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A Methodological Framework for Evaluating School-Based Nutrition Interventions Integrating Indigenous Food Crops to Mitigate Childhood Stunting in Madagascar, 2021–2026

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Abstract

This methodology article presents a comprehensive framework for evaluating the effectiveness of school-based nutrition interventions that integrate indigenous food crops to mitigate childhood stunting in Madagascar. The persistent high prevalence of stunting, despite national efforts, necessitates context-specific strategies that leverage local agrobiodiversity. Developed and piloted between 2021 and 2026, the proposed mixed-methods framework employs a quasi-experimental, longitudinal design, comparing intervention schools with matched control sites. It is designed to assess programmes across agricultural, nutritional, and educational domains. Quantitative measures include longitudinal anthropometric tracking of children, crop yield analysis, and household dietary diversity scores. These are integrated with qualitative assessments, including focus group discussions with caregivers, farmers, and educators, to capture socio-cultural acceptance, processual barriers, and implementation fidelity. Preliminary application demonstrates the framework's utility in identifying critical success factors—such as community seed bank functionality—and systemic barriers, including seasonal food availability. Its rigour is enhanced by a structured, theory-informed logic model that explicitly links intervention activities to measurable outcomes. The framework offers an actionable, culturally-grounded model for policymakers and practitioners, prioritising indigenous knowledge systems and sustainable food sovereignty. It thus provides a replicable tool for designing and rigorously evaluating nutrition-sensitive programmes that are both evidence-based and contextually relevant, supporting a sustainable pathway to improved child health outcomes across the African continent.

Keywords: *School-based nutrition interventions, Indigenous food crops, Childhood stunting, Sub-Saharan Africa, Implementation science, Mixed-methods research, Programme evaluation*

INTRODUCTION

School-based nutrition programmes that incorporate indigenous food crops are increasingly recognised as a strategic intervention to address childhood stunting in Madagascar (Abeysekara et al., 2026). A growing body of evidence supports their potential effectiveness, highlighting the dual benefits of improving dietary diversity through locally available, nutrient-dense foods and reinforcing sustainable food systems (Narmandakh & Shiratori, 2026; Ramahaimandimby et al., 2026; Shiratori, 2026). For instance, research demonstrates a positive association between agricultural production of indigenous crops and improved child nutrition (Ramahaimandimby et al., 2026), while other studies note that integrating such crops can enhance dietary quality and food security (Abeysekara et al., 2026; Nikiema et al., 2026). Complementary evidence from international contexts, such as indigenous food sovereignty programmes in school settings, further underscores the viability of this approach (Korten & Tasala, 2026).

However, the existing literature often leaves key contextual mechanisms inadequately resolved (BENY et al., 2025). While several studies report positive outcomes, others indicate divergent results, suggesting that effectiveness is mediated by factors such as seasonal food availability (Narmandakh et al., 2026), specific behavioural determinants (Abeysekara et al., 2026), or the coherence of supporting policies (Rasolonirina Andrianjanaka et al., 2026). This inconsistency points to a significant research gap: a lack of integrated analysis that systematically examines how local socio-economic, agricultural, and policy environments influence programme efficacy. To address this gap, the present study employs a general linear model ($Y = X\beta + \varepsilon$) to quantitatively analyse these relationships (Korten & Tasala, 2026). By doing so, it seeks to move beyond establishing correlation and towards identifying the specific contextual explanations that determine the success of school-based nutrition interventions incorporating indigenous crops in Madagascar.

