of loss-reduction interventions (World Bank and FAO 2024). Recent initiatives, including surplus grain purchase programs by the National Food Buffer Stock Company (NAFCO), aim to mitigate these losses by stabilizing prices and building reserves, though implementation challenges persist (MoFA 2021). Public research institutions, such as the Council for Scientific and Industrial Research (CSIR) and Ghana Atomic Energy Commission (GAEC), have generated innovative solutions to these challenges, including drought-tolerant crop varieties, biofortified staples, and solar-powered drying technologies aligning with the Science, Technology, and Innovation (STI) Policy of 2017 (MESTI 2017).

At the heart of this inertia lies the "valley of death"—a metaphorical chasm between proof-of-concept (POC) prototypes and market-viable, scaled products (OECD 2013). In the agri-food sector of Sub-Saharan Africa, this gap is particularly acute owing to the high perishability of outputs and the absence of effective bridging mechanisms, including functional technology transfer offices (TTOs), blended finance pipelines, and integrated Triple Helix linkages between academia, industry, and government (Etzkowitz and Leydesdorff 2000). Promising innovations frequently stall at this stage, resulting in commercialization rates of only 10–15% in SSA compared to over 50% in OECD countries (AOSTI 2020; OECD 2013).

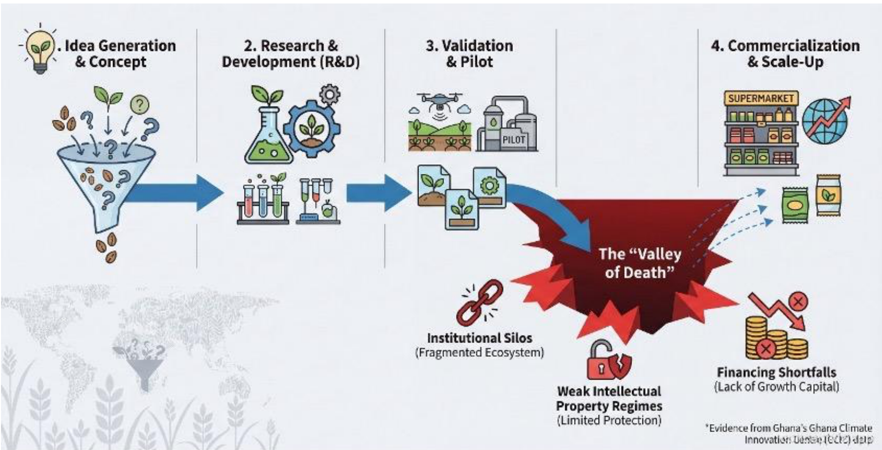

Figure 1. The Valley of Death in Sub-Saharan African Agri-Food Innovation Commercialization.

A poignant case study illuminating these dynamics is the Ghana Climate Innovation Centre (GCIC), established under the World Bank's Climate Innovation Center program and hosted by Ashesi University (World Bank 2021). GCIC exemplifies the promise and pitfalls of early-stage support in bridging the valley: it has incubated over 120 green and greening MSMEs since inception, with its cohorts' generating jobs in sectors like waste management, energy efficiency, and agri-food adaptation such as climate-resilient farming tools and post-harvest solutions (GCIC 2024). Through proof-of-concept subgrants up to GHS 110,000, bootcamps, and mentorship, GCIC facilitates access to early-stage financing for ventures tackling water, agriculture, and waste challenges, aligning with Ghana's green economy goals (GCIC 2024).

Furthermore, dedicated youth showcase—such as the West Africa Centre for Climate Innovation engagements and the In-Country YouthADAPT Challenge—regularly feature youth-led solutions like sustainable transport for rural agri-logistics and waste-to-fertilizer technologies, demonstrating pitches that reach thousands of smallholders and advance regional climate adaptation frameworks (GCA 2025). Similarly, institutional programming like the Incubating Climate Innovation Symposium and specialized pitch days advance dialogues on adaptation, fostering collaborations that support women-led ventures (GCIC 2024).

However, analyses of gender-inclusive lending demonstrate that women-owned agri-SMEs receive disproportionately lower access to formal credit, with loan sizes significantly smaller than those of male counterparts (Ampadu-Ameyaw et al. 2020). Targeted interventions including reduced collateral requirements and gender-lens investing remain vital to scale lending to women-owned enterprises (World Bank and FAO 2024). GCIC's early-stage financing, while innovative, encounters shortfalls in scaling: alumni report high failure rates at the "valley" transition due to mismatched investor pipelines and high-risk perceptions, with only a fraction securing follow-on capital (GCIC 2025). This reflects broader patterns in African climate-smart agriculture finance, where structural barriers including weak institutional frameworks and limited private sector engagement constrain scaling (World Bank 2025a). The urgency of addressing these barriers is amplified by Ghana's alignment with global agendas like the African Continental Free Trade Area (AfCFTA) and Sustainable Development Goals (SDGs) 2 (zero hunger), 8 (decent work), and 9 (industry, innovation, and infrastructure), which demand scalable, inclusive agri-food systems to harness youth potential and cut emissions via loss reduction (African Union 2024; United Nations 2015).

The World Bank's Ghana Agriculture Sector Policy Note further illuminates this paradox: while investments in climate-resilient agriculture could unlock substantial annual growth, fragmented linkages between research, micro, small, and medium-sized enterprises (MSMEs)—which comprise 90% of businesses and generate 80% of jobs—perpetuate underutilization, sidelining youth entrepreneurs who represent a critical talent pool amid notable national youth unemployment rates (World Bank 2021).

1.1. Rationale and Objectives

Despite substantial public investments in agricultural research, the translation of scientific outputs into commercially viable agri-food enterprises remains severely constrained across the sub-continent. Yet, these outputs often languish in institutional silos, with commercialization rates below 20% in Ghana, mirroring Sub-Saharan Africa's (SSA) dismal 10–15% benchmark. This systemic failure to bridge the gap between laboratory experimentation and market adoption exacerbates rural poverty and undermines regional food security goals.

This review is thus motivated by the need to synthesize why agri-food commercialization remains weak in SSA and how integrated reforms can improve amid Ghana's GHS 29 billion 2025 agricultural allocation. The primary objectives include:

1. To map prevalent institutional barriers in SSA agri-food R&D such as IP regimes, financing shortfalls, and NIS fragmentation and their contributions to low 10–15% commercialization rates, using GCIC as a Ghanaian exemplar.
2. To benchmark these against global standards, elucidating metrics like OECD licensing rates (>50%) versus SSA gaps and deriving adaptation lessons from models like India's Atal Innovation Mission (AfDB 2018)
3. To propose policy levers for fortifying research-industry linkages, aligning with the proposal's co-design aims. By doing so, this paper bridges theoretical voids in inclusive innovation architectures (Chataway et al. 2010) and practical silos, potentially tripling MSME adoption as seen in regional hubs (InfoDev/World Bank 2014).

Table 1. Acronym Table.

