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Development of portfolio management tools in crop breeding programs: a case study of cassava in sub-Saharan Africa

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The response to the diverse needs along the cassava value chain, the urge to increase genetic gain, and the need for rapid varietal turnover will necessitate not only technological innovations but also transformation of public breeding programs in sub-Saharan Africa (SSA). We developed guiding, flexible and adaptative tools for portfolio management of cassava breeding. The cassava breeding and product development pipeline process was mapped to illustrate activities of each stage, as well as to clarify key decision points. Stakeholders involved at all stages of breeding were identified. This allowed for identification of gaps and new crucial functions. To clarify accountability and reduce complexity in the decision-making at key decision points, the roles were mapped against decision-rights at each stage-gate. Cassava crop calendars for the different regions in SSA were developed to facilitate better planning. A product advancement template was developed to guide product advancement. The tools that have been developed and stage-gate mapping, will support regional efforts to establish more structured, transparent, participatory, efficient, inclusive, and demand-driven cassava breeding in the region. These approaches could be customized to other commodities.

KEYWORDS

cassava, product advancement, stage-gate, crop calendar, decision rights, breeding processes

1 Introduction

In the next 27 years, by 2050, the world population is estimated to reach 9.9 billion, with more than 25 percent of the people estimated to live in Africa. This will be an increase of the African population by around 90 percent compared to 2020 (World Population Data Sheet, 2020). This reality underscores food and nutrition demands in sub-Saharan Africa (SSA) where mismatch in scientific innovation tailored for agricultural growth and population growth rates is highest. Concerted efforts are, therefore, urgently needed to sustainably increase food quantities and quality, productivity per unit area, and incomes (Fraval et al., 2019; Bjornlund et al., 2022). This is especially true in the current context of climate change, depletion of natural resources such as biodiversity, land and water, rapid social changes and demographic growth, changes in nutrition, and need for quality food (IPCC, 2022; Olaosebikan et al., 2023). The performance of the agricultural sector is interlinked with how well the above-mentioned challenges will be addressed (Bhavani and Rampal, 2020). As agriculture is a crucial force of economic development, the hard nut to crack is how to address all the issues that face agricultural production while also delivering a breeding product that is tailored to the needs of the end-users (Tiffin and Irz, 2006; Aboyitungiye and Prasetyani, 2021; Dufour et al., 2021; Polar et al., 2022).

Plant breeding plays an important role in building and sustaining resilient food systems (CGIAR, 2021). Indeed, use of modern technological innovations and proven approaches has greatly enhanced breeding operations; thus, timely development and deployment of end-user preferred varieties in farmers' fields. It is, therefore, important that breeding programs continue to operate optimally to remain relevant and responsive to societal needs, whims, and evolving funding landscape (Renkow and Byerlee, 2010; Wossen et al., 2017; Mbanjo et al., 2021).

It has been shown that more structured breeding programs characterized by optimal stepwise process management, improve breeding operations efficiency, maximize genetic gain, and thus impact agricultural value chain actors, their families, and society (Cobb et al., 2019a). An example is the global wheat breeding program that resulted in the release of thousands of wheat varieties between 1970 and 1990 for both favorable and marginal environments covering well over 50 million hectares (Reynolds and Borlaug, 2006).

Accelerating technology adoption in plant breeding drives increasing specialization of the expertise required along a breeding pipeline. Breeding program efficacy would, therefore, largely benefit from improving the ability of teams to work in interdisciplinary contexts (Morris et al., 2006). This is especially important for public breeding programs that target environmental, nutritional, and social impact in addition to profitability. As public breeding programs are influenced by various stakeholders representing prioritizations of national or regional interests, as well as international organizations, strategies are frequently unarticulated or not even discussed and agreed among stakeholders. Consequently, breeding programs and networks, which are often project-based, and thus ending with project timelines are not sufficiently tied to the adoption and impact of their breeding products. Therefore, public breeding networks would largely benefit from raising the bar on transdisciplinary team management, discipline formalizing coordination and management, definition and assignment of accountabilities while simultaneously promoting transparency. This would fulfill the necessary shift articulated by Cobb et al. (2019b) to move "plant breeding towards a data-rich evidence-based and team-oriented process, and away from the romantic tradition of an individual breeder, "as an artist" stressing the problem of the breeder being the sole decision maker. This fundamental change would, in addition to system effectiveness, also provide for system stability; thus, safeguard return-on-investment.

Innovation, customized product development, and systematic last-mile product delivery in a transdisciplinary manner, as well as continuous re-evaluation of entire workflow is required for success (Cooper, 2018). Implementing a value-creating process and risk model (e.g., a stage-gate system) can successfully and efficiently accelerate superior product development (Cooper, 2008; Edgett, 2015). Accordingly, stage-gate systems, now widely promoted within CGIAR and some National Agricultural Research Systems (NARS), have been widely implemented in industry. An example is in the domain of production (manufacturing and assembly), as well as by service-based firms (Wuest et al., 2014; Sommer et al., 2015; Schultz et al., 2018). Aside from allowing for more focus, a stage-gate strategy provides for more systematic planning, and control all tailored toward driving process efficiencies. While these approaches have been adopted in other breeding programs such as beans, through the Pan-African Bean Research Alliance (Chirwa, 2017), they are still to be introduced, adapted, and scaled in cassava breeding in the region.

Documentation of key players, defining their roles and responsibilities at every step of the breeding process is critical to create focus and eliminate redundancy and waste. It is equally important to document interactions between various actors throughout the processes (Van der Werf, 2000). Role clarity also fosters cross-functional team culture, enhances team efficiency, and also helps to develop skills of individual team members (Van der Werf, 2000; Barke and Prechelt, 2019; Kholová et al., 2021). Therefore, a shift toward an evidence-based and inter-disciplinary organizational model is needed in breeding programs (Cobb et al., 2019a; Ceballos et al., 2021; Kholová et al., 2021). Crop breeding programs in Africa will need this transformative shift to enable them cope with societal needs (Mbanjo et al., 2021).