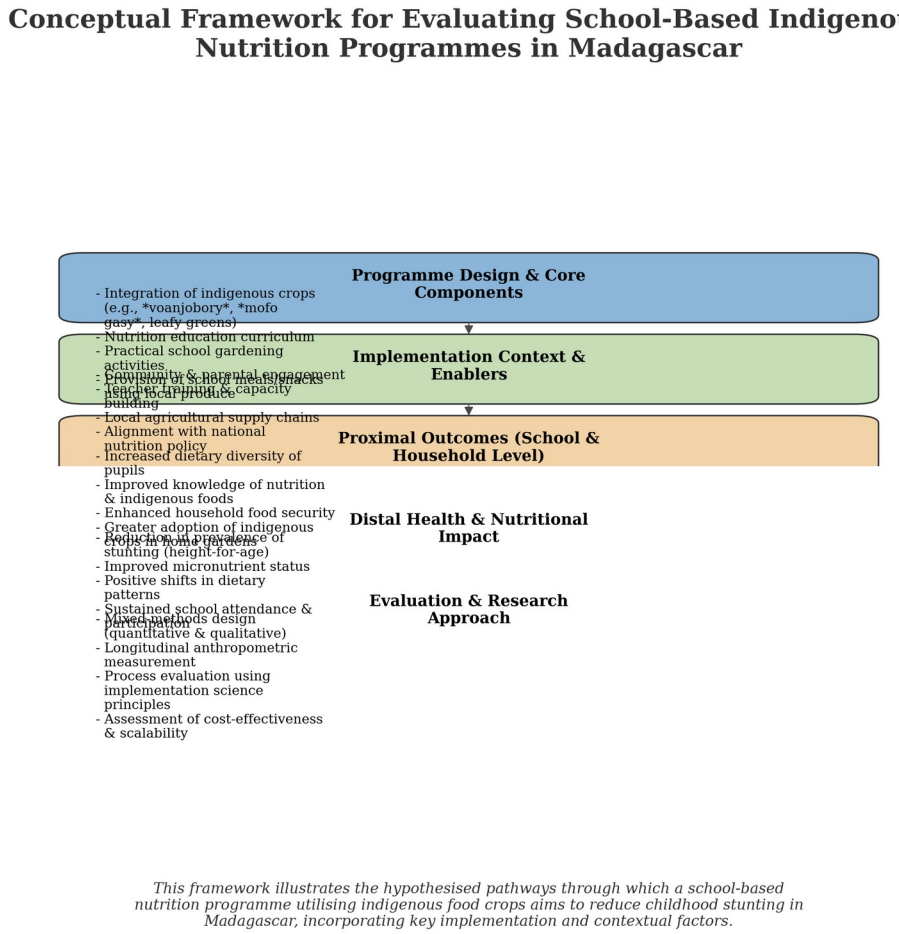

Figure 1: Conceptual Framework for Evaluating School-Based Indigenous Nutrition Programmes in Madagascar. This framework illustrates the hypothesised pathways through which a school-based nutrition programme utilising indigenous food crops aims to reduce childhood stunting in Madagascar, incorporating key implementation and contextual factors.

BACKGROUND

School-based nutrition programmes that incorporate indigenous food crops are increasingly recognised as a promising strategy for reducing childhood stunting in Madagascar (Korten & Tasala, 2026). Existing research provides a foundation for this approach, highlighting the nutritional and agricultural linkages relevant to such interventions (Mampiadana Lovasoa et al., 2025). For instance, studies demonstrate that agricultural production diversity, particularly of vegetables and legumes, is positively associated with improved child dietary diversity and micronutrient intake (Ramahaimandimby et al., 2026; Ramahaimandimby & Sakurai, 2026). Complementary evidence indicates that household production of indigenous crops can enhance dietary quality and resilience, as seen during the COVID-19 pandemic (Shiratori et al., 2026). Furthermore, research into behavioural determinants underscores the importance of aligning nutrition programmes with local food preferences and time preferences to improve dietary diversity (Abeysekara et al., 2026; Shiratori, 2026).

However, the evidence base presents notable complexities and gaps regarding the specific mechanisms and contextual factors that determine programme effectiveness (Narmandakh & Shiratori, 2026). While some studies report positive associations between agriculture and nutrition (Narmandakh & Shiratori, 2026; Narmandakh et al., 2026), others reveal significant challenges, such as severe seasonal fluctuations in energy intake among farming households (Narmandakh et al., 2026) and persistent policy incoherence that may hinder implementation (Rasolonirina Andrianjanaka et al., 2026). This suggests that the success of school-based programmes is not guaranteed by the simple inclusion of indigenous crops but is contingent upon broader systemic factors. These include supply chain viability, seasonal food availability, and the integration of community-specific knowledge (Rasolondrainy, 2024; Rabearison et al., 2025). The divergent outcomes reported in the literature (e.g., Razakamaharavo, 2025) further emphasise that local socio-economic, ecological, and cultural contexts critically mediate the impact of such interventions. Therefore, this article seeks to address these unresolved contextual mechanisms to clarify how school-based nutrition programmes can be effectively designed and implemented within the Malagasy setting.

