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Gender-intentional breeding case studies

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Gender-intentional breeding case studies

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Editorial: Gender-intentional breeding case studies

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plant breeding, gender research, gender-intentional, crop varieties, crop improvement

Editorial on the Research Topic
Gender-intentional breeding case studies

Women play a critical role in smallholder agriculture, yet their limited access to technology contributes to a significant gender gap in agricultural productivity. A major factor in this gap is the slow adoption of modern crop varieties. One key contributor to this lag is insufficient attention to user preferences, particularly quality traits valued by women. Gender-intentional breeding seeks to integrate gender considerations into crop development from the outset, to promote equitable adoption and to ensure new varieties meet the needs of both men and women.

Two Collections on Gender Intentional Breeding, of which this is one, provide insight into ongoing experience with gender intentional breeding and the contextual issues that determine the effectiveness of the approach. Research Topic One, *Gender-intentional breeding case studies,* consists of 12 case studies documenting experiences with gender-intentional breeding. Research Topic Two, *Gender Intentional Breeding :From Integration to Institutional Innovation,* consists of two additional cases, potato breeding in Kenya and sweetpotato breeding in Uganda, and 10 papers that address broad institutional and methodological challenges of the type confronted in the cases.

The importance of gender equity for agricultural development has been recognized for decades but attention to gender differences in demand for new varieties has fluctuated. As a result, relatively little of the growing body of experience with gender-intentional breeding has been systematically documented until now. Building on work that began in the 1990s, the Consultative Group on International Agricultural Research (CGIAR) launched a Gender and Breeding Initiative (GBI) in 2015, which accelerated gender integration into international and national breeding programs, particularly in Africa, where the GREAT training program supported capacity development.

Recognizing that a wealth of undocumented experience with gender-intentional breeding was accumulating across regions over several decades, in 2022 the CGIAR Genetic Innovation Action Area (GI) issued an open call for case studies, receiving 43 submissions from CGIAR centers, national agricultural research and extension systems (NARES), and NGOs. The Editors participated in the selection of the cases and mentored their development. The published cases were selected based on their focus on gender research, evidence of changes in breeding objectives, and diversity of geographic and institutional contexts.

The cases examine breeding outcomes, the process of integrating gender research into plant breeding and how breeding programs changed objectives, methods and management practices as a result. Many illustrate how gender-intentional breeding requires the

formation of multidisciplinary teams that include breeders and social scientists, and in some instances, food scientists. Several case studies show that embedding gender researchers in breeding teams led to changes in variety design and prioritization. Programs that initially used participatory varietal selection (PVS) without specific gender considerations revised their approach to include women's trait preferences and production constraints. A key innovation was the use of gender-responsive participatory research methods, such as TRICOT crowdsourcing trials, which allowed both men and women to evaluate varieties based on agronomic, processing, and consumption characteristics.

Gender-intentional breeding programs consistently reveal the widespread occurrence of both distinct and overlapping plant trait preferences among men and women. For example, in Mali and Burkina Faso, women preferred sorghum and millet varieties with soft grain for easier processing, while men prioritized yield and marketability. In Nigeria, women cassava processors valued high carotenoid retention and low water content in roots. Similar findings were reported in other crops, such as cowpea, sweet potato, and yam, where gender-informed trait preferences influenced breeders' selection. These insights led to modifications in breeding objectives, ensuring that new varieties incorporated user-preferred traits.

As a result of integrating gender research, breeding programs released several gender-intentional varieties. In Nigeria, new cassava varieties included processing-friendly traits preferred by women. In Uganda, sweetpotato varieties included quality traits like mealiness and aroma, important to women. In Mali, gender-intentional sorghum and millet hybrids were released, increasing adoption by women farmers. Several Cases emphasize the value of incorporating gender considerations early in the breeding cycle.

Changes in breeding programs extended beyond variety selection. Many programs revised their target beneficiary definitions, moving away from a generic "farmer" model to more inclusive frameworks that account for intersecting gender and social differences. Breeding objectives expanded beyond yield and disease resistance to include processing and nutritional traits, reflecting diverse user needs. Evaluation criteria evolved to prioritize gender-relevant traits, and participatory methods were refined to ensure equal representation of men and women in varietal selection. Seed dissemination strategies also shifted, incorporating community-based distribution models that empowered women as seed producers and entrepreneurs.

The cases also highlight challenges and areas for further improvement. Gender research requires dedicated funding, yet many programs rely on donations rather than institutional budgets. Ensuring that gender research informs early-stage breeding decisions remains a challenge, as does developing high-throughput screening methods for quality traits. To advance gender-intentional breeding, breeding programs must allocate funds for gender research, incorporate gender experts into breeding teams, and refine participatory methodologies to better capture diverse trait preferences.

An important lesson from the Cases is that gender-responsive breeding is more effective when integrated into a fully client-oriented and demand-led breeding strategy. The cases show how strengthening partnerships with community organizations and fostering transdisciplinary collaboration help to embed gender considerations into breeding efforts, ultimately contributing to greater adoption and agricultural sustainability.

In conclusion, the transition from conventional to gender-intentional breeding within a fully client-oriented approach, represents a significant shift in agricultural research. The experiences documented in these case studies provide valuable lessons for future breeding programs, demonstrating that gender-responsive approaches not only promote equity but also lead to more widely adopted and impactful crop varieties.

Author contributions

JA: Methodology, Writing – review & editing, Validation, Conceptualization, Data curation, Investigation, Writing – original draft, Formal analysis. VP: Writing – review & editing, Investigation, Resources, Formal analysis, Funding acquisition, Methodology, Project administration, Supervision, Conceptualization, Writing – original draft. HT: Formal analysis, Writing – original draft, Conceptualization, Funding acquisition, Supervision, Project administration, Resources, Methodology, Writing – review & editing, Investigation.

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Innovative approaches to integrating gender into conventional maize breeding: lessons from the Seed Production Technology for Africa project

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The integration of gender concerns in crop breeding programs aims to improve the suitability and appeal of new varieties to both women and men, in response to concerns about unequal adoption of improved seed. However, few conventional breeding programs have sought to center social inclusion concerns. This community case study documents efforts to integrate gender into the maize-focused Seed Production Technology for Africa (SPTA) project using innovation history analysis drawing on project documents and the authors' experiences. These efforts included deliberate exploration of potential gendered impacts of project technologies and innovations in the project's approach to variety evaluation, culminating in the use of decentralized on-farm trials using the tricot approach. Through this case study, we illustrate the power of active and respectful collaborations between breeders and social scientists, spurred by donor mandates to address gender and social inclusion. Gender integration in this case was further facilitated by open-minded project leaders and allocation of funding for gender research. SPTA proved to be fertile ground for experimentation and interdisciplinary collaboration around gender and maize breeding, and has provided proof of concept for larger breeding projects seeking to integrate gender considerations.

KEYWORDS

gender, crop breeding, on-farm trials, social inclusion, tricot, citizen science

1. Introduction

Gender integration in breeding programs responds to concerns that men and women are not taking up new crop varieties at equal rates (Orr et al., 2018; Tufan et al., 2018; CGIAR Excellence in Breeding Initiative, 2020). Crop breeding programs may seek to address gender gaps in variety uptake either through gender-responsive breeding or gender-intentional breeding. While the former involves assessing gender-based differences in farmers' needs,

priorities, and constraints, and monitoring and mitigating any negative gendered impacts, the latter may involve deliberately developing varieties that directly benefit women and/or address gender inequalities (Ashby and Polar, 2021).

The gender gap in uptake of improved varieties appears to hold true for maize seed in Africa, as illustrated in comparisons of male- and female-managed plots or male- and female-headed households (Kassa, 2013; Fisher and Kandiwa, 2014; Fisher and Carr, 2015; Fisher et al., 2019). This raises questions about whether maize breeding programs in Africa, which involve national agricultural research and extension organizations (NARES), the private sector, and CGIAR research centers, are adequately responding to the needs and priorities of women farmers (Voss et al., 2021). Much of the vanguard work on gender and breeding has focused on beans, roots, and tubers (Orr et al., 2018; Tufan et al., 2018), while maize breeding programs have arguably lagged behind. This may be linked to the CGIAR Gender and Breeding Initiative's initial priorities; women's outsized role in the production of tuber and legume crops relative to maize, which is more often jointly managed (Voss et al., 2023); and evidence that gender-based differences in maize preferences are less clear than for other crops (Voss et al., 2021).

Despite the high interest in gender integration into major conventional breeding programs such as maize (CGIAR Excellence in Breeding Initiative, 2020; Bill and Melinda Gates Foundation, 2021), this process presents challenges. The pursuit of either gender-responsive or gender-intentional breeding often requires a reordering of priorities and reallocation of resources within breeding institutions, which could have implications for breeding efficiency. It is therefore of critical interest to understand how these reforms can be realized in large, well-established breeding programs.

In the case study that follows, we document the process of gender integration into a centralized maize breeding project in eastern and southern Africa (ESA). For this, we use an innovation history analysis approach (Douthwaite and Ashby, 2005). We draw on the authors' personal experiences and project materials to document an innovative recent project, reflect on success and challenges, and identify lessons learned. We ground this case study in institutional and structuration theories as we examine processes of institutional change as a function of actions and interactions between actors within breeding programs (Barley and Tolbert, 1997). Through this analysis, we document how negotiations between actors within breeding programs can shift scripts, expectations, and behaviors in a way that create space for institutional innovation around gender and breeding.

2. Context

Women's heavy involvement in maize production in Africa and its general importance as a food source underscore the relevance of gender integration in maize breeding. Maize is widely grown as a staple crop in ESA, typically by both men and women, and often for both household consumption and commercial sales. Crop management varies by locale, with men and women independently cultivating maize in some regions with larger farm sizes, e.g., Zimbabwe (Cairns et al., 2021a), and jointly cultivating maize with their spouses in other regions, e.g., Kenya (Voss et al., 2023). In Tanzania and Mozambique, the family as a whole is often involved in land preparation, weeding, harvesting, and threshing of maize, although specific tasks can skew toward women or men depending on the context (Adam et al., 2020a,b).

Studies of maize systems in ESA highlight differences in management and gender gaps in productivity between male- and female-managed plots and male- and female-headed households. In Zimbabwe, significant differences were found in variety choice, use of intercropping, and recycled seed use between men's and women's maize plots (Cairns et al., 2021a). Women's plots in maize-growing regions have also been shown to be less productive than men's (Cairns et al., 2021b). Productivity gaps are generally attributed to men's advantages in accessing and controlling resources, including fertile land (Burke et al., 2018; Burke and Jayne, 2021), fertilizer (Adam et al., 2021), labor and labor-saving technologies (Andersson Djurfeldt et al., 2019), and information about new technologies (Fisher et al., 2019).

Efforts to mainstream gender in maize breeding programs in Africa began in earnest in 2015, when a large project at the International Maize and Wheat Improvement Center (CIMMYT) set out to incorporate gender-preferred traits into the maize breeding pipeline. The breeding team, with minimal training around gender and limited guidance from social scientists and gender researchers (for whom turnover in this period was high), started to routinely solicit gender-disaggregated preferences in on-farm trials to identify traits relevant for women. Collection of preference and adoption data became standard, frequently through gender-disaggregated studies of variety adoption (Fisher et al., 2015, 2019) or participatory varietal selection (PVS). In PVS, breeders and social science collaborators invited women and men farmers to regional varietal trials, which were "on-farm," but for which researchers supplied inputs. Farmers invited to visit these trials typically scored up to 20 varieties on a range of traits, and breeding teams used these data to validate advancement decisions and assess preferences along gender lines (Setimela et al., 2017; Worku et al., 2020). Because trial-hosting farmers often wanted to demonstrate their skills and field agents' priority was to execute successful trials with reliable farmers, this type of on-farm trial was not optimal for allowing a diversity of farmers to individually test and evaluate varieties in their farm environments. Fundamentally, neither PVS nor adoption studies have generated clear or consistent insight into gender-based preferences to guide gender-responsive or -intentional maize breeding (Voss et al., 2021).

3. Details: Seed Production Technology for Africa project

It was in this context that the Seed Production Technology for Africa project (SPTA) launched at CIMMYT in 2016, in follow up to the Improved Maize for African Soils (IMAS) project, with a second phase (SPTA2) funded in 2020. In collaboration with Corteva AgriScience, SPTA evaluated the use of a non-pollen producing maize gene, *Ms44*, to reduce the complexity of hybrid maize seed production by removing the need to detassel female parents in seed production. Hybrids produced using *Ms44* segregate 1:1 for pollen producing and non-pollen producing plants and are thus referred to as 50% non-pollen producing (FNP). This technology offers three key benefits: (1) increased female seed yield because detasseling is unnecessary, (2) improved quality assurance during seed production, and (3) increased yield of FNP hybrids due to reduced tassel growth

and greater partitioning of nitrogen to the ear, increasing nitrogen use efficiency (NUE; Fox et al., 2017).

The SPTA team at CIMMYT was smaller than many breeding projects. The project leader (PL), a male breeder, was highly committed to serving the most vulnerable farmers. In previous work in the private sector, he had engaged superficially with market segmentation research, and was greatly inspired by a CGIAR Gender Platform workshop on farmer typologies and gender (where he reported being one of the few breeders in the room). This engagement motivated him to consider not only standard genotype-by-environment interactions, but genotype-by-environment-by-farmer interactions. He had also been deeply influenced by a colleague's presentation on the gender gap in use of improved maize varieties. Although he had long been familiar with the "gender narrative," the robust and compelling econometric data she shared drove home the relevance of gender. During SPTA's implementation, the PL made it a priority to visit a subset of on-farm trials every year and speak to household members, which further underscored concerns around gender, labor, and resource access.

The primary breeding team also involved two female scientists (one of whom was deeply interested in gender issues) and three male breeders (from CIMMYT and NARES). Two female gender researchers at CIMMYT worked on the project consecutively alongside several male social scientists. These team members regularly exchanged knowledge and ideas informally in monthly project meetings and together worked to center gender concerns.

3.1. Early recognition of potential gendered impacts

The PL, having had some exposure to gender and breeding work, quickly recognized the potential implications of the *Ms44* gene for women and other resource-constrained farmers in Africa. Early research in the United States showed FNP hybrids had a higher yield than their pollen-producing pairs under sub-optimal nitrogen levels, suggesting relevance for low-fertility soils and low-input systems (Fox et al., 2017). The project proposals for SPTA's precursor, IMAS, discussed the genetic technology's anticipated benefits to women and resource-poor farmers but outlined no plans for collection and analysis of gender data, nor did it involve any social scientists.

In 2013, donors to the CGIAR MAIZE Research Program mandated a "gender audit" of the wider breeding program. The resulting report emphasized that while many CIMMYT projects engaged superficially with gender concerns, gender data and analysis were often lacking. The SPTA PL thus advocated for funding for gender research in SPTA, leveraging the gender audit report and the Bill & Melinda Gates Foundation's new mandate that the breeding projects they fund address gender. The SPTA proposal included funding for a gender specialist to collect and analyze gender data on preferences and assess potential social and economic impacts.

At the start of SPTA1, the gender researcher conducted a review underscoring that women in sub-Saharan Africa typically use less fertilizer than men (Adam et al., 2021). This challenge is frequently compounded by women's cultivation of smaller plots (Udry, 1996; Chirwa et al., 2011; Kilic et al., 2013) with lower quality soils (Ndiritu et al., 2014; Burke et al., 2018; Burke and Jayne, 2021). This review led the breeding team to explicitly target women and resource-poor farmers as end-users; the SPTA technology offered the possibility to increase yields on women's fields without the requirement that they increase fertilizer use—which, while desirable, is not always feasible—and increase the return on fertilizer investments. Understanding any gender-based differences in the performance of or preferences for new FNP maize varieties became a priority and led to pronounced shifts in the project's approach to variety evaluations (Figure 1).

3.2. Making variety trials more responsive to farmer realities and gender

A critical first step for SPTA was to validate the yield benefit of the FNP trait in low-input environments in ESA. In the first year of SPTA1, the PL judged that varieties had been adequately validated on-station, so resources for on-station trials were re-allocated to several dozen on-farm trials managed by the breeding team. The first year of data from on-farm testing in Kenya (2016) showed that yield levels in the trials were significantly higher than average for the area. This is a familiar problem in on-farm trials, which have been scrutinized for input and yield levels that are not representative of most smallholders' realities (De Roo et al., 2017; Laajaj et al., 2020). In this case, discussion between project breeders and extension agents revealed that many farmers were treating trials as demonstration plots and prioritizing them with their own fertilizer inputs.

As such, the SPTA team adjusted the on-farm trial protocols to better enable evaluation under reduced inputs levels. In the second

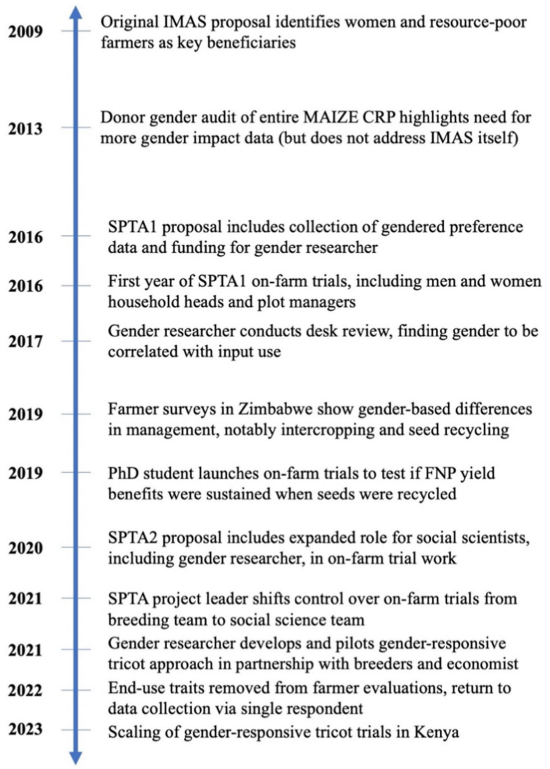

FIGURE 1
Timeline of gender integration into Seed Production Technology for Africa (SPTA) activities.

year of expanded on-farm trials (2017), farmers were given seed and fertilizer specifically to create a dedicated demonstration plot, separate from their trial plot where clear protocols ensured yield levels would be more representative. To satisfy basic gender inclusivity requirements, trials were hosted by both male and female household heads and plot managers. However, some tensions emerged around trials with female plot managers in cases where their husbands did not support the handover of control over trials, likely due to social norms around household headship and decision-making. Attentive members of the breeding team recognized that they had created unintended pressures on the women involved by overlooking household power dynamics. The project team saw this as an important learning opportunity, highlighting the need for more sensitivity to gender dynamics in on-farm trial execution.

These early on-farm assessments of FNP hybrids in large-scale trials showed a yield benefit of 200 kg ha^{-1} across yield levels, translating to a larger proportionate yield increase for farmers with the lowest yields (Collinson et al., 2022). Farmer evaluations in on-farm trials were conducted using gender-disaggregated PVS. These assessments showed acceptance, across genders, of the FNP trait; although farmers noticed differences in tassel and pollen formation between FNP hybrids and conventional hybrids, they favored FNP hybrids overall due to the improved ear size and increased yield (De Groote et al., 2023).

3.3. Revamping the on-farm trial approach

Members of the SPTA team had repeatedly observed that women's management and variety choices appeared to differ meaningfully from men's, despite similarities in *stated* preferences. In 2019, SPTA team members in Zimbabwe conducted a study on gender and maize management in partnership with a male systems agronomist. They found significant gender-based differences in management practices, including wider use of intercropping and recycled seed on female-managed plots and in female-headed households (Cairns et al., 2021a). The study also showed discrepancies between farmers' stated preferences in PVS evaluations and varieties they used at home—especially among women. These findings highlighted, first, that although SPTA's improved on-farm trial design enabled evaluation of FNP hybrids under realistic input levels, the prescription of other management practices might have unintentionally excluded agronomic practices used disproportionately by women. This led the breeding support specialist to advocate for two actions: to study the yield benefit associated with the FNP trait when seeds were recycled, in partnership with a female Ph.D. student, and to explore new approaches to on-farm trials that could enable variety evaluations under farmers' preferred management practices.

Second, the survey indicated that PVS-based evaluations of farmer preferences were not adequate to predict real-world demand for varieties. As the core questions of varietal performance in SPTA had been answered, the PL felt that the central challenge for the project was understanding what farmers would actually purchase. This would require a new approach to on-farm trials that would treat them as real-world testing grounds where resource-poor farmers could more directly evaluate new varieties. The PL believed seed demand was best assessed by economists and other social scientists, so the second phase of SPTA included modest funding for a gender researcher and economists to support research on demand creation. The PL also shifted responsibility for on-farm trials to the social science team with inputs from the breeding team.

The PL, having read about the triadic comparison of technologies ("tricot") approach to on-farm trials (van Etten et al., 2019), worked with the gender researcher and other members of the breeding team to develop a revised trial protocol. Building on previous experiences in participatory variety selection, the tricot approach engages a large number of "citizen scientists" to evaluate technologies under representative crop management conditions chosen by the farmer, using incomplete blocks of three varieties, with digital support throughout the process (van Etten et al., 2020). This approach minimizes researcher control, allows farmers with limited land to participate, and enables participants to test technologies on land they know well and make observations throughout the season. Although trial yields are often lower and more variable when researcher involvement is limited (Kool et al., 2020; Laajaj et al., 2020), the tricot approach allows for a large number of trials to be conducted within a set budget, and can thereby compensate for less robust data (Figure 2).

The SPTA team piloted an on-farm trial methodology following the tricot approach in 2021 with 112 farmers (55% women) in Kenya. This approach enabled farmer evaluations that were grounded in men's and women's personal realities, including their labor contributions, land quality, and input access. The SPTA team provided participating farmers with a set number of maize kernels (200 per variety) and only basic guidance, i.e., to plant trials in the middle of their maize field, away from trees, and ensure relatively consistent growing conditions (e.g., slope and soil type) among subplots. Otherwise, farmers were requested to practice their preferred management, including intercropping, but to apply consistent crop management across subplots. The team collected spacing data from farmers and field agents to estimate yields and genetic gains in lieu of standardizing planting arrangements.

The SPTA team also used the tricot trials to pilot new gender data collection methods. First, recognizing the prevalence of "joint" plot management, the gender researcher pushed for both men and women within households to participate in variety evaluations if both helped manage the trials. The gender researcher and breeding support specialist also advocated for expansion of the farmer evaluations to include processing, cooking, storage, and consumption traits (such as flour yield, flour quality, and taste), given that end-use traits are often a driver of gender-differentiated farmer preferences (Weltzien et al., 2019). CIMMYT breeding programs had not previously evaluated end-use preferences in on-farm maize trials (Figure 3).

Challenges emerged in verifying the managerial roles of different individuals within households and ensuring that the three trial varieties were stored, milled, and cooked separately across over 100 households. The CIMMYT and NARES team implementing the trials had limited capacity to refine approaches and improve data quality while attempting to scale-out the trials. As such, the team chose to abandon end-use trait evaluations after the pilot and narrowed evaluations to one individual per household (understanding end-use traits' importance remained a priority in separate research by the CIMMYT team). In partnership with the 1000FARMS project, SPTA tricot trials expanded to 356 farmers (65% women) in Kenya in 2022, and 1,380 farmers (56% women) in 2023. The team's experiences provided insights that helped other CIMMYT breeding projects adapt the tricot approach in ESA.

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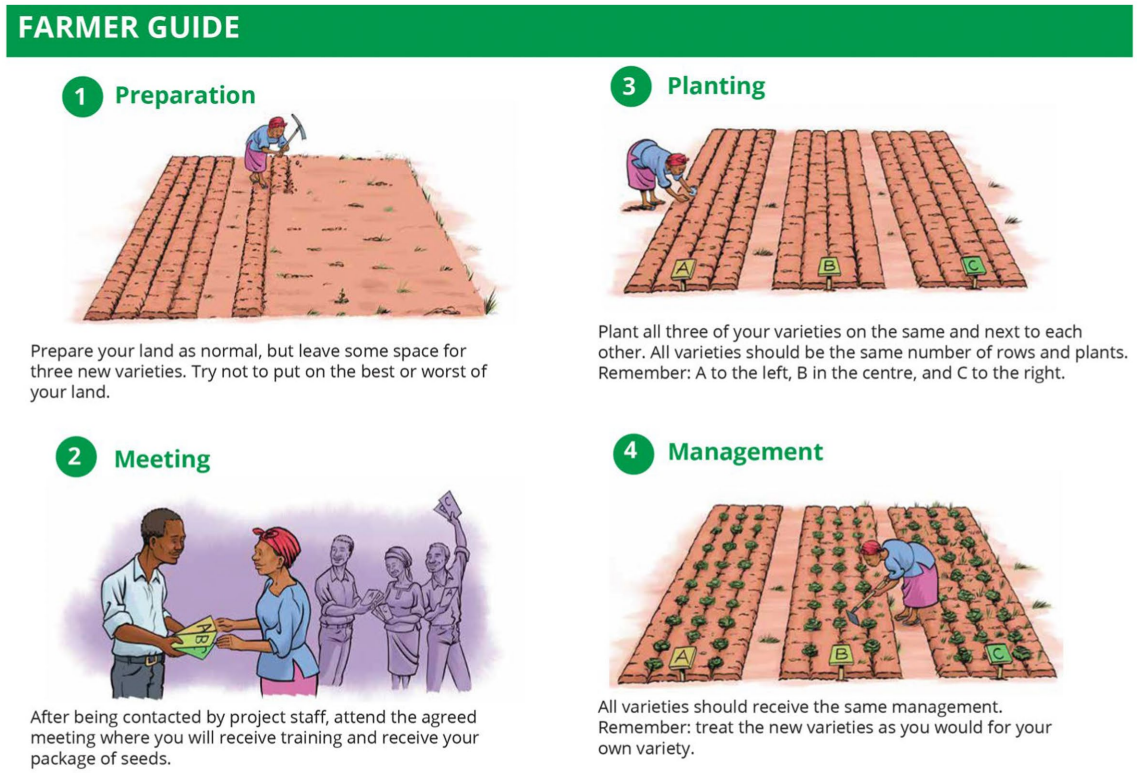

FIGURE 2
Participants in on-farm tricot trials received visual guidance emphasizing that they should practice their preferred management within the trial setup. Image provided by the 1000FARMS and Scaling Tricot projects: https://climmob.net/blog/wiki/graphic-resources/.