The success of product development is hinged on effective and high-quality decisions (Akdere, 2011; Ghadir et al., 2021). At each product development level, evidence-based decisions are made to inform next actions, as advancing deficient products has immediate and negative knock-on effects notable of which include resource wastage, investment losses, and poor market share of newly developed varieties and/or products (Schippers and Rus, 2021). Indeed, decision quality is correlated with involvement of relevant actors in terms of roles and disciplines (Ozer, 2005). Today, decision-making practice in cassava breeding operations is fragmented with sole responsibility designated to individual breeders. This setup is no longer adequate to extract the full value of increasingly inter-disciplinary product development processes; thus, needs to be revised to exploit the full innovative potential of public breeding programs and networks.

In industry, healthcare, and information technology process, mapping has been widely used to represent and evaluate business operations (Singh et al., 2011; Antonacci et al., 2018; Andriani et al., 2019; Johansson and Nafisi, 2020; Antonacci et al., 2021). Development of tools that logically enable product development in a graphical way not only allows visualization and control of core activities, but also ensures development of quality products (Klotz et al., 2008). In fact, a process-oriented management strategy has been viewed as a communication tool and has shown to enhance transparency, visibility, and understanding of current procedures (Antonacci et al., 2018, 2021). It is also in this light that we see such management system, not as a rigid inflexible structure as this could imply increase bureaucracy and inefficiency.

Accordingly, this paper aims to introduce and implement fundamental changes in cassava breeding programs across SSA. Specifically, the paper focused on establishing a scalable system for product advancement and management. In pursuit of this aim, the following strategic actions were undertaken: (1) a cassava stage-gate process with well-defined actions per stage was designed; (2) roles and disciplines of the extended breeding team involved in all stage-gate process beginning with product development and ending with launch were standardized; (3) decision rights at each stage-gate and people involved were mapped; (4) existing cassava breeding pipelines, as well as current competency levels, were documented; (5) tools, including crop calendar and product advancement guide were developed; and (6) stakeholder perceptions of the proposed breeding operation changes were assessed.

2 Methods

2.1 Cassava breeding programs involved in process improvement

The process analysis and improvement in cassava breeding operations was conducted by the International Institute of Tropical Agriculture (IITA), in collaboration with five African NARS breeding programs, including the Kenya Agricultural and Livestock Research Organization (KALRO) in Kenya, the Council for Scientific and Industrial Research—Crop Research Institute (CSIR—CRI) in Ghana, the National Crop Resources Research Institute (NaCRRI) in Uganda, the National Root Crops Research Institute (NRCRI) in Nigeria, and the Tanzania Agriculture Research Institute (TARI) in Tanzania.

These breeding programs were all partners in the Next Generation Cassava Breeding Project,[1] which enabled the establishment of an inclusive governance structure composed of (a) a core team that set the direction, defined the road map, managed deliverables and implementation; (b) an extended team that provided support to the core team and contributed to the task force activities by lending their expertise and assisting in the advancement of the project; and (c) a steering committee that provided strategic oversight and ensured that deliverables were timely attained. This governance structure ensured adequate representation of stakeholders relevant to the subject matter at various levels of operations (Kähkönen et al., 2013; Mosavi, 2014; Harrin, 2023).

2.2 Cassava crop calendar

The purpose of the cassava crop calendar was to capture variations in the schedule of cassava growing season across agroclimatic regions of SSA to enable identification of windows for cross-functional decision-making events. Accordingly, the cassava calendars were designed with representatives from regional IITA hubs and NARS representing four geographies, namely Southern Africa (Zambia, Malawi, Mozambique), Central Africa (Democratic Republic of Congo), East Africa (Uganda, Kenya, Tanzania, Rwanda, Burundi, South Sudan), and West Africa (Nigeria, Ghana, Benin, Togo, Cote d'Ivoire, and Sierra Leone). Consolidated inputs were consequently validated by stakeholders from local teams utilizing the team and governance structure described above. We mapped out when the various activities (i.e., planting, harvesting, and advancement decisions) occur in each of the studies' agroclimatic regions. The regional calendars were then consolidated into a single cassava advancement calendar.

2.3 Role standardization and stakeholder information

Role standardization refers to the procedure that simplifies a highly diverse collection of job titles of stakeholders across the institutions into a reduced set of roles. It is based on similarities in responsibilities and subject-matter expertise of the original job titles. Herein, stakeholders refer to individuals or groups of people holding said job titles whose consent to a simplified set of roles is required to ensure change success.

Core team members were requested to list all individual job titles and their incumbents involved in the product development process from product design to product launch. The information was collated, and each job title's responsibilities specified. The job titles involved in cassava breeding were then first associated to entities (referring to organizational units that participate in the product development process) and then categorized into disciplines (referring to specific fields of subject-matter expertise). The identified disciplines were then further differentiated into limited sets of roles critical to the product development process. This was achieved through a series of iterations in collaboration with NARS representatives on the Core—and Extended Teams. In the final step, individuals from IITA and the five NARS involved in cassava breeding program were mapped to the identified roles, disciplines, and entities.

2.4 Cassava breeding pipeline process analysis

Here, a pipeline is defined as the concatenation of different development stages from product concept design to the final product delivery to end-users. Accordingly, we mapped the cassava breeding pipeline to the most recent CGIAR stage gate available at the time to illustrate activities of each stage as well as to clarify key decisions to be taken between stages. A generic framework process for all stages was designed, annotated, and then challenged by a cross-functional and cross-organizational team during an implementation workshop where the initial workflows were commented, amended, and adjusted. We articulated the activities and procedures, activity duration, and people involved. Four types of process documents were designed: (a) a high-level map, which gives a quick and simple overview of the process without going into details of how it is done; (b) a Six Sigma concept to map Suppliers, Inputs, Process, Outputs, and Customers (SIPOC) of distinct processes. SIPOC help to visualize the processes at a high level, understand the overall picture, who the customers are

1 https://www.nextgencassava.org/

of a major process, the outputs from those processes, the inputs to those processes and who supply them; (c) a Swimlane flowchart that displays the steps in the process and specifies which function, department, or person is performing them and in what sequence. The components or teams are grouped into distinct sequences or lanes the flow of activities are connected between those components; and (d) a simplified process map showing the detailed process at each stage (Landel and Snyder, 2010; Heher and Chen, 2017; Barrera, 2020).