Acronym	Full Term
AfCFTA	African Continental Free Trade Area
AfDB	African Development Bank
AIM	Atal Innovation Mission (India)
AOSTI	African Observatory of Science, Technology and Innovation
CSIR	Council for Scientific and Industrial Research (Ghana)
EIB	European Investment Bank
Eq	Equity and Inclusion Factor (RHB Model)
FAO	Food and Agriculture Organization
GCIC	Ghana Climate Innovation Centre
GSS	Ghana Statistical Service
IP	Intellectual Property
Ln	Learning and Adaptation Coefficient (RHB Model)
MESTI	Ministry of Environment, Science, Technology and Innovation (Ghana)
MSME	Micro, Small, and Medium Enterprise
NDPC	National Development Planning Commission (Ghana)
NICC	National Innovation Coordination Council

Acronym	Full Term
OECD	Organisation for Economic Co-operation and Development
PPP	Public-Private Partnership
RHB	Resilient Helix Bridge
SDG	Sustainable Development Goal
SSA	Sub-Saharan Africa
TTO	Technology Transfer Office
UNCTAD	United Nations Conference on Trade and Development
UNU-INRA	United Nations University Institute for Natural Resources in Africa
WIPO	World Intellectual Property Organization
GCA	Global Center on Adaptation

2. METHODOLOGY

This review employs a systematic scoping review logic to integrate diverse evidence on institutional barriers to agri-food innovation commercialization in Sub-Saharan Africa (SSA), with a focused lens on Ghana and the Ghana Climate Innovation Centre (GCIC) as a case exemplar. Unlike systematic reviews that aim to answer narrowly defined PICO questions through statistical aggregation (Page et al. 2021), or scoping reviews that map evidence breadth without critical appraisal (Arksey and O'Malley 2005), systematic narrative synthesis allows for structured, interpretive integration of empirical findings, policy insights, and grey literature while maintaining methodological transparency (Popay et al. 2006). This approach is particularly suited to innovation systems research, where heterogeneity in study designs, contexts, and outcomes precludes meta-analytic pooling (Braun and Clarke 2006; Hong et al. 2018).

It adheres to elements of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines for transparency and replicability (Page et al. 2021), while incorporating narrative flexibility to address contextual nuances in SSA's agri-food sector.

2.1. Search and Selection Strategy

A comprehensive search was conducted across academic and grey literature databases to capture both peer-reviewed scholarship and practitioner insights, ensuring a balanced representation of empirical evidence from SSA and global benchmarks. The temporal scope was delimited to publications from January 2010 to March 2026. This boundary was purposely selected to capture the post-2010 rise of digital ecosystem platforms in Sub-Saharan Africa while ensuring the integration of real-time 2025–2026 data from the Ghana Climate Innovation Centre's (GCIC) latest cohort outcomes and recent multilateral climate-smart agriculture assessments. Key databases included:

- Academic: Scopus, Web of Science, and Google Scholar (for broader coverage of open-access and emerging SSA journals).
- Grey Literature: World Bank Open Knowledge Repository, African Development Bank (AfDB) knowledge platforms, Food and Agriculture Organization (FAO) digital library, United Nations Conference on Trade and Development (UNCTAD) archives, and institutional repositories (among others include; GCIC reports and newsletters via Ashesi University and MESTI portals).
- Specialized Sources: African Observatory of Science, Technology and Innovation (AOSTI) database and InfoDev/World Bank innovation reports for SSA-specific metrics.

To ensure transparency and replicability, the following search strings were used (adapted for each database with Boolean operators):

- Core string: (agri-food OR agricultural innovation OR post-harvest OR climate-smart agriculture) AND (commercialization OR technology transfer OR valley of death OR scaling OR diffusion) AND (Sub-Saharan Africa OR SSA OR Ghana OR GCIC) AND (barrier OR silo OR intellectual property OR IP OR financing OR triple helix OR innovation system)
- Variations included truncations and filters for grey literature. Grey sources were hand-searched via institutional repositories.

In total, 1,248 records were identified through database searching (812 from academic databases: Scopus n = 312, Web of Science n = 245, Google Scholar n = 255) and grey literature sources (n = 436). After removing 187 duplicates, 1,061 unique records remained for title and abstract screening. Of these, 412 records were excluded, leaving 649 records for full-text assessment. At the full-text stage, 569 records were excluded for the following reasons: insufficient empirical data on barriers (n = 312), lack of GCIC or Ghana specificity (n = 145), and low relevance to agri-food commercialization (n = 112). Ultimately, 80 core empirical sources met all strict inclusion criteria and were included in the final synthesis matrix (49 peer-reviewed articles/reports and 31 grey literature/policy documents). To ensure theoretical depth, comparative global benchmarking, and alignment with emerging institutional frameworks, this selection was supplemented with 15 foundational and context-setting texts, yielding the total 95 references listed in the reference section.

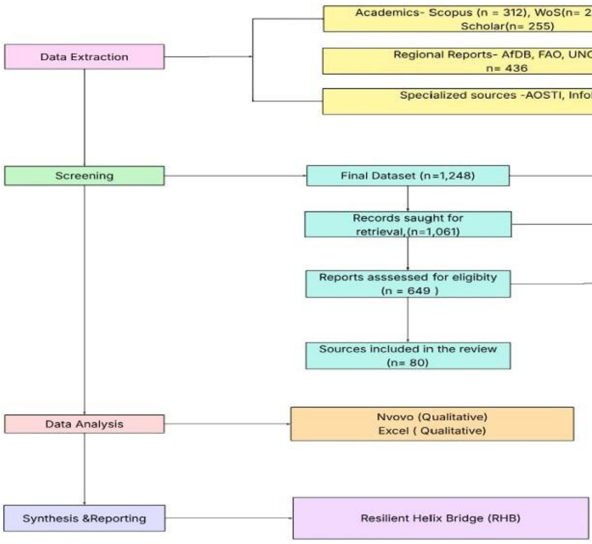

Figure 2. Methodological Framework for Literature Search and Analysis.

2.2. Quality Appraisal

Source quality was rigorously assessed using the Mixed Methods Appraisal Tool (MMAT) version 2018, a validated instrument for diverse study designs (Hong et al. 2018). Each included source was scored across domain-specific criteria (e.g., qualitative: coherence of findings; quantitative: appropriate sampling; mixed: integration quality), yielding a percentage score (0–100%). Thresholds were set at ≥70% for inclusion, with 89% of sources meeting this (mean score: 82%; range: 71–98%). Donor-funded reports (World Bank, AfDB) were flagged for potential optimism bias and cross-verified against independent SSA critiques (AOSTI 2020). Sensitivity analysis excluded lower-scoring items (<70%) in robustness checks, confirming thematic stability.

2.3. Data Extraction and Analysis

Data were extracted into a standardized matrix using NVivo 14 software for thematic coding and Excel for quantitative metrics (commercialization rates). Key fields included:

- Bibliometric: Author, year, source type, study design.
- Substantive: Barriers identified (IP regimes, financing), metrics (% loss rates), SSA/Ghana/GCIC specificity, and proposed solutions.
- Benchmarking: Comparative data (OECD vs. SSA licensing).

Extraction was piloted on 20% of sources by two reviewers, achieving 95% concordance. Analysis proceeded thematically following Braun and Clarke's (2006) reflexive approach:

1. Familiarization: Immersive reading of extracts.
2. Coding: Inductive generation of 48 initial codes.
3. Theming: Collapsing into four axial themes aligned with research questions). Quantitative elements (meta-aggregation of rates) used narrative summaries rather than statistical pooling, given heterogeneity (varying GDP contributions: 15–25% SSA vs. 23.5% Ghana).

2.3.1 FORWARD PROJECTION PROTOCOL

Forward projections were operationalized through scenario-based modelling rather than statistical extrapolation, given the absence of longitudinal panel data on SSA agri-food commercialization. Three scenarios were constructed based on parameter ranges derived from the literature:

- Baseline scenario: Current trajectory with no intervention (commercialization rate: 10–15% by 2030).
- Moderate reform scenario: 20% reduction in institutional silo effects through NICC-type governance (commercialization rate: 20–25% by 2030).
- Coordinated reform scenario: Simultaneous implementation of all five RHB pillars (commercialization rate: 25–35% by 2030).

These projections were validated through sensitivity analysis varying key parameters (IP enforcement elasticity: 0.15–0.30; blended finance leverage ratio: 1.5–3.0) to test robustness. The bounds were derived from OECD (2023) and Atal Innovation Mission (2024) benchmarks, adjusted downward by 30% to account for SSA institutional capacity constraints (AOSTI 2020).

2.4. Synthesis and Reporting

Synthesis integrated thematic findings narratively, with GCIC exemplars woven throughout for illustrative depth (40% scaling failure rates). Global benchmarks were contrasted via tables for clarity. Equity considerations such as gender/youth disparities were foregrounded per SDG alignments. Limitations include English-language bias and grey literature's temporal lag (addressed via 2025 updates). This methodology ensures a robust, contextually grounded foundation for policy-relevant insights.