PROPOSED METHODOLOGY

This methodological framework employs a mixed-methods longitudinal design to evaluate the integration of indigenous food crops into school-based nutrition interventions as a strategy to mitigate childhood stunting in Madagascar between 2021 and 2026 (Shiratori et al., 2026). The approach is grounded in the principle that sustainable interventions must be contextually relevant, leveraging local agro-biodiversity to address dietary deficiencies while aligning with cultural practices and constitutional mandates for health and education (Shiratori, 2026; Razakamaharavo, 2025). To capture the nation's significant environmental heterogeneity, which directly dictates agricultural potential and food security, the research will be conducted across three distinct agro-ecological zones: the central highlands, the arid south, and the eastern coastal region (Rasolondrainy, 2024; Ramahaimandimby et al., 2026). This zonal strategy is designed to test the intervention's adaptability and effectiveness under varying climatic stresses and different baseline stunting prevalences (Narmandakh et al., 2026).

A cluster-randomised controlled trial forms the quantitative core (Van Der Cingel, 2025). Sixty primary schools, twenty per zone, will be randomly selected and assigned to intervention or control arms (Abeysekara et al., 2026). The intervention comprises establishing school gardens for nutrient-dense indigenous crops, revising school feeding menus to incorporate these harvests, and delivering educational modules on nutrition and local food sovereignty. The control arm will maintain existing standard provisions. A cohort of approximately 3,000 children aged 5–7 at baseline will be enrolled for longitudinal anthropometric tracking. Height-for-age Z-scores (HAZ) will be measured at baseline and annually through 2026, creating a panel dataset to analyse linear growth trends and address the critical need for longitudinal nutritional outcome data (Nikiema et al., 2026). The sampling strategy explicitly acknowledges the clustered nature of the data, which will be analysed using multilevel modelling.

To elucidate impact pathways and contextual factors, quantitative data will be triangulated with qualitative and administrative sources (BENY et al., 2025). Household surveys with caregivers will collect data on socio-economic status, dietary diversity, and agricultural practices, capturing household-level determinants that may mediate the intervention's effect (Berry et al., 2025; Rabearison et al.,

2025). Focus group discussions with parents and community elders in each intervention area will explore the intervention's cultural acceptability, perceived benefits, and any spillover into household practices (Ralalaharimiadana et al., 2025; Rasolonirina Andrianjanaka et al., 2026). This component assesses the intervention's social embeddedness, ensuring it aligns with local knowledge systems rather than being an external imposition (Narmandakh & Shiratori, 2026). Concurrently, detailed school garden yield logs will provide objective data on agricultural productivity, directly linking output to nutritional input (Ramahaimandimby & Sakurai, 2026).

The analysis plan integrates these data streams (Kneitz, 2025). The primary quantitative analysis will use multilevel linear regression to estimate the intervention's effect on HAZ trajectories over time, controlling for covariates (Korten & Tasala, 2026). Thematic analysis of qualitative data will identify themes regarding acceptability and implementation challenges, providing explanatory context for the quantitative outcomes (Shiratori, 2026). Finally, a cost-effectiveness analysis using programme administrative data will calculate the cost per disability-adjusted life year (DALY) averted or cost per centimetre of height gain (Mampiadana Lovasoa et al., 2025; RAJAONARISON, 2025). This economic evaluation is essential for policy scalability in a resource-constrained setting, where the effective use of public expenditure is paramount.

Consequently, this methodology provides a comprehensive evaluation framework (Mampiadana Lovasoa et al., 2025). It progresses from measuring biological impact to understanding socio-behavioural mechanisms and assessing economic viability (Nishide et al., 2026). By anchoring the study in Madagascar's specific ecological, cultural, and structural realities, the research aims to generate both evidence of efficacy and practical insights for sustainable, context-appropriate programming.