2.5 Analysis and assignment of decision-making rights

Herein, a decision is defined as the agreement by a diverse group of experts on operational, tactical or strategic actions to be taken to ensure the best possible outcome for distinct stages of cassava product development from analysis of market, research, and production data. To ensure a decision-making process that is inclusive of all relevant expertise and stakeholder interests, while still effective and efficient (as time windows to make such decisions are often very small), decision authority and mandate must be adequately distributed among experts. Therefore, decision rights were mapped across the stage plan according to the RAPID (R = Recommends, A = Agrees, P = Performs, I = Inputs, and D = Decides) model (Rogers and Blenko, 2006) to establish clarity on mandate, accountabilities, and responsibilities for decision-making in cassava product development (Table 1). This was done at IITA and NARS with the support and interaction of the core team representatives from both institutions. The decision rights were mapped for each stage and at all levels, including entity (defined as the highest-level grouping), disciplines (defined as domain of specialization), and roles (defined as responsibilities and expectations of each team member). Decision rights mapping was initiated at the core team level followed by a series of iterations with disciplinary representatives from IITA and NARS in the Extended Team and other institution members.

2.6 Template development

Templates to facilitate transparent communication of data and facts in a comparable manner were developed by representatives of the core team to improve information that informs advancement decision-making for variety selection by cross-functional and inter-disciplinary teams. The templates were developed and reviewed utilizing the project's organization and governance structure, as well as consulting additional stakeholders.

2.7 Implementation workshop

We undertook a consultative stakeholder workshop (referred to as implementation workshop) aimed at operationalizing the assets created during the project (i.e., Stage-Gate process, crop and advancement calendar, standardized roles, and decision rights maps). The workshop exposed preliminary deliverables, captured the problems that participants anticipate, and provided participants with useful information and learning. Competencies of staff considered critical to operate effectively in cross-functional and cross-institutional decision-making on the sub-Saharan cassava breeding pipeline were identified across IITA and the five NARS partners using a 1 (i have no or very little competence) to 5 (I am highly proficient expert) Likert scale (Sullivan and Artino, 2013; Joshi et al., 2015).

TABLE 1 Decision right definition modified from Robert and Blenko, 2006.

Mapping	Decision-making role	Description
R	Recommends	- Assess and make judgments of relevant facts and data, consults people giving input, develop decision-making options - No veto right
A	Agrees	- Negotiate agreements on recommendations and options, consult with recommenders and performers - **Has a veto right**
P	Performs	- The implementer /doer might also give input as to feasibility and execution implications - Responsible for follow up and implementation of decisions made within allotted time
I	Gives Input	- Deliver facts, no judgments, stand-by for but not necessarily participating in final decision-making - No veto right
D	Decides	- Calls and leads decision-making events, ensures timely input, resolves disagreements, ensures decision communication - **Accountable for decision outcome**

3 Results

3.1 Cassava crop calendar

Cassava crop calendars show that for each region of SSA (Supplementary Figures 1A–D), peak intensity varies as a consequence of differences in rain commencement. Therefore, there is no single calendar that can be used across the different regions. It was also observed that across SSA, breeding operation decisions are continuously made throughout the year. The gathered information allowed us to define the most appropriate time when important decision-making meetings (e.g., product advancement meeting) could be suggested. For example, in east Africa, the month of April to May would be ideal for planting, while in central and west Africa, the months of May to July and September to October would be most ideal. With the unimodal rainfall pattern of the southern Africa region, the planting would be concentrated from December to mid-January. Merging the calendars from the different regions allowed to identify timing windows when geography-wide, cross-institution advancement, and decision meetings could be held. Thus, the crop calendar is a planning tool to enhance efficiencies of breeding programs (Figure 1; Supplementary Table 1).

3.2 Standardized roles across IITA and NARS

Across both IITA and NARS, an array of 150 individual job titles were mapped to 27 harmonized roles, which were grouped into 12 disciplines in reference to decision-making in cassava advancement (Table 2). A further level of grouping was added by associating the 12 disciplines to three entities: (1) marketing, outreach, and social impact; (2) research and development; and (3) seed supply chain. For example, under marketing, outreach, and social impact entity, four disciplines (market/socioeconomics, product management, social/gender science, sale and extension) and five roles were defined (Table 2). In the end, this analysis revealed common patterns of organization between IITA and the different NARS partners, and how individual experts are proportionally spread across roles, disciplines, and entities in each organization. Evidently, a very strong focus on research and development was noticed. However, marketing, outreach, and social impact, as well as seed supply chain disciplines, were underrepresented. The resource gap was more apparent among the NARS (Table 2). A crucial resource gap was identified for product management wherein only one product manager is available for the whole region and across institutions, who, in addition, also provides support to other commodities. Communication was also identified as a crucial need for most of the breeding programs.

3.3 Stage-gate mapping of cassava breeding pipelines

Cassava breeding pipelines were mapped along the stage-gates to highlight decision points as advancement is being made from one stage to the next (Figure 2). A summary of which decisions are to be made was also highlighted. For example, Stage 0 is where the target product profile (TPP) is updated. At this stage, the fully functional transdisciplinary team, as well as funders and/or development partners, are part of the decision team. Stages 1 to 5 are components of various technical breeding processes. Stages 5 to 6, the last-stage delivery, comprises of final performance and/or registration trials as per the country's varietal release guidelines. Again, decision-making for this stage needs the involvement of a large and diverse group of experts. Finally, what gets advanced to official releases equally needs a full cross functional team.

3.4 Decision-making

Introduction of stage-gates require establishing clear roles and accountability beginning at Stage 0 up to Stage 7. However, within stages 1 to 5, decision-making is more confined to the technical part of the team, although other disciplines are also involved but to a lesser extent (Supplementary Tables 2–5; Figure 3). Stages 1 to 5 are the technically dominated stages where varieties are crossed and selected following the "recipe," the product profile, determined at Stage 0. From Stage 5, there is a clear institutional change, especially with respect to IITA who mostly has a recommending role or agreeing one (seed supply chain) because it is the NARS organizations that have the mandate to access the relevant variety release agency (decision role) to release varieties. What gets advanced to national performance trial and on-farm trials will be decided by the national programs. What gets recommended for release and delivery to the market is largely a responsibility of market/socio economic, gender, and social inclusion science teams, with CGIAR partner (IITA) playing a more supportive role. The seed supply chain both at IITA and NARS would agree with regards to the potential of the varieties to be delivered to users.