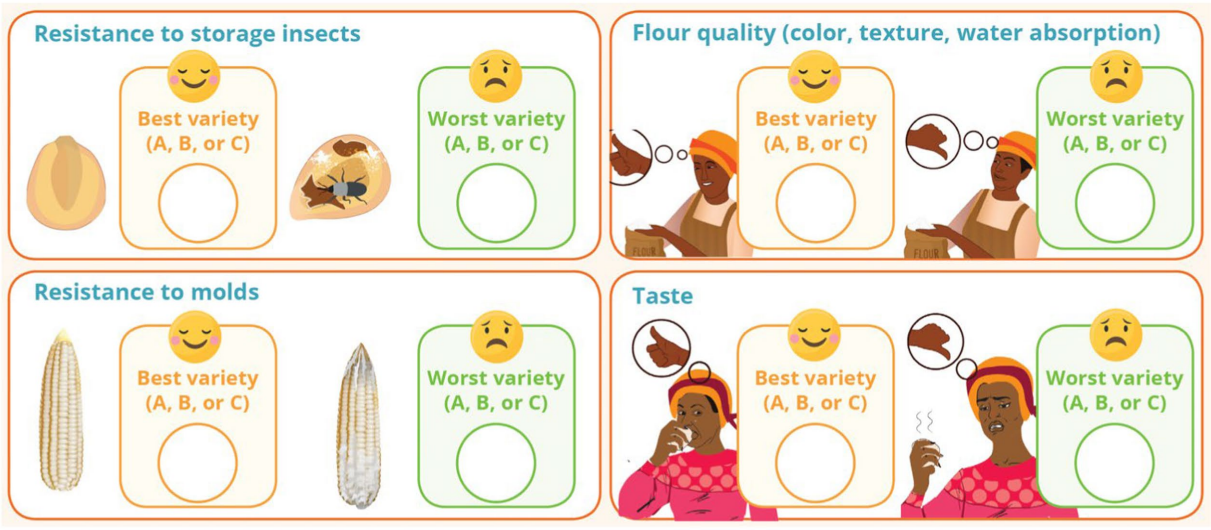

FIGURE 3
Participants in on-farm tricot trials were asked to rank their three varieties on agronomic and end-use traits.

3.4. Role of gender in project activities

The SPTA project is a case in which gender considerations were present from the earliest stages of the project due to the commitment and training of breeding team members. However, collection and analysis of gender data was not included until SPTA1, when a donor mandated inclusion of gender considerations and funding. In SPTA2, the gradual expansion of social scientists' involvement and funding increased the project's attention to gender (Table 1).

TABLE 1 Methods and approaches in the Seed Production Technology for Africa (SPTA) project case.

Breeding activities undertaken	Gender focus in activities
Participatory varietal selection	Specific gender focus
Social science surveys	Specific gender focus
Trait preference studies	Specific gender focus
Mother-baby trials +citizen science	Specific gender focus

The discussion above highlights SPTA's focus on gender through PVS, social science surveys, trait preference studies, and ultimately, trials using a citizen science approach. Social science surveys intentionally sought to uncover variation in management practices and seed choice between male- and female-headed households and male and female plot managers. Both PVS and tricot trials prioritized equal representation of men and women in evaluations. Social scientists and breeders centered gender in trial planning and analysis, working together to refined approaches.

The Seed Production Technology for Africa project's growing gender focus culminated in adoption of the tricot approach. Tricot trials allowed for wider integration of gender considerations and diverse farmer needs, constraints, and preferences in the breeding process, rather than limiting gender assessments to *ex post* studies of technology acceptance. Tricot evaluations allowed farmers to assess varieties in their household and farm context, accounting for gender-related concerns such as labor requirements, end-use traits, and performance on low-fertility land. Although these were clear advantages of the tricot approach, the team also encountered challenges in collecting additional gender data, primarily in overseeing post-harvest storage and use and engaging with multiple respondents within households.

3.5. Changes to breeding processes and practices

Fundamentally, the integration of gender into SPTA's breeding processes generated greater confidence in the FNP trait's appeal. The pilot tricot trials provided experientially-derived gender preference data that showed no major gender-based differences in preferences to necessitate gender-intentional breeding. Rather, these methods enabled gender-responsive breeding—confirming that new FNP varieties do not generate negative gendered impacts and hold appeal under women's and men's real-world production conditions. As expanded tricot trials generate more data, clearer insights around gender-based preferences may emerge. For now, since the FNP trait showed particular promise for farmers with low yield expectations, the trait will be made available in key new stress tolerant hybrids to ensure that diverse farmer preferences do not limit access to or use of the FNP trait.

The Seed Production Technology for Africa project on-farm trial data did highlight wide variation in farmers' management practices, including widespread use of intercropping among both women and men in Kenya (Figure 4). In combination with evidence of variation in farm practices along gender lines (Cairns et al., 2021a), these data validate the wider use of decentralized on-farm testing under farmer management.

Research in SPTA has influenced on-farm testing and advancement decisions within CIMMYT's wider breeding programs, including expanded use of gender-disaggregated data. On-farm trials for product advancement throughout the maize breeding program have shifted to accommodate farmers' preferred management practices. However, the long-term impacts of these changes to the breeding process are yet to be seen. While no varieties developed through SPTA have yet been released, FNP hybrids have entered the varietal release process in Kenya and South Africa.

4. Discussion

A number of "good practices" are evident in this case study, including trainings on gender for breeders; provision of funding for gender research; accounting for gender in identification of end users, breeding objectives, and variety design; and especially, attention to gender in farmer assessments and on-farm trial design. Each of these elements contributed to changing scripts and behaviors within institutions involved in maize breeding.

4.1. Creating space and budget for gender research and interdisciplinarity

The SPTA story drives home, perhaps above all else, the value of productive and respective collaborations across disciplines. In this case, the collaboration was enabled by PLs who embraced social scientists' and gender researchers' contributions and allocated funding to support them beginning in SPTA1. This allowed exploration of gender-relevant topics and testing of new gender-responsive variety evaluation tools.

Unfortunately, an openness to serious gender integration is not universal within breeding teams (Tarjem, 2023). Gender analyses are sometimes perceived to be overly complex, not adequately rigorous, and/or a distraction from the core goals of breeding. In the SPTA case, an understanding of the relevance of gender grew in part from prior trainings and exposure to robust gender data. This led actors to break with traditional institutional scripts about how breeders should interact with social scientists in breeding projects.

Opportunities for gender integration widened with a shift in control over on-farm trials to social scientists, an action that challenged existing behavioral scripts around breeding. Such shifts in dynamics can generate tension, but in SPTA, open collaboration between social scientists and the breeding team enabled the joint design of gender-responsive on-farm trials. The breeding team and social science teams each welcomed the knowledge and experience of the other, while the small size of the team enabled closer collaboration than is feasible in many larger scale projects. Furthermore, the PL and breeding program director added explicit mention of gender research to the job description for the female CIMMYT scientist on the project breeding team, empowering her to more actively and intentionally pursue these topics within her scope of work.

4.2. Accounting for gender in identification of end-users and market segments

The Improved Maize for African Soils and SPTA projects emerged from a specific desire to increase maize yields under low-input conditions. Even in the earliest project proposals, women and other resource-constrained farmers were identified as potential target

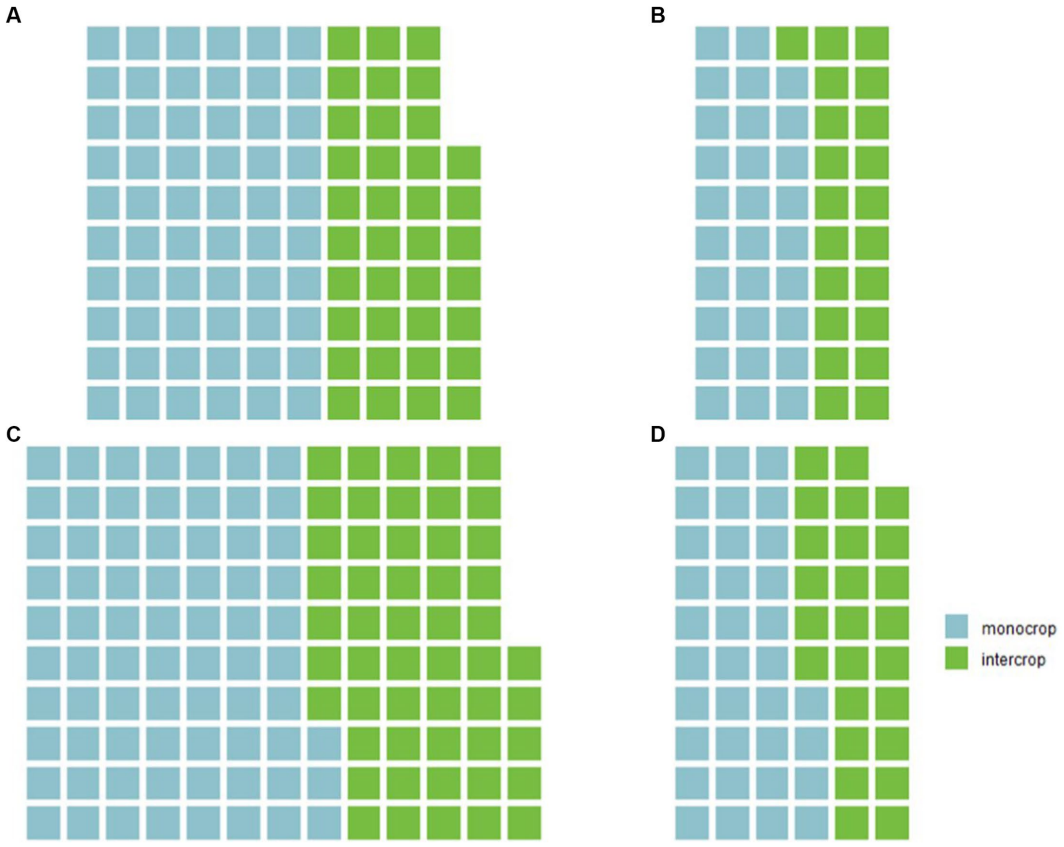

FIGURE 4
The number of **(A)** women farmers in Embu, **(B)** men in Embu, **(C)** women in Kiriyanga, and **(D)** men in Kiriyanga using monocropping and intercropping illustrate the diversity of farmer management in 2022 tricot trials in Kenya.

demographics, and the SPTA PI's dedication to serving the most vulnerable market segments strengthened this focus. After an early donor gender audit identified the need for added attention to gendered project impacts, project leaders increased the focus on farmer assessments and expanded research questions to include those relevant specifically to women (e.g., impacts of the FNP trait on seed recycling).

4.3. Accounting for gender in breeding objectives

From the earliest stages of the project, breeding varieties for performance under low-input conditions was a priority—initially through on-station trials and later through on-farm trials. In breeding, on-station trials are critical to ensuring high repeatability while allowing many varieties to be screened together. The focus of SPTA trials was to confirm performance and acceptance of the trait within the target population of environments (TPE), and later to engage farmers as citizen scientists. The breeding team actively took up recommendations of the donor gender audit, engaging gender specialists and other researchers to explore differences in management and resource constraints. This allowed for refinement of on-farm testing protocols, culminating in a design geared specifically toward understanding performance under diverse management practices and capturing farmer preferences in their personal household context.

4.4. Accounting for gender in variety design decisions

Gender integration in SPTA was not focused on breeding separate varieties for women and men, but rather on validating the gender-responsiveness and utility of the FNP trait for resource-poor farmers. Recognizing that men and women may seek a range of maize varieties for various reasons, the breeding team prioritized inclusion of the FNP trait into key female lines developed for stress prone environments. Men and women farmers were then allowed to evaluate FNP hybrids on their own farms to ensure their other variety needs and priorities were met. However, without clear indications of differing preferences, there are no signs that varieties specifically targeted at women are necessary.

4.5. Accounting for gender in on-farm trial design

A key innovation in the SPTA project was partnership between the breeding and social science teams in developing gender-responsive

on-farm testing methods. These approaches ensured, initially, that centralized on-farm trials were representative of management by women and resource-poor farmers. Later, on-farm trials were redesigned to be decentralized, inclusive, participatory, and reflective of diverse farmer management. In that sense, SPTA stepped beyond the gendered trait and variety assessments typically used to assess variety acceptance in breeding programs (e.g., passive PVS). Increased participation of men and women farmers in the SPTA breeding process turned farmers from relatively passive recipients of new technologies into active developers of those technologies; citizen science approaches allowed for farmer evaluation of varieties in their real-world context. These changes also increased the breeding team's confidence that FNP varieties respond to women's needs and priorities.

4.6. Accounting for gender in farmer evaluations

Recognizing the potential benefits of the SPTA technology to women, SPTA prioritized equitable participation of men and women as on-farm trial hosts and in PVS, yielding over 50% participation by women and included many resource-poor farmers. Although the social science team piloted inclusion of gender-relevant end-use traits in tricot evaluations, these assessments proved too challenging to manage at scale with available capacity; other projects have found success in more structured consumer testing via home preparation using a tricot approach (Moyo et al., 2021). Still, given the participation by a diversity of farmers, the project breeding team gained increased confidence about the performance and appeal of FNP varieties under realistic farmer management conditions, including women's unique management practices.

4.7. Lessons learned and case study limitations

Central to gender integration in this project was greater involvement of social scientists, including gender researchers, in on-farm trial design and management. The handover of on-farm trials to the social science team was unprecedented within maize breeding programs. There are many reasons why breeders might be reluctant to relinquish control over trials, including a desire to standardize approaches across projects, concern that social science teams and farmers lack the experience or technical knowledge to implement effective on-farm trials, or reticence to reform a system that has functioned adequately for decades in developing improved germplasm. Territoriality between breeders and social scientists may be worsened by programmatic divisions within research institutes; in this case, gender research fell under the purview of a program that is separate from the breeding program.

Another challenge in shifting control over on-farm trials involved trade-offs between researcher-managed trials and citizen science approaches. On-farm trials in breeding programs must provide evidence that new varieties perform in the TPE. Researcher-managed trials may provide more internally valid varietal comparison data to guide breeders' advancement decisions, although this has been questioned (Kool et al., 2020). Citizen science approaches generate more realistic performance data and have higher external validity—a growing priority for donors, breeders, and social scientists working to understand adoption. Generating robust data requires either highly standardized on-farm protocols or extensive and resource-intensive on-farm trial networks (e.g., tricot trials). Although the decentralized on-farm trial approach in SPTA has proved useful for validating FNP varieties, including gender-responsiveness, these data have not yet been used in maize variety release decisions in ESA, which still rely on national performance trials.

The tricot approach has also introduced new challenges for NARES field staff who have typically implemented researcher-managed on-farm trials. Tricot trials are often more complicated to oversee than standardized trials because they hand over management to smaller-scale, resource-poor farmers without experience hosting trials. Indeed, some data quality concerns persisted in SPTA's on-farm trials, but the project team was actively developing and implementing methods to improve data quality (e.g., use of multiple tiers of supervision, spot-checking, and distribution of visually detailed instruction booklets, variety scorecards, and storage bags). Transitioning on-farm trials to more participatory approaches requires capacity building and collaborative design processes that balance these trade-offs and acknowledge required changes to institutional scripts.

The heightened involvement of social scientists in SPTA required breeding team members to make space (including financially) for collaborators to conduct research and implement changes. In this case, this was enabled by specific actors, including the SPTA's PL—someone deeply committed to serving the most vulnerable farmers and trained to think about farmer heterogeneity. He felt that social scientists rather than breeders were those best trained to assess seed demand and sought to strengthen their role in the project, in a departure from existing institutional scripts around breeding. Other project team members, two of whom were women, and one of whom was independently interested in gender integration, also embraced greater engagement with social scientists. It is worth noting that the PL's interest in gender emerged from voluntary participation in trainings and a colleague's presentation of robust, quantitative gender data, which captured his attention in ways that other gender discussions never had. This is an excellent example of a social scientist researcher using compelling quantitative data to speak persuasively to collaborators in the biophysical sciences, illustrating the importance of the type and quality of gender data that gender researchers produce and share with breeder colleagues.

Breeding projects seeking to achieve similar gender integration can take several lessons from this case. This includes the value of seeking out allies in breeding and social science teams who are willing to collaborate, test innovative approaches, and critically examine entrenched behavioral scripts in breeding institutions. Identifying such allies is not always easy, and building institutional capacity for and commitment to interdisciplinarity is critical. This includes, for example, ensuring that breeders are regularly exposed to accessible, carefully thought-through trainings related to gender and farmer behavior, and that social scientists in crop research institutes have adequate understanding of breeders' data needs and decision-making processes. In the world of crop improvement, such collaboration and interdisciplinarity is not always rewarded. Social scientists are often pressured to generate meaningful independent research in their fields, so collaborations with breeders may not advance their careers. Breeders' success, meanwhile, is measured in reference to trials with

adequate heritability, which means trials' internal validity is paramount while reaching under-served populations may go unrewarded. These incentive structures must be examined to ensure that breeders' and social scientists' shared goal of effective product development is prioritized. As seen in this case, breeders' active partnership with social scientists in on-farm trials may increase confidence in collaboration and trust across project teams.

Finally, the SPTA case highlights the value in starting small. This was a limited project within a larger breeding portfolio where a close team could build productive partnerships. By first collaborating to pilot and develop proof of concept for new models, the team began reforming long-standing practices. Ultimately, the project team's willingness to collaborate generated important proof of concept, know-how, and protocols that have helped shift how on-farm trials in other maize breeding projects, all of which are managed by breeding teams, are designed. Shifting the institutional scripts governing gender and breeding is a sea change and will not happen overnight, but the actions and interactions of a dedicated group of multidisciplinary collaborators may start the process.

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.

Author contributions

RV: Conceptualization, Funding acquisition, Investigation, Writing – original draft, Writing – review & editing. JC: Conceptualization, Funding acquisition, Investigation, Project Conceptualization, Funding acquisition, Project administration, Supervision, Writing – review & editing. FM: Investigation, Writing – original draft, Writing – review & editing. GM: Investigation, Writing – review & editing, Data curation. EH: Investigation, Writing – review & editing, Data curation. DL: Investigation, Writing – review & editing. KM: Investigation, Writing – review & editing. SC: Investigation, Writing – review & editing, Funding acquisition. SW: Investigation, Writing – review & editing. VW: Investigation, Writing – review & editing.

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Conflict of interest

SC is an employee of Corteva Agriscience. Corteva Agriscience owns the rights to genetic technology described in this case. There are no competing interests as Corteva Agriscience is providing the technology royalty-free to licensed seed companies producing seed for smallholders in the region under the terms of the Seed Production Technology for Africa agreement (https://www.cimmyt.org/content/uploads/2019/03/CIMMYT-SPTA-project-brief-2020-07-web.pdf).

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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Transforming food systems: a gendered perspective on local agricultural innovation in Cuba

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Compared to many countries, Cuba has made significant progress in advancing women's rights and gender equity; however, disparities remain. In the country's rural communities and agricultural sector, women continue to face barriers to equal participation and recognition for the value of their work. This case study shares the story of gender equity efforts that have been conducted within the framework of a broader development project—the Project to Strengthen a System of Innovation in Local Agricultural Development (PIAL, for its initials in Spanish). PIAL began in 2001 as a participatory plant-breeding initiative aimed at increasing the genetic diversity of key crops such as maize and beans. Over the course of two decades, the project's goals expanded to include an emphasis on increasing women's participation. In the beginning, those efforts focused on including women in the participatory plant-breeding activities, which enabled them to prioritize traits they cared about such as grain texture, cooking speed, and taste in the selection process. Over time, the participatory nature of the PIAL methodology empowered women to identify and pursue capacity-building in other areas of local agricultural innovation. While PPB remained central to PIAL, women also chose to pursue opportunities in seed bank management, leadership training, and small-scale farm-based entrepreneurship. The results of the PIAL work on gender have included not just more inclusive plant breeding, but also important economic improvements for rural women as they have been able to diversify their livelihoods, and social change as they have gained confidence and recognition as leaders in their households, communities, and beyond.

KEYWORDS

participatory plant-breeding, gender, Cuba, local agricultural innovation, community development

1. Introduction

Compared to many nations in the Global South, Cuba is characterized by relatively high levels of women's participation across a range of activities. Policies and attitudes have helped advance gender equity in the economic sphere and with respect to domestic and care responsibilities. Still, inequities remain, as patriarchal cultural norms and structures are deeply rooted and continue to exert problematic influences, particularly for women (Bock and Shorthall, 2017). In the agricultural sector, significant gaps in gender equity continue to exist, and must be addressed in favor of women, who have been historically disadvantaged. For example, many women would benefit from training and capacity-building in productive

activities, including crop and variety characteristics, management practices, and post-harvest conservation (Munster, 2017).

Given existing gender disparities in the country's agricultural sector (Cárdenas et al., 2017), it was necessary to establish gender policies that focused on equitable relations between women and men. The National Institute of Agricultural Sciences (INCA, for its initials in Spanish) and the Project to Strengthen a System of Innovation in Local Agricultural Development (PIAL, for its initials in Spanish) implemented a gender mainstreaming strategy with the aim of offering new opportunities for women's development that could serve as a tool to implement and evaluate a gendered approach in Cuban agricultural contexts (United Nations Development Program, 2019). The work to address gender within PIAL began with efforts to include women in participatory plant-breeding; however, over time, women identified their own priorities, and the scope of activities expanded into many other areas of agricultural innovation and sustainable community development.

Throughout the process, there was an emphasis on both individual change and collective action, creating space for radical changes in social thinking along with a transformation in social structures (Benítez et al., 2012). This case study report shares the story of how gender was mainstreamed into the PIAL framework, what activities and methods were employed, what key impacts were achieved, and what lessons were learned.

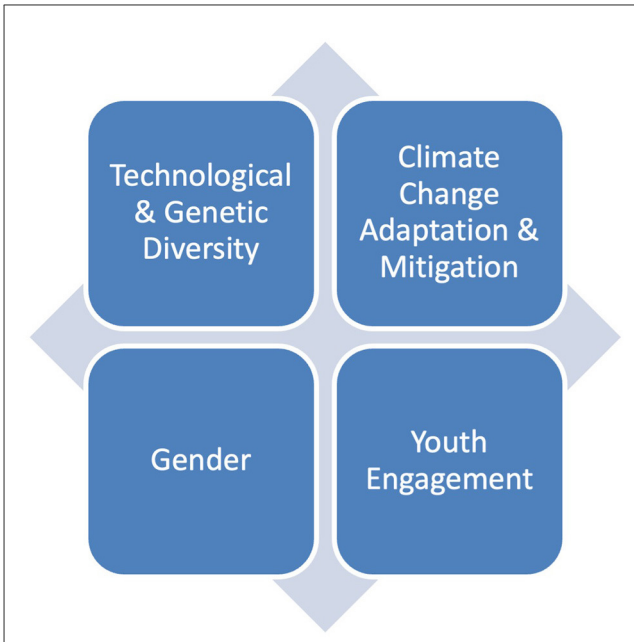

FIGURE 1
Four cross-cutting axes of PIAL in its later phases.

2. PIAL and it's evolving gender strategy

2.1. Phase 1 (2001–2006)

In 2001, INCA developed a Participatory Plant Breeding (PPB) project that aimed to take the important genetic resources located within the institute and place them in the hands of farmers throughout the country. With support from several research centers and national and international funders, that project continued for more than 20 years as researchers, farmers, and other stakeholders employed a Participatory Action methodology to increase the diversity and availability of various crops (mainly grains) on Cuban farms, household gardens, and other plots of land in 75 municipalities across 12 provinces (see Figure 1).

The primary mechanism driving this diversification has been *Ferias de Diversidad* (Diversity Fairs), wherein farmers grow multiple varieties on their farms and invite others to see the results and select their preferred seeds. These Fairs were important as many Cuban farmers were not connected to formal seed improvement programs run by research centers such as INCA and thus did not have ready access to improved varieties (Ortíz et al., 2015). Through the Diversity Fair system, varieties that had been developed by INCA plant breeders were shared with farmers to be grown out on their farms and further adapted and improved. To date, more than 680 such Fairs have been hosted by PIAL. The objective of this work is to ensure that a diversity of species and varieties of economic importance to the country are available to Cuban farmers. Project results quickly showed that the participatory approach led to an increase in both yields and genetic diversity on the farm and to significant social recognition for farmers when they selected their own varieties and shared them via the Fairs (Benítez et al., 2012).

The starting point for the varietal selections that took place via the Diversity Fairs was improved varieties that had been developed by plant breeders at INCA. These breeders manage research programs designed to improve varieties of interest to the Ministry of Agriculture and of importance to the country for economic and food security reasons. PIAL facilitated enhanced collaboration between these institution-based breeders and Cuban farmers. As the project advanced, improved varieties developed through INCA's breeding programs were introduced into the Diversity Fairs to gauge their acceptance by Cuban farmers and to enable those farmers to continue their farm-based breeding efforts, sharing results back to INCA. This reciprocal collaboration helped ensure that breeding efforts better reflect the diversity of climate and agricultural contexts across Cuba and farmer preferences and priorities. Notable plant breeding successes have included the development by INCA breeders of the Odile bean variety (among others), the Felo maize variety (among others), and multiple varieties of rice, soybean, and tomato (see Acosta et al., 2007; Ortiz et al., 2007; Cárdenas et al., 2021; Escalona et al., 2023). In two cases, farmers engaged in PPB through PIAL developed their own maize varieties, crossing varieties that had been shared with them through Diversity Fairs by INCA breeders.

Although women did participate in Diversity Fairs in the project's first years, their engagement in varietal selection was minimal; rather, they tended to play secondary roles, such as preparing meals and supporting event organization and logistics. Research by Verde et al. (2003) found this was largely due to ongoing gendered divisions of labor, wherein women's role in "productive" activities (including plant breeding) was subordinated to their role in "reproductive" activities (primarily related to the

family and household), and their decision-making power relative to their male counterparts was limited. This is consistent with research demonstrating that, around the world, women's role in agricultural production is frequently under-recognized and undervalued (see Bock and Shorthall, 2017; Moyles, 2018; Bezner Kerr et al., 2019) and they are often excluded from agricultural research and development efforts (Bezner Kerr, 2017).

The study by Verde et al. (2003) underscored anecdotal awareness amongst project leaders that women's participation in the Diversity Fairs could and should be enhanced. As this awareness was growing, breeding efforts were also evolving. Whereas, initially the focus was almost exclusively on on rice (the production of which tended to be male dominated), the Diversity Fairs began to include beans, and then—in response to demand by participating producers—other grains such as corn, soybeans, and chickpeas, along with high-value crops such as vegetables and tubers, flowers, and ornamental plants. As this wider array of crops became integrated into the PIAL breeding activities, women's engagement in the Fairs became more active. The increasing involvement of women that occurred during this time was supported by project researchers and technicians—along with municipal, Ministry of Agriculture, and Communist Party of Cuba officials—who actively tried to recruit women into breeding and selection activities, receiving financial support from the Swiss Agency for Development and Cooperation (COSUDE) for those efforts.

A key component of women's integration into breeding activities was to ensure that varietal selection did not just take place in the fields but also through tasting dishes prepared using different varieties. This enabled attentiveness to traits that were of special importance to women, such as cooking quality and taste. As women became more involved in the breeding, these traits began to be considered, along with more traditional indicators such as yield and pest resistance, by plant breeders and technicians connected to the project. During this time, women also began to collect genetic material and refrigerate it in their homes to preserve and multiply it. These storage efforts gradually expanded in scale and evolved into more formalized Local Seed Banks, which will be discussed in more detail below as women have played a defining role in their operation. Through their inclusion in Diversity Fairs and breeding activities as well as the seed storage efforts, by the end of Phase 1 of the project, women's participation had increased, although gender considerations had not yet been centered in the work.