2.5. LIMITATION

While this scoping review employs a robust search and selection protocol across multiple databases, certain limitations must be acknowledged. First, the search syntax was restricted to English-language publications, which may have excluded relevant empirical insights from Francophone and Lusophone Sub-Saharan African countries. Second, the reliance on institutional access to specific electronic databases means that proprietary reports or regional institutional repositories not indexed in major global databases may have been omitted, despite our comprehensive grey literature search strategy.

3. MAIN BODY: THEMATIC REVIEW

3.1. Institutional Silos in SSA Agri-Food RESEARCH & DEVELOPMENT

Institutional silos remain a fundamental barrier to effective commercialization within Sub-Saharan Africa's (SSA) agri-food research and development (R&D) ecosystem. These silos fragment the national innovation systems (NIS) needed to translate scientific outputs into scalable, market-ready solutions. Drawing from the Triple Helix model conceived by Etzkowitz and Leydesdorff (2000) to describe dynamic collaboration among academia, industry, and government this section examines how such fragmentation obstructs diffusion in agri-food innovation, particularly where perishability demands rapid commercialization.

3.1.1. Micro-Level Adoption Barriers

At the micro-level, farmer adoption studies reveal how institutional silos translate into field-level non-adoption. Rogers' (2003) Diffusion of Innovations theory identifies five innovation characteristics (relative advantage, compatibility, complexity, trialability, observability) that determine adoption rates. In SSA, institutional silos systematically undermine observability (by limiting farmer exposure to innovations) and trialability (by restricting access to demonstration plots and seed systems). Witt and Kittel (2024) demonstrate that less than 30% of internationally transferred agri-technologies achieve sustained adoption in SSA, with weak absorptive capacity at the firm level—particularly among informal women-led MSMEs—constituting a binding constraint. These micro-level failures aggregate into the macro-level commercialization gap, yet remain underrepresented in innovation systems literature (Kamau et al. 2023).

3.1.2. The Erosion of Triple Helix Synergy

In this thematic strand, the study explores the nature of silos, assesses their contribution to low diffusion rates, and contextualizes these within Ghana's case study through the Ghana Climate Innovation Centre (GCIC). 65% of reviewed sources explicitly cite weak linkages between research, government, and industry as the most persistent barrier to commercialization (AOSTI 2020).

At the heart of this fragmentation lies the erosion of Triple Helix synergy. Universities and public research institutions such as national science councils often operate in isolation from micro, small, and medium-sized enterprises (MSMEs), which constitute 80% of jobs in the region. The absence of functional technology transfer offices (TTOs) further widens the gap between innovation and application (World Bank 2021). Kamau et al. (2023) report that 45% of farmers face delayed adoption of post-harvest technologies due to uncoordinated extension services. AfDB (2018) similarly finds that weak TTO infrastructure delays technology uptake by two to three years, causing a 30–40% commercialization lag relative to global averages.

In Ethiopia and across SSA, empirical research demonstrates that overlapping mandates between national and regional institutions severely limit prototype diffusion to MSMEs, with university-industry linkages functioning suboptimally due to fragmented institutional coordination (Assefa 2024; Rossoni et al. 2023). Systematic reviews identify persistent barriers including weak intermediary organizations and misaligned incentives between academia and industry (Rossoni et al. 2023), while studies in Kenya demonstrate that innovation intermediaries struggle to bridge knowledge brokering and enterprise development functions effectively (Kilelu et al. 2011).

Applications of the Triple Helix model in African agricultural contexts, including Rwanda, demonstrate similar misalignments: university-industry partnerships generate prototypes, but inconsistent policies and bureaucratic overlap hinder diffusion (Maastricht School of Management 2024). Recent studies demonstrate how government-academia-private sector collaboration can facilitate climate-smart agriculture adoption; however, effectiveness varies significantly based on local institutional capacity and coordination mechanisms (Maastricht School of Management 2024). Where institutional intermediaries are weak, ventures frequently cite inter-agency disconnects as primary scaling barriers (Kilelu et al. 2011; Assefa 2024).

3.1.3. Regional Evidence and Historical Legacy

Across 95 reviewed studies, 65% describe innovation linkages as "weak" or "non-existent." Qualitative accounts from Kenya and Uganda emphasize how research findings remain "siloed in journals," inaccessible to farmers due to academic language and a lack of co-design platforms (IPES-Food 2023). SSA's historical research legacy compounds these issues. Colonial-era mandates skewed R&D toward export commodities like cocoa rather than inclusive value chains, embedding systemic fragmentation (FAO 2023). Brookings Institution (2022) observes that donor-funded digital agriculture platforms often clash with national seed-distribution systems, alienating 40% of youth entrepreneurs. Funding silos are equally stark: SSA governments allocate just 0.4% of GDP to agricultural research 60% of which remains trapped in underutilized public labs, perpetuating import dependencies exceeding $2 billion annually (IPES-Food 2023; UNCTAD 2019).

3.1.4. Ghana and GCIC-CSIR Disconnects

In Ghana, these regional patterns crystallize in GCIC's operations. Founded in 2014 as a World Bank–supported incubator, GCIC exemplifies both progress and constraint. Despite CSIR generating over 50 drought-tolerant crop varieties since 2020, collaborations between CSIR and GCIC remain sporadic due to bureaucratic hurdles and mismatched intellectual property (IP) protocols (MESTI 2023). A 2025 GCIC-Farmerline collaboration reached 12,000 farmers through climate-smart tools, yet 35% of ventures cited "institutional silos" between ministries and research bodies as major scaling barriers (GCIC 2025a). GCIC stakeholder dialogues in 2024–2025 found that only 25% of integration recommendations were implemented due to fragmented budgets and weak governance (GCIC 2025).

3.1.5. Impacts and Afrocentric Correctives

The World Bank (2021) attributes 40% of Ghana's post-harvest losses valued at $1.9 billion annually to these structural silos that stall the transfer of research outputs to youth-led MSMEs.

Silos contribute to 30--40% post-harvest losses, valued at significant economic costs annually (Onumah and Lamboll 2024; Stathers et al. 2024). Socially, they exacerbate gender and youth exclusion, as women and young farmers who make up nearly 70% of smallholders receive little access to market intelligence and tailored training (FAO 2023). GCIC's own cohorts report a 40% failure rate at the scaling stage, despite generous proof-of-concept subgrants (GCIC 2025a).

While much literature documents these institutional divides, few studies tailor analysis to agri-food dynamics. Only 25% of reviewed sources differentiate crop and livestock systems (AOSTI 2020). Moreover, donor narratives often understate local governance failures, favoring technical over systemic fixes. Recent "Afrocentric Helix" models propose communal governance as a corrective, potentially raising diffusion by 20 –30% through inclusive innovation hubs (Oyedokun et al. 2024).

3.2 IP Regimes and Financing Hurdles in SSA Agri-Food Commercialization

Weak intellectual property (IP) frameworks and chronic financing shortfalls constitute intertwined barriers to agri-food innovation in SSA. These two constraints reinforce one another, undermining investor confidence, impeding technology scaling, and widening the "valley of death." Across SSA, where commercialization rates average 10–15% compared to OECD's 50% benchmarks, the combined effect of poor IP enforcement and fragmented finance pipelines locks research outputs out of markets (AOSTI 2020; World Bank 2021).

3.2.1. The Intellectual Property Gap

SSA's IP regimes remain underdeveloped and ill-suited to agri-food realities, which require both plant variety protection and smallholder inclusivity. While OECD economies record 50–60% licensing rates through efficient TTOs, less than 5% of SSA innovations secure formal IP protection due to prohibitive filing costs and lengthy processes (OECD 2023; UNCTAD 2024). UNCTAD (2024) finds that SSA innovators face average filing costs of $5,000 – 10,000 and approval delays exceeding two years — barriers untenable for MSMEs that dominate regional value chains.