3.5 Process maps

We mapped out all the processes in the cassava breeding pipeline, from product conception and design (Stage 0) through trialing and

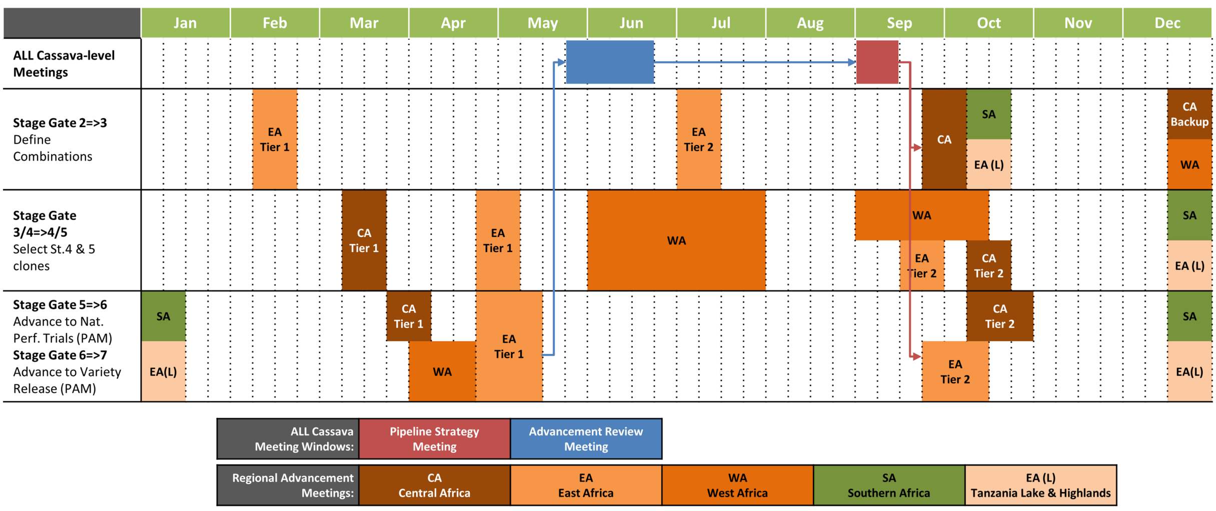

FIGURE 1
All cassava stage-gate advancement calendar. Regional calendars were merged into a single cassava advancement calendar. Crop calendar is a crucial tool for crop management and activity planning for example, key periods for trialing, planting, and harvesting as well as when to schedule critical meeting such as product advancement.

TABLE 2 Detailed overview of the roles and disciplines involved in advancement decision-making in cassava product developement across IITA and the five national agricultural research systems.

Entity	Standardized discipline	Standardized role	IITA	CSIR-CRI	KARLO	NaCRRI	NRCRI	TARI	Grand total
Marketing, outreach & social impact	Market-/Socio Economics	Socio Economist	2	1	1	1	2	2	**9**
		Value chain specialist	2		1				**3**
	Product Management	Product Manager	1						**1**
	Social-/Gender Science	Gender Scientist	1	1		1	1	1	**5**
	Sales and Extension	Dissemination Specialist						1	**1**
									0
Research & development	Breeding	Breeder	7	1	4	2	5	1	**20**
		Breeding Manager	1						**1**
		Lead Breeder	1	1	1	1	1		**5**
		National Program Lead						1	**1**
	Breeding Operations Services	Breeding Operations Manager	1						**1**
		Phenotyping Specialist	1						**1**
		Trait Development Specialist	2	1	2	1	1	1	**8**
		Trial Manager	3				2		**5**
		Field and Laboratory Technical Support		6			1		**7**
	Data Science	Biometrician	1	2					**3**
		Data Analyst	2	1					**3**
		Data manager	1			2	1		**4**
	Disciplinary Expert	Agronomist	2	3		2	2	2	**11**
		Entomologist	1	1		1		1	**4**
		Food Scientist	2	4	1	1	1	2	**11**
		Pathologist	1	5	4	1	2	1	**14**
	Management Oversight	Administrative Manager	5		3	1	2		**11**
		National Program Lead				1			**1**
	Project Management	Project Management Resource Person	1						**1**
		Project Team Lead	1						**1**
	Communication	Communication Expert				1	1	1	**3**
									0
Seed supply chain	Production & Logistics	Seed System specialist	2	5	2	1	2	3	**15**
Grand Total			**41**	**32**	**19**	**17**	**24**	**17**	**150**

selection to launch (Stage 7), as well as all the key intermediate steps, including trait discovery and deployment, population improvement, and candidate selection. Example maps with descriptive captions are provided in Figures 4, 5 and Table 3 and all maps (illustrating the process from stage 0 to 7) are available in Supplementary Figures 2A–Y. The process map could be categorized into three different phases, target product profile, trait discovery and deployment, and breeding pipelines. The process map shows what activities are performed, the flow of activities, who does it, and when activities should be done.

3.6 Template development

A collection of templates to guide advancement process and guide the decision team was developed (Supplementary Files). Two areas were covered with regards to informing the product profile (Stage 0) and with regards to late-stage advancement (Stages 5 to 6). The first is from the breeder's technical perspective and sums up how clones performed in breeding trials with regards to the traits in the product profile and in relation to the current breeder's and commercial checks. It also includes a strengths, weakness, opportunities, and threats

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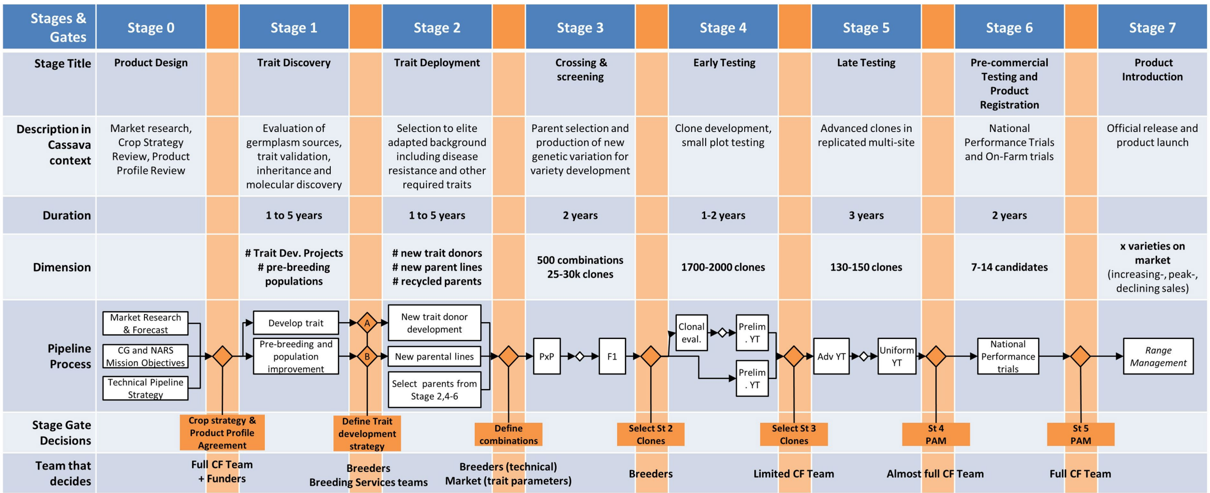