2.2. Phase 2 (2007–2011)

As the PIAL project entered its second phase, a series of Gender Pilot Projects were initiated in four provinces (Pinar del Río, Havana, Villa Clara, and Holguín). These pilot projects sought to increase women's involvement in and capacity for agricultural activities, particularly those related to crop diversification and varietal selection, but also across a range of other areas identified by the women themselves (e.g., poultry management, and food preservation). More broadly, they aspired to empower rural women and transform their realities, and those of their families, facilitating attitudinal and material shifts in women's household and community roles (Benítez et al., 2020).

Women from each province were chosen and trained to serve as *referentes de género* (gender representatives) at the municipal, provincial, and national scales. These women—farmers, researchers, and other specialists—took part in intensive gender training emphasizing sensitization to gender focal points, empowerment, leadership, and women as agents of change. The methodologies employed for that work included Gender-Focused Participatory Diagnostics (see below for more detail) and Gender Indicator Development. The Gender Pilot Projects proved successful at enhancing women's engagement with PIAL. Building upon that success, in 2011, gender mainstreaming was formally identified as an essential cross-cutting axis for the PIAL project.

2.3. Phases 3 (2012–2016) and 4 (2017–2022)

During the latter phases of PIAL, gender became increasingly central, as exemplified in its identification as one of four foundational axes for the project, along with technological and genetic diversity, climate change adaptation and mitigation, and youth engagement (Romero et al., 2018). The explicit recognition of the synergies across these axes ensured that activities would jointly take into consideration making progress toward gender equity while also increasing the diversity of seed varieties, for example, by ongoing attention to women's active participation in seed-breeding, saving, and sharing processes.

Specific actions that supported attentiveness to gender included: dedicated funding for gender-focused project activities; inviting the person responsible for coordinating gender work to join the PIAL National Coordinating Group; permanently incorporating gender-focused research and training into the project framework; and developing new programming based on priorities identified by women. Some elements of the PIAL methodology in its later phases that illustrate the connectivity between gender and technological and genetic diversity include (see Benítez et al., 2020 for further detail):

1. **Gender-focused participatory diagnostics**. These will be discussed in more detail below.
2. **Capacity-building exchange workshops**. Women, youth, and men from the 10 provinces where PIAL actively participated in these workshops, which employed a social learning approach to foster new knowledge and skills in areas participants themselves identified as priorities. This included more traditional activities related to agricultural innovation, diversity, and sustainability, along with gender-specific topics such as hegemonic masculinities, self-esteem, and gender-based violence.
3. **Women-led Local Agricultural Innovation Groups**. These farmer-led groups (GIALs, for the initials in Spanish) are dedicated to on-farm experimentation and trials to develop and refine agricultural innovations, including but not limited to PPB. While women, youth, and men can lead a GIAL, since the implementation of the PIAL gender strategy, groups have increasingly been led by women, thereby ensuring women's agricultural research questions and innovation ideas are addressed.

4. **Micro-grants**. These competitive grants were awarded to PIAL participants for initiatives they proposed related to developing and/or sharing agricultural innovations and good practices. More than half of these grants went to women participants.
5. **Provincial, national, and international exchange visits**. The spaces created at multiple scales for exchange amongst women, men, and youth enable participants to gain valuable leadership experience as knowledge-sharers and capacity-builders. They also served as the basis for achieving greater crop diversification as information about multiple crops and newly developed varieties could be shared more widely amongst producers, decision-makers, and research technicians. All this brought with it an increase in diversity on farms, which resulted in a better quality of life for families (for more detail, see Benítez et al., 2020).
6. **Strategic Planning with a Gender Approach**. The project offered courses in strategic planning, which served as a vehicle for women and men to build strategic plans for strengthening economic initiatives related to, for example, crop production, food preservation, animal husbandry, orchard management, small and large livestock rearing, feedstock production, and flower and ornamental plant production. Project personnel made a concerted effort to include women in these courses, and gender parity across all participants was very nearly achieved.
7. **Multi-actor management platforms**. As PIAL began to focus on institutionalizing its processes, these platforms were developed to foster connectivity between the project and strategic institutional allies such as the National Association of Small Farmers (ANAP), the Federation of Cuban Women (FMC), the Ministry of Agriculture (MINAG), the Communist Party of Cuba (PCC), and a variety of research Institutes, universities, local governments, and local development projects.

3. Analysis: evolution of PIAL gender and participatory plant breeding efforts

3.1. Implementing gender-focused participatory diagnostics

An essential component that highlights how PIAL synergistically developed its gender-focused and PPB work is the implementation of Gender-Focused Participatory Diagnostics (DPEG, for its initials in Spanish) (Aguilar et al., 1999). This methodology aimed to simultaneously improve gender equity and strengthen local agricultural systems in communities where PIAL was active.

The implementation of DPEG as a core part of PIAL was, in part, a direct response to anecdotal recognition on the part of project technicians and specialists that women's participation in PPB processes had been relatively low. This inequitable participation represented a limitation for the project and was contrary to its goals of facilitating participatory processes and knowledge dialogues grounded in horizontal relationships amongst so-called "experts" and producers in rural communities. In striving for broad-based, horizontal participation, knowledge-sharing, and dialogue, it was clear that more rural women needed to be engaging with PPB processes. Conducting systematic gender-based diagnostics in a participatory manner was an important step toward achieving that goal.

A suite of gender analysis tools was introduced into PIAL through collaboration with researchers and specialists from various institutions (universities, research centers, Ministry of Agriculture centers), who were supported by training from an international expert in the field. Specific personnel charged with carrying out the gender analyses were elected by provincial project coordination teams. The tools included activities designed to identify, explore, and assess a wide range of gendered issues in farming communities, including gender roles, socio-economic and cultural positioning and condition of women and men, people's interests, priorities, aspirations, and needs, gaps in gender equity, access and control of resources, participation in family and farming (and other productive) decision-making, and engagement with formal and informal community organizations.

These activities were carried out using a combination of methods, such as participatory workshops, farm visits, and semi-structured interviews. Participants included female and male farmers, along with cooperative leaders, representatives of organizations such as the Federation of Cuban Women (FMC) and National Association of Small Farmers (ANAP), agricultural officials, and other rural and agricultural stakeholders. Importantly, the work was supported by the FMC, along with ANAP and governments, at multiple scales. It was guided by a "Gender and Development" approach, with the aim of analyzing power relations and supporting equitable redistributions of resources and power, in recognition of the theoretical and material importance of women's inclusion in global processes of economic, political, and social change (Romero and Ortiz, 2017). Initial DPEG results demonstrated the relatively disadvantageous situation of women in Cuban agricultural contexts.

3.2. Transforming women's role in Diversity Fairs

As mentioned above, Diversity Fairs are a central component of PIAL and serve as the fundamental method for the participatory selection of varieties of rice, bean, chickpea, soybean, tomato, cover crops, and other species. The DPEG work helped systematize and clarify some of the contributing factors that constrained women's participation in these Fairs during the project's first phase and point the way toward how their engagement might be enhanced.

The explicit incorporation of a gender approach in the project, beginning in 2007, was linked to a notable transition with respect to women's engagement in the Diversity Fairs. Not only did more women begin to participate, but the quality of their participation changed from playing a more passive role (e.g., meal preparation and other hosting and/or organizational activities) to engaging more directly and acting as participants in the PPB activities associated with the Fairs. Women's role in selecting preferred

varieties proved important, as they brought new perspectives to the process, for example, prioritizing traits such as cooking quality, texture, and grain size and color, which had previously been overlooked as men focused on characteristics such as yields, and susceptibility to pests and disease.

The evolution of women's role in the Diversity Fairs speaks to the effectiveness of the DPEG efforts and the increasing emphasis placed on gender within PIAL, as the diagnostics and follow-up activities built awareness and capacity that favored women's active participation in PPB. Enhanced women's participation, in turn, ensured that the new varieties developed through PIAL would embody traits prioritized by women as well as men. It also contributed to women's self-esteem and facilitated their empowerment in multiple arenas beyond just the PPB work.

The transformation of women's engagement in the PIAL Diversity Fairs from relatively passive agents who fundamentally performed traditional reproductive roles to active agents of agricultural development and innovation offers an important illustration of women's capacity to act as agents of change in their communities. The gradual process of achieving this transformation was supported by the implementation of new forms of learning-in-action and the creation of new inter-institutional and human capacities to manage innovative processes, which are all essential to stimulate selection, maintenance, and dissemination of plant diversity (UNESCO, 2014).

3.3. Creating and consolidating local seed banks and local seed certification

At the same time, as a diversity of grain seeds, developed via PPB, was being introduced and disseminated in 45 municipalities across 10 provinces of the country, work was also being done to create the first PIAL Local Seed Banks. Because gender had already become a project consideration when the seed banks were initiated, there was attentiveness from the beginning to achieving equitable participation of women and men, with many women taking on leadership positions and working on selecting seeds to be stored.

Building upon early successes with seed bank development, in 2013, PIAL began to use "learning-in-action" cycles, wherein project personnel would work with community members to identify "bottlenecks" constraining development and innovation and collectively develop and implement strategies to address them. Like all PIAL work at the time, there was attention to gender as part of the process. In the first cycle, there was a strong emphasis on Seed Safety Diagnostics. In three municipalities representing the eastern, central, and western regions of the country (Bahía Honda, Manicaragua, and Gibara), a survey was conducted to identify gendered actions related to women's role in managing grain seed diversity and other locally important species. Results pointed to low participation of women as heads of farms, leading to calls to emphasize the role of women in the development of agricultural production systems, including production, processing, and marketing.

In 2016, a second learning-in-action cycle began, this time emphasizing production and local seed certification in 10 municipalities. This helped to consolidate and strengthen the Local Seed Banks, and the work on seed banks, seed safety, and local seed certification was expanded into all 75 municipalities where PIAL was active. At that time, the first Local Seed Certification Committees were created. Unlike the early days of the Diversity Fairs, women played active roles—including taking on leadership positions—in these committees from their inception, often serving as custodians of the Local Seed Banks, and were highly engaged in related activities.

The seed-focused learning-in-action work received significant support from the NGO USC Canada (currently SeedChange). There was also the active participation of the National Association of Small Farmers (ANAP), the Ministry of Agriculture (MINAG), the Ministry of Higher Education (MES), the Cuban Association of Agricultural and Forestry Technicians (ACTAF), and the Ministry of Science and Environment (CITMA). Importantly, this seed work was done in conjunction with the DPEG methodology described above. As such, there was ongoing attentiveness throughout the learning-in-action cycles to identifying, exploring, and assessing gendered roles, relationships, and power dynamics, and to working consciously toward gender equity in the activities.

3.4. Influencing public policy

As it evolved, PIAL explicitly sought, and secured, significant support from local governments. Buy-in from these authorities was important as local governments are responsible for local development within their municipalities. By forming strong alliances with these state bodies, social transformation processes were facilitated, wherein women played a key role in defining policies and processes, generating changes in favor of more equitable participation, empowerment, social recognition, improvement of self-esteem, and the generation of new opportunities for women and men in agricultural contexts. Integration of PIAL into local government structures also enabled good practices developed across the various axes of the project, including gender and technological and genetic diversity, to be institutionalized. One example of such institutionalization is that knowledge and methodologies generated through PIAL were incorporated into a research center and university curricula.

In addition to working with local governments, PIAL exerted policy influence at a national scale. For example, personnel from the project's national coordinating group worked in close collaboration with the Ministry of Agriculture and Federation of Cuban Women to develop a national equity strategy in the spheres of innovation and governance. This proved useful when the country had to respond to the COVID-19 pandemic. Part of the pandemic response involved boosting food production, and the equity strategy ensured that women and men from rural and urban areas were included in planning those efforts. A cornerstone of that work was the active promotion of family farming in patios and small plots to produce vegetables, medicinal plants, and herbs. Here, again, women played an important leadership role in producing fresh and safe food that positively impacted communities in a crisis.

PIAL also played a role in supporting Cuba's broader (and well-known) policies related to the promotion of urban and peri-urban agriculture, particularly by bringing its gender emphasis to the Urban, Suburban, and Family Agriculture (AUSUF) Movement. PIAL personnel and other researchers and technicians from the country's National Institute of Agricultural Sciences, worked to increase and diversify vegetable production in urban and peri-urban patios and plots across three provinces. This work was done using the same participatory, gender-focused approach that had been introduced through PIAL in close coordination with local governments and Popular Councils. The use of that methodology saw women's participation in the urban and peri-urban agriculture efforts in those three provinces increase to 35%. The work also incorporated PIAL expertise regarding seed conservation and handling, the use of bioproducts, and other agroecological methods; thus, there were capacity-building efforts to ensure the food being produced would be safe.

4. Overview of key impacts

4.1. Economic and productive results

The joint work of researchers, specialists, and technicians, accompanied by the National Association of Small Farmers, the Federation of Cuban Women, decision-makers from local governments, peasant organizations, and others, allowed the introduction of diverse technologies in farming communities across the country. More than 100 unique income-generating initiatives were strengthened in the twelve provinces where PIAL was active, 35% of which were led by women participants in agricultural innovation processes. Some of these activities were directly related to PPB, as the new varieties that were developed created economic opportunities for women and men; however, people pursued other initiatives as well based on their own preferences and priorities, including sales of flower arrangements, preserves, dairy products, and artisanal crafts (which often incorporated seeds).

Although not all income-generating projects were *directly* tied to PPB, there was a strong link between people's ability to develop new economic opportunities and the increasing species and varietal diversity on their farms that was facilitated by the PPB process. Indeed, project evaluations demonstrated that, prior to engaging with PIAL, farming families typically had very low levels of species and varietal diversity in their agroecosystems. The diversification process enabled women and men to begin to see a wide range of new economic possibilities that they could pursue according to their individual interests. PIAL also supported these endeavors as the Diversity Fairs and later introduced Innovation Festivals and Local Seed Banks (in which women played a fundamental role), which became important sites for micro-industry development, as new entrepreneurs could exchange products and ideas and provide motivation and support to each other.

The income generated through PIAL activities significantly affected participants' economic well-being. For example, the research found that women engaging in PIAL-related income-generation projects earned an average of 500 Cuban pesos (CUP) over and above their regular monthly salary. In some cases, that amounted to almost doubling their income. Notably, at the same time, food costs were typically reduced as more diversified farming systems reduced dependency on food purchasing.

4.2. Sociocultural impacts: changing subjectivities

While the economic impacts for women engaged in PIAL activities were important, the sociocultural changes sparked by the project were equally if not more meaningful. These changes in attitudes, behaviors, and perceptions occurred for both women and men and could be identified at the individual, family, and community scales. Women saw significant increases in their self-esteem as a result of their active participation and leadership in PIAL, and they also gained greater socio-economic independence. This translated into meaningful changes in the roles they played in their family units and the quality of the relationships within and beyond those units. Men also experienced changes in their perceptions related to productive and reproductive roles, and their shifting perceptions supported enhanced gender equity. The project also worked with young people to help ensure that the next generation of rural Cubans are motivated to appreciate their agrarian culture and to imagine gender relations in new, more equitable ways.

The innovation spaces generated from the gender axis (Innovation Fairs and Festivals, Culinary Festivals, Flower Fairs) have also constituted a good practice, where women, men, youth, and children have been motivated, achieving effective social inclusion and broad-based citizen participation, where women systematically exhibit the different modalities in which they work to develop their manual, artisanal, floristic, and culinary capacities (Benítez et al., 2021).

5. Summary: lessons learned

Many lessons can be drawn from the PIAL experience integrating gender as a cross-cutting axis in its PPB and other activities. Some of these lessons are summarized briefly here:

1. Adopting a gender-focused approach that included a participatory diagnostic methodology (DPEG) based on participatory action research principles and practices made it possible to make visible and strengthen the incorporation of women from Cuban contexts in activities in the agricultural sector.
2. Beginning with a "Women in Development" approach and later transitioning to a "Gender and Development" approach enabled the inclusion of both women and men in project actions. This was essential for evaluating power and gender relations in families and communities.
3. Capacity-building accompanied by national and international specialists constituted a basic tool to achieve awareness, changes in attitude, and understanding that help implement the tools of

the Innovation System, both for decision-makers, and female and male producers.

4. Incorporating this approach to the participatory selection of varieties constituted a key element for the inclusion of women in processes of local agricultural innovation. It enabled attentiveness to their preferred traits (e.g., cooking quality, grain size, texture, taste) in breeding efforts.
5. The creation of Local Seed Banks and Seed Certification Committees with the participation and leadership of women constitutes a strength for the local agricultural innovation system.
6. Having a strategy aimed at generating job opportunities has been a fundamental step for the social empowerment of women, enabling them to become leaders, make decisions, and earn income, which translates into an improvement in their quality of life and the well-being of their families.
7. Employing a gender-focused approach to characterizing local systems in economic, agricultural, and social terms made visible exclusions, inequities, and discrimination that had previously not been appreciated or fully understood in the agricultural sector.
8. Establishing micro-grants for the execution of gender-sensitive budgets was a strength in the project, facilitating capacity-building and leadership opportunities for women within agro-productive value chains.
9. Having the participation of women, men, youth, and children in the innovation spaces convened from the gender axis constituted opportunities for the exhibition of productions, the exchange of experiences, the commercialization of products, and the social recognition of producers.
10. Collaboration with organizations and institutions and the revitalization of processes with a gender perspective in the institutional sphere represents a strength for the development of local agricultural innovation.
11. Collaboration with the Ministry of Agriculture (MINAG), in synergy with the Federation of Cuban Women, constituted an opportunity to support the gender strategy in order to offer employment opportunities, income for women and men in the agricultural contexts of the country and also to boost food production.
12. The evaluation of the results through gender dimensions and indicators made it possible to visualize changes as well as continued disparities for women and within families.

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

Ethical approval was not required for the studies involving humans because in the Cuban context, there is no structure for formal ethical approval. The research was approved by the scientific advisory committees of the involved institutions. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and institutional requirements because in the Cuban context, participants in research of this nature are not required to provide informed consent. Written informed consent was not obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article because in the Cuban context, this is not standard practice.

Author contributions

BB, AC, RO, RA, and RC contributed to conception, design, and execution of the work discussed in the case study. BB and EN wrote the first draft of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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Conflict of interest

The 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.

Publisher's note

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Gender trait preferences among smallholder cowpea farmers in northern Ghana: lessons from a case study

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Introduction: This case study reports on how a gender responsive breeding program contributes to meeting the trait preference of men and women for improved cowpea varieties in northern Ghana.

Methods: Fifty-eight early-maturing, medium-maturing and dual-purpose cowpea lines were planted at the CSIR-SARI research fields and women and men farmers invited for participatory plant breeding (PPB) in 2016. Selected lines from the PPB were further evaluated in 2017 using participatory varietal selection (PVS) in 5 districts in northern Ghana. In addition, 20 focus group discussions (FGDs) were held in 2018 in 10 randomly selected communities with 260 participants (130 women and 130 men) across the districts where the PVS had been held previously.

Results and discussion: The study finds drought tolerance, short cooking time and pest resistance to be the most preferred cowpea traits among both men and women. The study also finds that gender differences exist in trait preference, especially for traits such as seed coat color, earliness, pod above canopy and indeterminate growth habit. As breeding programs focus on improving genetic gains for tolerance of biotic and abiotic stresses, equal attention must be given to breeding for traits desired by women.

KEYWORDS

cowpea breeding, gender-responsive breeding, trait preferences, gendered institutions, production constraints, gender lens

1. Introduction

1.1. Why plant breeders in Ghana paid attention to gender

Before 2015, cowpea [*Vigna unguiculata* (L.) Walp.] breeders in northern Ghana had uneven success introducing improved crop varieties to local smallholders, especially women. Cowpea was considered a woman's crop, because they did most of the work, from planting to processing. Yet men kept most of the money when cowpeas were sold. After 2015, social scientists joined plant breeders in field research to see what traits farmers valued in cowpeas, and if men and women had different perspectives. As part of this work, the researchers realized that women failed to adopt new cowpea varieties for social reasons, e.g., lack of land, and cash. Women had

no access to new seed. In villages where these constraints were addressed, women and men did begin to adopt new cowpea varieties.

Cowpea is one of the most important grain legumes in semi-arid Africa, Latin America and Asia, due to its contributions to food and nutritional security, revenue for smallholder farmers and other value chain actors (Boukar et al., 2019; Dakora and Belane, 2019; Shyam, 2019; Carvalho et al., 2022). Cowpea has a high protein content which ranges from 23% to 32% with high levels of essential amino acids (Muñoz-Amatriaín et al., 2017; Kebede and Bekeko, 2020). In addition, the grain contains iron and zinc (Boukar et al., 2012), crucial for women and children who are deficient in these essential micronutrients on a global level (Olson et al., 2021). In northern Ghana, cowpea is considered a woman's crop, as it is mostly grown by female smallholders, who depend on it for much of their livelihood (Padmanabhan, 2007). Women provide most of the labor for cowpeas, from planting through weeding, harvesting, transport, threshing, bagging and marketing.

In recent years, various constraints have led to the decline of cowpea productivity in northern Ghana. Farmers achieve only 50% of the potential yield of 2.50 t/ha [Ministry of Food and Agriculture (MoFA), 2016]. Women's trait preferences are not being met by breeding programs. Recent empirical evidence points to earliness, white seed coat color, large seed size, short cooking time, good taste and high yield as the most preferred traits of cowpea in Ghana and sub-Saharan Africa (Quaye et al., 2009; Salifou et al., 2017; Herniter et al., 2019). However, these studies ignored preferences by gender. Agricultural technologies are not gender neutral (Polar et al., 2017). Men and women may have different reasons for adopting a new agricultural technology.

Male farmers usually achieve higher yields of cowpea than females, who have less access to land, credit and other resources. Because of these constraints, women are also less likely to adopt improved cowpea varieties. Releasing crop varieties that meet gender trait preferences may not necessarily lead to adoption, if these constraints persist. Adoption requires community and institutional changes, including new farming behavior and rethinking rural attitudes and norms. These concerns have driven breeding programs to adopt gender research on the trait preferences of men and women. However, breeding programs must also leverage community institutions to achieve widespread adoption of improved cowpea varieties.

1.2. Context

The Council for Scientific and Industrial Research—Savanna Agricultural Research Institute (CSIR-SARI) has the mandate to develop technologies for increased agricultural productivity for improved food security, nutrition and livelihoods of smallholder farm households in northern Ghana. However, in the past, improved seed from breeding programs and other technologies were generated without integrating gender, even though men and women farmers have different needs, and unequal access to technology, resources and opportunities (Quisumbing et al., 2014).

A muti-disciplinary team of two breeders and two socio-economists (with specializations in gender studies, monitoring, and evaluation and agribusiness management) implemented the Tropical Legume III (TLIII) Project, which targeted men and women farmers, processors, consumers and traders who were mostly small-scale. Before 2015, the cowpea improvement program consisted mainly of breeders. However, there was the realization that breeding was targeted towards end-users with different needs and that technology transfer was complex, and that specialized skills were called for. This was when the social scientists were included into the cowpea improvement program in 2015, and the program began to engage more with farmers. The project also collaborated with the Seed Producers Association of Ghana (SEEDPAG) and Heritage Seeds, a private seed producing company, to produce certified cowpea seed for farmers. SEEDDPAG and Heritage Seeds also mentored and provided technical assistance to multi-stakeholder platforms (MSPs) under the community seed production.

Recent literature reports breeding programs incorporating trait preferences of both men and women, e.g., for improved cassava in Nigeria, and for beans in Kenya and Uganda (Tufan et al., 2018). However, the role of gendered institutions in breeding, dissemination and adoption is seldom reported in the literature. The gendered institutions are MSPs, village savings and loan associations (VSLAs), community seed production and farmer participatory varietal selection (FPVS). They are called "gendered institutions" because of the deliberate efforts made by the breeding program to include women, who were previously excluded. The case study documents the experiences of implementing a gender-responsive breeding program over five years from 2015 to 2019. This study included gendered preferences for cowpea traits, access to land and the role of informal institutions as part of the social targeting and demand analysis stage of the breeding process, as explained by Tufan et al. (2018). The social targeting and demand stage is incomplete without considering the gender analysis framework, consisting of six interdependent, interacting components: assets, markets, information, risks, institutions and policies. The effect of one component, for example, assets, needs to consider the influence of the others (Tufan et al., 2018). These components may in turn affect breeding stages. For example, a cowpea improvement program may target women's trait preferences, only to find that varietal adoption is still be stymied by local institutions that restrict women's access to land.

2. Analysis

2.1. Research and information generated on gender

In 2015, the Cowpea Improvement Program of CSIR-SARI was redesigned to respond to the gendered needs of smallholder farmers through the Tropical Legume III (TLIII) Project, with support from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and the International Institute of Tropical Agriculture (IITA). Improved cowpea varieties were introduced, mainly to women smallholders, to improve cowpea productivity and reduce the gender yield gap. Women were organized in groups or encouraged to join multi-stakeholder platforms (MSPs), to gain access to the new seed. The MSPs produced community seed to sell to their members and other farmers. Some of the women's groups also operated VSLAs. The MSPs and the VSLAs, herein referred as gendered institutions, were created by the breeding program to help overcome gender-based constraints, for example, women's poor access to land, cash and labor.

Field demonstrations and farmer field days were used to disseminate cowpea varieties with farmers (including women's groups) in the Guinea and Sudan Savanna agroecological zone of northern Ghana, which is prone to drought and poverty (Antwi et al., 2015). CSIR-SARI collaborated with the Ministry of Food and Agriculture (MoFA), which provided extension services to introduce the improved cowpea varieties to farmers.

Social scientists were brought on board the crop breeding program in 2015. In 2017 farmer participatory varietal selection (PVS) revealed which traits men and women preferred in cowpea varieties. Focus Group Discussions (FGDs) were organized in December 2018 to validate these cowpea trait preferences. From the FGDs, it was found that women were not adopting new varieties because of various gender-based production constraints.

There was a training by the GREAT program for biological and social scientists in 2018 on how breeding programs could be gender-responsive for agricultural transformation (Mangheni and Tufan, 2022). The Bill and Melinda Gates Foundation (BMGF) requested this training for scientists implementing BMGF-funded programs, to better incorporate gendered needs into breeding objectives.

By incorporating gender and hiring social scientists, the breeding program became more engaged with farmers, starting institutions within the communities (MSPs, VSLAs) and engaging with local authorities to improve breeding efficiency and to promote new cowpea varieties for men and women. Social scientists helped breeders incorporate gender with: yield trials, on-farm trials, demonstration fields and the promotion of the newly released varieties. The breeding team prioritized breeding objectives that addressed women's needs. For example, women prefer traits that make a good soup or a cowpea variety that produces pods above the canopy for easier harvesting.