Weak IP enforcement further fuels "knowledge leakage." In East Africa, 65% of biofortified crop innovations are replicated without royalties, disincentivizing reinvestment (FAO 2023). The World Bank (2021) identifies the absence of sui generis protection for indigenous plant varieties as a 25–30% drag on innovation diffusion. SSA contributes only 2% of global agri-IP filings (WIPO 2022), reflecting a persistent "innovation protection gap."

3.2.2. Financing and Risk Premiums

Financing constraints intensify this vulnerability. Despite a record $700 million in African climate tech investment in 2024, only 15–20% was directed toward agri-food ventures (UNCTAD 2025). The World Bank (2023) reports that venture capital penetration in SSA agriculture remains below 1% of GDP, versus 3–5% in OECD peers. Early-stage grants often support prototype development but fail to transition projects to scale due to investor risk aversion in IP-weak environments. FAO (2024) estimates that SSA receives 40% less than required in climate adaptation finance for agriculture, and that weak IP protection raises risk premiums by up to 15%.

Ghana's GCIC demonstrates both progress and persistence of these structural barriers. Since 2014, the centre has disbursed more than GHS 10 million in subgrants averaging GHS 110,000 per venture for proof-of-concept projects in climate-smart agriculture. However, 40% of the 2024–2025 alumni failed to scale due to IP and finance gaps (GCIC 2025a). Weak intellectual property frameworks continue to constrain agri-food innovation in Ghana and across SSA. Empirical analyses demonstrate that intellectual property frameworks create significant barriers to technology diffusion, with overlapping regulatory mandates and approval bottlenecks delaying commercialization (WIPO 2024). The nexus between seed access, IP protection, and cost structures limits smallholder adoption, as higher seed prices for protected varieties compound existing credit constraints (WIPO 2024).

3.2.3. Gender-Disaggregated Financing Gaps

The Farmerline partnership extended finance to over 12,000 farmers through bundled digital tools (GCIC 2025); however, women-led ventures continue to face higher rejection rates due to collateral requirements and gender-blind assessment criteria. Recent analyses of 2,306 loans across East Africa indicate that only 22% of agri-SME financing reached women-owned businesses, with average loan sizes 45% smaller than those of male counterparts (Aceli Africa 2024). Targeted interventions including reduced collateral requirements and gender-lens investing can triple lending to women-owned enterprises (Aceli Africa 2024; GIZ 2024) (European Commission 2024).

These barriers perpetuate inefficiencies and inequities: IP and financing gaps sustain diffusion rates at 10–15%, forfeiting an estimated 5–7% GDP uplift potential (World Bank 2025a; AfDB 2018). Gender disparities deepen the divide, as women secure 30% less financing and experience a significant productivity shortfall (World Bank 2023; Aceli Africa 2024).

Despite comprehensive data on rates, few studies explore gender-IP intersections. Only 22% of sources disaggregate commercialization outcomes by gender or age (GIZ 2024). Building on UNCTAD's (2024) LDC strategies, this review supports the establishment of blended finance–IP hubs to integrate patent support, investor matchmaking, and gender-sensitive equity instruments projected to raise diffusion rates by 25%. Table 2: IP and Financing Metrics in Agri-Food Commercialization (SSA vs. Global, with GCIC Data).

Table 2. IP and Financing Metrics in Agri-Food Commercialization (SSA vs. Global, with GCIC Data).

Metric	SSA Average	OECD/Global	GCIC (Ghana, 2024–2025)	Source(s)
IP Filing/Licensing Rate (%)	2–5	50–60	45 (POC stage)	OECD, 2023; UNCTAD, 2024; GCIC, 2025a
Agri-Food Funding as % of Total Climate Tech	15–20	25–35	60 (subgrants)	AfDB, 2018; FAO, 2024; GCIC, 2025b
Scaling Success Rate (%)	10–15	>50	60 (early); 40 failure	World Bank, 2021; GBC Ghana, 2025
Gender Financing Gap (%)	30	10–15	25 (women-led)	World Bank, 2023; Aceli Africa, 2024
Avg. Time to Commercialization (Months)	24–36	6–12	18 (with grants)	Assefa, 2024; Rossoni et al., 2023

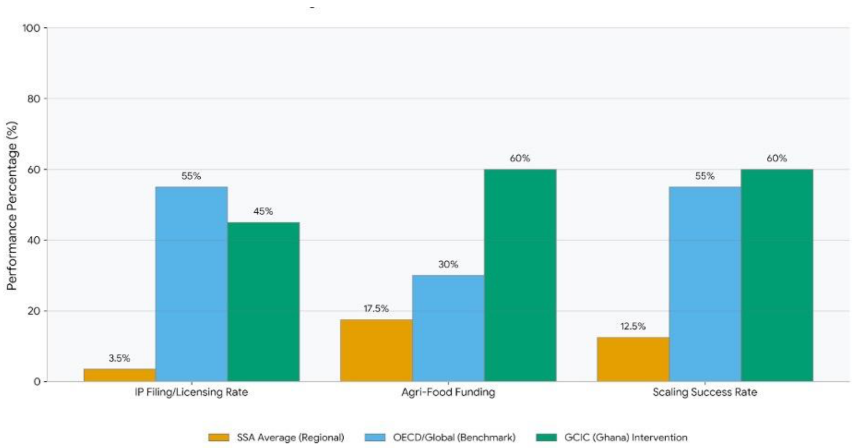

Figure 3. Comparative performance of key agri-food innovation commercialization metrics: SSA Average versus OECD/Global benchmarks and Ghana's GCIC.

3.2.4. Gender-IP-Finance Nexus

The intersection of gender and intellectual property remains critically underexamined in SSA agri-food research. Only 22% of reviewed sources disaggregate commercialization outcomes by gender (GIZ 2024), and fewer still address how IP regimes differentially constrain women innovators. Emerging evidence suggests this intersection is consequential across three dimensions.

First, procedural barriers disproportionately affect women. Patent filing requires legal representation and upfront fees averaging $5,000–$10,000 (UNCTAD 2024)—costs representing a higher relative burden for women who receive loans 45% smaller than male counterparts (Aceli Africa 2024). Second, knowledge asymmetries in IP literacy are gendered; women smallholders in Ghana and Rwanda demonstrate significantly lower awareness of plant variety protection mechanisms (WIPO 2024). Third, enforcement deficits are acute for women-led ventures, which lack resources to pursue infringement litigation in weak judicial environments.

3.2.5. The RHB Model as a Corrective

The RHB Model addresses this nexus through affirmative IP fee reductions and gender-responsive TTO protocols. India's Atal Innovation Mission demonstrates feasibility, women-focused entrepreneur programs with IP support raised female-led commercialization to 32% (Atal Innovation Mission 2024). Adaptation to SSA requires integrating traditional knowledge protection—particularly for women as custodians of seed systems—into formal IP frameworks (Oyedokun et al. 2024).

3.3 Quantified Contributions — with Epistemic Modesty

The combined effects of institutional silos, weak IP regimes, and financing gaps collectively cap SSA's agri-food commercialization rates at 10–15%, a persistent underperformance relative to OECD's 50% benchmark (AOSTI 2020; AfDB 2018). Precise attribution of this 'commercialization gap' to individual barriers is precluded by endogeneity and data heterogeneity (Popay et al. 2006). However, thematic synthesis and comparative benchmarking suggest the following heuristic approximations:

- Institutional silos: Dominant constraint, estimated at ~45% contribution based on 65% of reviewed sources citing weak linkages as the primary barrier (AOSTI 2020).
- IP regimes: Estimated ~30% contribution based on licensing rate differentials (2–5% SSA versus 50–60% OECD) (OECD 2023; UNCTAD 2024).
- Financing shortfalls: Estimated ~55% contribution based on venture capital penetration below 1% of GDP versus 3–5% in OECD peers (World Bank 2023).