FIGURE 2
Cassava stage-gate process. Cassava product development is mapped into distinct stages and gates, each with a specific objective. The cassava stage-gate process is divided into seven stages, starting with product design (stage 0) and ending with product release (Stage 7). A brief description of what happens at each stage, which include target product profile, trait discovery and deployment, and population development is defined in the blue column, followed by decision points (amber column with diamond symbols) where decisions are taken. An overview of what decisions are made and who made them is presented. Stage 0 entails deciding on crop strategy and establishing or updating product profile. A full functional team, including donors, and funders are involved. Stage 1: Trait discovery and pre-breeding; Stage 2: Trait deployment. It is an intersection to the standard breeding process; stage 3: one makes combinations (decide which parents to put in nursery) and make crosses. Stage 4: clones' selection. Stage 5: A late-stage yield trial within the research organization. Candidate clones are selected to advance to national performance trials (Stage 6). Stage 7: Official release and product launch.

		Standardized Discipline	Decision Right in Gate 0=>1 Crop strategy & Product Profile Agreement	Decision Right in Gate 1=>2 Define Trait development strategy	Decision Right in Gate 2=>3 Define combinations for Crossing	Decision Right in Gate 3=>4 Select Clones for Early Screening	Decision Right in Gate 4=>5 Select Clones for Late Development & Testing	Decision Right in Gate 5=>6 Advance candidates to National Performance- and On-Farm Trials	Decision Right in Gate 6=>7 Advance candidates to variety release
IITA	Marketing, Outreach & Social Impact	Market Economics	A	I	I			A	R
		Social-/Gender Science	A	I	I			R	R
		Product Management	D	I	I	I		A	R
	Research & Development	Management Oversight	A	A	I	I	I	R	R
		Breeding	A	D	D	D	D	R	R
		Breeding Operations Services	I	R	R	R	R	I	P
		Data Science	I	R	R	R	R	R	I
		Project Management	R	I	I	I	I	R	R
		Disciplinary Expert	A	A	R	R	R	R	R
	Seed Supply Chain	Production & Logistics	A	I	R	I	R	R	A
NARS: NRCRI, NaCRRI, TARI, CSIR-CRI, KALRO	Marketing, Outreach & Social Impact	Market Economics	D	I	I		I	A	D
		Sales and Extension	A	I	I		I	R	A
		Product Management	(D)			(I)			(D)
		Social-/Gender Science	A	I	I	I	R	A	A
	Research & Development	Management Oversight	A	A	I	I	I	A	A
		Breeding	A	D	D	D	D	D	A
		Breeding Operations Services	I	R	R	R	R	I	P
		Communication	I					I	
		Data Science	I	R	R	R	I	R	R
		Disciplinary Expert	A	R	R	R	R	R	R
	Seed Supply Chain	Production & Logistics	A	I	R	I	R	A	A

FIGURE 3
Decision-making rights mapping at discipline level. Facts and/or data are needed for decision-making. Depending on the stage, these inputs must be reviewed, suggestions for possible change made, or, when dealt with data, they must be analyzed and summarized for team assessment. The appropriate disciplines should be involved at each step and since each will contribute differently, their decision-right should be well-defined. There are some who recommend (R), agree (A), provide inputs (I), and they ought to be someone who resolve any disagreements and decide (D). Any decision must be followed by an action, known as implementation (P).

(SWOT) analysis and a determination of the unique selling points of varieties, and if this differs per region given the genotype by environment results.

The second is from the social and gender segmentation perspective within the largest breeding pipeline: processed granulated and paste products. Results are based on market intelligence and information, including participatory research and consumer testing (Wossen et al., 2017; Teeken et al., 2018, 2021a,b; Ndjouenkeu et al., 2021), which highlighted the need to consider preferences of specific crop users (i.e., small- and medium-scale men and women farmers and women