The CSIR-SARI cowpea improvement program needed to help communities overcome agronomic constraints such as poor soil fertility, pests, and drought (Salifou et al., 2017) and institutional issues such as access to credit, and the high cost of labor and other inputs (Akudugu et al., 2012; Bashir et al., 2018). New institutions were established, for example MSPs in Manga in the Upper East Region, and Tumu in the Upper West Region, to give women and men access to seed and credit. The cowpea improvement program also considered social constraints that limit the adoption of cowpea varieties. The program involved local authorities and opinion leaders to improve women's access to land and to give both genders equal opportunities and benefits.

2.2. How attention to gender influenced the breeding initiative

To improve the adoption of new legume varieties among women and men farmers, the Tropical Legume III project integrated gender responsiveness into the breeding program from 2015 to 2019 through ICRISAT and IITA, implemented by national agricultural research systems (NARS), including CSIR-SARI. Before 2015, the cowpea improvement program was gender-neutral. In the early 2000s, yield, resistance to drought, insect pests and striga (a parasitic weed) were major concerns for breeders in Ghana and in most national breeding programs in sub-Saharan Africa (Singh et al., 2002). Many breeding programs did not include social scientists, and failed to take into account the trait preferences of the men and women who would use the new cowpea varieties.

From 2007, with help from IITA, breeding efforts in Ghana were geared towards producing cowpea varieties tolerant for drought, heat, aphids and striga (Boukar et al., 2019). By 2015 and onwards donor agencies and the Consortium of International Agricultural Research Centers (CGIAR) encouraged national breeding programs to be demand-driven and to focus on the preferences of the market and of farmers.

Before 2015, breeding approaches such as field trials, mother-and-baby trials, farmer field schools and demonstrations were established practice at the cowpea improvement program at CSIR-SARI. However, these gender-blind approaches rarely considered the needs of men and women. This changed when social scientists joined the breeding program in 2015. The program began using gender-responsive methods, such as participatory plant breeding (PPB), and participatory varietal selection (PVS): experimenting with farmers in organized groups to improve breeding efficiency. Women farmers participated, but they seldom invited to become lead farmers, hosting field demonstrations.

From 2016 to 2018, field trials, farmer participatory varietal selection (PVS) and focus group discussions were designed to consider gender and to increase the adoption of new cowpea varieties. The breeding program began to identify constraints faced by men and women. There was also a deliberate effort to implement breeding activities that would benefit women. With advice from the social scientists, the program began to use FGDs, allowing researchers to identify men and women's perspectives of constraints and cowpea trait preferences. The FGDs revealed that women had almost no access to land, or credit, and nowhere to get improved seed. Women were also less represented in the multi-stakeholder platforms (MSPs), which the project had previously set up.

To help women cowpea farmers overcome institutional constraints, which were reinforced by local norms and values, the breeding team established gendered institutions such as VSLAs for women, while renewing the emphasis on MSPs. The program maintained its primary role of breeding to overcome biotic and abiotic production constraints, but also began to consider that women's access to land could be improved by engaging with village chiefs and opinion leaders, who have a role to play in disseminating cowpea varieties. After the FGDs showed that few women took part in the multi-stakeholder platforms (MSPs), the program increased female membership in the MSPs to 30%–50%. The MSPs went into community seed production with the help of the breeding team, to improve access to improved seed. Five MSPs on average produced 1 metric ton of quality declared seed (QDS) which was sold to members at reduced prices and to farmers outside the MSPs. The funds from the sales went directly to the MSPs. Heritage Seeds, a locally registered seed company and SEEDPAG, who were partners in the TLIII Project, provided technical assistance to the MSPs.

The cowpea breeding team established village savings and loan associations (VSLAs), mostly as women's groups, to make small loans. The breeding program popularized already released varieties (Wankae, Kirkhouse Benga, and Padi-Tuya) through demonstrations, experiments conducted by organized groups and community seed production. These varieties were chosen because they actually did meet men and women's trait preferences, as documented during the PVS in 2017 and FGDs in 2018. All of these varieties were white, except Kirkhouse Benga which

was white with purple marks. They were resistant to striga and moderately drought-tolerant. They were early maturing (on average, 65 days) and on most of them, their pods grew above the canopy. The breeding team made efforts to involve women in all the project activities; sometimes the men were even outnumbered. This increased adoption of improved cowpea varieties among both men and women in northern Ghana (Wahaga, 2019; Adams et al., 2021). The methods used to pay specific attention to gender are shown in Table 1. In the project communities 50% to 60% of farmers adopted the promoted varieties: Wankae, Kirkhouse Benga, and Padi-Tuya.

The study findings that women preferred brown seed coat, indeterminate growth and pods that grow above canopy were incorporated into the ongoing Accelerated Varietal Improvement and Seed Delivery of Legumes and Cereals in Africa (AVISA) project, which started in 2019 and has led to the release of two cowpea varieties (SARI-tuya and Tuzievellenga). SARI-tuya has large, white seeds, is high yielding, has pods above the canopy and is resistant to striga, all traits shown by the gender research to be preferred by men and women. Tuzievallenga was developed in response to women's preference for a brown, early maturing variety; it is also high yielding and resistant to striga, traits that men also value. Both of these new varieties have high iron and zinc content, a trait not mentioned by farmers, but included by the breeding team to meet the nutritional requirements of women and children in northern Ghana. In some instances, the stated preference for good taste reflects a craving for iron and zinc. Some of the best performing genotypes now in breeding pipeline include the traits preferred by women.

2.3. Methods and approaches: advantages and shortcomings

The cowpea improvement program began using participatory plant breeding (PPB) in 2016, farmer participatory varietal selection (PVS) in 2017 and FGDs in the monitoring survey in 2018.

2.3.1. Participatory plant breeding

Fifty eight (58) early-maturing, medium-maturing and dual-purpose cowpea lines received from IITA were given a preliminary evaluation at the CSIR-SARI research field. The lines were planted and women and men farmers were invited for participatory plant breeding (PPB) in 2016. PPB refers to the entire process of setting breeding objectives, making crosses, developing and releasing improved varieties and suppling basic seed classes to growers (Ashby, 2009). With the PPB, the breeders made the selection on what lines would be advanced to next breeding stage based on both the suggestions and preferred traits from farmers. Thus, the context of PPB in this study emphasizes selections made due to suggestions from farmers. The PPB was limited to only farmers and they were 20 in number: 10 men and 10 women. Four of the women were also processors. Two of the men were also traders, in addition to being farmers. The PPB process finally led to the selection of 20 promising lines based on the participants' preferred traits. On average, 12 field visits were made by scientists together with the farmers during PPB activities in the 2016 cropping season. These number of field visits made the PPB costly and time consuming, confirming the conclusion of Witcombe et al. (1996) that PPB is costly and time consuming. The other limitation of PPB was that the stakeholders were not involved in the development of these lines since the lines were brought from IITA, as noted earlier.

TABLE 1 Methods and approaches used in the case study.

Activity	Paid specific attention to gender?
Participatory plant breeding (PPB)	Yes
Participatory varietal selection (PVS)	Yes
Mother-baby trials	Yes
Farmer-experimenters formally organized in groups, committees or networks to contribute to breeding	Yes
Study of trait preferences	Yes
Farmer-to-farmer visits or exchanges	Yes
Farmer field school experiments or demonstrations	Yes
Other activities, VSLAs and MSPs	Yes
Focus group discussions (FGDs)	Yes

2.3.2. Participatory varietal selection

The selected lines from the PPB were further evaluated in 2017 with the key cowpea stakeholders (men and women farmers, women processors, men and women traders, agricultural extension staff and agro-input dealers) in advanced yield trial (on-station) via participatory variety selection (PVS). In the context of this case study, PVS exclusively refers to farmers taking part in the evaluation of finished improved varieties based on their preferences from a set of suitable choices before release to the general public, as explained by Witcombe et al. (1996) and Ashby (2009). Fourteen promising lines were selected for multi-location trials, using the mother-and-baby approach at five locations: Nyankpala, Yendi, Manga, Damongo, and Tumu. The locations were purposively selected to represent the agro-ecologies in northern Ghana in order to have research results that is stable and consistent across different agro-ecologies. Nyankpala and Yendi in the Northern and Tumu in the Upper West regions represent the guinea savanna. Manga in the Upper east region represents the Sudan-savanna. Damongo in the Savanna region represents the transitional zone. A randomized complete block design with three replications was used at all five locations for two years (2016 and 2017). One hundred and fifty (150) women and 90 men cowpea value chain actors in 2017 attended the PVS (Table 2). The PVS participants selected varieties based on grain yield, maturity, pod length, grain color, grain size, and biomass yield.

PBB and PVS are fairly similar approaches, which efficiently document farmers' preferences for certain traits and varieties. PVS can be easily set up to gauge the different responses of men and women. However, these methods reveal little about the institutional constraints that hinder adoption of new varieties. Subsequently focus group discussions were held in the study areas.

2.3.3. Focus group discussions

The breeders and social scientists held 20 focus group discussions (FGDs) in 10 communities that were randomly selected with 260 participants (130 women and 130 men) across the districts where the PVS had been held in 2017. The participants to the FGDs were also randomly selected as random sampling provides better estimate of

TABLE 2 Traits selected by cowpea producers in PVS across the five study location.

	Percent of farmers (men and women) selecting each trait by study location															
Trait	Tumu		Manga		Damongo		Nyankpala		Yendi		Total					
Gender	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	%	Male	%	Grand total	%
White seed coat	29	11	21	13	25	30	25	14	12	15	112	74.7	83.0	92.2	195.0	81.3
Brown seed coat	13	1	7	2	5	2	6	0	7	2	38	25.3	7.0	7.8	45.0	18.8
Early maturing	35	8	23	11	26	25	27	10	16	13	127	84.7	67.0	74.4	194.0	80.8
Medium maturing	7	4	5	4	4	7	4	4	3	4	23	15.3	23.0	25.6	46.0	19.2
Large seed size	33	11	23	15	24	30	24	13	15	16	119	79.3	85.0	94.4	204.0	85.0
Medium seed size	9	1	5	0	6	2	7	1	4	1	31	20.7	5.0	5.6	36.0	15.0
Taste	42	12	28	15	30	32	31	14	19	17	150	100.0	90.0	100.0	240.0	100.0
Medium cooking time	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
Short cooking time	42	12	28	15	30	32	31	14	19	17	150	100.0	90.0	100.0	240.0	100.0
High grain yield	37	9	16	9	27	25	30	13	15	14	130	86.66	70.0	77.8	193.0	83.33
High biomass yield	5	3	12	6	3	4	3	1	0	3	20	13.0	20.0	22.2	40.0	16.66
Indeterminate	38	8	21	11	25	15	23	4	13	14	120	80.0	52.0	57.8	172.0	71.7
Determinate	4	4	7	4	5	17	8	10	6	3	30	20.0	38.0	42.2	68.0	28.3
Pod above canopy	40	9	16	10	26	25	30	9	14	13	126	84.0	66.0	73.3	192.0	80.0
Pod within canopy	2	3	12	5	4	7	1	5	5	4	24	16.0	24.0	26.7	48.0	20.0
Insect pest resistance	42	12	28	15	30	32	31	14	19	17	150	100.0	90.0	100.0	240.0	100.0
Drought tolerance	42	12	28	15	30	32	31	14	19	17	150	100.0	90.0	100.0	240.0	100.0

Farmer Participatory Varietal Selection (FPVS) Survey, 2017. NB. number of women = 150; number of men = 90; population of participants (grand total) = 240.

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parameters in a study compared to purposive sampling (Singh and Masuku, 2014). These districts were Yendi and Tolon districts in the Northern region, Bawku East in the Upper East region, Damongo in the Savanna region, and Sissala East in the Upper West region, as shown in Table 3. After each FGD, data were taken on each participants' adoption of any improved cowpea variety, total output, land ownership, access to land, education, land area under cowpea production and age, as described in Table 4.

The interactive nature of FGDs enabled participants to validate responses from one another (Powell and Single, 1996) and let the breeding team investigate participants' behaviors and motivations (Carey and Smith, 1994). FGDs not only reconfirmed the results from the PVS, they also led to the discovery of agronomic and institutional constraints faced by men and women in cowpea production. Qualitative data were collected from respondents through the FGDs held between 12th to 28th December 2018. There were separate FGDs for men and women, to allow the women to express themselves freely. Smaller groups were chosen because larger FGDs are challenging to manage and they limit each participant's opportunities to speak (Morgan, 1997). The interviewers consisted of a lead facilitator, two note-takers and an observer. The lead facilitator was a social scientist. The note-takers were another social scientist and an agricultural extension officer. The observer was a breeder. The lead facilitator would ask for permission to take pictures and make audio recordings. Participants invariably consented.

During the interviews the lead facilitator asked the questions. The note takers wrote down the responses. The observer took notes on the clarity of the questions asked, the validity of the responses, body language and eye contact of the lead facilitator and the participants and whether the participants were comfortable with the venue, the questions asked and the general atmosphere of the meeting. After each FGD, the facilitators would then meet to go through the responses, compare notes and validate the responses. The data was then entered into an excel file for analysis. The qualitative data was organized around themes, and sometimes included direct quotes from the interviews. Reporting qualitative data this way makes the findings comprehensive and clearly presents their typicality (Rubin and Rubin, 1995). The recordings were transcribed, which made it possible to recover the respondents' exact phrases during data entry and to analyze their responses qualitatively and descriptively (Bertrand et al., 1992).

TABLE 3 Cowpea traits ranked by men and women in FGDs (in order of preference).

Region	District	Men	Women
Northern region	Yendi	Pest resistance High yielding Good taste Drought tolerant Shorter cooking time Larger grain size Early maturing White seed coat Higher fodder	Drought tolerant Higher yielding Pest resistance Early maturing Shorter cooking time Good taste Larger grain size Indeterminate growth habit Brown seed coat White seed coat Pod above canopy
	Tolon	Pest resistance High yielding Good taste Drought tolerant Shorter cooking time Larger grain size Striga tolerance	Drought tolerant Higher yielding Pest resistance Early maturing Striga tolerance Shorter cooking time Good taste Larger grain size Indeterminate growth habit
Upper east	Bawku east	High yielding Pest resistance Good taste Drought tolerant Striga tolerance	Shorter cooking time Good taste Brown seed coat Higher yielding Striga tolerance Pod above canopy
Savanna region	Damongo	Short cooking time High yielding Pest resistance Good taste Striga tolerant Drought tolerant Early maturing	Shorter cooking time Good taste Higher yielding Pest resistance Larger grain size Indeterminate growth habit Brown seed coat
Upper west	Sissala east	High yielding Pest resistance Good taste (3rd) Striga tolerant Larger grain size Drought tolerance Pod above canopy	Pest resistance Shorter cooking time Good taste Brown seed coat Higher yielding Striga tolerance Pod above canopy

Focus Group Discussions (FGD), 2018.

3. Changes in the breeding process and practice because of learning about gender

For years, the team consisted only of breeders and field technicians. In 2015, social scientists with expertise in gender and agribusiness joined the program, which began to breed varieties for men and women who may have different preferences for cowpea traits. Crucially, the breeders joined social scientists in the field studies in 2017 and 2018. This not only helped to build team spirit, but also ensured that the breeders accepted the study conclusions.

In addition to organizing PVS, desired traits were also differentiated by gender, and by region. For example, women in the Northern region considered drought tolerance as most important whereas women in the Upper East and Savanna regions wanted short cooking times (Table 3). This finding has influenced the breeding program to always conduct PVS and FGDs on trait preferences across regions since 2019. Traits are now being selected to target particular regions. The variety design always includes both agronomic and consumer traits for wide user acceptability. The choice of materials to advance to the next stage of breeding is then based on the different preferences of men and women. Thus, lessons from PVS and FGDs now feed into organizing PPB. Women are now among the lead farmers when new materials are evaluated on-station or on-farm.

TABLE 4 T-statistic mean differences between subsidy and non-subsidy households.

Variable	Description	Male respondents: mean	Female respondents: mean	Difference
Adoption status	1 if a respondent adopted any improved cowpea variety; 0 otherwise	0.275	0.108	0.167***
Total output (Kg)	Total yield a farmer obtained in Kg	2750	1900	850***
Land_ownership	1 if respondent owned land; 0 otherwise	0.908	0.225	0.683***
Access_land	1 if respondent had access to land; 0 otherwise	0.942	0.392	0.55***
Education	1 if respondent has at least basic education; 0 otherwise	0.475	0.192	0.283***
Land area (Acres)	Land area under cultivation	2.00	1.267	0.733***
Age	Age of respondent in years	40.31	38.93	1.38

Focus Group Discussions' (FGDs) participants individual-level data, 2018. NB. ***, **, and *standard for 1%, 5% and 10% at statistical significance. These are the power of significance or confidence levels upon which the data must be interpreted.

The definition of markets and the strategies for seed multiplication and dissemination also changed. MSPs were trained to produce quality declared seed which they sold to their members and to neighbors. Women farmers became more involved in community seed production. Farmer groups and VSLAs were formed in the study communities to empower women, who gained access to credit. Two cowpea varieties were finally released in November 2022 that had been developed in response to gender related-concerns.

4. Breeding outcomes and impacts

4.1. PVS and preferences for traits of improved cowpea varieties

During the PVS, men and women farmers in the five locations expressed their preferences for specific cowpea traits (Table 2). All of the 150 females and the 90 males preferred drought tolerance, short cooking times and pest resistance (Table 2). Most farmers selected grain yield (83.33%), but was preferred by slightly more women (87%) than men (79%) (Table 2).

Several other traits were selected by most farmers, with men and women mainly in agreement. For example, 85% of all farmers selected large seed size: 79% of the women and 94% of the men. White seed coat, selected by most farmers (81%), was more chosen by more men (92%) than women (75%). Early maturity was selected by most farmers (81%), but was important to a few more women (85%) than men (74%). Pod above canopy was also important to most farmer (80%), especially to women (84% vs. 73% for men). Women and men generally prefer the same traits, with some slight differences, especially for characteristics with market importance.

More women preferred pods that grow above the canopy, because they are easier to harvest, a task generally done by women. Women also preferred indeterminate growth habit because such varieties provide fresh leaves to make soup and other dishes. Some women respondents (25%) preferred brown seed coat to prepare *waakye* (rice and cowpea cooked together) and red-red (boiled cowpea with palm oil eaten with fried plantain). The women say that brown cowpeas are cheaper than white ones and can be used for home-made flour which is prepared with sprouted cowpea seeds; the seed coat is removed during processing, so its color does not matter. All the cowpea varieties released by CSIR-SARI before implementing gender responsive breeding were white, but based on the results from this preference studies, one of the two cowpea varieties approved by National Variety Release and Registration Committee for release in November, 2022, Tuzievallenga, is brown and there are several others in the pipeline.

Early maturity was the fifth most selected trait of the 16 evaluated by farmers (Table 2). Female respondents were slightly more likely than males to prefer early maturing varieties. Some men preferred medium-maturing varieties, which were perceived to yield more. Women farmers said that early maturing varieties would allow multiple cropping per year, while also escaping terminal drought, which in today's changing climate is now more common in northern Ghana.

4.2. Focus group discussions

The sex-disaggregated focus group discussions (Table 3) supported the team's conclusions about trait preferences from PVS (see the previous sub-section). Across the regions, men and women gave attention to agronomic traits (insect pest resistance, high yield and drought tolerance), and consumer traits (shorter cooking time and good taste). These traits are must-haves for any new improved cowpea variety.

Specific to certain districts, gender differences in cowpea trait preference for women were shorter cooking time in Bawku East in the Upper East region and larger grain size in Damongo in the Savanna region. In Upper East men preferrene was pest resistance while women valued shorter cooking time (Table 3). Spraying to control pests is done mainly by men, but they would like to spray less often, which they now do on average five times a season. Faster cooking cowpeas would give women more time for other activities, while using less fuel wood (Martey et al., 2022).

Results from the individual-level data of the FGDs' participants revealed statistically significant differences between men and women cowpea farmers in terms of adoption, total output, land ownership, access to land and land area under cowpea cultivation in Ha, as indicated from the two-sample t-statistic mean differences in Table 4. There was, however, no systematic difference between men and women in terms of age. According to Moore and Kirkland (2007), *p-values* in the *t table* for the two-sample t-statistic method are accurate when the sizes of the two samples being compared are equal. In addition, the two-sample t-statistic mean differences are more robust than one sample t-statistic methods, and robust also against

non-normality. From Table 4, the level of adoption among men cowpea farmers was about 28% as against about 11% among women cowpea farmers. Total output, on average, among men cowpea farmers was higher (2750Kg) compared to women cowpea farmers (1900Kg). Conversely, land under cultivation, on average, was also greater among men (2Ha) compared to women (1.267Ha). It suffices to say that the low adoption of cowpea improved varieties and low output among women as compared to men in the sample could be due to land ownership, access to land and education that favour men relative to women, as shown in Table 4. Though the two-sample t-statistic mean differences do not imply causal effects, FGDs of both men and women confirmed this finding.

5. Gender constraints in cowpea production

Women were not rejecting new cowpea varieties for their genetic traits; women were facing extreme social barriers to adoption, as women participants explained in the sex-disaggregated focus group discussions. For example, from the discussions, it came to light that land ownership across the studied communities was by inheritance. Male farmers inherit farmland from their fathers. However, all community lands are entrusted to the chief of the community. Few farmers borrow land. One man said:

> "One can also borrow or beg land to farm, without necessarily owning land. You can in turn give a portion of your produce to the landowner after harvest. Women in the community have access to land, but this is based on the decision of their husbands. Women in this community mostly grow okra and pepper. That is why we do not allocate lands permanently to them. These crops also enrich the soil. After a time, we collect back the lands to grow cereals and allocate different lands to the women. We men have the responsibility to feed the family, not the women."

This suggests that women not only have little access to land, but they are sometimes loaned a field so that they can enrich the soil for a following cereal crop grown by men.

Another man said:

> "Over here there is not enough land to cultivate maize, so we do not allocate lands permanently to women. Therefore, when the man is in need of land, there are fewer challenges taking the lands back from the women."

Women only have access to land through their husbands. This is a major constraint to the adoption of improved cowpea varieties. Poor access to land explains why it has always been difficult to get women as lead farmers to host demonstrations, which the breeding team did not realize until this study. Some of the women said: "Our husbands control all the land." Societal norms tend to privilege men, given them more power over women, and allowing men to wield more control over assets and resources (Sen, 1990; Pérez et al., 2015). The FGD revealed that few men, and no women, had access to improved seed. Few claimed to get improved seed from CSIR-SARI through field demonstrations. They explained that unlike maize, they do not buy improved cowpea seeds at agro-input shops, and that cowpea seed is expensive.

Men and women either use recycled seed from the previous harvest or they plant grain they buy in the market. Males and females have equally poor access to improved seed. Astonishingly, the FGDs revealed a lack of representation of women in the MSPs that were established by the cowpea breeding team. After learning this, the program took steps to involve women in the platforms, which also began to produce seed that was available in the study communities (see the previous sub-section: How attention to gender influenced the breeding initiative).

Men take more of the cash from the sale of cowpea, claiming that this is because they take care of the whole family. Most women do not sell their cowpea. They produce it to feed the family. They only sell during difficult times when they need money. Even when women have to sell, they are obliged to inform their husbands. Women and children provide labor for all the field activities, including planting, harvesting and fetching drinking water for the workers. Household gender relations seriously affect the intra-household distribution of income (Farnworth, 2011). Men and women may collaborate to bring wealth into the family, but the men often take most of the money (Sen, 1990). In response to this finding, the team organized VSLAs to give women access to credit (discussed above).

6. Discussion

The coming together of breeders and soil scientists in a breeding program offers them the opportunity to develop market-driven breeding objectives that meet the needs of end-users, including men and women. According to Tiwari et al. (2022), this includes matching breeding goals to product performance for each segment of end-users or market. The finding from the study that drought tolerance, short cooking times and pest resistance (Table 2) were preferred by both men and women is consistent with that of Karikari et al. (2023). Karikari et al. (2023) found that farmers in the Upper West region of Ghana preferred cowpea traits that are drought tolerant, pest resistant and short cooking time. The implication is that cowpea farmers are adapting to climate change and variability through the choices they make regarding trait preference. These choices include the preference for early maturing cowpea trait. From the study, the finding that female respondents were slightly more likely than males to prefer early maturing varieties indicates that women farmers as well, are increasingly becoming conscious of the negative impact of climate change and variability and are willing to adapt. Rabé et al. (2022) also found early-maturity as a preferred trait among cowpea farmers in Niger. Unlike this study, Rabé et al. (2022) did not look at trait preferences between men and women cowpea farmers. These findings are supported by the conclusion of Moussa et al. (2023) that farmers' strategies for tackling climate change and variability in Southern Niger included adopting early maturing varieties with high yield and tolerant to drought, pests, and diseases. Increased urbanization, coupled with the growing market for cowpea in Ghana has also influenced the preference for a consumer trait such as less cooking-time among cowpea producers and consumers (Mishili et al., 2009).

As observed in Table 2, most farmers selected grain yield (83.33%), but was preferred by slightly more women (87%) than men (79%). Similar studies have consistently found preference for high grain yield among cowpea farmers (e.g., Rabé et al., 2022; Karikari et al., 2023; Moussa et al., 2023). These studies (Rabé et al., 2022;

Karikari et al., 2023; Moussa et al., 2023), however, assumed preference for traits among producers and end-users to be gender-blind, therefore did not consider trait preferences for both men and women. From the study, the finding that more women preferred pods that grow above the canopy for the reason that such cowpea are easier to harvest confirms (Ridgeway, 2009; Sylla et al., 2023) that gender relations fit into social structures that define agricultural tasks. Such tasks such as harvesting of cowpea as generally done by women may also define trait choices by women farmers. Women also preferred indeterminate growth habit because such varieties provide fresh leaves to make soup and other dishes. This finding confirms that of Horn et al. (2015) and Owade et al. (2020) who found farmers using fresh cowpea leaves and pods as vegetables. These vegetables are rich in minerals including vitamins and iron which are deficient in sub-Sahara Africa. This makes cowpea a good crop in fighting against food and nutrition insecurity in SSA (Owade et al., 2020).

From the FGDs, the finding that across regions, producers prefer different traits highlights the importance of considering geographical location in trait development, besides gender. PVS results may be limited by inadequate means of verification. Sex disaggregated focus group discussions can provide such means of verification and validating results from PVS. A similar approach was employed by Kyebalyenda et al. (2022) in studying preferred genotypes and different sensory attributes in cowpea for vegetable use in eastern Uganda. Across the regions, the FGDs highlight how men and women gave attention to agronomic traits (insect pest resistance, high yield, and drought tolerance), and consumer traits (shorter cooking time and good taste).