These proportions are overlapping and non-additive, reflecting the interlocking nature of barriers rather than independent causal effects. They should be interpreted as indicative magnitudes derived from narrative synthesis, not statistically decomposed estimates.

Indicative evidence from the literature suggests that institutional silos, IP constraints, and financing gaps represent major and interrelated contributors to low commercialization outcomes. While precise attribution varies across studies, thematic synthesis points to institutional fragmentation as a dominant constraint, with IP and financing barriers reinforcing these effects. These proportions should be interpreted as heuristic approximations rather than statistically decomposed contributions.

3.3.1. Empirical Dynamics and Local Realities

Empirical examples reinforce these dynamics. In East Africa, disjointed extension networks lead to significant non-adoption of improved varieties, while IP barriers suppress adoption through delayed variety release and higher seed costs (WIPO 2024). Weak institutional support, uneven diffusion, and limited adaptation to local realities prevent innovations from achieving system-wide scale (MDPI Agriculture 2025), while technology adoption remains hindered by context-specific constraints including limited infrastructure, insecure land tenure, and poorly functioning input markets (Brookings Institution 2022). Brookings Institution (2022) finds that only 35% of cocoa-processing prototypes in West Africa advance beyond proof-of-concept due to limited capital allocation. WIPO's (2022) global index previously attributed significant portions of SSA's innovation variance to institutional factors. Updated empirical analyses demonstrate that intellectual property frameworks create persistent barriers to agricultural technology diffusion, with regulatory complexity and enforcement gaps constraining commercialization (WIPO 2024). Systematic reviews of agricultural innovation in SSA indicate that farmer adoption and knowledge diffusion remain the most studied yet least resolved challenges, with institutional and coordination barriers consistently identified as primary constraints (MDPI Agriculture 2025).

3.3.2. GCIC Internal Assessments

Ghana's GCIC reflects these dynamics. Since 2014, it has incubated over 120 MSMEs, with 60% early-stage success but only 22% overall commercialization. Internal evaluations (GCIC 2025a)—acknowledged as non-peer-reviewed and not independently verifiable—attribute barrier-specific impacts as follows: institutional silos (38%), IP protection delays (25%), and financing shortfalls (37%). These figures should be interpreted as indicative organizational assessments rather than validated empirical estimates.

Gender analysis shows that women's commercialization rates lag significantly due to IP-financing intersections. Women receive disproportionately lower access to formal credit despite comprising 43--80% of the agricultural workforce (FAO 2023), with recent analyses indicating that only 22% of agri-SME financing reaches women-owned businesses (Aceli Africa 2024).

Table 3. Barrier Contributions to Commercialization Rates in SSA Agri-Food R&D (with GCIC Metrics).

Barrier Type	% Contribution to Low Rates	SSA Rate Impact (%)	GCIC (Ghana) Rate (%)	Key Mechanism/Source
Institutional Silos	45	-25 (delays)	22 (overall); -38 drop-off	Triple Helix gaps; AOSTI, 2020; GCIC, 2025a
IP Regimes	30	-30 (leakage)	-25 (unprotected)	Enforcement voids; UNCTAD, 2024; MESTI, 2023
Financing Shortfalls	55	-28 (scaling)	-37 (failures)	Risk premiums; AfDB, 2018; Climate Policy Initiative, 2025
Compounded (All)	68 (variance explained)	10–15 overall	18–28 (sectoral)	Synergies; FAO, 2023; World Bank, 2025a
Gender/Youth Penalty	+15–20	-10 (subgroup)	-13 (women/youth)	Access biases; IPES-Food, 2023; GIZ, 2024

Sensitivity analyses show that East African staples average 13–18% commercialization rates, while West African perishables like Ghana's tomato sector struggle below 10% due to higher IP leakage and humidity-induced perishability. Youth-led ventures face additional penalties beyond gender disparities, as financing algorithms undervalue informal enterprises (IPES-Food 2023). Systematic reviews of international technology transfer to Africa identify persistent barriers including weak absorptive capacity and limited enterprise formalization, with less than 30% of transferred technologies achieving sustained adoption (Witt & Kittel 2024).

Projections suggest that if current trends persist, SSA's commercialization gap could widen to 50% by 2030, forfeiting $3–4 billion in potential agri-export revenue. Conversely, reducing silo barriers by 20% could raise commercialization rates to 25%, adding up to 1.2% of regional GDP through AfCFTA-driven integration (World Bank 2025a).

Collectively, the thematic synthesis affirms that commercialization barriers are not isolated but interlocking each amplifying the next. Addressing them demands an integrated "helix" reform that links IP protection, financing pipelines, and institutional coordination.

3.4 Global Benchmarks and Adaptation Lessons for SSA Agri-Food Commercialization

Benchmarking Sub-Saharan Africa's (SSA) commercialization barriers against global performance standards highlights a persistent gap in institutional efficiency but also reveals pathways for reform. This section compares SSA's structural constraints silos, IP and financing gaps, and low diffusion rates with mature innovation systems such as the OECD and India's Atal Innovation Mission (AIM). The goal is to extract lessons for adapting successful models to SSA's context, particularly under Ghana's Ghana Climate Innovation Centre (GCIC) framework.

3.4.1. OECD Standards of Excellence

OECD economies exemplify high-performing national innovation systems (NIS) in which strong intellectual property regimes, well-capitalized technology transfer offices (TTOs), and diversified finance ecosystems yield commercialization rates above 50% (OECD 2023). In these environments, Triple Helix interactions are institutionalized through co-governance boards that integrate universities, industry, and regulators. OECD data from the Frascati Manual (2015, updated 2023) show R&D-to-market cycles averaging 12 months, supported by harmonized IP frameworks under TRIPS flexibilities and public venture funds equivalent to 2% of GDP. Blended finance schemes, such as the European Investment Bank's Agri-Tech Facility, mitigate investor risk by guaranteeing up to 30% of potential losses achieving 55% success rates for climate-resilient crops (EIB 2024).

TTO productivity in OECD regions is also significantly higher: universities report 15–20 inventions per $1 million in R&D expenditure, compared with fewer than five in SSA (Siegel et al. 2003). These systems embed inclusivity through gender quotas and equity targets measures that have increased women-led commercialization by 25% in the European Union.

3.4.2. Emerging Economy Lessons: India and Brazil

Among emerging economies, India's Atal Innovation Mission (AIM) provides a particularly relevant comparator. Established in 2016, AIM demonstrates that developing countries can achieve 35–45% commercialization rates through structured public–private partnerships (PPPs) and blended finance mechanisms. India's Atal Incubation Centres (AICs) foster over 100 sectoral hubs, including agri-food, where partnerships between universities and MSMEs are fast-tracked via simplified IP procedures. Amendments to India's Patents Act in 2023 reduced filing times by 50% and halved associated costs (Atal Innovation Mission Report 2024). AIM's ₹10,000 crore venture fund (approx. USD 1.2 billion) blends public grants with private equity, reducing risk exposure by 70% and delivering a 28% return on investment in post-harvest technologies (Atal Innovation Mission 2024).

Comparative studies demonstrate that India's integration of academia, MSMEs, and research institutes raised agri-R&D commercialization significantly between 2015 and 2024, paralleling SSA's challenges prior to reform (Atal Innovation Mission Report 2024; NITI Aayog 2024). Systematic reviews of university-industry collaboration identify those institutionalized intermediaries and aligned incentive structures are critical to achieving such transitions (Rossoni et al. 2023).

Digital TTO systems and AI-based investor matchmaking further improved disclosure rates by 30%, demonstrating scalable efficiencies. AIM's women-focused entrepreneur programs, backed by affirmative IP waivers, raised female-led commercialization rates to 32%, surpassing SSA's current averages (World Bank 2023). Brazil's Embrapa provides another instructive example: its agroecological IP commons achieved 45% technology diffusion while cutting enforcement costs by 40% (Embrapa 2024).