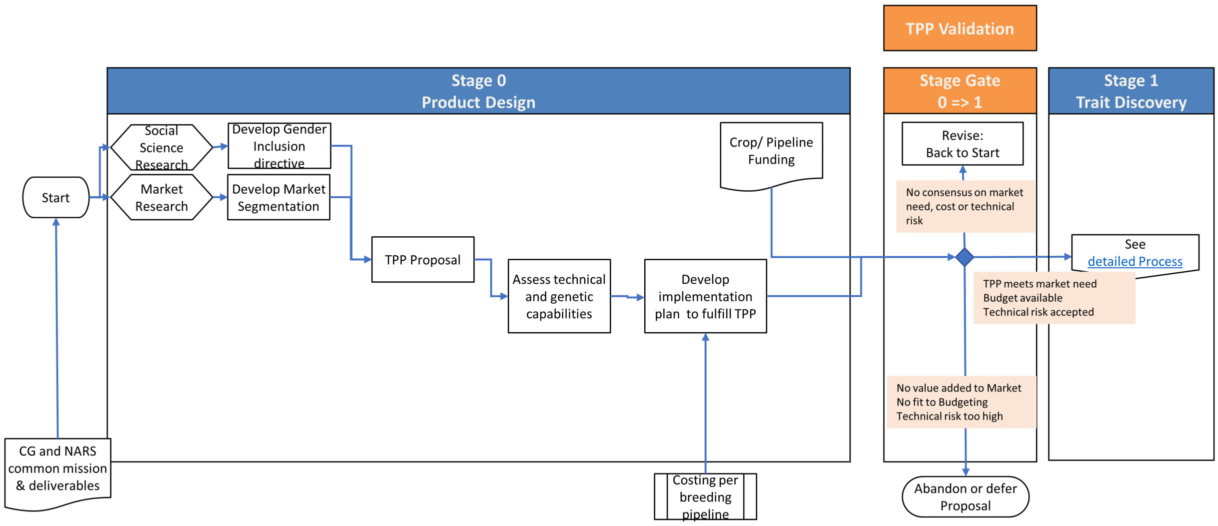

FIGURE 4
Stage 0 (product design) high-level map The crop strategy is defined and reviewed using information provided by market intelligence and social scientists that capture the need of the market. This information is used to develop gender inclusive directives, market segmentations, and, ultimately, the target product profile (TPP). The technical feasibility of the proposed TPP is evaluated by breeders and trait-development breeders, and an implementation plan is developed based on crop/pipeline funding information. A decision point is indicated by a diamond. It is possible that there is no consensus and the TPP must be revised, or if there is no value added to the market, no fit with budgets, or the technical risks are too high or the technical feasibility unsatisfactory; in this situation, the proposed TPP will be abandoned or deferred. However, if the TPP meets market demand, there is adequate money, and technical risk is accepted. The TTP will be validated and proceed to the next stage.

processors). Results pointed to the need to consider consumers of cassava food products in the rural and urban areas, as well as identified priority traits that must be included in the product profile (Stage 0). Variety preferences by intersectional groups of farmers and processors are presented, as well as the outcome of consumer testing in rural and urban areas segmented by relevant social dimensions. Data are then triangulated, and a variety of recommendation based on the late-stage testing is provided. It must be highlighted that late-stage participatory processing reveals information on which varieties to advance (Stages 5 to 6) but at the same time, such participatory work allows to inform trait prioritization among users. This is especially the case for Tricot-scaled participatory variety evaluation of which data are systematized, stored, and analyzed in ClimMob[2] and stored in Breedbase[3] (de Sousa et al., 2024).

3.7 Implementation workshop and outputs

The purpose of the implementation workshop was to disseminate, review, and revise the findings and outputs, assess the current gaps, and to articulate the way forward toward implementation. Accordingly, a total of 64 participants from both IITA and five NARS organizations attended the workshop. Of these, 75 percent were from research and development, 17 percent from marketing, outreach, and social impact, and 8 percent from seed supply chain. The implementation workshop delivered 20 competencies (knowledge, skills, values and behaviors need to execute specified functions) critical for cassava advancement decision-making (Table 4) and brought more clarifications on the stage-gate system and roles and responsibilities.

Participants recognized the importance of developing a clear crop strategy, adopting a structure, and formalizing and standardizing product management and development. They also acknowledged the benefits and advantages of using appropriate tools (i.e., process maps, product advancement template), as well as forwarded suggestions and feedback for further improvement and actions to be taken. The participants additionally recognized the necessity to move from competition to collaboration among the cassava community and across disciplines to reinvigorate partnerships within the community. Other crop representatives also requested the scaling of the tools and concepts. Some of the identified challenges included lack of competence and resources, hindrances related to the achievement of deliverables, insufficient dedication, focus, and commitment to carry the approach forward, and inadequate clarity on criteria and concepts.

4 Discussion

The overarching goal of this project was to develop a scalable system for efficient cassava product advancement and management. This undertaking was done jointly between the IITA and selected NARS. Accordingly, we undertook activities with the hope to develop a more systematic and organized approach that optimize focus; thus, efficiency of product development. Rapid breeding and variety turnover necessitate the establishment of an efficient system to manage product development. Realigning and repackaging breeding and standardization of product management and advancement will have considerable benefits, including a significant improvement in efficiency and effective market-driven variety development. Successful

2 www.climmob.net
3 https://breedbase.org/

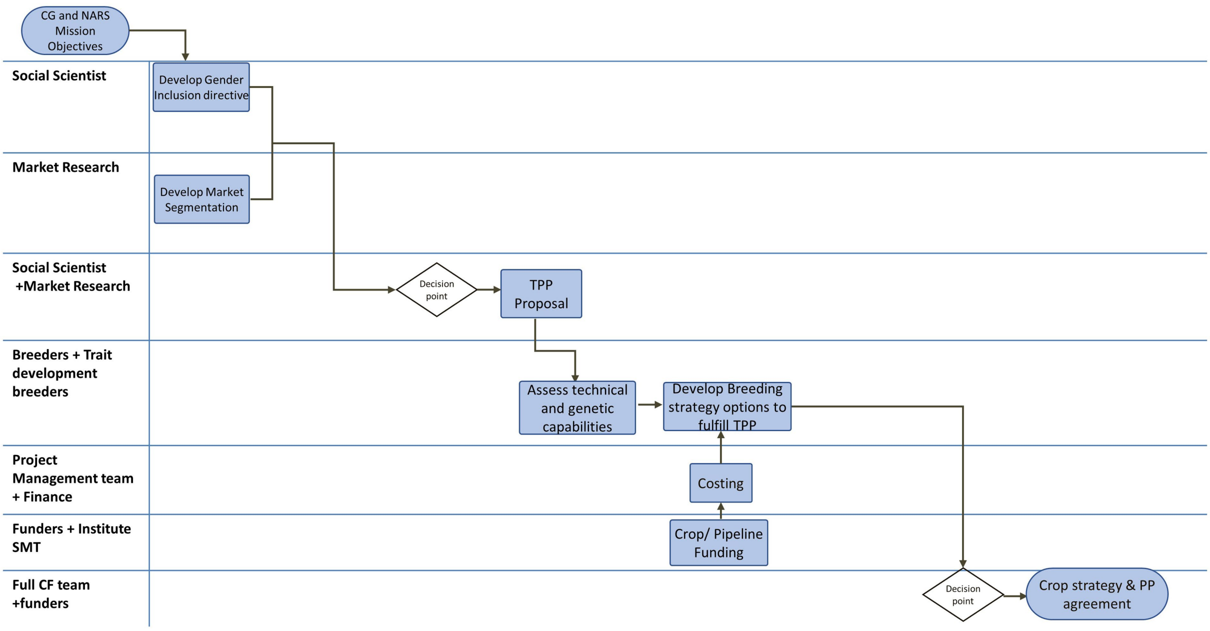

FIGURE 5
Product design swimlane flowchart. On the left side, the various teams involved in Stage 0 are listed and each has its horizontal "swimlane." The diamonds represent decision points. The teams are grouped into distinct lanes. The flow of activities is connected between the teams. While social scientist and market research specialist are involved in the development of target product profile (TPP), its feasibility is assessed by breeders and trait development breeders, who also develop the breeding options to fulfill the TPP. A full cross-functional (*CF*) team should validate the crop strategy and final product profile agreement, and funders should be involved as well.

structure and reorganization require careful planning and development of management tools and models.