The observation from the sex-disaggregated focus group discussions that women had limited access to land can be considered as one of the social barriers to adoption in northern Ghana. The nexus between gender relations and social structures also define access to land and other agricultural inputs (Ridgeway, 2009; Sylla et al., 2023). Rules embedded in communities regulate activities, decision and roles mostly in favour of men to the disadvantage of women (Kabeer, 1994). The involvement of traditional and opinion leaders in breeding programs in local communities is therefore critical in promoting access to and ownership of land by women.

6.1. Good practices

Participatory varietal selection allows farmers and other actors on the cowpea value chain to select their preferred lines (Horn et al., 2015). Because the breeding team implemented PVS with gender in mind, the improved varieties were accepted by women and men end-users. Because the PVS were participatory, lines that were rejected became good materials for crossing with desirable lines during the PPB stage, which gets the genotypes right from the onset so that they meet the expectations of men and women end-users. As the PVS became more gender-sensitive, they gave a sense of ownership to participating women's groups and a sense of accountability to the breeding team. The limitation of PVS is that it does not offer the participants an opportunity to explain themselves and to query one another, unlike focus group discussions (FGD).

Separate FGDs for men and women in 2018 allowed them to discuss their trait preferences. The breeding team became more enlightened on both agronomic and consumer trait preferences. Subsequent varietal designs and evaluations in on-farm trials and field demonstrations since 2019 have focused on the information obtained from the PVS and FGDs. This gave both sexes the opportunity to interact well with the breeding team. Involving village chiefs and opinion leaders eased some of the constraints women had previously faced in the project communities. The MSPs with 30%–50% membership of women provided the platform for community seed production. The VSLAs also helped women buy improved seed, mineral fertilizer and to hire labor. There was increased adoption of improved cowpea seeds in farm communities, and there are plans to upscale these novel practices to other districts in northern Ghana to generate wealth and empower women.

6.2. Lessons

Women's unequal access to land, credit and membership in farmer-based organizations were discussed in the communities that took part in the study. These discussions with the chiefs, opinion leaders, local government officials and the research team led to the formation of gendered-institutions (MSPs and VSLAs). Women's access to farmland, for cowpea and other crops, increased in the intervention communities. The MSPs produced seed of preferred cowpea varieties, specifically, Padi-Tuya and Wang-Kae which have short cooking time. This improved access to improved cowpea seed and adoption of varieties, especially for women farmers. The community seed production, improved access to land by women, the MSPs and VSLAs will remain after TLIII project. Further research on these enduring effects on income, food security and nutrition between male and female-headed households will be worth undertaking in a larger sample size to provide evidence for policy formulation on mainstreaming gender into national breeding programs.

As breeding programs focus on improving genetic gains for tolerance of biotic and abiotic stresses, equal attention must be given to breeding for traits desired by consumers. Gender differences exist, especially for traits such as seed coat color, earliness, pod above canopy and indeterminate growth habit. Breeding varieties with desired traits is not always enough to ensure their adoption. Programs must realize that women cannot adopt new varieties without access to seed, land and money. Gendered institutions such as MSPs, VSLAs, and seed producers' groups can help to foster the adoption of improved cowpea varieties.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

AJ: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Writing – original draft, Writing – review & editing. EO: Data curation, Formal analysis, Methodology, Visualization, Writing – review & editing. A-RM: Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – review & editing. TT: Investigation, Methodology, Supervision, Validation, Writing – review

& editing. MM: Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – review & editing. FK: Methodology, Supervision, Validation, Visualization, Writing – review & editing. HM: Validation, Visualization, Investigation, Methodology, Writing – review & editing, Supervision.

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Conflict of interest

The 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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Prioritizing preferred traits in the yam value chain in Nigeria: a gender situation analysis

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This study describes what did and did not work in the prioritization of preferred traits within the value chain of yam and associated food products (boiled and pounded yam) in Nigeria. Demand-led breeding protocols have enhanced participatory methods along gender lines to increase the clarity of information on the yam traits preferred by farmers and other end users. Drawing on the experience of the cross-cutting gender team at the National Root Crops Research Institute (NRCRI), Umudike, and partners, this study documents the successes and constraints in the use of gender-inclusive approaches for effective breeding. Methods in our gender studies involve critical assessment of the distinction between quantitative and qualitative research, with particular attention to measurement. Various techniques for data collection, such as interviews, observation, and archival studies, are assessed to locate their potential for constructing successful research projects. The methods used include participatory varietal selection, participatory plant breeding, focused discussions with farmer groups, value chain mapping, G+ tools, trait preferences (processing and consumption), triangulation of multi-disciplinary datasets, and social survey research. Yam production in southeast Nigeria is dominated by men, while women are the main processors. Gendered power play, access to resources, and decision-making have been found to constrain women's participation in yam production (and in yam research). Sex disaggregation was applied within the value chain studies to capture the complementarity and differences in the perceptions of women and men. The methods used facilitated the development and release to farmers in 2023 of three improved yam varieties with consumer-preferred characteristics such as high yield, high dry matter content, white tubers, and good boiling and pounding capability. The success stories also show that effective communication and cooperation within the gender cross-cutting team and farmer groups are important for better results. When gender specialists, food scientists, and breeders work together, innovations are created, challenges are overcome, and information is shared.

KEYWORDS

yam, gender team, plant breeding, trait preferences, production, processing, consumers

Introduction

Why yam breeders in Nigeria pay attention to gender

Nigeria is a multi-ethnic society; the different regions have unique cultures that influence the type of yam cultivated and the foods that consumers value (Obidiegwu and Akpabio, 2017). Breeders at the National Root Crops Research Institute (NRCRI) have been working on breeding yams that meet cultivation and use requirements. The NRCRI, in partnership with collaborators, released 35 yam varieties (Appendix 1) in Nigeria from 2001 to 2023. Roots and tuber crops are crucial in Nigeria, yams in particular, but demand for these crops is shaped by their short shelf life and by the many kinds of foods that households prepare using them. In Nigeria, yam is widely grown in regions where women contribute more farm labor, managing the use of the crop and adding value to it (Rahman, 2006).

Nigeria is the world's top yam producer, harvesting ~50 million metric tons per year (FAO, 2020), followed by Ghana (85.3 million tons), Côte d'Ivoire (77 million tons), and Benin (32 million tons). However, Nigeria's productivity ranks a distant 34th (7.9 tons per hectare), half that of nearby countries such as Ghana (8th, 18.2 tons per ha) and Benin (12th, 13.7 tons per ha). The average productivity per farm tends to be lower in countries where women make up more of the agricultural labor force than men (Udry, 1996). In several West African cultures, wealth is controlled by the man who serves as the head of the household, and in the past, yam was the ultimate form of wealth, as it was the major crop and agriculture was the main form of business (Obidiegwu and Akpabio, 2017). Hired labor in many areas of the world is performed by men, while most farm-based family labor is carried out by women and children (Shaw, 2004). Yams are not always just a women's crop or a men's crop, and their perceived gender affiliation varies widely by region and ethnic group (Cook et al., 2009). Among the Igbo people of southeast Nigeria, yam is reported to be a men's crop (Ezumah and Domenico, 1995), although Madu et al. (2021e) found evidence to the contrary. There are some areas where women play important roles in yam production, particularly water yam (probably because less value is attached to this). The present study aimed to highlight the lessons learned based on the methodologies used to prioritize preferred traits within the yam value chain in Nigeria along gender lines. The article is structured as follows: the context is first presented, followed by analyses, methods, and approaches, breeding outcomes and impacts, and discussion (good practices and lessons learned).

Context

Such an old and important crop as the yam is surrounded by various myths, some with regional variations. Some of these myths claim that yam is not cultivated by women and cannot be harvested before the associated celebration time, otherwise it will affect the next year's harvest. In southeast Nigeria, yam is associated with a god called Ahajoku who is responsible for bumper harvests and must be appeased (but only by men). Women are sometimes allowed to cultivate other species that are considered less important, such as *Dioscorea bulbifera* or the water yam (*Dioscorea alata*), rather than the favored white yam (*Dioscorea rotundata*) or yellow yam (*Dioscorea cayennensis*). In Nigeria, yam is cultivated during a particular season, which affects the breeding program, as the output will be poor if the planting date is altered; therefore, yam is a one-season crop, unlike cassava. In the riverine areas, the yam planting season is from December to January, while elsewhere it is in April and May. Gender shapes the meaning, value, and prestige assigned to tasks (Wharton, 2011). The Igbo culture, for instance, defines yam as a male crop, and society confers prestige to male yam farmers. Higher valuation of men's work or roles is a reflection of male dominance, which is strategically aimed at granting men preferential access to opportunities and placing greater value on them as a means of exerting authority or control over others (Friedl, 1975, cited in Ubelejit-Nte and Erondu, 2022).

In Nigeria, women are mainly responsible for preparing yams to eat (Cook et al., 2009; Madu et al., 2018, 2021d). Fresh yams can be boiled, pounded, roasted, fried, etc. Boiled yam is an important food that can be eaten at all meals and as a snack. Pounded yam, a beloved food in much of Nigeria, is a glutinous dough that is mainly processed by women, who peel, boil, pound, and knead the tubers (Otegbayo, 2018). Boiled yam pieces are prepared (usually by women) by peeling, washing, and slicing the yam into pieces before boiling or steaming them (Otegbayo et al., 2005). In many places, men and women eat boiled and pounded yam approximately equally often, but this is not always the case in places where yam products are diversified (Nweke et al., 2013). For example, in Benue and Ebonyi States, Nigeria, men are more likely to eat pounded yam (Madu et al., 2018). In southwest Nigeria, tribes such as the Ijesha in Osun, Ekiti, and Ondo States have strong preferences for yam, while the Ijebus make a food called *ikokore* from the water yam. According to Obidiegwu and Akpabio (2017), yam ownership and cultivation are linked to gender and class, emphasizing male achievement and social prestige. People in the upper-income group tend to eat yams more often than the lower-income group (Nweke et al., 2013).

Barlagne et al. (2016) emphasized the dearth of knowledge of consumers' preferences regarding yam traits and product quality, despite its high nutritional value (Bradbury and Holloway, 1988) and contribution to calorie intake in West Africa (Asiedu and Sartie, 2010). Madu et al. (2021d) also noted a gap in knowledge of preferences in relation to root, tuber, and banana (RTB) crops among different user groups, e.g., food processors, retailers, and consumers, because breeding programs have historically focused on yield and other agronomic traits at the expense of post-harvest and consumer preferences. Additionally, descriptions of product traits are often oversimplified and too short, omitting information on the optimal range of an attribute that users need. Moreover, little or nothing is known about how gender relations and norms interact with preferred characteristics in relation to particular yam varieties and value chains (producers, processors, consumers, etc.).

Analysis

Research generated

In a bid to improve fragmented and weak crop breeding, the AfricaYam project, funded by the Bill and Melinda Gates

Foundation (BMGF), began AfricaYam Phase I in October 2014, creating active yam breeding programs with faster and more precise methods for developing yam varieties that combine high and stable yield with good tuber qualities. Phase I ended in August 2020. Phase II focused on modernizing the yam breeding programs in West Africa for more efficient development of consumer-preferred varieties with higher yield, greater resistance to pests and diseases, and improved food quality following well-defined, gender-responsive product profiles.

The institutional actors driving this change are the International Institute of Tropical Agriculture (IITA); the National Root Crops Research Institute, Umudike, Nigeria; Ebonyi State University, Abakiliki, Nigeria; two research institutes under the Council for Scientific and Industrial Research (CSIR) in Ghana (the Crops Research Institute in Kumasi and the Savanna Agricultural Research Institute in Tamale); the Centre National de Recherche Agronomique (CNRA) in Côte d'Ivoire; and l'Université d'Abomey-Calavi (UAC), Dassa, Benin. In recognition of the increasing popularity of yams in East and Central Africa, the National Crops Resources Research Institute (NACRRI) in Kampala, Uganda, also joined the program. Breeding has become a multidisciplinary effort involving breeders, geneticists, food scientists, agronomists, social scientists, and end users. Research organizations outside the sub-region also play major roles in the project: the Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), Montpellier, France; the Iwate Biotechnology Research Center (IBRC), Japan; the James Hutton Institute (JHI), UK; the Japan International Research Center for Agricultural Sciences (JIRCAS), Japan; and the Boyce Thompson Institute for Plant Research (BTI), Cornell University, USA.

The beneficiaries of this intervention include farmers producing seed yam and ware yam; farmers and traders who store and wholesale seed yam and ware yam; farmers and specialist processors who transform fresh yam tubers into dry chips and yam foods; retailers of yam tubers, products, or prepared food; processors who buy dry chips from farmers and mill flour; transporters; exporters; and rural and urban consumers. The rural poor dominate yam production on small farms. Women conduct the retail trade and food processing. AfricaYam pays special attention to the rural poor and female producers and processors. The impact on traders and exporters will boost demand for yam products and enhance the livelihoods of producers and processors. Poor rural and urban consumers will benefit from reduced yam product costs for longer portions of the year, leading to improved wealth and health. Higher yields will result in more judicious use of farmland and less need to clear virgin lands. Increased income will fund farmers' capacity to invest in improved soil, water, and weed management technologies.

How attention to gender has influenced yam breeding in Nigeria

Attention to gender in relation to breeding programs was triggered by the Breeding Program Assessment Tool (BPAT) in 2021, which recommends using a product profile to consider user preferences. The BPAT, developed with the support of the BMGF, facilitates a structured review of key technical, capacity, and management components of plant breeding programs to help design improvements that increase their efficiency and achieve higher rates of genetic gain. To modernize standard operating protocols and best practices, the BPAT recommends the more systematic use of product profiles, based on market intelligence and stakeholder consultations, to ensure that new varieties are designed to meet the preferences of women and men farmers, consumers, traders, processors, and other value chain actors (EIB, 2021). The design of new crop management systems may also be necessary, including the integration of consumers' preferences for more sustainable food systems (Selfa et al., 2008; Rastoin and Ghersi, 2010; Tsolakis et al., 2014; Barlagne et al., 2016). In the past decade, the breeding team at NRCRI has adopted the novel idea of product profiling, disaggregated by gender. Training funded by several projects (RTBfoods, NextGen, etc.) has taught researchers how to use these product profiles as a tool.

A multidisciplinary team of breeders, agronomists, pathologists, food scientists, social scientists, and gender specialists was assembled at the start of the RTBfoods project (targeting boiled yam, pounded yam, *fufu*, and *gari*). From 2017 to 2022, research findings on consumer preferences were used to develop a breeding framework to increase the efficacy of selection and adoption of improved root and tuber crop (RTC) varieties in Africa. A key factor in the success of the breeding program was the integration of knowledge contributions from all participating disciplines to enhance demand-led breeding. This was not the case in the past, which was a contributing factor in the non-adoption of some varieties. The findings were so compelling that this multidisciplinary team transformed into a gender team, which was persuaded of the necessity of considering gender to ensure that breeders could take users' wishes into account and create types that farmers would want to cultivate. The deployment of yam varieties with consumer-preferred traits incorporated into the product profiles is expected to trigger wide-scale adoption, enhancing household food availability, income, and nutrition security while improving the wellbeing of different value chain actors.

Methods and approaches

Gender-inclusive yam studies have benefited from lessons learned in the NextGen cassava breeding project, and much later in the RTBfoods project, which captured both yam (boiled and pounded) and cassava (*gari* and *fufu*) product profiles. Robust gender-inclusive studies for yam started in 2017–2018, continuing for 5 years under the method initiated by RTBfoods (Table 1). Before RTBfoods, social scientists worked occasionally with AfricaYam breeders, although they were not considered part of the team; they held benchmark and rapid appraisals of what men and women said about certain traits, focusing on consumers, with no gender disaggregation. Outcomes from gender-inclusive studies of cassava triggered activities relating to other root and tuber crops at the NRCRI. In previous years, the gender stereotyping of yam as a male crop has constrained the inclusion of gender considerations

TABLE 1 Timeline of the methods used to incorporate gender-based trait preferences into yam variety development.

Steps	Data gathering	Year	Team
1. Scope of the study and gaps in research	Desktop research, workshops, and meetings to identify gaps and constraints acting as barriers to variety adoption among end users. A cross-cutting team was identified to aid the breeder's selection of prioritized traits to enhance targeted demand breeding.	2018	Gender specialist, economist, food scientist, extension specialist, and breeder.
2. Gendered food mapping: understanding the drivers of trait preferences	Participants in the value chain (producers, processors, marketers, and consumers) were identified from a gendered perspective. The multiple uses and products of yam and the possible trade-offs between uses were described. The quality characteristics and descriptors were identified by stakeholder group (e.g., producers and processors) and demand segments (e.g., rural consumers). An understanding of how gender influences preferences and the prioritization of characteristics was developed.	2018	Gender specialist, market economist, and food scientist.
3. Participatory processing diagnosis	Multiple yam varieties, including a local check, were used. Qualitative and quantitative data were elicited from four product champions to corroborate the outcomes of the gendered food mapping step.	2018	Gender specialist, market economist, food scientist, and extension specialist.
4. Consumer testing	Products from the processing diagnosis were assessed among larger groups (including men and women) in urban and rural areas to understand the consumers' demands in terms of the quality characteristics of boiled and pounded yam and to provide a clear visual mapping of the most-liked products, associated with high-quality characteristics and high overall liking scores, and of the least-liked products.	2019	Gender specialist, market economist, food scientist, breeder, and extension specialist.
5. Triangulation	Prioritized trait profiles from steps 2, 3, and 4 were triangulated to improve user acceptability of the produce (fresh yam), raw material (peeled yam), and ready-to-eat product (boiled and pounded yam).	2021	Same as above.
6. G+ tool	The G+ tool was applied at the following stages: produce (fresh yam), processing (peeled yam), and consumption (boiled and pounded yam). Weights were assigned, with intensity representing positive or negative impacts (balancing economic and non-economic drivers), thereby prioritizing trait preferences.	2022	Gender specialist, market economist, food scientist, and extension specialist.
7. Variety release	Product advancement meetings were organized to discuss and screen genotypes that should be advanced and released. Three new varieties were released in 2023 with consumer-preferred traits, such as high yield, high dry matter, flour production, and good boiling and pounding capabilities. These varieties were UMUDa35-Delight (*D. alata*, water yam), UMUDr33-Blessing, and UMUDr34-Sunshine (*D. rotundata*, white yam; Africa Yam Team, 2023).	2023	Breeders, food scientists, extension specialist, pathologist, seed system specialists, and gender specialists.

in breeding, probably exacerbated by village meetings in which women would defer to the men in replying to questions from social scientists.

From 2018 to 2022, the team followed the steps of the RTBfoods method for integrating gender into product profiles for boiled and pounded yam (Forsythe et al., 2021; see Table 1). In Step 1, the scope of the study and the gaps in research were set, i.e., the state of knowledge (SOK) for boiled and pounded yam was established (Madu et al., 2018; Otegbayo, 2018). In Step 2, a set of ranked quality characteristics was elicited from users who played different roles in the value chain, and an in-depth social context on boiled yam (Madu et al., 2021d) and pounded yam (Otegbayo et al., 2021) was established. In Step 3, in-depth research was conducted with experienced processors to identify more quality characteristics of boiled and pounded yam (Madu et al., 2021a). The processors know yam, and they understand what the market and consumers expect in the final products. Under this method, it was found that the processors (almost all women) prepare the boiled and pounded yam in their local fashion. In one location in Anambra State, the women rejected our way of cutting the yam and presenting it to the male consumers, explaining that the men would not eat yam served our way.

Based on the results of Step 3, the team developed questionnaires for use in Step 4, which yielded robust data on preferences for the final product among a diverse set of consumers (Otegbayo et al., 2020; Madu et al., 2021b,c).

The results obtained in all the steps were then triangulated to identify priorities for the food product profile. The integrated method enables a deep understanding of quality characteristics, translating tacit knowledge into data that can be further investigated by scientists (for a discussion of tacit knowledge, see Polanyi, 1966, cited in Forsythe et al., 2021). The team also used laboratory-based sensory evaluation to corroborate the results of Steps 3 and 4, using scientific and industry-standard methods, to support breeding and product development work.

The Gender Plus (G+) tools are designed to help gender researchers and breeders to make joint, evidence-based decisions about the significance of gender differences and trade-offs beyond yield, disease resistance, tolerance of environmental stressors, and other agronomic traits (Forsythe et al., 2021; Polar et al., 2022). The team applied the G+ tools to product profiles to describe the characteristics that can determine whether or not a variety is likely to be grown or eaten as boiled or pounded yam. The use of these methods led to positive results discussed in several multidisciplinary product profile meetings, including the varietal release committee, which informed the release and adoption of new clones bred at NRCRI.

A range of methods (Table 2) were used along the whole value chain, from pre-harvest (PVS, PPB, etc.) to post-harvest (processing diagnostics, consumption trait preferences, G+ tools, social survey research, etc.). The yam varieties used for these studies were harvested as part of the AfricaYam field trials.

We organized our studies so that everyone on the gender team worked within their area of expertise. Some researchers (gender specialists and extension specialists) conducted FGDs in which farmers were separated into groups by gender. Other researchers (economists, food scientists, enumerators, etc.) held individual, key informant, and market interviews. In Ebonyi State, for example, various dialects of the Igbo language posed a communication barrier for our enumerators, but that was taken care of by the guide interpreter whom we employed for the studies. For example, in the Ezzamgbo community, one farmer described the taste and feel of a particular yam variety in the local dialect as *ona afia na onu*, which means that the yam draws very well. Guides and extension agents who understand the local dialects were able to interpret what the farmers were saying. Some of the words used in the study area were difficult to understand because they were borrowed from the languages of neighboring tribes. Some of the local dialects included sounds not found in the standard Igbo repertoire of 36 phonemes.

However, the diverse nature of the team did come with challenges when the members emphasized their own disciplines. For example, the food scientist leading the processing diagnosis and laboratory tests and the social scientist conducting consumer studies demanded yams for cooking and tasting, while the breeder and agronomist protested that this would use up the yams needed to plant the next year's trial. Unlike cassava, the yam tuber is both food and seed. This challenge almost caused the gender team to lose focus, but assertive leadership helped all the players to understand that we needed each other. During consumer studies, the breeders did not understand that we were dealing with human beings of diverse personalities, natures, and ages. The breeders were always concerned about moving to the next field trial in different locations or regions. This concern was mitigated by getting them involved in consumer studies so they could appreciate the process, which went a long way in dealing with the problem. The most effective solution was bringing all actors to the field to witness the process firsthand. This enabled us to appreciate each other's roles and attempt to accommodate one another. Meetings and presentations for sharing updates and expectations were also effective.

Breeding outcomes and impacts

Our work shows that yams are still in high demand in Nigeria. However, 68% of those who cultivate yam as a primary livelihood belong to the poorest income group (Agbaje et al., 2005). Increased yam improvement research could reduce poverty. The gender team at NRCRI used a holistic approach with various tools (G+ tools, triangulation, ranking, etc.) to facilitate the adoption of preferred varieties.

The gender team conducted a baseline survey (Table 1, Step 2) using social survey research (Table 2), e.g., focus group discussions, key informant interviews, individual interviews, and market interviews. We documented the key priority traits desired by farmers, consumers, and marketers and found that there were similarities and differences between different sections of the country (Otegbayo et al., 2020). In addition, quality traits (study of trait preferences, Table 2) were found to vary by region; in the west of Nigeria, a food called *amala* is made from dried yam ground into flour. Drying the yams makes them dark, so the color of the tubers does not matter. However, in southeast Nigeria, white tubers were found to be important for making pounded and boiled yams. These traits were also emphasized within the triangulation and G+ tools (Table 2). The product chain includes production, usually by men assisted by women and youths on male-owned farms. Adult men usually harvest and transport the yams, while men and women sell them. Marketers and consumers include hoteliers, households, food vendors, schools, and hospitals (Madu et al., 2018). In the southeast and southwest regions, consumers were found to have preferences for certain yam traits at various stages: (1) agronomic and postharvest, (2) in processing, and (3) as prepared foods (Otegbayo et al., 2021). Men, who produce yams, emphasize yield and color, while women processers pay attention to texture, taste, ease of peeling, aroma, mealiness, poundability, and color.

In collaboration with the gender team, the agronomic team selected yam farmers to take part in the PVS on-farm trial (Table 2). Since yam is a male-dominated crop, with myths enshrining its virility, it was considered that the presence of many women could disrupt the PVS. Some communities were skeptical that we wanted to include equal numbers of women and men in trials and consumer studies. Taking that as a lesson, we decided to take it one step at a time; women sometimes opted out of the study, saying that they were not yam farmers, but they can help the men in some activities such as weeding and packing harvested yams into the barn. Women are allowed to participate in yam production if they are past reproductive age or if they are widows (and household heads). Young men and women have no rights to produce yam; they only help the men, which meant that young people were excluded from on-farm trials. However, in the course of preference ranking of varieties by farmers, we used sex disaggregation to determine the preferred varieties or trait preferences. Our holistic approach considered production, marketing, processing, and sensory characteristics (taste tests).

Consumer testing (Table 1, Step 4) in urban, semi-urban, and rural settings revealed preferred traits for boiled and pounded yam, generating positive results that led to the release in 2023 of three promising new varieties bred by the NRCRI in collaboration with the IITA: UMUDa35-Delight, UMUDr33-Blessing, and UMUDr34-Sunshine. These remarkable varieties are tasty, high-yielding, high in dry matter, well-suited for making flour, boiling, and pounding, and resistant to anthracnose disease (Table 1, variety release; Africa Yam Team, 2023). This long-term commitment to consulting farmers' opinions or involving them directly in selection can produce notable improvements in adoption rates, and released varieties will be more strongly appreciated by farmers, especially women in Africa (Witcombe et al., 2005; Njuguna et al., 2016; Weltzien et al., 2019; Polar et al., 2021).

Discussion

The study investigated the prioritization of traits within the yam value chain in Nigeria along gender lines, from

TABLE 2 Methods and approaches in yam variety development.