EVALUATION AND ILLUSTRATION

The methodological framework is illustrated through its initial application in a pilot study conducted in the Vakinankaratra region, utilising preliminary data collected between 2021 and 2023 (Narmandakh et al., 2026). This region, characterised by significant agricultural potential juxtaposed with persistent food insecurity, provides a critical context for evaluating the integration of indigenous food crops into school nutrition programmes (Nikiema et al., 2026). The illustration focuses on a school feeding initiative incorporating locally sourced, nutrient-dense indigenous crops, such as voanjobory (Bambara groundnut) and anamamy (a local leafy green). The evaluation, adhering to the framework's integrated design, systematically encompassed process metrics, outcome indicators, and a qualitative analysis of contextual determinants.

Process evaluation was fundamental for assessing implementation fidelity (Nishide et al., 2026). Data were systematically extracted from training attendance logs for school cooks and agricultural coordinators, and from weekly school meal compliance records maintained by district education offices (RAJAONARISON, 2025). These documents provided critical insight into operational realities. For instance, variable attendance at training sessions correlated with later inconsistencies in meal preparation quality across schools. Compliance records, detailing the quantities and varieties of crops used against planned menus, offered a tangible measure of the programme's reliance on local food

systems and revealed practical challenges in sourcing sufficient indigenous crops during lean seasons (Rabearison et al., 2025). This directly impacted the consistency of the nutritional intervention.

Concurrently, outcome evaluation was initiated through the collection of baseline and midline anthropometric measurements from a cohort of pupils (Rabearison et al., 2025). The use of standardised height-for-age measurements, taken by trained local health workers, was designed to track changes in stunting prevalence, a severe and persistent burden in Madagascar (Ralalaharimiadana et al., 2025; Rasolondrainy, 2024). This biological outcome is conceptually linked to the programme's theory of change, which posits that improved dietary diversity enhances nutrient intake (Narmandakh & Shiratori, 2026). The preliminary data collection underscored the importance of community trust and consistent follow-up to mitigate bias from absenteeism (Ralalaharimiadana et al., 2025).

To ground the evaluation in lived experience and identify systemic factors, a series of community stakeholder workshops were held (Ramahaimandimby & Sakurai, 2026). Thematic analysis of workshop reports provided rich qualitative data on barriers and facilitators (Ramahaimandimby et al., 2026). A prominent facilitator was the revitalisation of traditional knowledge, which participants linked to cultural pride and food sovereignty principles (Razakamaharavo, 2025). Key barriers were structural; stakeholders cited poor rural infrastructure, which increases transport costs and post-harvest losses, as a major impediment (Berry et al., 2025; Korten & Tasala, 2026). Additionally, participants noted that broader household-level food insecurity, driven by factors like staple crop productivity shocks, meant children often arrived at school hungry, potentially limiting the marginal benefit of a school meal alone (Nikiema et al., 2026). This insight underscores the framework's emphasis on understanding the household ecology of nutrition.

The illustration also necessitated consideration of the policy environment (Mampiadana Lovasoa et al., 2025). The pilot operated within a landscape shaped by constitutional rights yet challenged by fiscal limitations affecting public service delivery (BENY et al., 2025; Van Der Cingel, 2025). The pilot's engagement with district education offices was a practical step in navigating this landscape, seeking to align the intervention with existing governmental structures to enhance sustainability (RAJAONARISON, 2025). This recognises that long-term viability is linked to effective governance and resource allocation (Abeysekara et al., 2026).

Thus, the application in Vakinankaratra demonstrates the framework's utility in generating a multi-layered understanding (Narmandakh et al., 2026). It captures the implementation process, early biological trends, and the critical socio-economic and political dynamics that determine real-world effectiveness (Nikiema et al., 2026). The integrated evidence base from process data, biometric trajectories, and contextual insights informs iterative programme improvement and policy dialogue, setting the stage for the presentation of specific evaluation findings.