We have developed and shared cassava calendars that have been customized to different regions. Such tools have been shown as a critical management tool and may aid in planning (Bauer et al., 1992; Franch et al., 2022). The primary purpose of the crop calendar is for planning breeding activities, including crossing, planting, evaluation, harvesting, and selection; for scheduling critical events (i.e., product advancement meetings) and to inform the public about what we do. We designed a stage-gate system for managing cassava products from design to delivery. The stage-gate approach is widely used in private companies to improve breeding operations and thus impact when released varieties are accessed and utilized by society (Cooper, 2008). Despite being widely acknowledged as a potent instrument for managing product development, some have expressed concern over the approach, which they believe to be too linear, rigid, and bureaucratic; hence, not adaptative enough as it does not encourage innovation and experimentation (Cooper, 2017). In cassava, we are optimistic about its integration and widescale adoption by breeding programs as we see the stage-gate as a guiding flexible principle that provides a thorough understanding of the process and necessary activities among stakeholders to increase focus. Elsewhere, reluctance to adopt it has been overcome by incorporating elements of adaptivity and agility into the original stage-gate approach (Smolnik and Bergmann, 2020). More transparency, control over the breeding pipeline, and the delivery of customs-tailed products will all be made possible by the implementation of such a system for managing cassava breeding pipelines.

Implementation of the stage-gate approach requires specification of activities that must be performed at each stage, and providing a criterion that must be met at each gate, inputs for each stage, as well as the involvement of specific members that are assigned specific tasks, roles, and decision rights. Herein, we described and defined the entire cassava breeding program through process mapping across IITA and its NARS partners. We mapped vital activities at each stage. In the workflow diagrams, we described individual steps and actors in cassava product development. This mapping will help to increase activity transparency while guaranteeing adequate output control at each stage. This mapping is not meant as a rigid inflexible bureaucratic grit but as a flexible and living tool that clarifies the breeding process for all: the whole extended breeding team and other stakeholders. Such management tools are needed and help with operations management and better coordination of tasks, as well as identifying wastes, inefficiencies, blockages, and improvement opportunities in the current processes. Prior to allocating costs for activities, process mapping is a requirement, and it is the first step toward improving processes (Klotz et al., 2008; Abreu et al., 2017). Such a tool will promote inclusive and participatory processes, collaboration across teams and within cassava network, and could be an effective instrument for resource mobilization.

Advancement and management of cassava products are transdisciplinary undertakings as evidenced by the varied roles and disciplines documented in our study. Stakeholder mapping underscored resource gaps (i.e., the requirement for product managers to support and/or justify breeding pipeline investments). We also found overlap between many functions and we identified new roles. Stakeholder mapping highlighted the need to prioritize not only research and development but also other higher-level entities (i.e., marketing, outreach, social impact, and seed supply chain) all of which are currently underrepresented. A limitation to the stakeholder mapping was that it did not capture (external) crop users in the crops value chain (farmers, processors, marketers, and consumers). In our mapping, they were represented by the disciplines and people mapped under Marketing, Outreach and Social Impact. Effective

TABLE 3 SIPOC diagram that illustrates high-level overview of the trial process for stage 3 (crossing and screening).

Supplier	Input	Process	Output	Customer
• Breeder	• Product Profile • Phenotypic data • Genomic data • Pedigree information • Analysis strategy (Selection index) • Selected candidates	•Parental selection	•Crossing plan •Seeds list	Hybridization team
• Hybridization team	• Seed list • Crossing plan	•creation of genetic variation (Intercrossing)	•Botanical seeds	• Seedling nursery team
• Seedling nursery team	• Botanical seeds	•Seedling transplant bed • seedlings evaluation	•Established seedling nursery •Selection of vigorous seedlings	• Seedling nursery team
• Seedling nursery team	• Selection of vigorous seedlings	•Evaluate F_1 seedling in the field • Collect phenotypic data	• Phenotypic data	•Data analyst
• Data analyst	• Phenotypic data	•Conduct data analyses •Select candidate for advancement	• Preselected planting list •Data analysis summaries	•Breeder
• Data analyst	• Preselected planting list • Data analysis summaries	Final selection	• Final planting list and planting material for early testing (CET, PYT)	•Field operation team

A high-level overview of the trial process for stage 3 and its key components is provided by the SIPOC. The relevant inputs and outputs required at each step, who supplies them, the key activities, and who are the customers are captured.

TABLE 4 Competencies for advancement decision-making in a cross functional and cross-organization context.

Product development	Effectiveness	Cross-functional management	Leadership	Transformation
•Product Management	• Data management (Analysis and visualization)	• Competency to integrate various disciplines in decision- making	• Leadership and mediation in a cross-functional team	• Communication to different stakeholders
• Marketing	• Science knowledge management	• Capacity to address gender, diversity, and inclusion issues	• Negotiation and conflict resolution	• Flexibility and openness to change
• Market research	• Project management (Planning, monitoring, evaluation)		• Resource mobilization	• Meeting facilitation
• End-to-end variety development process	• Process optimization		• Mentoring and coaching	• Change management
• Country specific variety release processes	• Continuous improvement			

stakeholders' representation and engaging diverse source of knowledge is key to success. As a result, it will be crucial to engage stakeholders outside the breeding team (i.e., farmers, processors, and marketers) to provide useful perspectives. This information will be integrated with known facts to further enrich and make the system more relevant and practical. For example, new scaled and systematized participatory citizen science approaches to participatory variety selection have been identified as a way to create a network of users to socially inclusively engage value chain actors as citizen scientists (van Etten et al., 2020; de Sousa et al., 2024) as well as feedback from seed businesses. Product development success has been linked to team effectiveness, which can be connected to team composition, participation of relevant stakeholders, and effective communication and coordination across various entities, roles, and disciplines (Edmondson and Nembhard, 2009; Majava et al., 2015). An overview of the stakeholder landscape and mapping of roles offers an opportunity to consider how the various partners could complement one another equally. It also offers a good understanding of the strengths and weaknesses of each organization.