Activities	Description
Participatory varietal selection (PVS)	From 2017 to 2022, the NRCRI gender team participated in the RTBfoods and African Yam projects, employing methods involving farmers to enhance demand-led breeding. Yam tubers were selected to represent good and bad yams after a pilot sensory (taste test) evaluation with four women processors. Qualitative and quantitative information was acquired at each processing step (with raw tubers and the boiled and pounded yam), indicating how gender influences preferences and prioritization of produce and product characteristics (Madu et al., 2021b,c,d; Otegbayo et al., 2021).
Participatory plant breeding (PPB)	Analyses of data from PVS (see above) formed part of the inputs to enhance PPB.
Citizen science with mass volunteer participation	A well-structured questionnaire was used, sampling producers, processors, and yam consumers. Key informant interviews (KIIs) with women market leaders, focus group discussions (FGDs) with men and women, individual interviews (IIs), and market interviews (MIs) captured information on boiled and pounded yam. The participants signed consent forms.
Experimenting farmers organized in groups contribute to the breeding program	Women leaders (market leaders, opinion leaders, and local chairpersons of social or faith-based groups) participated as key informants. Because they command credibility in their communities, they were able to mobilize and convince other women's groups to participate in the surveys on trait preferences for targeted breeding.
Evaluation by farmers (comparisons) and selection of materials	Pair-wise ranking was adopted to enable farmers to select preferred yam varieties at various stages (fresh, peeled, boiled, and pounded) following Forsythe et al. (2021). At the production stage, more men were consulted because they dominated yam farming, while more women participated in the processing and end-product stages.
Social survey research	Sociodemographic data were gathered from the participants and interviewees.
Value chain analysis or mapping	Madu et al. (2021e) mapped the value chain for yam in the southeast region of Nigeria, including rural–urban trade flow, proportion consumed and processed, and value chain actors (men, women, youths, etc.). Nweke et al. (2013) also mapped the value chain for yam in Nigeria.
Study of trait preferences	The AfricaYam project is mainly focused on varietal creation, and the RTBfoods project focuses on the quality of RTB-based processed foods (Lebot et al., 2022). The NRCRI gender team (a cross-cutting team) participated in the RTBfoods project to complement the objectives of the AfricaYam Project and to identify quality characteristics of boiled and pounded yam for different user groups using a five-step method (Forsythe et al., 2021). Participants (disaggregated by gender and rural vs. urban) described high-quality food products from a list of sensory, processing, and agronomic characteristics.
Use of G+ tools for consumer or product profile assessments	The G+ tool (Polar et al., 2022) was used to validate and synthesize the trait preferences stated by actors on the yam value chain to prioritize breeding (Madu et al., 2022).

planting to plate. Surveys and on-farm trials used methods that involved critical assessment (both quantitative and qualitative), with particular attention to measurement. Various data collection and fact-finding instruments were used, such as individual, market, and key informant interviews, observations, and FGDs, to enhance demand-driven research and prioritize traits to aid breeding. The data elicited were synthesized using various methods, particularly the G+ tool, which helped in prioritization and in defining trade-offs between preferred traits. The cross-cutting gender team facilitated successes, good practices, and lessons learned, culminating in the release of three improved varieties with some of the traits prioritized by consumers. This approach is expected to increase the adoption of the new yam varieties and can also serve as a guide for future research studies.

Good practices

Markets and consumers

Participants were gender-disaggregated to include each node of the value chain (Table 1, step 2). These nodes include the direct players (producers, processors, and consumers) and the indirect players who facilitate the chain (transporters, loaders, input dealers, and credit agencies). All these actors had a say in describing the yam qualities that would meet demand, leading to enhanced livelihoods.

Breeding objectives

Going forward, all projects now have a gender component that will incorporate a benchmark study and a rapid appraisal as a guide for breeders. Incorporating consumers' preferences avoids the disadoption of released varieties. Working together in the field, as well as analyzing and triangulating agronomic, processing, and consumption data, informs and guides breeders.

Methods for evaluating varieties

Gender-disaggregated multidisciplinary studies have begun to be incorporated into the early stages of variety design to enhance the consideration of gender in prioritization of preferred traits.

Seed multiplication and dissemination

The use of certified seed (cassava, yam, and sweet potato) by companies such as Umudike Seeds Ltd., village seed entrepreneurs (VSEs), aeroponics, and various research institutes helps to ascertain the quality of the seeds being disseminated and keep track of them. VSEs help in the rapid dissemination of planting materials; they comprise men and women who serve as outgrowers and maintain quality control in the production of seed.

Lessons learned

Breeding strategy

The bottom–top approach, with a mix of methods, promoted a better understanding of the breeding protocol and of how to develop demand-led, gender-intentional product profiles.

Criteria for evaluating the importance of traits

Pair-wise ranking, hedonic scales, scores, percentages, and ranks were used to rate the importance of choice traits (Table 1, Steps 2, 3, and 4). We needed to be careful to avoid confusing the use of ranks (1 through 5), where 1 was the most preferred, with mean scores (where 5 represented the most preferred), but we were successful in this. When we evaluated multiple traits, some were tied with each other for the same rank. The G+ tool helped to disentangle the importance of tied traits.

Relative importance or weight given to different traits

In future yam studies, economic values will be assigned to traits to prioritize actors' preferences for those traits (Balogun et al., 2022). This method changes the traditional economic approach to ranking tools, balances economic and non-economic drivers, and quantifies the views of participants by gender and social strata.

Prioritization of traits in breeding

This involves the use of a multidisciplinary approach from the start of breeding to select the traits that end users prefer and to involve these actors (gender disaggregated). Breeding for end users facilitates the release and adoption of new varieties. Holistic information should be provided by all stakeholders. Women should be encouraged to become involved in the different stages, not only in cultivation, which is dominated by men.

Choice of materials to advance to the next stage of breeding

High- and medium-throughput methods like near-infrared spectroscopy should be developed and used. Consumer-preferred traits should be correlated with the biophysical properties identified in the lab to obtain a threshold for selection (RTBfoods). High-throughput methods save time and money when making breeding decisions, so that promising clones will not be dropped but non-promising ones will be. This method has already been developed for rapid characterization of the color and texture of gari-eba.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found at: https://agritrop.cirad.fr/602044/, https://agritrop.cirad.fr/602099/, https://ifst.onlinelibrary.wiley.com/doi/full/10.1111/ijfs.14770, https://www.researchgate.net/publication/351706422_State_Of_Knowledge_Report_Synthesis_Report_for_Yam_in_Nigeria, https://mel.cgiar.org/reporting/download/report_file_id/25482, https://agritrop.cirad.fr/602029/, https://agritrop.cirad.fr/602029/1/RTBfoods_Participatory%20processing%20diagnosis_Boiled%20yam_Nigeria.pdf, https://mel.cgiar.org/reporting/download/report_file_id/25467.

Ethics statement

The studies involving humans were approved by the National Root Crops Research Institute that has the mandate for Root and Tuber Crops Research in Nigeria. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

All authors made significant contribution to the study, conception, study design, execution, acquisition of data, analysis, and interpretation. All authors read through the different drafts of the study, and made substantially and critical contributions to the review of the article. BO contributed to most to the study and including writing of the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The 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.

The reviewer OU declared a past collaboration with the authors BO, OO, TM to the handling editor.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsoc.2023.1232626/full#supplementary-material

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Closing gender gaps through gender-responsive, demand-led breeding in Burundi

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Gender inequality persists in Burundi's agricultural sector, especially in the bean value chain dominated by women. Women often have less access to improved seeds and to productive technologies. Interventions dubbed "gender-responsive plant breeding" have been launched to develop new varieties to address the gender gaps in variety adoption. Gender responsive planting breeding in Burundi targets to develop bean varieties that respond better to gendered varietal and trait preferences. This paper provides a background of gender-responsive bean breeding in Burundi, documenting the methodologies that were used to integrate gender issues in bean breeding and socio-economic research. It also covers successes of gender-responsive breeding to date, primarily focusing the interdisciplinary teams that drove the process, development and release of varieties that incorporated traits favored by women and men actors. Evidence from surveys and value chain analysis reveal that gender-responsive breeding program increased the adoption of improved varieties by women and improved yields and productivity. The paper reveals that gender-responsive and demand-led bean breeding programs require stakeholders engagements to develop products that align with preferences of diverse actors at different nodes of the bean value chain.

KEYWORDS

bean breeding, gender equity, gender-responsive breeding, Burundi, traders, value chain, demand-led breeding

1 Introduction

1.1 Why did the breeding initiative pay attention to gender?

Common bean is one of the most widely produced, traded, and consumed leguminous crops in sub-Saharan Africa. Important dynamic in common bean production, trade, and consumption is the dominant role of women. Therefore, bean breeding programs have for the past decade paid attention to gender issues in the bean value chain. Even though breeding programs are important tool for improving food security and nutrition in sub-Saharan Africa (Kondwakwenda et al., 2022), they need to take gender issues into account to address social issues – gendered needs and preferences of end users and gender-differentiated adoption and outcomes – associated with

technology adoption (Tufan et al., 2018). Gender considerations in plant breeding ensures that breeding products responds to diverse needs and priorities of men and women farmers, traders, processors, and consumers. Traditional gender roles and relations in Burundi favour men's effective participation in agriculture (Rames et al., 2017). Gender roles in Burundi's bean value chain are clearly defined. Men are primarily responsible for managing land and agricultural inputs. In contrast, women typically provide farm and post-harvest labour in bean production. Women are heavily involved in labour-intensive activities, such as land preparation and weeding and harvesting and post-harvest activities. Despite their contribution to bean production. Household power dynamics in Burundi's farming households often excluded women from decision-making in agriculture, limiting their access to resources and technologies (e.g., land, seed, and other farm inputs) as men, and prevents them from benefiting from their participation in bean production (Nchanji, 2020).

The significant participation and contribution of women in bean value chain in Burundi informed breeding initiatives' attention to gender. While there is substantial women's presence in Burundi's bean sub-sector, there are limited comparative studies that capture gender dynamics and existing gender gaps in use of bean technologies (Nchanji et al., 2023a). Biofortified bean breeding initiatives also paid attention to gender to address malnutrition and food security issues among rural households (Nchanji et al., 2023b). Women in Burundi play a crucial role in household nutrition and food security and therefore their involvement and consideration in bean breeding programs was vital for effective tackling of malnutrition. As noted by Nchanji (2020), women benefit less from participation in the bean value chain compared to men. Thus, breeding initiatives in Burundi paid attention to how gender integration can contribute to women's empowerment, increased access to resources, and economic benefits. Finally, breeding initiatives attention to gender was also a culmination of the recognition of the need to make breeding programs inclusive and effective by considering diverse needs and preferences of all stakeholders as emphasized by breeding programs elsewhere in Eastern and Southern Africa (Nchanji et al., 2022).

2 Context

The team that worked on gender responsive breeding was drawn from the Institute of Agricultural Science of Burundi (ISABU) and the Alliance of Bioversity International and CIAT (ABC). The ISABU team was composed of two bean breeders, a gender expert, two agronomists, and one socio-economist. The ISABU team was supported by experts from ABC through the Pan-Africa Bean Research Alliance (PABRA) programs in Burundi. The ABC team consisted of a gender and social Inclusion expert, an integrated crop management (ICM) expert, a regional bean breeder, seed systems and impact assessment experts, a nutritionist, and a socio-economist. The breeders owned the breeding process and made decisions about bean traits, guided by information from team experts.

The role of common bean in addressing food and nutrition problems and empowering women in Burundi was recognized by the Burundian government four decades ago. As the government, through ISABU, initiated several bean breeding programs in response to government commitment food security and nutrition and women empowerment commitment (PABRA, 2021). The breeding programs were further strengthened after the establishment and commencement of PABRA activities in Burundi in 1998. The International Center for Tropical Agriculture (CIAT)- supported PABRA in early 2000 to work with ISUBU Burundi to rebuild it bean research programs following years of civil war which culminated in launch of a flagship project - Improving food security, nutrition, incomes, natural resource base and gender equity for better livelihoods of smallholder households in Sub-Saharan Africa – in 2015 the project focused on improving food security, nutrition, incomes, natural resource base, and gender equity. This project aimed to strengthen seed production and increasing women's access to production resources.

The journey towards gender-responsive bean breeding in Burundi's bean breeding programs can be grouped into three periods: before 2015, 2015 to 2018, and after 2018. Before 2015, breeding programs in Burundi were driven by breeders, focusing on farmers' varietal and trait preferences, with no consideration of gender. Additionally, breeders paid little attention to the interests of traders, processors, and consumers, who were not invited to the PVS studies. Data was collected solely by breeders and agronomists, and traits were ranked to reflect farmer preferences.

A series of awareness raising events on gender in breeding took centre stage in the 2015–2018 period, which was marked by increased attention to gender. The gender expert from ABC made three presentations on the importance of gender integration in participatory varietal selection (PVS) during different meetings in Burundi. The ISABU team received training in integrating gender in PVS and other breeding activities. Breeders and agronomists attended four regional breeding meetings in Tanzania, Kenya, Ethiopia, and Uganda where gender integration was intentional. The most recent training happened was May 2023 in Tanzania. Furthermore, PABRA sponsored ISABU agronomists and breeders to attend a training in Nairobi, where other value chain experts were invited. The meeting oriented the ISABU team to widen its interest in the bean value chain.

PABRA also sponsored ISABU breeders and agronomists to attend the Gender-Responsive Equipped Agricultural Transformation (GREAT) training in Uganda, where breeders from several African countries shared experiences about integrating gender in breeding and seed systems, including challenges, solutions, and opportunities. The GREAT training was an eye opener for the Burundi breeders about entry points for gender-responsive bean breeding. For instance, the GREAT training enabled ISABU breeders and agronomists to recognize opportunities for gender-responsive breeding, including benefits for targeting smallholder women farmers, entrepreneurs, and farmer organizations, in increasing use of plant breeding products. The training also enhanced the capacity of ISABU breeders and agronomists in designing research projects that maximize delivery of equitable outcomes for all genders.

During the 2015–2018 period, PABRA gave financial support to the ISABU team to collect data with a gender lens. This support led to two publication of research papers on gender dynamics and social norms in bean production among smallholders in Burundi (Nchanji et al., 2023a,b). A stakeholders' meeting was also organized in Burundi, attended by bean traders and processors, to enable the ISABU team to understand that crop variety and traits preferences are not uniform, but vary across gender, sociocultural contexts, agro-ecological factors, and type of stakeholder (Nchanji et al., 2023b). During the workshop, the ISABU team created a common

understanding of demand-led breeding, which not only concerned gender equity, but also inclusivity. The ISABU gender expert became part of the data collection team to ensure that PVS was not farmer-centric, but included data collected from men and women farmers, traders, processors, and consumers.

After 2018, all team members assumed clearly defined roles and responsibilities. Breeders were still dominant, but other team members now helped to guide breeding objectives, and to give greater attention to demand-led breeding. The ABC gender expert trained the ISABU team on how to integrate the gender product profile tool (G+ tool) with existing data collection tools, such as PVS (Nchanji et al., 2022). The G+ tools, initially adapted for gender-responsive PVS in Kenya (Nchanji et al., 2021), were further customized and applied to similar breeding programs in Burundi. Communication between gender specialists, the socio-economist and breeders became frequent. The ISABU breeders currently use information from gender analysis and market studies in product advancement decisions. Bean breeding in Burundi are now focuses on multiple themes, including end-user traits, yield potential, and tolerance to biotic and abiotic stresses (Mukankusi et al., 2019).

The breeders' takeaway messages from the training were that breeding objectives should focus on the needs of traders, processors, and consumers, and not just on men and women farmers. Breeders also learned to align breeding objectives with the national development goals, including nutrition and health, and equality. The breeders and agronomists appreciated and understood different roles, responsibilities, and needs of women and men in the bean value chain, the importance of inclusive design processes of breeding programs, development of gender-sensitive research methodologies, and importance of building networks and collaborations with other researchers and institutions focused on gender-responsive agricultural research.

3 Analysis

3.1 What research or other sources of information on gender were generated?

After the GREAT training, ISABU conducted gender study to understand gender differences among different actors and to provide evidence for gender-responsive breeding. The data were collected in 2019 using several methods. The gender-responsive PVS tool collected socioeconomic and varietal and trait preferences of men and women farmers. Gender gap questions from the G+ Product Profile tool was adapted and incorporated into the PVS to capture the social implication of farmers' preferred varieties and traits. The incorporation of the gender gap questions was based on experiences in gender-responsive breeding by PABRA in biofortified bean varieties in Zimbabwe (Nchanji et al., 2021). For instance, they asked if the preferred traits increased or reduced drudgery for women, and if the best traits changed women's access to inputs or influenced women's control of benefits and income.

Sex-disaggregated PVS data that also collected information on men and women varietal and trait preferences were used to inform breeding decisions, especially which varieties and traits to prioritize for different actors and bean regions. PVS results indicated that it was nice to have additional traits beyond the biotic and abiotic stress traits. For instance, contrary to the expectation that women would rank cooking time among the"first best"traits, they ranked it fourth. While men ranked price and marketability of the beans as the reason for choosing the top-ranked or best variety, women emphatically preferred high yield. The PVS data also shed light on the preferences of different stakeholders, such as consumers. Consequently, breeders deliberately used the PVS varietal and trait preferences data to define breeding objectives and strategies, and to develop new varieties that met the needs of the local men and women farmers.

ISABU and CIAT also conducted social surveys to understand bean production in local contexts. In the first study, Nchanji et al. (2023b) collected and analyzed data on gender dynamics in Burundi's biofortified bean value chain to illuminate the roles of men and women in the bean value chain. The data also highlighted how marital status, education, source of seed, land area cultivated, pesticide use, household income, hired labour, and gender of the household head influenced farmers' demand for extension, a critical driver of adoption of bean varieties. The second social survey study focused on the implications of social norms on gendered differences and access to climate-smart agricultural technologies and the gains in closing the gender gaps through gender-responsive plant breeding (Nchanji et al., 2023c). The study highlights that gender-responsive plant breeding has resulted in gender-responsive systems that now recognize challenges, interests, and preference of women. Nchanji et al. (2023c) acknowledges that gender-responsive breeding in Burundi has positively influenced women farmers use of certified seeds and allocation of land under bean production for women.

The interdisciplinary team from ABC and ISABU also conducted value chain analysis with traders, processors, and consumers to inform bean breeding (PABRA, 2021, 2022). Meeting with traders and processors collected information on the importance they place on different traits and the criteria they use to evaluate bean varieties. A consumer study in 2020 assessed the uptake of bean products (flours) produced by processors supported that were supported by PABRA program that aimed scale up production of composite bean flour for weaning infants and lactating mothers using biofortified beans (PABRA, 2021). The data helped to explain the uptake of nutrient-dense food products promoted by PABRA. The consumer data also provided insights on the potential demand for processed bean-based foods and drivers of demand for these products, made from bean varieties developed by the gender-responsive breeding program.

3.2 How attention to gender influenced the breeding initiative

Attention to gender has influenced the gender breeding pipeline in Burundi in several ways. First, gender-specific approaches ensured that the breeding initiative was not only in line with ISABU's objectives, but also those of actors in bean value chain. The breeding team's attention to gender ensured that future bean varieties would consider farmers' gendered traits. The breeders' attention to gender also helped to prevent any issues that could arise from a poor understanding of social issues. These influences can best the illustrated through a narrative of what occurred before and after the GREAT training in 2019.

The ISABU team was encouraged by the gender expert at the Alliance of Bioversity and CIAT to attend the GREAT course on gender-responsive breeding. The training acknowledged that despite the contribution of breeding in last five decades, most efforts targeted higher yield and resistance to climate change, pests, and diseases. The training highlighted how gender-responsive breeding is increasingly becoming popular and its implications on the genetic diversity of crops and how they address social issues (Polar et al., 2022). They described gender-responsive breeding as research that helps solve social problems such as food insecurity, poverty, and gender inequality by considering the social contexts where farming takes places and developing new bean varieties that are better suited to the needs of men and women.

The ISABU breeders and the social scientists learned that men and woman had different roles that affected their choice of varieties and traits. Additionally, the gender roles had to be continuously considered if the breeding products were to be inclusive. These realizations precipitated the inclusion of women farmers, traders, and consumers in the design stage of bean breeding. The Burundi bean research team realized that this was essential for the success of the plant breeding because of the crucial role played by women. They realized that women have unique perspectives of production and entrepreneurship problems and solutions that are often overlooked by conventional breeding. The ISABU breeders and economists understood that women are often more attuned to the needs of local communities, which can help breeding programs successfully address social issues in adoption and use of breeding products. Including women in plant breeding created a more diverse environment for better outcomes for everyone.

After the GREAT training, the ISABU team gave greater attention to gender, refining the PVS tools that breeders had previously used. Rather than relying on PVS to identify potential varieties for release, breeders at ISABU, with valuable contribution from gender expert who was previous not involved in bean breeding programs, incorporated the "gender-responsive PVS" tool into plant breeding programs, to identify traits that meet the needs of men and women farmers and traders. In addition to sociodemographic questions, the PVS tool asks the gendered implications of "best traits" on drudgery, demand for inputs, and women control over benefits and/or income from bean production (Ashby and Polar, 2021) Learnings about gendered preferences were incorporated in biofortified bean breeding programs in the country.

The ISABU breeding team's attention to gender also enabled them design new bean varieties that captured cooking time, nutrition, ease of threshing, and organoleptic traits in addition to yield, drought tolerance and pest resistance traits that were targeted by breeders before 2015 (Table 1). The gender-responsive breeding team used organoleptic tests to understand consumers' preferences, and helped breeders evaluate the quality of the varieties they in the breeding pipeline. This organoleptic evaluation assessed taste, smell, texture, and the appearance of processed products, such as boiled beans, flour, cakes, porridge, and snacks. ISABU breeders identified desirable traits and used them to create new varieties that appealed to consumers, especially women who are responsible food preparation and household diets. Organoleptic testing also helped breeders identify any potential problems with new varieties, such as off-flavours or discoloration, which were to be addressed before variety release.

TABLE 1 Traits considered in bean breeding in Burundi before and after gender-responsive breeding.

Traits considered before 2015	Traits considered between 2015 and 2015	On-going
Drought tolerance	Drought tolerance	Drudgery
Resistance to pests and diseases	Resistance to pests and diseases	Pod shattering
High yielding	High yielding	
	Nutrition	
	Ease of threshing	
	Input requirements	
	Taste	

Certain traits like short cooking time and biofortification with zinc and iron gained traction.

4 Methods and approaches: advantages and shortcomings

The bean breeding team in Burundi learned that men and women have different preferences for bean varieties, which reflect gender roles and inequalities. Bean breeding programs before 2015 were not gender-intentional when analyzing farmers' trait preferences. Breeders were farmer-centric, designing products that they thought would be suitable for farmers in general. Participatory variety selection (PVS) were typically done through general conversations with a few farmers. After 2015, several methods of data collection started to be used to collect social, economic, and breeding data (Table 2). Breeding initiative paid attention to gender after several PVS exercises (with about 50 to 60% female participation) revealed that men and women had different trait preferences. Women's increased participation in PVS was a recognition of their role in bean production and household food security. Women were recognized as vital for agricultural development, and their access to preferred, locally-adapted varieties was important in increasing yields, improving household nutrition, and promoting the equitable distribution of benefits.

The GREAT training, adoption of value chain analysis as a driver of breeding, and social surveys that documented gender gaps with implications for variety design also shaped attention to gender-responsive anddemand-led breeding in Burundi. These experiences not only exposed breeders to the social and market dimensions of breeding for gender equality but also emphasized that an effective, gender-sensitive breeding program must cater to a spectrum of stakeholders such as traders, processors, consumers and other actors, not just farmers. For instance, the gender expert at ISABU was never involved in the bean breeding program, but following the GREAT training, she took participated in designing the PVS tools (Table 3) and, she became part of the analysis team. Adopting the demand-led, client-oriented breeding approach promoted by PABRA created a fertile ground for the social survey research that strengthened the case for gender-responsive breeding. National food and nutrition security and gender policies implemented by the Ministry of Agriculture were also critical drivers of gender-intentional breeding.

TABLE 2 Methods used to generate more evidence on gender gaps and increase women's participation in bean breeding in Burundi.

Activity	Attention to gender	Method
Participatory Varietal Selection (PVS)	Yes	Intentional/targeted involvement of more women
Social survey research – gender analysis	Yes	Random and purposive selection of farmers using an intersectional perspective from multiple farmer groups
Consumer and trader studies	Yes	Direct interviews with key diverse respondents and focus group discussions during organoleptic tests. Key informant interviews and informal discussions in stakeholder meetings Gendered quantitative surveys
Value Chain Analysis	Yes	Qualitative value chain mapping through diverse and mixed focus group discussions and quantitative data collection farmers from farmers, traders and processors.

TABLE 3 Preliminary results of PVS data.

Top reason reason for selecting a trait? (%)	Female (n = 45)	Male (n = 35)
Price	33	38
Yields	36	29
Biofortified – this means "nutritional value" to the farmers?	22	13
Cooking time	4	11
Grain color	4	5
Seed quality	4	2

4.1 What in the breeding process and practice has changed because of learning about gender?

The plant breeding process and practice has changed significantly due to increased awareness of gender and social uses. Since 2019, the ISABU team has a gender analyst who is included in team meetings and contributes to decisions about which traits are important and which varieties to release. Bean breeders are now more attentive to the needs of different genders, ethnicities, and communities when they are developing new varieties. This has led to more attention being paid to the nutritional and health benefits of new varieties, as well as the potential for varieties to be used in different cultural contexts. Plant breeders are now more aware of the potential implications of their work on social issues, and they are working to develop varieties that result in positive outcomes for all stakeholders.

4.2 Breeding outcomes and impacts, especially those related to the impact on gender equity

The gender-responsive breeding initiative released three bean varieties to meet the needs of smallholder farmers between 2019 and 2021. The development of the varieties MAC52, MAC54, and BFS18 incorporated insights on gender differences in trait preferences. The varieties are fast-cooking and rich in iron and zinc, and they taste better. They are adapted to local diverse agro-ecologies, making them well-suited for smallholder farmers. The release of these varieties enabled men and women smallholders to access superior bean varieties with the potential of increasing yields and incomes, while eliminating gender inequalities along the bean value chain. With access to varieties that are better adapted to their local conditions, women farmers can produce more with less effort and resources. The improved nutritional properties of the varieties may improve the diets of rural communities, while helping to reduce food insecurity and social inequalities.

The gender dynamics study in 2021 indicated that 60% of farmers (62% women and 57% men) had adopted the MAC44 bean variety in Muyinga and Gasorwe communes of Muyinga province (Nchanji et al., 2023c). The second study showed that gender-responsive activities in Burundi closed gender gaps in the adoption of improved bean varieties, with more women adopting improved seed than men. 75% of men and young farmers used improved varieties compared to 85% of women farmers in Kirundo and Bwambarangwe communes in Kirundo province and Muyinga commune in Muyinga province (Nchanji et al., 2023c). The adoption rates are high because the communes were ISABU and PABRA program sites. The adoption has improved productivity resulting in increased income, food security, nutrition, and health. These positive impacts have been greater for women than for men. From the impact study in 2020, men and women who planted improved bean varieties recorded a 40% increase in bean yields. Partial (planted both improved and local varieties) adopters improved their bean yields by 27%. The greater bean yields resulted in 61% higher incomes for men and women, and a 15.8% increase in bean profitability (Katungi et al., 2020).

The importance of gender-responsive breeding is now increasingly being recognized in Burundi. There is increasing understanding by breeding teams, agronomists, socio-economists, and gender experts that breeding should not only recognize the differentiated roles and needs of women and men in agriculture but also equitably benefit all genders and actors in the bean value chain. For instance, plant breeders are now paying more attention to the potential of new varieties to provide multiple benefits to different social groups, such as providing food security and economic opportunities to women. The breeding initiatives are also now targeting to contribute to women empowerment and by not only developing products that captured men and women trait preferences but also contributing to addressing inequalities by generating products that improve agricultural productivity and economic benefits at different nodes of the bean value chain. Such gender-centred initiatives promises to break cultural, social, and economic barriers that constrain women participation in bean value chain beyond production and informal trade.