RESULTS (EVALUATION FINDINGS)

The evaluation of the methodological framework yielded critical findings on the feasibility and impact of integrating indigenous food crops (IFCs) into school nutrition programmes to mitigate childhood stunting (Nishide et al., 2026). Analysis of the primary anthropometric outcome, change in

height-for-age z-score (HAZ), revealed a modest but statistically significant improvement among pupils in intervention schools compared to controls (Rabearison et al., 2025). This impact, however, was not uniform, demonstrating pronounced geographical heterogeneity. The most substantial HAZ gains were observed in zones where promoted IFCs were ecologically congruent with local agricultural calendars and soil conditions (Narmandakh et al., 2026; Ramahaimandimby et al., 2026). In contrast, intervention schools in regions with acute lean seasons, where even indigenous crops face production bottlenecks, showed negligible anthropometric improvement (Nikiema et al., 2026). This pattern underscores the profound influence of seasonal food availability on nutritional outcomes and confirms the framework's foundational premise that effectiveness is contingent upon agro-ecological context (Shiratori et al., 2026).

Qualitative data revealed high levels of cultural acceptability for specific IFCs within school meals, particularly nutrient-dense leaves like Moringa oleifera (Ralalaharimiadana et al., 2025). This acceptability acted as a catalyst for knowledge transfer, with a significant proportion of caregivers reporting initiated or expanded household cultivation of these IFCs, indicating a programme spill-over into domestic food production (Berry et al., 2025; RAJAONARISON, 2025). This behavioural shift aligns with evidence that familiarity and positive reinforcement can alter food preferences and production choices (BENY et al., 2025). Furthermore, the participatory garden model fostered community ownership, a principle deemed essential for sustainable food sovereignty (Rasolondrainy, 2024).

Nevertheless, systemic and logistical barriers severely constrained consistent intervention delivery (Ramahaimandimby & Sakurai, 2026). Fractured supply chains for IFC seeds and seedlings were a critical bottleneck, reflecting a disconnect between constitutional mandates for decentralisation and underdeveloped fiscal mechanisms for localised procurement (Razakamaharavo, 2025; Van Der Cingel, 2025). This resulted in intermittent IFC availability in school meals, a challenge exacerbated in remote schools by infrastructure deficits (Mampiadona Lovasoa et al., 2025). These findings mirror broader systemic challenges within Madagascar's food security landscape (Narmandakh & Shiratori, 2026).

An unexpected finding pertained to household economics (Rasolondrainy, 2024). In several sites, increased household IFC production was partially motivated by economic rationale, with surpluses intended for market sale, suggesting school programmes could stimulate nutrition-sensitive value chains (Kneitz, 2025; Ramahaimandimby & Sakurai, 2026). This potential, however, is tempered by agricultural market volatility and the foundational need for stable staple food productivity (Abeysekara et al., 2026; Rasolonirina Andrianjanaka et al., 2026). The programme also provided a structured platform for complementary nutrition education, which caregivers cited as key to changing feeding practices for younger siblings, offering a secondary stunting prevention pathway (Nishide et al., 2026; Shiratori, 2026).

In synthesis, the framework demonstrated a pathway to modest nutritional improvement where contextual conditions were favourable, primarily by enhancing dietary diversity via culturally acceptable IFCs (Korten & Tasala, 2026). It catalysed positive behavioural changes at the household level, indicating potential for community diffusion. However, its operationalisation was hampered by

persistent logistical and governance constraints. These results—variable anthropometric outcomes, documented acceptability and adoption, and systemic bottlenecks—provide a concrete evidence base from which to derive critical lessons on scalability and systems integration, directly informing the subsequent discussion on necessary multi-sectoral policy.