Decisions are made throughout different stages of the product development in breeding programs. Making poor or incorrect decisions can have a negative impact on the overall product development, product performance, and on the achievement of desired outcomes and impacts. We established role clarity and accountability among the stakeholders using the RAPID decision-making model (Rogers and Blenko, 2006). This provides a clear delineation of responsibility. It was shown that the different stakeholders contribute differently at various product development stages. Demarcating each stakeholder's responsibility at various stages can prevent disagreements, conflicts and ensure a more effective, efficient, and inclusive decision-making process. It is crucial to emphasize the need to widen the decision-making group. Indeed, it has been demonstrated that effective stakeholder representation and participation, involvement of relevant actors, and the right team composition throughout the different stages and gate could result in a high-quality information input; thus, a high-quality decision, and a more impactful and durable outcome. Similarly, effective communication and coordination across the different entities, roles, and disciplines is essential (Edmondson and Nembhard, 2009; Majava and Haapasalo, 2015; Reed and Curzon, 2015). An operational roadmap featuring multiple checkpoints and well-informed decisions supported by diverse perspectives will ensure that the right strategy will be designed, the right parents will be crossed, the right clones will be selected and advanced, the developed product will be in line with the predefined product profile, the right product will be delivered to the end-users and a high rate of genetic gain for key traits will be achieved.

Expertise gaps can impede the product's development and advancement. We highlighted critical competencies that would be required for collaborative advancement decisions, as well as the gap in competencies and required resources. A critical need identified is the need for product management that effectively represents and brings together all the relevant information from marketing, outreach and social impact to inform the product profile. It will be critical to leverage expertise and knowledge within each entity across processes. Among the marketing, outreach and social impact, clear capacity building is necessary on product development from product profile to varietal release. Furthermore, across IITA and NARS, people realized the need for capacity development on cross-functional management competencies and transformation competencies, and with a relatively greater need among the NARS. This could be achieved using classical solutions such as training, workshops, mentoring, participation at technical conferences, and content repositories. The already existing cassava community of practice and partnership (CoPP) initiated by the Next Generation Cassava Breeding Project (see "Footnote 1") could be exploited for this purpose to connect cassava stakeholders, encourage knowledge transfer, and bridge expertise gaps within and between organizations (O'Dell and Trees, 2014). Effective partnerships and interorganizational collaboration within the cassava network will close the existing gap (Bröring and Cloutier, 2008). It will also be crucial to set up a system that continuously support learning and leveraging of newcomers' skills.

The currently developed templates encompass social and gender information, information obtained from crop users along the food chain through participative research, and the technical breeding results. Other aspects of the template will have to be further developed with food science and other relevant disciplinary experts, as well as with the seed supply chain entity, to assure an inclusive and complete input from all the relevant entities and their disciplines. For effective product management and advancement, the concepts and tools developed must be put into practice. Although these tools and concepts are widely used in the private sector, public breeding programs have not yet adopted them. We anticipate slow adoption at the start, which will eventually increase owing to the publicity and relevance that have been emphasized during design and the traction it is gaining at higher CGIAR and government levels as well as among donors who stress the need for adoption of new technologies and equally realizing social impact (CGIAR, 2021; Donovan et al., 2022; Polar et al., 2022). Transdisciplinary mapping stakeholders and their role and decision-making rights do not necessarily assure an inclusive non-disciplinary biased outcome. This is the reason why learnings from studies of power dynamics (Tarjem, 2023; Tarjem et al., 2023) related to the asymmetries between natural and social sciences that are rooted in different epistemological traditions and unequal funding will have to support effective implementation. Awareness must be raised through socialization and communication within the cassava community to acquaint stakeholders with the developed assets and provide them the opportunity to give their perspectives, which may be a source of innovation in the change and/or improvement process. Leadership support and effective communication at all levels could be other essential conditions for these changes to take place. A team culture must be developed, and champions need to be empowered (Waddell and Sohal, 1998; Gesme and Wiseman, 2010; Kuzhda, 2016).

5 Conclusion

The management of product development is complex and requires alignment and effective collaboration between a broad range of stakeholders and technical experts in various disciplines. Therefore, workflow structuring, and management are essential for an end-user-driven, product-oriented variety development that is efficient, effective, and destined to deliver genetic gain in farmers' fields. In this light, we developed tools for portfolio management of cassava breeding, including a cassava calendar for planning and managing activities and templates to guide product advancement. We designed a clear stage-gate system within which we mapped cassava breeding processes to control outputs at each stage, ensure that the relevant inputs are supplied, and the outputs optimized. Successful product development being transdisciplinary, depends on the stakeholders participating, the clarity of stakeholder roles, who has what right to do what and who is accountable for decision-making, as well as coordination between the many actors at various levels. This information is essential to develop and organize cross-functional teams and provide them with highly effective collaborative structures. Capturing the stakeholder landscape has made it possible to find gaps and overlaps, as well as opportunities for team reconfiguration. The integration of the many skill sets will be necessary for the transdisciplinary of product management and advancement. Team effectiveness, being one of the factors that affects how efficiently products are developed, it is crucial to evaluate the available competencies and upskill them as needed. Finding the initial resources required for a such committed transdisciplinary team, routine operationalization of the developed tools, the reluctance in accepting change, and the power dynamics between natural and social sciences are some of the anticipated challenges. The present pilot work done in cassava currently serves as a model for cross-organizational collaboration and is being scaled to other CGIAR crops.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The individual(s) provided their written informed consent for the publication of any identifiable images or data presented in this article.

Author contributions

CE: Conceptualization, Funding acquisition, Writing – review & editing. EM: Conceptualization, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. RK: Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – review & editing. BT: Investigation, Methodology, Resources, Writing – review & editing. IR: Investigation, Methodology, Resources, Writing – review & editing. RP: Resources, Writing – review & editing. LJ: Resources, Writing – review & editing. DN: Resources, Writing – review & editing. HK: Resources, Writing – review & editing. FG: Resources, Writing – review & editing. VW: Resources, Writing – review & editing. EP: Resources, Writing – review & editing. RO: Resources, Writing – review & editing. VB: Resources, Writing – review & editing. PN: Investigation, Methodology, Resources, Writing – review & editing. JD: Resources, Writing – review & editing. SW: Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Visualization, Writing – review & editing. PK: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – review & editing.

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Conflict of interest

SW is employed by Weber & Fritz Consulting.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2024.1322562/full#supplementary-material

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