5 Good practices and lessons

5.1 Good practices

The gender-responsive bean breeding initiative in Burundi generated multiple good practices that are critical for similar future initiatives. Key among these is the all-inclusive engagement of stakeholders, including women farmers, traders and consumers, from design to implementation which ensures of breeding programs, to ensure that breeding objectives are aligned with needs and priorities diverse groups. Another best practice is that interdisciplinary approaches to breeding are required to enable mainstream breeding teams and social scientist to contribute their knowledge to enrich the breeding process. Additionally, trainings such as GREAT course are instrumental in enhancing breeding team's understanding and implementation of gender-sensitive approaches in breeding programs. The development and adaptation of data collection tools to local contexts, including the gender responsive PVS, helps in the identification of the traits, which were important not only for men but also for women. Commitment to data-driven decision-making also helped to effectively address gender gaps.

Another important lesson drawn from gender-responsive plant breeding in Burundi is that balancing abiotic and biotic traits with traits like cooking time and nutritional value that is particularly very important to women is critical. Furthermore, continuous monitoring is needed to assess the gender impact of gender-responsive breeding to ensure initiative's alignment with broader national policies on food security, nutrition, and gender equity. Finally, gender-responsive breeding initiatives in Burundi demonstrated the need for scalability and sustainability in similar projects.

5.2 Lessons

The gender-responsive initiatives in Burundi in the last decade offer important lessons for agricultural innovations. First, there should a strong emphasis on integrating gender considerations in agricultural research and development to cater for diverse needs and priorities for effective and inclusive innovations and outcomes. Second, interdisciplinary approach, collaboration of expertise from agronomists, gender experts, socio-economists, and breeders, is pivotal for the success of gender-responsive breeding. Collaboration during breeding is crucial in integrating skills and nuanced perspectives to the intersection of agriculture and gender. Key to the effectiveness of the gender-sensitive breeding was training and capacity building, as demonstrated by the GREAT program. Specifically, training was essential for creating gender-responsive awareness among breeders and agronomists. Another important lesson is that alignment breeding program initiative with national and regional policies on food security, nutrition, and gender equity is paramount for sustainable impact. Finally, assessment of gender impact of breeding programs and addressing emerging challenges that may prevent inclusive adoption are essential for the success of gender-responsive agricultural initiatives.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were carried out by ISABU - a government entity - in accordance with the local legislation and institutional requirements. The participants provided their verbal and written informed consent to participate in this study.

Author contributions

BN: Conceptualization, Formal analysis, Funding acquisition, Methodology, Project administration, Visualization, Writing – original draft, Writing – review & editing. EBN: Conceptualization, Formal Analysis, Funding acquisition, Methodology, Visualization, Writing – original draft, Writing – review & editing. CL: Formal Analysis, Methodology, Writing – review & editing. EN: Data curation, Supervision, Writing – review & editing. MH: Data curation, Supervision, Writing – review & editing. IM: Data curation, Supervision, Writing – review & editing.

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Conflict of interest

The 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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Gender-inclusive consumer studies improve cassava breeding in Nigeria

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Including gender research in cassava breeding makes it easier for farmers to adopt new varieties that meet the specific needs and preferences of both male and female farmers, leading to increased adoption of new varieties, improved productivity, and better economic outcomes for the entire farming community. Gender was included in 2013 in variety development at the National Root Crops Research Institute (NRCRI), Umudike, Nigeria in response to the dis-adoption of some varieties by farmers who had not been part of varietal development from the start, and in light of social roles which influence the responsibilities, resources and livelihood outcomes of men, women and youths. Gender inclusion has given plant breeders accurate information about the cassava traits preferred by all end-users, not just male farmers. At NRCRI, gender studies intensified in the last 5 years, contributing to the development and release of improved varieties. Quantitative and qualitative research by the gender cross-cutting team modeled trait profiling and consumer preferences, to aid demand-led breeding. Some of the methods were acquired at several trainings on how to quantify qualitative responses for prioritization. Gender research techniques include participatory varietal selection (PVS), participatory plant breeding (PPB), mother-baby trials, focus group discussions (FGD), surveys, value chain mapping, G+ tools, experiments in farmer field schools (FFS), demonstration farms, and tricot. These gave the cross-cutting team a better understanding of gender relations, power, decision-making, ownership and control of resources, and have mitigated operational and field challenges during the surveys. These methods also elicited feedback from end-users that led to better naming of newly released varieties, reflecting perceptions of agronomic performance, and food qualities, which made the varieties easier to identify and remember.

KEYWORDS

social movements, institutions and governance gender, good practices, end-users perception and processing traits, cassava, plant breeding traits, Nigeria, plant breeding gender

Introduction

Cassava, an important staple in Nigeria, is widely eaten by people of all ages, and is in great demand in all regions. Cassava is processed into many kinds of foods, which are culturally important for different social groups, across various agro-ecologies.

Gender studies is an essential field of study that examines the social, cultural, and biological differences between men and women, and how these differences impact various aspects of society. One area where gender studies are particularly relevant is in the field of agriculture and food production. As indicated by the Food and Agriculture Organization of the United Nations, "Women are the key actors in processing and food preparation" (FAO, 2011). Therefore, it is crucial for breeders to consider female-preferred traits when developing new agricultural products.

In many cultures, women are primarily responsible for food preparation and processing. This means that the traits they value in agricultural products, such as taste, texture, and ease of preparation, are of utmost importance. Neglecting to consider these preferences can result in a disconnect between the products being developed and the needs and desires of the individuals who are responsible for utilizing them.

Furthermore, gender studies can also shed light on the unequal distribution of labor and resources within the agricultural sector. According to the World Bank, women make up 43% of the agricultural labor force in developing countries, yet they often have limited access to resources such as land, credit, and technology (World Bank, 2009). Understanding these disparities is crucial for developing more equitable and sustainable agricultural practice.

This diversity in cuisine influences varietal adoption. When a recently released variety lacks the traits of interest to end-users, they may try the new cassava, and then abandon it. For instance, women who process cassava into yellow *gari* in Benue State were early adopters in 2011 of yellow, cassava, biofortified with vitamin A. But in Oyo State, the local market demanded white *gari*, so yellow cassava was only adopted where yellow *gari* was made for sale in cities like Lagos. *Gari* (or cassava semolina) is a gelatinized, fine to coarse granular flour made from grated and fermented cassava roots (Teeken et al., 2021). Women adopters who did adopt yellow cassava said that it needed improvements such as roots that would not rot after 12 months in the ground, dryer roots (less water content) and cassava that would retain more carotenoid after processing into *gari*. The women processors are able to assess the carotenoid retention by observing the intensity of the orange color in the gari (Ilona et al., 2017; Olaosebikan et al., 2019), which informed breeders as they developed the second and third waves of biofortified cassava, released in 2014 and 2021.

Through conventional breeding, these improved, biofortified, third wave cassava now have more dry matter, mealier texture, and the roots can be left unharvested for longer without rotting. If communities lose access to the planting material of improved varieties, farmers return to planting local cultivars, which are readily available. Even if end-users like the new varieties, they are often dis-adopted because farmers do not always save stems, and the planting material may become locally unavailable (IITA, 2015; Bentley et al., 2017). Unlike grain crops, cassava is reproduced vegetatively, with stems, which are perishable, so it is difficult for farmers with little land to conserve the varieties. Women have limited access to land, so they grow less cassava and process more of it (some of which they buy). Women tend to run out of stems more often. Dis-adoption of new varieties, either because farmers do not like the new varieties, or cannot get the planting material, limits the achievement of key breeding objectives, such as improving yields and livelihoods.

By 2015, evidence documented by social scientists at NRCRI and partner institutions, showed that men and women may prioritize different cassava traits (Bentley et al., 2017; Teeken et al., 2018). Some specific traits are preferred by the men and women who perform particular tasks in the cassava value chain. Because consumers rejected varieties lacking preferred traits, cassava breeders recognized the need for information to design varieties that meet the demand of producers, marketers, processors and consumers. The researchers also realized that this information should capture the different needs of women and men.

Age, class, ethnicity and gender affect access to resources (Madu et al., 2021a). Gender differences on their own are too simplistic to explain all of varietal choice and adoption. Categorizing users to include gender while taking into account other important social characteristics is vital. When selecting participants in our studies, the team used a task group focus. We define a "task group" as a set of people with hands-on experience in cassava farming, marketing and processing. We never used sex as a direct criterion for selecting informants; instead we identified the different tasks performed by men, women, or both in cassava production and processing and marketing, and then we selected participants who were well-informed on various tasks. These task groups usually include men and women who perform the tasks locally ascribed to their sex. We also considered intersectionality, where participants come from different age groups, or ethnic groups, where each one might represent a different mode of production (more mechanization vs. less, or hired vs. household labor).

This task group approach focuses on who does what along the value-chain and allows for a close integration with participatory trials, post-harvest processing, and breeding, which are all connected to specific tasks. People can simultaneously belong to different task groups and the extent to which men and women do certain tasks, and belong to one group or another are informative about gender roles, norms and possibilities within farming, processing and selling. The task group approach fits in the "social targeting and demand analysis" breeding stage, but could also be used within participatory breeding strategies (generation of new varieties). Some cassava processing activities like grating may have mixed a gender composition. Toasting *gari* and preparing *eba*/*fufu*/*akpu* are mainly by females, but male youths may help their mothers. *Fufu* is a traditional fermented food product in southern, western and eastern Nigeria and other parts of West Africa (Rosales-Soto et al., 2016; Chijioke et al., 2020), usually described as a "wet paste food product" ranking second after *gari* as a food product from cassava (http://www.cassavabiz.org/). In some regions men do the jacking: to press grated mash with a hydraulic truck jack.

Context

Most Nigerians rely on cassava, yet the country never has enough of it and the prices of derived products such as *gari*, *fufu*, and cassava flour, keeps increasing (Ekott, 2021). Globally, Nigeria ranks first in cassava output (60 million tons) and land devoted to the crop (7.7 million hectares) but 66th in productivity (7.75t/ha). In Nigeria, about 90% of cassava roots are processed into food (as

opposed to alcohol, for instance). Seventy percent of the cassava produced is made into *gari*, and almost all of the rest is prepared into foods like *elubo* or *lafun*, *fufu*, or *abacha* (Otunba-Payne, 2020). *Gari* is preferred over *fufu*, with its short shelf life and tedious processing methods (Chijioke et al., 2020).

More than 500 million people in Africa eat cassava foods daily (Bakum, 2020). Cassava is more resilient than maize and wheat to climate change and is expected to play an important role in ensuring food security in Africa in the decades ahead. Some cassava varieties can be eaten fresh, and some derived products (e.g., starch) are crucial as industrial raw material. The potential demand for cassava is high, in part because the diverse ethnic groups of Nigeria make it into so many kinds of foods. Preferences for food characteristics can be influenced by socio-economic status, household size, culture, and health perceptions (Bello et al., 2020). Some cassava projects like NextGen and RTBfoods developed research methods to identify traits preferred by men and women farmers, processors and end-users for specific food products. These make cassava breeding demand-driven, gender-responsive and inclusive; to enhance the probability of adoption of newly released varieties (https://www.nextgencassava.org/).

These projects have used different approaches to identify trait preferences, such as direct ranking (Abeyasekera et al., 2002; Dao et al., 2015; Teeken et al., 2018), or choice experiments (Asrat et al., 2010; Blazy et al., 2011; Acheampong et al., 2018). Some trait preference studies have addressed social differences among cassava producers, processors and end-users (Chijioke et al., 2020; Ndjouenkeu et al., 2020; Teeken et al., 2020, 2021; Forsythe et al., 2021; Madu et al., 2021a,b,c,d). Bechoff et al. (2018) indicated a dearth of information on gender-specific crop trait preferences, because they are rarely considered in breeding programs. Teeken et al. (2021) noted that various studies have identified gendered trait preferences, without analyzing how they interact with household characteristics, and geography. The complexities involved in processing major cassava products (*gari* and *fufu*), mainly by women, calls for introducing a crosscutting team and gender mainstreaming, to breed varieties that meet end-users' needs for *gari* and *fufu* (Chijioke et al., 2020). Success stories are needed to explain how newly released varieties incorporated end-users' preferences.

Analysis

Multidisciplinary approach for inclusive cassava breeding

Gender studies at NRCRI Umudike started around 2015 for cassava, introduced by the NextGen Breeding Project, a multidisciplinary collaboration among gender experts, breeders, food scientists, social scientists, extensionists, statisticians, and economists during field trials. In the beginning, gender experts and social scientists were saddled with the task of identifying stages win the breeding cycle where gender approaches help to make breeding inclusive and reduce gender-blind trait prioritization.

This was followed by a mixed methods approach involving surveys, feedback exercises and a gender- intentional method for selecting participants with purposive sampling. The baseline and monitoring surveys, stakeholder interviews, and focus group discussions (FGD) targeted all actors within the cassava value chain (producers, processors, marketers and end-users). The extension specialists within the institute and national extension agents worked hand-in-hand when visiting or selecting communities, and for community engagements before the interviews. The multidisciplinary team validated the survey instruments before fieldwork. Field data were cleaned, stored and organized for analyses. The breeders managed samples (leaves and roots) from the field, while the food scientists performed laboratory testing and sensory panel testing of food products (Forsythe et al., 2021). In the early years, breeders only relied on the laboratory, trained panelists and sensory testing for food product evaluations, which were useful, but rarely depicted real-life experience. Recent projects such as NextGen Cassava Breeding, RTBfoods and 1000FARMS, have piloted methods for consumer testing, such as check-all-that-apply (CATA), just-about-right (JAR) and triadic comparison of technologies (tricot) (van Etten et al., 2019a, see Table 1).

These methods were used to document trait preferences for roots, *gari* and *fufu* among men, women and youths in the different value chain segments. The G+ tool was used to document trait trade-offs (Forsythe et al., 2021; Polar et al., 2022) to corroborate priority ranks assigned to the traits. Going beyond sensory traits (e.g., taste), our studies also identified the influence of socio-demographic characteristics, location and food habits on the preferred quality traits of *gari* and *eba* in Nigeria (Teeken et al., 2021; Olaosebikan et al., 2023). There is now a well-established and cordial relationship among the economists, data curators, application developers, data analysts, statisticians, breeders, social scientists and food scientists as they work together to analyze traits and present them in an easy- to-understand format that can be incorporated into the breeding programs.

How attention to gender influenced cassava breeding in Nigeria

The socio-economic team brought to breeders' attention issues raised in previous adoption studies, e.g., the social dynamics, and cultural norms that influence the assignment of responsibilities, and scarce resources and the livelihood outcomes of men, women and youths (Quisumbing et al., 2014; Orr et al., 2018; Polar et al., 2021a,b). The responses of men and women in several surveys indicated significant complementary and some dissimilarity in trait preferences and varieties adopted and dis-adopted. Going forward, NRCRI participated in trainings and projects such as Gender-Responsive Equipped Agricultural Transformation (GREAT), RTBfoods (for four product food profiles; boiled yam, pounded yam, *fufu*, and *gari*), and NextGen Project (including tricot, Rhomis, 1000 minds surveys). These projects aimed to package gendered consumer preferences into insights that breeders could use. This increased the efficacy of selection aimed at increased adoption of improved root and tuber crop (RTC) varieties in Africa.

TABLE 1 Methods and approaches.

Activities/timeline	Description
Participatory Varietal Selection (PVS)-—2020–2022, still ongoing, scaling to other crops in Nigeria	The Triadic Comparison of Technologies (tricot) method was managed by farmers in their own fields. Farmers were given 3 varieties of cassava and a protocol to set up small plot trials that were easy to manage. Farmers were trained as citizen scientists to collect data electronically and give feedback to the researcher. Farmers reported their choices of the agronomic and food quality traits of the varieties. Important criteria for adoption, which are easily overlooked at researcher-managed trials, are accounted for by the men, women and youths participating as citizen scientists (van Etten and Steinke, 2021). This approach is now being adopted by the variety release committee in Nigeria. The team (breeder, gender expert, social scientist and food scientist) participated in anchoring tricot trials for a PhD students' work in breeding in (2020–2021). All the disciplines worked together harmoniously bringing in their expertise
Participatory Plant Breeding (PPB)	From the PVS, demand-driven research and decision-making is enhanced to facilitate screening of promising genotypes to advanced stages of plant breeding, resulting in the release. The farmers, especially participants in the mother-baby and tricot trials, assessed the traits in the field
Mother-Baby Trials (2017–2019)	NRCRI and IITA set up mother-baby trials in South-East and South-West Regions of Nigeria to engage women and men small holders and processors from 2017–2019 to enhance targeted and demand-driven breeding (Teeken, 2019). Preferred varieties included NextGen clones (Teeken et al., 2021)
Citizen science involving mass volunteer participation in the research (2017–2022)	Using the RTBfoods method, interviews with women leaders and community leaders, focus-group discussions with participants in the value chain. Marketers study (especially SoK, gendered food mapping, and consumer testing). Elicited trait preferences from many and diverse farmers
Experimenting farmers formally organized in groups or committees or networks to contribute to the breeding	Female farmer-processors who participated in the tricot and mother-baby trials successfully organized themselves into groups to enhance access to information on new technology
Farmers evaluating and selecting segregating materials	Similar to PPB. Successfully conducted with participants in the RTBfoods, NextGen projects. Farmers participated in the pair-wise ranking of the genotypes at harvest and processing stages (Forsythe et al., 2021)
Social survey research	Life history analyses conducted among cassava farmers in 2018 in Imo and Osun states. Adapted GENNOVATE life history interview guide to obtain qualitative information on the importance of cassava livelihood and the social categories of actors. Gender roles, trait prioritization, asset management, independence, aspiration to power and freedom, were elicited and disaggregated by gender (Olaosebikan et al., 2021). Social segmentation was gender disaggregated (with key informant interviews, FGDs) in terms of livelihoods, wealth categories (Forsythe et al., 2021). RHoMIS–Rural household multi-indicator survey (Hammond et al., 2017), tricot (de Souza et al., 2024), poverty probability index (PPI) and 1,000 minds surveys were conducted between 2020 and 2021 to gain in-depth understanding of preferred traits by geographical location (Balogun et al., 2021)
Value Chain Analysis or Mapping (2021)	The value chain mapping for *gari* showed percentage contribution to the different nodes by production, processing, wholesale, retail, consumption (fresh and processed forms), all disaggregated by gender
Study of trait preferences	Trait preferences disaggregated by gender were elicited in RTBfoods, NextGen, and tricot-Rhomis projects by NRCRI and IITA from 2017 to 2023 for targeted breeding and demand-driven research (Madu et al., 2021a; de Sousa et al., 2023)
Use of G+ Tools for consumer or product profile assessments	G+ tools were applied for product profiles (*gari* and *fufu*). Possible harm and positive benefits were highlighted for traits at the production, processing, and consumption stages for both *gari* and *fufu* (Madu et al., 2021a,b)
Farmer-managed or small-scale, seed production	In their study on Differentials in the Cassava Seed System among Entrepreneurs in Southern Nigeria: A Gender Situation Analyses, Madu et al. (2022) highlighted issues on gender roles, seed drivers, seed flow, profitability, constraints militating against the cassava seed system
Farmer field school experiments or demonstrations	The adopted village project and school outreach program is a pilot project designed to facilitate the transfer of agricultural technologies developed by NRCRI through participatory demonstration plots in schools and communities. Both genders and youths are involved in farming activities in primary and secondary schools and rural communities (NRCRI, 2012).

(Continued)

TABLE 1 (Continued)

Activities/timeline	Description
Tricot Model	Cassava farmers (male, female and youths) managed and assessed 3 pre- released varieties of cassava throughout the value chain to determine which variety is best, intermediate and worst, based on preferred traits. This model informs the breeders and the variety release committee of the desired traits by gender (de Souza et al., 2024). The trial could not always be implemented for a year, as some volunteers were migrants who rent land. Herders destroyed some farms

Methods and approaches

Impact of multidisciplinary training and approaches in cassava development

The GREAT training in 2017 provided hands-on practical training on how to mainstream gender into breeding. It also strengthened the relationships among disciplines, enabling them to work together as a team. Most teams during the GREAT training comprised three individuals who could have been a breeder, a gender specialist, a food scientist, or a social scientist. The team relationships fostered and were scaled into projects like RTBfoods, which further showcased the benefits of achieving objectives as an inter-disciplinary team, especially the deep understanding of traits preferred by end-users (Forsythe et al., 2021) and how this knowledge could be translated into markers and biophysical characteristics for use by breeders and food scientists. These exercises within the RTBfoods and Nextgen projects have provided knowledge of new trait categories for the cassava ontology database, cassava base and breed base (Agbona et al., 2022).

Figure 1 shows five main stages in the development of gender-responsive breeding at NRCRI following the RTBfoods method. The RTBfoods project from 2017 to 2022 adopted an integrated field approach for developing food product profiles for *gari* and *fufu* along gender lines (Forsythe et al., 2021). Step 1 provides the scope of the study and identifies the gaps in research (SOK-State of Knowledge) (2017 and 2018). Step 2, in 2018, studied ranked quality characteristics among actors playing different roles on the food chain and described in-depth context of the research for *gari-eba* (Madu et al., 2021a). For Step 3, champion processors were engaged in 2019 for a deeper analysis of *gari-eba* and *fufu* quality characteristics (Madu et al., 2021b,e; Teeken et al., 2021).

Processors are an important interface, linking agriculture (knowledge of raw materials) with the market and end-users (knowledge of consumers' expectations). Step 4, from 2019 to 2022, provides robust data on final product preferences among a diverse set of end-users (Madu et al., 2021c,d). Developing questionnaires and implementing Step 4 benefited from the experience of Step 3. A gender specialist, a market economist, a food scientist, and extension specialists were among the Gender Team that conducted the fieldwork during all four steps. The team participated in several gender workshops and trainings organized by NextGen and RTBfoods projects covering fieldwork and social surveys to integrate gender. During fieldwork, several specialists were on hand to respond to agronomic, processing and use issues raised by the respondents.

Results from the different steps were then triangulated to prioritize traits for the Food Product Profiles, so that traits preferred by end-users could guide breeders. This is a bottom-up approach rather than the conventional top-down approach (breeders' product profile) used by breeders. The integrated method enables a deep understanding of the quality characteristics, translating tacit knowledge into data that can be further investigated by scientists (Polanyi, 1966, cited in Forsythe et al., 2021). Triangulation (Figure 1) is a synthesis of 4 steps (Forsythe et al., 2021) of research with value chain actors. The lab- based sensory evaluation corroborated the results from Steps 3 and 4, using scientific and industry standard methods.

In addition to the four Step methods for defining Food Product Profiles, the team also applied the G+Product (Table 1) Profile Query Tool. The G+ tools helped gender researchers and breeders make joint, evidence-based decisions about gender differences and trade-offs when deciding to include gendered and food product traits such as color, *gari* and *fufu* yield, going beyond agronomic traits previously emphasized by breeders. The G+ tool (Table 1) was applied to the products, to describe the characteristics that can determine whether or not a variety is likely to be grown and eaten as a cassava food product (Polar et al., 2022). Characteristics were assessed using the positive benefit and "do no harm" tool to decide gender impact scores for aspects such as drudgery reduction, use of hired labor, access to essential inputs, product quality and quantity, and positive valuation of traits by men and women. Advantages of this tool include: easy to comprehend and use, application of both quantitative and qualitative responses to determine trade-offs and prioritize important traits.

The quantitative and qualitative surveys combined the following tools: rural household multi-indicator survey (Rhomis), poverty probability questionnaire, and 1000minds surveys (social survey research, Table 1). For instance, the 1000minds-Rhomis results reinforce the importance of recognizing social differences among men and women, and how individual and household characteristics interact to influence trait preference variability. This information can inform trait prioritization and guide development of breeding products that have higher social impact, serve the more vulnerable and align with development goals (Teeken et al., 2021; see Balogun et al., 2021).

How the breeding changed as a result of the gender research

To meet end-users' requirements, breeders must understand the priorities, and constraints that women and men along the value chain assign to crop and animal products. Disaggregating trait preferences by sex will enhance the adoption of innovations among

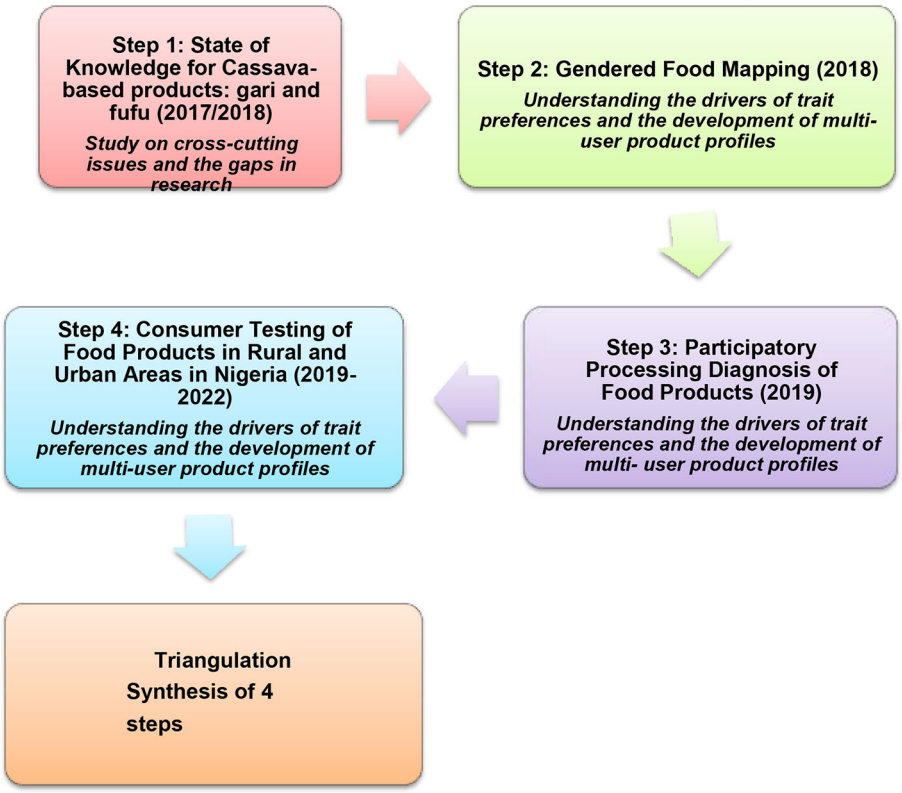

FIGURE 1
Timeline and steps in the method and integrated field approach to enhance variety development.

farmers, thereby, strengthening food and nutrition security (Tufan et al., 2018).

Research toward this end started with on-farm trials (PVS, mother-baby trials) to assess which traits end-users value for cassava and its products, and if users were willing to pay for any of these attributes (e.g., disease resistance and nutrient-rich varieties). Project researchers evaluated the trials with the farmer-processors as the crop grew, combining this information with social science tools to inquire into the aspirations and possibilities of participants. This more accurate qualitative research approach allows participants to correct, and refine their opinions. We subject most of our participatory breeding and survey data to gender and content analysis to extensively inform breeding.