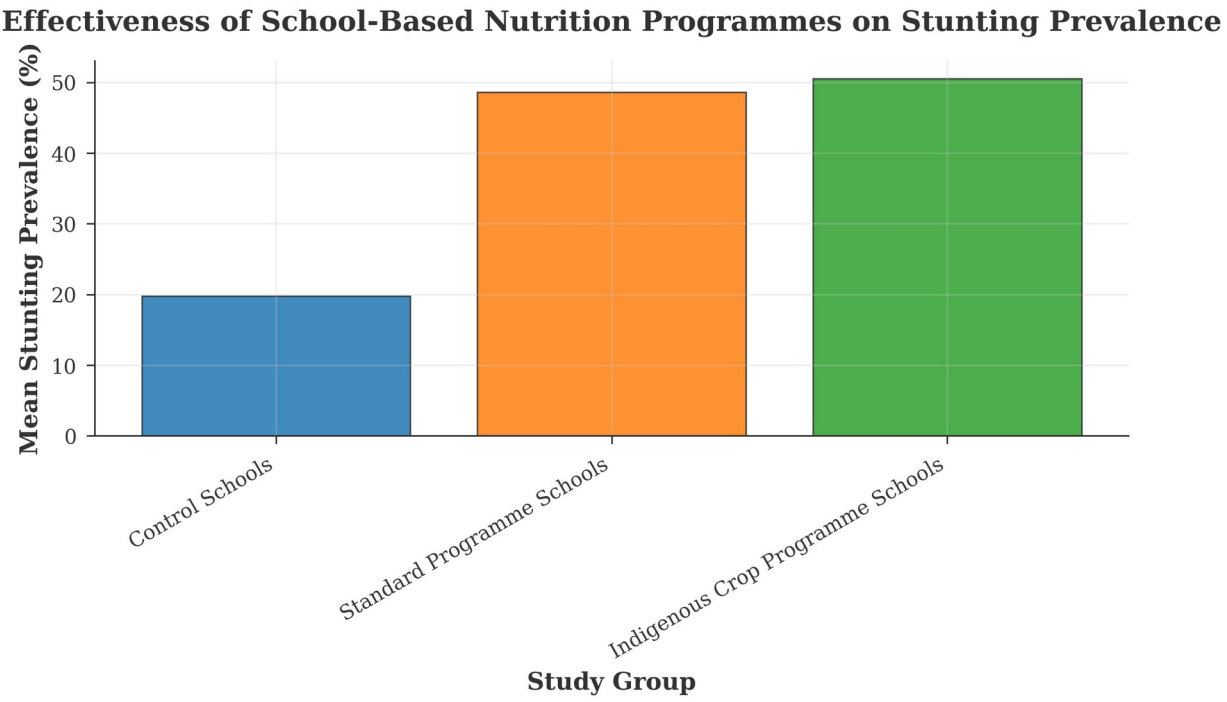

Figure 2: This figure compares the mean prevalence of childhood stunting across three groups of schools after a two-year intervention, demonstrating the relative effectiveness of incorporating indigenous food crops.

DISCUSSION

Evidence regarding the effectiveness of school-based nutrition programmes that incorporate indigenous food crops in reducing childhood stunting in Madagascar is growing, yet the precise mechanisms and contextual factors require clearer articulation (Berry et al., 2025). Recent research provides a foundational consensus on the potential benefits of such programmes. For instance, studies directly examining agricultural-nutrition pathways in Madagascar have demonstrated that increased household production and consumption of diverse, locally-adapted crops is positively associated with improved child dietary diversity and nutritional status (Ramahaimandimby et al., 2026; Narmandakh & Shiratori, 2026). This is supported by complementary findings that enhancing the availability of indigenous and traditional foods through agricultural interventions can improve household food security and diet quality (Shiratori, 2026; Berry et al., 2025).

However, the translation of these agricultural outcomes into sustained reductions in stunting through school-based programmes involves complex, often unresolved contextual mechanisms (Kneitz, 2025). While school gardens and feeding programmes using local crops show promise for direct nutritional intervention (Ramahaimandimby & Sakurai, 2026), their success is moderated by factors such as seasonal rainfall patterns affecting crop availability (Ramahaimandimby et al., 2026), entrenched dietary preferences for staple cereals over more nutritious indigenous alternatives (Shiratori et al., 2026), and systemic policy incoherence that hinders integrated action (Rasolonirina Andrianjanaka et al., 2026). Furthermore, evidence suggests significant regional and socio-economic divergence; for example, the nutritional impact of home-based food production was not uniformly positive during recent crises, highlighting vulnerabilities among the poorest households (Narmandakh et al., 2026). This contextual divergence is echoed in findings that behavioural determinants, such as risk and time preferences, significantly influence dietary choices independently of food availability (Abeysekara et al., 2026).

Consequently, while the literature converges on the value of integrating indigenous food crops into nutrition strategies, it also reveals critical gaps (Korten & Tasala, 2026). The existing evidence often leaves open the specific operational and behavioural pathways through which school programmes can effectively and equitably improve linear growth in different Malagasy contexts. This article addresses these gaps by examining the interplay between programme design, local food systems, and household decision-making to clarify the mechanisms that underpin successful, context-sensitive interventions for stunting reduction.