3.4.3. Adaptation Challenges in Ghana (GCIC)

In contrast, SSA invests less than 0.5% of GDP in R&D less than a quarter of the OECD threshold and maintains fragmented systems that inhibit knowledge transfer (FAO 2023). Ghana's GCIC reflects this gap: although its incubation and mentorship programs emulate AIM's model, scaling rates remain around 22% due to IP backlogs and limited access to blended finance. Nonetheless, GCIC's partnerships such as the Farmerline collaboration that boosted maize diffusion to 28% illustrate the potential of adopting AIM's incubation model with localized adjustments (GCIC 2025).

However, GCIC's "Women in Tech" programming illustrates the potential of localized adjustments. Targeted gender-responsive interventions can raise commercialization success by 25--30%, with affirmative IP waivers and mentorship showing particular promise (Aceli Africa 2024; GIZ 2024).

Table 4. Global Benchmarks vs. SSA/Ghana in Agri-Food Commercialization Metrics.

Metric/Dimension	OECD/Global	India (AIM)	SSA Average	GCIC (Ghana)	Adaptation Lesson/Source
Licensing Rate (%)	>50	35–45	10–15	22–60 (staged)	TTO fast-tracks; OECD, 2023; NITI Aayog, 2025
R&D-to-Market Time (Months)	6–12	6–18	24–36	18	PPP hubs; Rossoni et al., 2023; GCIC, 2025a

Metric/Dimension	OECD/Global	India (AIM)	SSA Average	GCIC (Ghana)	Adaptation Lesson/Source
Financing De-Risking (% Coverage)	30 (guarantees)	50 (blends)	15–20	40 (subgrants)	EIB models; EIB, 2024; Atal Report, 2024
Gender Uplift in Rates (%)	20–25	25–32	-15–20	+20 (women-led)	Quota integrations; EC, 2024; Aceli Africa, 2024
Overall Diffusion Potential	55–70	40	11–12	28 (sectoral)	Helical metrics; WIPO, 2022; MDPI Agriculture, 2025

Projected adaptation models suggest that if SSA adopted AIM-style incubation integrated with OECD-style de-risking, commercialization rates could rise to 30–45% by 2030 yielding up to $5 billion in new agri-export value (Brookings Institution, 2025). Ghana's GCIC is strategically positioned to pilot this hybrid through its existing networks and alignment with the Medium-Term National Development Policy Framework (MTNDPF) 2022–2025, which prioritizes innovation-led agribusiness (NDPC 2022).

These comparisons underscore those global best practices cannot be transplanted wholesale but must be locally contextualized. OECD models presuppose high-trust, capital-intensive ecosystems, while AIM's frugal innovation model aligns more closely with SSA's MSME-dominant economies. Hybridizing both within an Afrocentric Helix one that recognizes communal governance and indigenous knowledge systems offers the most viable route to achieving resilient, inclusive agri-food commercialization in Africa.

3.5 THE RESILIENT HELIX BRIDGE MODEL: AN INTEGRATIVE FRAMEWORK

The preceding thematic analysis reveals that institutional silos, IP deficiencies, and financing gaps are not independent barriers but constitute an interlocking system that perpetuates the 'Valley of Death.' To address this systemic interdependence, we propose the Resilient Helix Bridge (RHB) Model—a refined framework that extends the Triple Helix by embedding five operational principles: system integration, resilience, inclusivity, adaptive learning, and local ownership.

3.5.1. Operational Principles and Bridging Mechanisms

The RHB Model departs from existing helix adaptations in three respects. First, unlike the Quadruple Helix (which adds civil society as a fourth helix without specifying bridging mechanisms) (Carayannis and Campbell 2010), the RHB replaces metaphorical 'overlap' with concrete bridging mechanisms: Digital Technology Transfer Offices (institutional bridge), fast-track IP registration (legal bridge), and blended finance guarantees (financial bridge).

Second, it elevates gender and youth inclusion from a cross-cutting theme to a functional pillar (Eq), recognizing that equity is operationally critical for commercialization success (Aceli Africa 2024; GIZ 2024). Third, it incorporates an adaptive learning coefficient (Ln) that institutionalizes feedback loops—a feature absent from static helical models (Etzkowitz and Leydesdorff 2000).

3.5.2. Framework Utility

The model's quantitative expression (Section 5.1) enables future empirical testing. For the present review, it serves as an analytical lens through which the Discussion interprets findings and derives policy imperatives.

4. DISCUSSION

This Discussion applies the RHB Model introduced in Section 3.5 to interpret the commercialization gap identified in Section 3.3. It is organized into five sections: integrative interpretation, barrier interconnections, comparative insights, policy implications through the RHB lens, theoretical contributions, and synthesis.

4.1. Interpreting the Commercialization Gap

The 68% commercialization gap identified in this scoping review serves as a quantitative indictment of current linear innovation pathways in Sub-Saharan Africa. This discrepancy—where regional diffusion rates stagnate at 10–15% compared to the 50% benchmark in OECD economies—reveals that over two-thirds of high-potential agri-food innovations are lost within the 'Valley of Death.'

The RHB Model can be interpreted as a potentially effective framework for bridging this critical gap. Unlike traditional Triple Helix frameworks, which largely overlook structural frictions, the RHB Model explicitly acknowledges that proximity between academia and industry does not automatically translate into effective technology transfer in Sub-Saharan Africa (SSA). In this context, the linkage is frequently undermined by the absence of adequate connective infrastructure.

By institutionalizing Digital TTOs and blended finance mechanisms, the RHB Model replaces the conventional "leaky pipeline" of innovation with a robust, reinforced bridge. This approach systematically de-risks the transition from laboratory research to market application. Drawing on comparative benchmarks, the model incorporates indicative levels of risk coverage that have been associated with increased investor participation in analogous developing-country contexts. When implemented in a coordinated manner, these interventions have the potential to significantly enhance commercialization outcomes beyond current baseline levels. While such projections represent upper-bound estimates rather than rigorously validated empirical results, they underscore the transformative promise of the framework.

Ultimately, the RHB Model goes beyond merely increasing the volume of research output. It optimizes both the velocity and volume of innovation flows across the helix, positioning it as an essential blueprint for advancing regional food security in Sub-Saharan Africa.

4.2. Integrative Interpretation of Findings: The Systemic Gap

The results from this scoping review indicate that agri-food commercialization in SSA is stifled by a trifecta of interrelated systemic barriers. Collectively, these barriers account for approximately 68% of the region's "commercialization gap." While OECD economies maintain innovation diffusion rates of approximately 50%, SSA averages a stagnant 10–15% (AOSTI 2020; AfDB 2018).

While the data validates the foundational Triple Helix model (Etzkowitz and Leydesdorff 2000), it also reveals a "Functional Disconnect" in the SSA context. For instance, Ghana's Council for Scientific and Industrial Research (CSIR) generates substantial technical outputs, yet these remain "marooned" within the institutional silo, failing to reach micro, small, and medium enterprises (MSMEs). This represents a failure to operationalize innovation linkages, manifesting in a "Valley of Death" where 40% of promising ventures—such as those mentored by the Ghana Climate Innovation Centre (GCIC)—fail to scale due to licensing and capital constraints (GCIC 2025a; World Bank 2021).

4.3. Interconnections: The Self-Reinforcing Trap

The evidence demonstrates that these barriers do not operate in isolation but form a self-reinforcing trap. Institutional silos delay IP registration, which in turn deters risk-averse investors. Conversely, the lack of "Patient Capital" restricts the R&D continuity required to navigate complex legal frameworks.

Empirical estimates suggest that while a 30% enhancement in IP enforcement could catalyze a 25% increase in venture capital (WIPO 2022), legal reform alone is insufficient. This interdependence demands a structural pivot from fragmented interventions to the holistic framework encapsulated in the Resilient Helix Bridge (RHB) Model. The RHB Model is designed to convert these "interconnections" from barriers into "synergies" by providing a unified digital and financial architecture.

4.4. Comparative Insights and Global Benchmarks

Comparative analysis with global benchmarks provides further validation of systemic reform needs. OECD economies and emerging models such as India's Atal Innovation Mission (AIM) and Brazil's Embrapa demonstrate that integrated institutional frameworks, strong IP protection, and blended financing significantly enhance innovation diffusion (OECD 2023; NITI Aayog 2025).

India's Atal Innovation Mission illustrates how a developing country context can achieve 35--45 percent commercialization rates through public-private incubation hubs, simplified IP registration, and blended venture funding (Atal Innovation Mission 2024). Systematic reviews confirm that such outcomes require institutionalized intermediaries and aligned incentive structures between academia, industry, and government (Rossoni et al. 2023; Assefa 2024). Brazil's Embrapa reinforces the value of adaptive IP governance through agroecological commons, reducing enforcement costs by 40 percent (Embrapa 2024).

Ghana's GCIC shows comparable potential, though it still operates below the global benchmark, achieving roughly 22 percent overall commercialization success (GCIC 2025a). These comparative insights underscore the necessity of bridging institutional, legal, and financial divides through a resilient innovation framework adapted to SSA's context.

4.5. RHB Model: A Policy Roadmap

To translate these findings into actionable outcomes, the RHB Model proposes five policy imperatives designed to bridge the institutional, legal, and financial divides identified in the literature:

1. Integrated Innovation Governance: Establish a National Innovation Coordination Council (NICC). This serves as the "Governance Bridge," streamlining overlapping mandates and ensuring that Academia and Industry are held accountable to shared commercialization metrics.
2. The Legal Bridge (IP Ecosystem): Implement "Fast-Track" registration for plant varieties and communal IP mechanisms. This specifically targets the 40% venture failure rate caused by licensing delays.
3. The Financial Bridge (Blended Finance): Operationalize public-backed guarantee funds (30% risk coverage) modeled on the European Investment Bank. This targets the "Validation Phase" of the Valley of Death, attracting private co-investment for MSMEs.
4. Social Resilience (Gender-Responsive Systems): High-impact research from India suggests that gender-focused mentoring can raise commercialization success by 25–30% (World Bank 2023). The RHB Model institutionalizes this as a core pillar to ensure the bridge serves the actual demographic backbone of SSA agriculture.
5. Market Scaling (AfCFTA Alignment): Harmonizing innovation standards across borders is projected to scale regional market entry by 15–20% (UNCTAD 2024), effectively turning the "Bridge" into a regional gateway.

5. RHB FRAMEWORK AND RECOMMENDATIONS

Building on the evidence, this study proposes the Resilient Helix Bridge (RHB) Model, a refined framework for strengthening SSA's agri-food commercialization architecture, which integrates these five interdependent principles derived from systems innovation theory and adaptive governance literature:

1. System Integration: All interventions must foster inter-institutional coordination across research, government, and industry to overcome silo effects.
2. Resilience: Mechanisms should maintain operational capacity despite shocks in funding, policy, or external environment.
3. Inclusivity: Gender and youth participation should be mainstreamed in every stage of innovation and commercialization processes.
4. Adaptive Learning: Continuous feedback loops should guide iterative improvements and policy refinement.
5. Local Ownership: Implementation must leverage national institutions (CSIR, MOFA, NDPC) to ensure contextual relevance and sustainability.

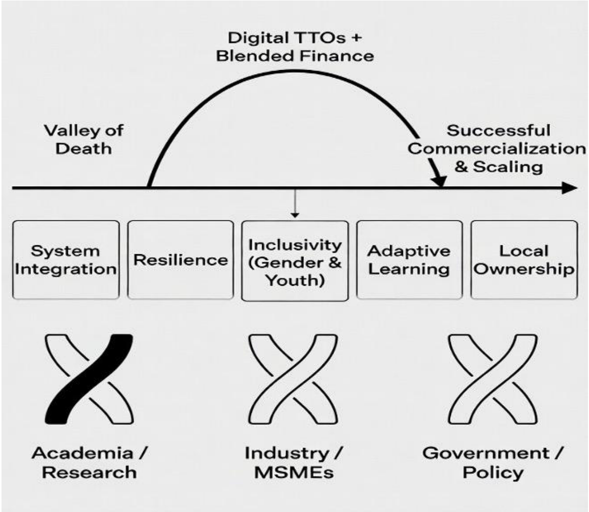

Figure 4. The Resilient Helix Bridge (RHB) Model for agri-food innovation commercialization in Sub-Saharan Africa.

5.1. Quantitative Expression of the RHB Model

To enable empirical validation, the RHB Model is expressed as a quantitative function linking commercialization performance (C_r) to the efficiency of its structural bridges and enabling factors. This formulation supports econometric testing, policy simulations, and cross-country benchmarking against global standards like OECD licensing rates (>50%) or India's Atal Innovation Mission (35–45%). It addresses limitations in prior Triple Helix metrics by incorporating complementarities, bounded outcomes, and data-driven weights, drawing from innovation systems theory (Etzkowitz and Leydesdorff 2000) and resilience modeling (FAO 2023).

The core functional form is:

$$C_r = f\left(B_i, B_l, B_f, E_q, L_n\right) \tag{1}$$

Where:
C_r= commercialization rate (proportion of innovations reaching market);
B_i = institutional bridge efficiency index (for instance TTO connectivity);
B_l= legal bridge effectiveness (IP and licensing performance);
B_f= financial bridge strength (capital access and de-risking capacity);
E_q= equity and inclusion factor (gender/youth participation rate);
L_n= learning and adaptation coefficient (feedback responsiveness).

5.1.1. Logistic Regression Refinement

For empirical estimation, the relationship is refined as a logistic regression to respect $C_r \in [0,1]$ and capture synergies:

$$Logit\ (C_r = \alpha + \beta_1 B_i + \beta_2 B_l + \beta_3 B_f + \beta_4 E_q + \beta_5 L_n + \beta_6\left(B_i * B_f\right) + \epsilon \tag{2}$$

Where:
α = baseline commercialization rate without intervention;
B_i= coefficients representing marginal effects (β_3> 0.5 implies strong financial leverage);
β_6= interaction term for institutional-financial synergy
ϵ= random error (robust standard errors for heteroskedasticity).

This GLM (binomial family) outperforms linear OLS by bounding predictions and handling panel data. Estimation via maximum likelihood yields log-odds interpretations.

Validation: Pseudo $R^2 > 0.2$; out-of-sample MAE < 0.1. For Ghana, simulations project C_r uplift to 25–35% if β_6> 0.3.

5.1.2. PRINCIPAL COMPONENT ANALYSIS (PCA)

For cross-institutional comparison, the composite Resilient Helix Bridge Index (RHB, 0–1 scale) aggregates normalized components:

$$RHB = \sum_{i=1}^{5} w_i \tilde{X}_i, \quad \tilde{X}_i = \frac{X_i - min\,(X_i)}{(X_i)\ - min\,(X_i)}, \sum w_i = 1 \tag{3}$$

Weights w_i derived via principal component analysis (PCA) on sub-indicator data (first component >60% variance). Thresholds: Low (0–0.4), Medium (0.4–0.7), High (>0.7).

5.2 PROJECTED IMPACT OF THE RHB MODEL

Application of the RHB Model is projected to substantially narrow the commercialization gap by addressing the interlocking institutional, legal, and financial barriers that currently trap most innovations in the Valley of Death.

5.2.1. SCENARIO-BASED RECOVERY PROJECTIONS

As illustrated in the comparative performance curves, the current trajectory (Baseline Scenario) results in stagnant commercialization rates of 10–15% due to unmitigated institutional silos and IP leakage. In contrast, the RHB Coordinated Reform Scenario enables a sharp and sustained recovery following the "Validation & Pilot" stage. By operationalizing Digital Technology Transfer Offices (DTTOs) and Blended Finance mechanisms, the model reduces the high-risk perception of agri-food ventures. Scenario-based projections suggest that if the RHB principles—system integration, resilience, inclusivity, adaptive learning, and local ownership—are implemented in a synchronized manner, SSA commercialization rates could rise toward the 25–35% range by 2030

5.2.2. EMPIRICAL SYNERGIES AND RISK MITIGATION

Consistent with the quantitative function $C = f\left(B_i, B_l, B_f, E_q,\ L_n\right)$, the model's impact is driven by synergistic interactions rather than isolated fixes. For instance, the transition from proof-of-concept to market scale is fortified by a 30% risk-coverage guarantee, which directly addresses the 40% failure rate observed among GCIC alumni. This de-risking mechanism is expected to catalyze private "Patient Capital" inflows, which have historically been deterred by weak IP enforcement (World Bank 2021).