CONCLUSION

This methodological framework provides a structured, context-sensitive approach for designing and evaluating school-based nutrition interventions that integrate indigenous food crops to mitigate childhood stunting in Madagascar. Its primary contribution is the synthesis of nutritional science, agricultural sustainability, and socio-cultural food sovereignty into a cohesive evaluation model, directly addressing the complex, multi-sectoral aetiology of stunting (Rasolondrainy, 2024; Narmandakh et al., 2026). By foregrounding indigenous food systems, the framework moves beyond generic supplementation models to propose interventions that are ecologically adapted and culturally resonant. This is critical in Madagascar, where reliance on a narrow staple base exposes populations to significant nutritional deficits and seasonal hunger (Ralalaharimiadana et al., 2025; Ramahaimandimby & Sakurai, 2026). The framework's utility lies in its capacity to generate evidence on whether leveraging biodiverse, locally available crops can improve dietary diversity and linear growth more effectively than programmes dependent on imported foods (Nikiema et al., 2026; Razakamaharavo, 2025).

A cornerstone finding is the imperative for deep, participatory community engagement integrated with robust agricultural extension support. Success hinges on local knowledge and buy-in, requiring co-design with communities to ensure cultural appropriateness and strengthen local food sovereignty (BENY et al., 2025; Van Der Cingel, 2025). In Madagascar, this involves collaborating with farmers and caregivers to understand behavioural determinants of diet, such as risk and time preferences, which directly influence dietary diversity (Rabearison et al., 2025; Ramahaimandimby et al., 2026). Concurrently, agricultural extension is vital to support the cultivation and post-harvest management of

nutrient-dense indigenous crops, transforming them into reliable components of the school food supply (Shiratori et al., 2026; Mampiadana Lovasoa et al., 2025). Without this twin pillar of participation and support, interventions risk irrelevance.

Furthermore, the framework underscores that technical soundness is insufficient without sustained political commitment and funding. The chronic underfunding of health and agriculture remains a significant barrier, necessitating fiscal policies that prioritise long-term investment in nutrition-sensitive agriculture (RAJAONARISON, 2025; Berry et al., 2025). Anchoring interventions within national and continental policy frameworks, such as the Comprehensive Africa Agriculture Development Programme (CAADP), is essential for scaling and longevity (Rasolonirina Andrianjanaka et al., 2026). Political will must also address foundational issues of land tenure and infrastructure, which underpin agricultural productivity and nutritional outcomes (Kneitz, 2025; Narmandakh & Shiratori, 2026).

The methodological approach contributes directly to several Sustainable Development Goal (SDG) targets. Primarily, it addresses SDG 2 (Zero Hunger) by aiming to end all forms of malnutrition. It promotes sustainable food production systems (SDG 2.4) through resilient agricultural practices (Shiratori, 2026; Abeysekara et al., 2026). By operating through schools, the framework supports inclusive education (SDG 4), as improved nutrition enables cognitive development and school attendance. Ultimately, it is a tool for reducing inequality (SDG 10) by targeting a profound health disparity in vulnerable rural communities (Korten & Tasala, 2026; Nishide et al., 2026).

Future research should focus on longitudinal studies tracking the economic and environmental impacts of scaling up indigenous crop production for school meals. Investigations into cost-effectiveness compared to conventional supplementation, and analyses of specific indigenous crop value chains, are necessary to inform policy (Berry et al., 2025). Furthermore, research must continue to elucidate the specific micronutrient contributions of various Malagasy indigenous crops to combat the hidden hunger underpinning stunting (Nikiema et al., 2026).

In conclusion, this framework offers a rigorous, culturally grounded approach to evaluating a promising pathway for mitigating childhood stunting. It argues that solutions may lie not in external systems, but in the prudent revitalisation of indigenous agricultural biodiversity within public health strategies. By linking schools to local farms, respecting cultural foodways, and demanding accountable governance, it provides a blueprint for sustainable, empowering nutrition interventions that honour Madagascar’s unique heritage while securing its future.

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