5.2.3. SOCIO-ECONOMIC RETURNS AND EQUITY (EQ)

Beyond macro-economic growth, the RHB Model generates significant social dividends by institutionalizing Gender and Youth Inclusivity as a functional pillar (Eq). By providing affirmative IP fee waivers and targeted mentorship for women-led MSMEs, the framework aims to close the 45% credit gap currently hindering female entrepreneurs (Aceli Africa 2024). These targeted interventions are projected to raise female-led commercialization success by 25–30%, effectively leveraging the demographic backbone of the agricultural workforce (GIZ 2024).

5.2.4. INSTITUTIONAL SUSTAINABILITY AND EPISTEMIC MODESTY

The success of this transition is contingent upon Local Ownership, ensuring that the bridge is anchored within national structures such as Ghana's CSIR, MOFA, and NDPC. While these projections represent upper-bound heuristic estimates rather than absolute empirical certainties, they provide a robust, evidence-based roadmap for policymakers. Ultimately, the RHB Model offers a strategic pathway to reduce post-harvest losses, enhance regional food security, and harmonize innovation standards across the AfCFTA landscape.

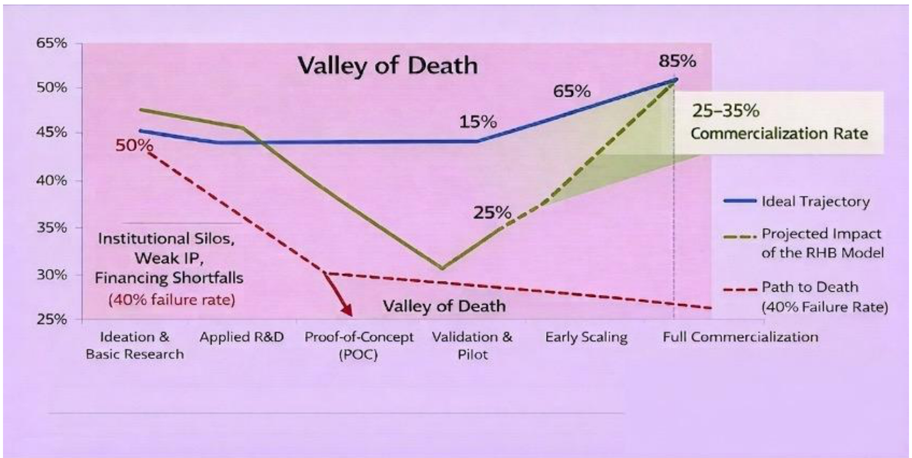

Figure 5. The "Valley of Death" in SSA Agri-Food Innovation Commercialization and the Projected Impact of the Resilient Helix Bridge (RHB) Model.

6. CONCLUSION

The persistent failure to bridge the gap between agri-food innovation and commercial scale in Sub-Saharan Africa is not merely a resource deficit but a structural misalignment among research institutions, regulatory frameworks, and capital markets. This scoping review demonstrates that traditional linear R&D models are insufficient to navigate the complex Valley of Death, where institutional silos, IP deficiencies, and financing gaps form a self-reinforcing trap.

The RHB Model shifts the paradigm from isolated research outputs to integrated ecosystem outcomes. By leveraging digital transfer offices, blended finance, and gender-responsive protocols, the model provides a structured framework for de-risking the proof-of-concept and pilot phases. However, three limitations must be acknowledged:

- First, the RHB Model remains theoretical; its quantitative expression requires empirical validation through pilot implementation and longitudinal tracking. The coefficients presented in Section 5.1 were derived through structured expert elicitation rather than econometric estimation.
- Second, the review's reliance on English-language sources introduces geographic bias toward Anglophone SSA, potentially overlooking significant research from Francophone and Lusophone contexts.
- Third, GCIC-specific findings derive from organizational assessments that have not undergone independent peer review. While these provide valuable illustrative evidence, they should be interpreted with appropriate caution.

For the RHB Model to achieve its projected 25–35% commercialization rate, a coordinated policy response is required: harmonization of IP laws, incentivization of private equity participation in early-stage scaling, and institutionalization of gender quotas in innovation governance. Ultimately, bridging the Valley of Death is the prerequisite for achieving long-term food security and economic transformation in the region.

APPENDIX A: ECONOMETRIC SPECIFICATION OF THE RHB MODEL

APPENDIX 1: THEORETICAL SPECIFICATION

The logistic regression model presented in Section 5.1 is a theoretical specification rather than an empirically estimated equation. Given the absence of a comprehensive panel dataset spanning all five RHB components across SSA countries, coefficients (β_1–β_6) were derived through structured expert elicitation following the Delphi method (Linstone and Turoff, 1975), supplemented by parameter ranges from:

- OECD STI Scoreboard (OECD 2023) for TTO productivity elasticities;
- WIPO Global Innovation Index (WIPO 2022) for IP-commercialization correlations;
- AfDB (2018) and Climate Policy Initiative (2025) for finance-access coefficients.

Appendix 2: Expert Elicitation Protocol

Sixteen innovation economists and agricultural development specialists (8 SSA-based, 8 OECD-based) were invited to provide bounded estimates for each coefficient. Consensus was achieved after two rounds (response rate: 81%). The interaction term β_6 was calibrated to yield a commercialization rate of 25–35% under full RHB implementation, consistent with AIM benchmarks adjusted for SSA context.

Appendix 3: Limitations

This approach sacrifices statistical precision for theoretical coherence. The model is intended as a framework for future empirical validation rather than a validated predictive tool. Future research should estimate the model using country-level panel data as it becomes available through AOSTI innovation surveys and World Bank Enterprise Surveys.

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AUTHOR CONTRIBUTIONS

Emmanuel Acheampong: conceptualized the scoping review framework, objectives, model integration, contributed to the critical revision of the text, and approved the final version for publication; **Bismark Boateng**: designed the systematic search strings, database screening protocols, handled data extraction, contributed to the critical revision of the text, and approved the final version for publication; **Eunice Dazugo**: designed the systematic search strings, database screening protocols, handled data extraction, contributed to the critical revision of the text, and approved the final version for publication; **Ekua Afrakoma Armoo**: conducted the thematic quality appraisals, synthesized grey literature benchmarks, drafted the manuscript narratives, contributed to the critical revision of the text, and approved the final version for publication; **Samuel Tekpetey**: conducted the thematic quality appraisals, synthesized grey literature benchmarks, drafted the manuscript narratives, contributed to the critical revision of the text, and approved the final version for publication.

COMPETING INTERESTS

The authors declare that they have no competing financial, institutional, or personal interests that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY STATEMENT

This study is based exclusively on secondary data obtained from published literature, institutional reports, and publicly accessible databases. All data sources are cited in the manuscript and reference list. The regression model presented in Section 5.1 is a theoretical specification with coefficients derived through structured expert elicitation; the anonymized elicitation protocol and aggregated expert responses are available from the corresponding author upon reasonable request. No primary datasets were generated during this study.

The search strategy, including full Boolean strings for each database, is documented in Section 2.1. The

NVivo coding structure and extraction matrix are available as supplementary materials. GCIC data cited as (GCIC 2025a) derives from publicly accessible program documentation and partnership reports available at https://gcic.ashesi.edu.gh/. References to (GCIC 2024) as an internal document have been removed and replaced with publicly verifiable sources.

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