Life history research (social survey research) was done with the participants who participated in the PVS and mother-baby trials. The study found that the impact on cassava-related livelihoods for men and women is greater when complemented with capacity building need by each task group (Olaosebikan et al., 2021). The use of household labor for weeding poses a challenge to women farmers, who need varieties that suppress weeds. Impacts on cassava-related livelihoods go beyond food and economic benefits, extending to women's aspirations to the power and freedom to make major life decisions.

The PVS and mother-baby trials (Table 1) aimed at enhancing the adoption of genotypes for release. Highly motivated participants maintained quality trials. In the task group approach, more experienced and knowledgeable participants were selected which gave insights to traits that breeders can work on. Results show that NextGen varieties are competing favorably with common farmer varieties. Acknowledging farmers as research partners encouraged their interest, dedication and curiosity. The use of social science research methods helped to facilitate participatory plant breeding.

During research, the team gained a better understanding that gender is shaped and articulated by the different social identities to which people belong. Currently, we are piloting the tricot citizen-science approach (Table 1-Tricot model) that involves men and women purposively selected to evaluate new varieties. This trial helps to target certain varieties to specific groups (farmers, processors etc.), and identifies who buys which cassava-based products, and who has access to resources. Other issues include: power, decision-making, diversity and communication, and the changes that would enhance gender equality and increase access to opportunities and benefits from production, processing and marketing. We included participants from different local groups and socio-economic classes. Each group represented a different mode of production (more or less mechanized and using different labor sources) to also target drudgery.

Breeding outcomes and impacts

Previous to including gender analysis in the research, the breeders felt that social science was unimportant, saying, "(social

scientists) ask too many questions and waste too much time in the field." This attitude prevailed until the start of the NextGen project, which came with the gender component, and an NRCRI Multi-disciplinary Breeding Team was created that engaged social scientists in field trials and all nodes of the value chain. The Team participated effectively in all the methods and approaches listed in Table 1, following the procedure in Figure 1. Qualitative and quantitative data were taken at the pre-harvest stage, with farmer participation in mother-baby and tricot trials. The social scientists learned on the job and helped collect agronomic data. Eliciting qualitative data from the participants revealed the social reasons behind why they preferred particular agronomic traits. This was also followed with post-harvest activities, processing and consumption (led by a food scientist). The breeders saw the need to understand trait preferences and ranking at all nodes of the value chain, instead of merely gathering field data on yield and morphological characteristics (such as stem diameter). Some varieties preferred for traits like yield, disease resistance, or even dry matter (processing), were dropped during sensory (taste) tests. For example, a particular farmer who assigned a low score to one variety during a field assessment later gave it a high ranking at the final product stage; she said *"I wish I could apologize to the cassava variety for scoring it low at field assessment, because of its architectural formation*." The G+ tool was perfectly suited to reconciling such differences, so traits could be prioritized, allowing breeders to concentrate on demand-driven traits.

Our studies have shown clear evidence in produce (root) and product (*gari* and *fufu*) trait preferences among men, women and youths within the different value chain segments; this came out more clearly in the task groups, where gender interacted with other social identifiers. This also is supported by trait trade-offs (with the G+ tool) (Polar et al., 2022), to corroborate priority ranks assigned to the traits. Our studies also identified the influence of socio-demographics and consumption patterns on the preferred quality traits (Teeken et al., 2021). Our finding (Chijioke et al., 2020), reveals a link between the preferred root quality traits (root size, heaviness, appearance), processing traits (ease of peeling, texture and high retting ability) and overall quality of cooked *fufu*. These quality attributes provide insight to cassava breeders as they redirect breeding activities (Table 2).

As a result of the successful gender studies, cassava breeding initiatives have recently prioritized two more food product profiles, focused on food security, and on improved nutritional quality and industrial needs. These include (1) processed foods, which extend the short shelf life of the cassava root, and (2) fresh cassava for eating after boiling at times of the year when yam is expensive or unavailable (Olaosebikan et al., 2023).

Discussion

Good practices

The gender findings demonstrate that it is imperative to introduce a multidisciplinary, multi-stakeholder approach in crop breeding, and to include the science behind food processing, marketing and consumption. This will help to breed varieties that meet end-users' needs and enhance the adoption of these new varieties. Female-preferred traits should be of utmost importance to the breeder, since women are the key actors in processing and food preparation. Findings identified the importance of demand-led gender-responsive breeding, trade-offs between traits as a guide for breeders.

Our successes in the research were achieved as a result of imbibing team spirit in our work, where we assist one another to make sure that tasks and timelines are completed. We organize planning meetings, team and capacity building, feedbacks and appraisal exercises, which enable us to plan tasks and set timelines to ensure we meet our deliverables. The team members are always ready to assist each other in the field. This includes mentoring by experienced leaders to teach resources (effective gender budgeting), and mobilization when needed to ensure smooth delivery of assigned tasks. Communication was also effective, making use of social media platforms such as WhatsApp, in-person and virtual meetings. With minor hitches, we bridged some of these gaps by carrying each other along, sharing ideas, and engaging more respondents, especially women who dominate the cassava value chain in Nigeria. Capacities of researchers were built on gender mainstreaming; making them more aware and gender-sensitive going forward in future projects and programs. The synergy among the multi- disciplinary team has enhanced effective breeding programs.

Outcome of lessons from learning visits facilitated by gender experts for Nigeria include: the importance of verbatim notes, and quotes; using words as the community expresses them; quantifying qualitative statements; using pictures in the sand, bottles, to compare sizing, shape etc. Pairwise ranking was more reliable in terms of understanding priorities than ranking, but is still not perfect; the G+ tool made better analyses. Some respondents are less responsive and have more trouble with the questions. The interview followed with "step by step" questions, which helped the respondents flow along Dufour et al. (2019). At the start of fieldwork, debriefing after each day's work follows with the whole team to discuss how questions should be asked, challenges and modifications. Roles for facilitation and note-taking were clearly defined. Interaction and support by all team members empowered one another. Showing organization and a friendly disposition, along with continual engagement with the respondents, was necessary. Scheduling of interviews and meetings was essential, especially for women (to enable non-interference with religious and social engagements). Expectations with the mobilizer were discussed and expectations were clarified at start of the interview. Piloting the tools is vital and each team member needs to have the same interpretation of the questions.

Women tend to answer questions clearly, while men always seem to be in a hurry. There is need for gender-inclusive methods, integrating activities for men and women for targeted breeding objectives. An enabling environment should be provided for men and women to air their voices, freedom to discuss, argue and reach a consensus in FGDs and other meetings. Opinions become more transparent as women and men are involved in decision-making and managing trials (mother-baby and tricot trials). Ways in which gender norms shape their preferences for varieties and traits can therefore be elicited. Sometimes women need a space, without men, to be able to express themselves better. Key informants, such as

TABLE 2 Changes in breeding initiatives emanating from gender inclusivity.

Definition of market(s) or consumers to be targeted	Gender analysis showed that men and women have different roles in cassava value chains that affect their trait preferences. Men and women were involved in each node of the value chain. These include the direct players (producers, processors, end-users etc.), and the indirect players who facilitate the chain (transporters, loaders/off-loaders, input dealers, credit agencies etc.). Product testing now extends beyond the four walls of the laboratory to end-users in villages, towns and cities. In addition to gender disaggregation and integration, the field team is now intentional and sensitive to enabling equity, e.g., purposively sampling diverse ethnic groups during surveys. A value chain approach is an effective way to make sure stakeholders other than male farmers and female food vendors have a say in varieties with the right qualities
Breeding objectives	Setting objectives with stakeholders was valuable for organizing product profile and advancement meetings with the inter-disciplinary team, to validate the continued inclusion of existing traits such as yield, and disease resistance. Social and gender analysis showed the importance to breeding objectives of prioritizing gender and task traits such as color, easy to peel, increased dry matter content. There is a planned stakeholder's validation meeting to discuss traits needed to boost cassava's resilience in the face of climate change and conflicts
Breeding strategy or methodology	Screening promising genotypes with key traits. Multi-disciplinary meetings facilitate in-depth understanding of traits, a robust ontology database (https://www.cassavabase.org/tools/onto/) and new learning. The breeding method has changed because of the knowledge that preferences vary for men and women. Gender is now taken into account in breeding efforts
Criteria used to evaluate the importance of different traits	Gender analysis broadened the Team's criteria for evaluating traits. Beyond food security, a gender-responsive poverty index (PPA) and industrial criteria to meet specific needs have been incorporated. Stress-resilient traits should be added next. Multi-disciplinary criteria are used to evaluate traits. Farmers, processors, marketers and consumer preferred traits are triangulated with biophysical and functional analysis for a deeper understanding of traits
Relative importance or weight given to different traits	Gender analysis using the G+ tool together with the assigning of economic values to traits has facilitated analysis of trade-offs and weighting traits for their prioritization. Using the G+ tool to prioritize trait preferences and assign gender impact scores improved the prioritization of weighted traits
The traits given priority by the breeding	Including gender analysis in the multidisciplinary approach from the start of breeding made it easier for the Team to identify traits preferred by the end-users, with the involvement of the consumers (gender disaggregated). Breeding for the end-users facilitated adoption of new varieties by all stakeholders. Involving women allowed discovering crucial traits such as final product weight, retting ability, color, texture, and in-ground storability
Methods for evaluating new material on- station or on- farm	The tricot approach (van Etten et al., 2019b) has been adopted for on-farm trials by the Variety Release Committee in Nigeria, shortening the time frame in the breeding cycle (the Nigerian variety release system is one of the lengthiest in Africa). Validate and disseminate new technologies with ease, collaborating with many participants under diverse conditions (van Etten and Steinke, 2021). Results are quick, and local systems are strengthened because more choices are available. Variety selection is influenced by gender
Choice of materials to advance to the next stage of breeding	Tricot gives multiple opportunities to include many genotypes and many farmers. In Nigeria, 30 genotypes were tested with 320 farmers in 2 regions in the first phase of the trial. Based on farmers' evaluations, some clones were dropped because they lacked priority traits. We were then left with 28 genotypes for the next level of evaluation. It is easy and logical to have the farmers help decide which varieties to drop, and to explain why. This approach captures gendered interests
Seed multiplication and dissemination	Use of certified seed companies like Umudike Seeds Ltd, Village Seed Entrepreneurs (CSEs), and different research programs in NRCRI, Umudike. Building an Economically Sustainable Integrated Cassava seed Systems II (BASICSII) project ensures that women are effectively involved as CSEs to encourage use of certified seeds. This helps to ascertain the quality of seeds been disseminated and to keep track of them. The CSEs help in rapid dissemination of planting material (Bentley et al., 2020)

(Continued)

TABLE 2 (Continued)

Tricot Model	The tricot approach provides a rating scale from 1 to 3. Choosing between best and the worst is easier and gives an unbiased trait assessment. End-users' cognitive load is less: they deal with 3 different varieties per assessment (faster interviews, so less fatigue), more accurate data. More varieties can be evaluated at once. More farmers are involved without increasing the time spent on consumer testing. Plot trial is manageable for both men and women. Direct and easy data collection (ODK), bar-coding-unique identifier, and automated archiving & analysis in ClimMob cloud server. Structural integration of gender and socio-economic variables. Allows the integration of just about right (JAR) and check all that apply (CATA) and Overall Liking (OL). Transparent and easy monitoring of data collection can be shared with project implementers, partners and donors. ClimMob ODK-GPS enabled collection is more efficient in locations with excellent internet connectivity. This approach allows more participants to be engaged in on- farm trials at more locations. Engaging farmers in research gives them ownership over it, makes products more acceptable, and promotes extension services which are a major driver of adoption of new varieties
Varietal naming and product launch (2021)	Feedback from end-users have informed the naming of new varieties from the usual numbered or scientific coding, names such as TMS30572 to names suggested by farmers depicting how the varieties are perceived such as Ayaya (CR36-5) which in local dialect means beautiful, Fine face (IA980505), Game changer (TMS13F1160P0004?) Obasanjo2 (TMS13F1343P0022), Sunshine (TMS/IBA070593), Hope (NR130124), Dixon (TMS/IBA90581). These names are easier to remember, especially for women, facilitating their access to cassava seed, knowing the exact seed they want
Participants and respondent designation changed	Cassava value chain actors have changed from mere participants and respondents to citizen science partners in research, with signed agreements between the research institute and partners. They are research partners providing needed information, evaluation and guidance to the breeders. Participating men and women become role models in their communities

role models, community and women leaders helped to explain ambiguous responses from some individuals.

Sometimes we experience some hitches when respondents (especially the men) are impatient to spend extra time as we elicit responses. As we probe to shed light on an earlier response, the farmer sometimes become tense and responds "I thought you asked me this question before." The respondents, especially the women, are usually engaged in many activities on their farms and at home. Sometimes they combine farming with petty trading to make ends meet, so they find it difficult to settle down in one place to answer questions for long. An example, one of our farmers also owns a restaurant. During our interview, she couldn't concentrate to respond to questions because of customers coming in for meals, so we (the socio-economist and the food scientist) resorted to washing dishes to ease some of her burdens, giving her the time to answer our questions. We discovered that when we combined male and female farmers in the FGDs, we tended not to get the desired results, because the women usually remained silent and quietly agreed with the men, probably because of power play, and the local norm that women shouldn't speak up in the presence of the men. So we learned to separate the communities into male and female groups, and the women would speak freely.

Key informants selected for our interviews are usually indigenes, local leaders, women leaders and others who are knowledgeable about the community. This yields correct information about the community under study. We select knowledgeable farmers for the studies, irrespective of their social class. When we start to work in a community, we usually go through the village heads to explain our mission and to get to know them. When we start the survey proper, we introduce ourselves to the community, explain the purpose of our visit and read out the consent forms before inviting people to sign them, to indicate their willingness to participate.

In most of the study communities, many farmers are attracted to our style of work, especially in the Tricot and RTBfoods projects, where the farmers go home with all the farm produce after our data collection and also take home some small gifts that we give them to acknowledge the time they have given the project. This motivates farmers to enthusiastically join the project. At the end of the study, most farmers will have access to planting materials for the next season and also for sale. They also get a lot of *gari* after processing cassava as part of the mother-baby trial. On several occasions farmers requested more studies in their communities, indicating interest in our work because it addressed their demands. The farmers who participated in our projects now stand out in their communities and have become role models to others who look forward to such opportunities in future. Listen to the words of four participating farmers in a Nextgen video (NextGen, 2022).

The tricot feedback initiative created another platform for participants to interact as citizen science partners, and it provided suggestions to improve the project. This facilitated co-learning, cooperation, result validation and accuracy, and fostered motivation by presenting research results back to citizen scientists about experiences with the tricot evaluation, which helped to improve the next tricot initiative.

Lessons learned

The team used participatory gender product profiling trials (see methods and Approaches, and Table 1) across Nigeria to

assess popular local and improved varieties and to evaluate traits, including taste and suitability for food preparation. Robust interdisciplinary methods included economics, and qualitative and quantitative tools to capture how farmers, traders, processors, and consumers described high-quality food products in their own words. Respondents were selected to reflect the diverse social makeup of a community. Outcomes include success stories behind on-farm trials and social surveys where traits were prioritized, in order to guide breeders. The study has shown the importance of integrating gender in crop breeding with the use of innovative techniques (tricot, G+ tool etc.) to elicit data from respondents. There are now cassava varieties in the breeding pipeline based on these gender studies. We are currently undertaking a benchmark survey on the adoption of disease-resistant and nutrient-enhanced cassava varieties, including the awareness of women, men, and youths, gender roles in the cassava value chain and factors that encourage or discourage uptake by women and the poor.

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 studies involving humans were approved by the National Root Crops Research Institute that has the mandate for Root and Tuber Crops Research in Nigeria. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

TM and BO contributed most to the work including writing of the manuscript. All authors made significant contribution to the work reported, conception, study design, execution, acquisition of data, analysis, and interpretation, read through the different drafts of the work, and made substantially and critical contributions to the review of the article.

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Conflict of interest

The 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.

The reviewer RS declared a shared research partnership group (CGIAR) with the author OO to the handling editor at the time of review.

Publisher's note

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Understanding specific gender dynamics in the cowpea value chain for key traits to inform cowpea breeding programs in Malawi, Mozambique and Tanzania

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Introduction: Cowpea is an important food and nutrition security crop in Malawi, Mozambique and Tanzania and it is mainly produced by women farmers mainly on a subsistence scale. The majority of these farmers use local varieties despite the availability of improved varieties in the region. Low acceptability and adoption of improved varieties have also hampered cowpea breeding efforts. The low adoption, especially among women farmers, has been attributed to the failure by breeding programs to involve farmers in the process of designing and developing improved varieties with a view to meeting their priorities and preferences. Despite women constituting the majority of cowpea farmers in these countries, no comprehensive gender analysis on cowpea value chain had been instituted to understand the traits that are gender and youth responsive and how to incorporate them in the product profiling so that the developed varieties benefit men, women and youth. The main objective of the gender study was, therefore, to identify preferred traits by different gender groups within the whole cowpea value chain to inform cowpea breeding programs in the three countries.

Methods: The study employed quantitative and qualitative methods to elucidate preferences, including value chain mapping, a quantitative survey of farmers, focus group discussions and key informant interviews targeting farmers/consumers, traders, policymakers and processors.

Results and discussion: Results showed that the top-ranking traits in order of importance across the countries and gender were; (1) high grain yield, (2) good grain taste, (3) early maturity time, (4) large grain size, (5) good leaf taste and (6) short cooking time. It was further noted that different gender groups preferred almost similar traits though minor variations were noted in terms of prioritization of these traits. These results have had two major influences on our cowpea breeding program: firstly, the breeding program changed the way it prioritizes traits to include ones that reflect the needs of men, women and the youth in the cowpea value chain. Secondly, our breeding objectives are closely aligned to gender differences in the target population of farmers and other

users, by incorporating key priority traits that address the needs of both men and women, including the youth. That is to say, product targets and specific product profiles are more gender sensitive. Since the breeding work is ongoing, the expectation is that the development of improved varieties resulting from this gender sensitive process will translate into higher adoption levels of these varieties (compared with previous releases), which might have ripple effects on food, nutrition and income security in the region.

KEYWORDS

cowpea value chain, gender sensitive cowpea breeding, priority traits, product profiles, trait preferences

1 Introduction

Cowpea (*Vigna unguiculata* (L.) Wallp.) is a leguminous crop that is grown in most parts of the world but it is mainly produced and consumed in sub-Saharan Africa (Boukar et al., 2019). Most of the production in sub-Saharan Africa is by smallholder farmers, especially women in marginal conditions, often as an intercrop with maize, sorghum, or millet (Ehlers and Hall, 1997). Cowpea is one of the primary sources of inexpensive, high-quality protein and micronutrients (Fe, Ca, Zn), and thus, it can positively impact the health of men, women and children (Nielsen et al., 1997; Thomson, 2008; Nelson et al., 2008; Carsky et al., 2010; Boukar et al., 2011, 2016; Muñoz-Amatriaín et al., 2017). Cowpea is important to the nutrition and income of smallholder farmers, especially women and youth in Malawi, Mozambique and Tanzania, and it also contributes to the sustainability of the cropping system through fixation of atmospheric nitrogen and prevention of soil erosion.

Malawi, Mozambique and Tanzania national breeding programs in collaboration with other partners, had in the past released improved cowpea varieties to address food and nutrition security. However, the majority of the farmers still grow unimproved varieties/local cowpea −90% in Malawi, 89.1% in Mozambique and 68.7% in Tanzania (IFPRI, 2020). Like in many parts of Sub-Saharan Africa (Murdock et al., 2013), cowpea in Malawi, Mozambique and Tanzania is primarily produced by women as well as the youth as a source of food and income. It was unclear whether the reported low adoption rates reflected the fact that the varieties released in these countries do not meet women and youth preferences. Earlier studies (Chiulele et al., 2011; Hella et al., 2013) in Malawi, Mozambique and Tanzania showed that farmers preferred cowpea with large grain size, brown colored grains, early maturity and high grain yield among others. These studies, however, did not collect gender disaggregated data on trait preferences. However, men and women may have different reasons for adopting a new crop variety as also echoed by Polar et al. (2017) that agricultural technologies are not gender neutral. What was very clear, however, at the onset was that the national breeding programs in these countries, in the past, failed to involve women and youth farmers in the process of designing and developing improved varieties with a view of meeting their priorities and preferences. Plausibly this led to low adoption of improved varieties. Therefore, it was imperative to conduct a comprehensive gender analysis on the cowpea value chain to understand the traits that are gender and youth responsive and how to incorporate them in product profiling so that varieties developed and released benefit men, women and youth. To address this gap, Lilongwe University of Agriculture and Natural Resources (LUANAR), Instituto de Investigação Agrária de Moçambique (IIAM) and Tanzania Agriculture Research Institute (TARI-ILONGA) joined to form the Center of Innovation for Crop Improvement for East and Southern Africa (CICI-ESA). The center also works together with the Department of Agriculture and Research Services in Malawi and Sokoine University of Agriculture in Tanzania. The CICI-ESA breeding program prioritizes the inclusion of male, female and young farmers in Malawi, Mozambique and Tanzania in the process of designing and developing more productive and nutritious cowpea varieties. As such, the team conducted a comprehensive gender-sensitive cowpea value chain analysis in the three countries to understand specific gender and youth dynamics in the cowpea value chain. Specifically the study was conducted to: (i) understand the role of men, women, and youth within the whole Cowpea value chain, (ii) identify preferred traits by different gender groups within the whole cowpea value chain to inform cowpea breeding programs, and (iii) map out cowpea markets to identify core processes of the value chain, the enabling environment, value chain actors, service providers, market information, financial services, and transport services that would inform other cowpea marketing opportunities for both small scale and large scale farmers.

2 Materials and methods

2.1 Study sites/locations

This study was conducted in three countries namely, Malawi, Mozambique and Tanzania (Figure 1). Specifically, in Malawi, the study was implemented in six cowpea growing districts (two districts per region) namely, Chikwawa and Mulanje, (southern); Dedza and Salima (central); Karonga and Mzimba (northern). Similarly, six cowpea growing districts were sampled as study sites across three provinces of Mozambique, namely, Rapale, Mogovolas, and Meconta (Nampula); Ancuabe and Chuire (Cabo Delgado); Alto Molocue (Zambezia). Finally, in Tanzania, six districts were also sampled across three regions namely, Kongwa and Bahi (Dodoma); Kilosa and Mvomero (Morogoro); Iringa Rural and Kilolo (Iringa). The selected districts within each country were selected for the study because they are the major cowpea producing areas in each region/province of each country.

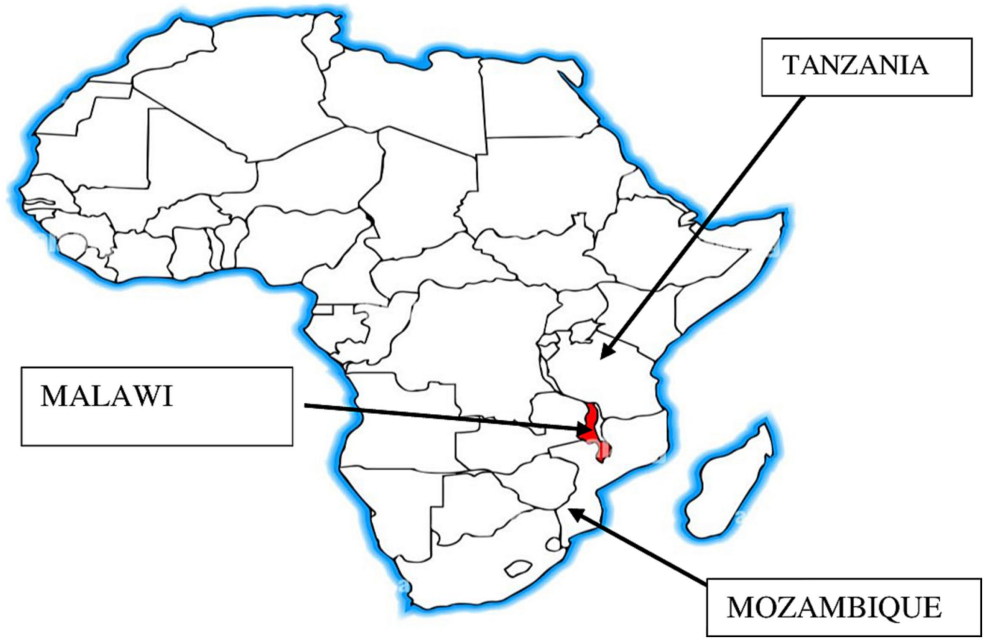

FIGURE 1
Map showing study countries for the gender sensitive value chain analysis study.

2.2 Team composition of the gender study

A multi-disciplinary team from the three countries championed the gender analysis study, each with specific roles. The research team was led by breeders who wanted to understand the sociocultural contexts of running a breeding program that integrates specific gender dynamics and whether these dynamics can influence the prioritization of traits, formulation of breeding objectives and defining product profiles. Breeders played a key role in the gender study through identification of study areas where cowpea is mainly grown, defining and explaining the different cowpea traits as well as leading in product profile development. Social scientists (gender experts, social economists, nutritionists, and sociologists), were at the core of operationalizing a cowpea-gendered study under two themes; 'priority setting and crosscutting issues'. Social economists led the design of the quantitative methodologies, which included trait preference surveys (i.e., sampling design including sample size, sampling framework and survey tools). Gender experts led the design and analysis of the qualitative methodologies (value chain mapping, focus group discussions and key informant interview guides).

2.3 Trait preference survey/gender sensitive value chain analysis

The study followed a gender-sensitive value chain mapping approach which is a process that includes both quantitative and qualitative data collection. The quantitative-engendered mapping exercise helps researchers to determine labor allocation, returns, and ownership along the chain, amongst other parameters, while the qualitative mapping exercise complements the quantitative data by collecting data on the factors that shape particular outcomes for men and women along the chain (USAID, 2009).

2.4 Quantitative survey design and sampling procedure

A multi-stage sampling technique was used to select a sample of farm households as described below randomly:

Stage 1: identification/selection of survey sites–the districts (6 districts within the 3 regions/provinces of each country-total of 18 districts) were selected by critically assessing the Agricultural Production Estimates (APES) data, and those districts where cowpea is mostly grown were purposively selected. However, the selection of the focal sites within each of the selected districts was done in liaison with Agricultural Officers as well as specific consideration context with regards to land inheritance systems such as patrilineal and matrilineal predominance.

Stage 2: random selection of sample villages clusters. This was done from a listing of villages within the selected survey sites, using a simple random sampling technique.

Stage 3: random selection of sample households using lists of farm households involved in the cowpea value chain. The entry point to each study site within each district was the Agricultural Officers who have the knowledge and lists of farmers involved in cowpea value chains. These lists summarized by the village were used to select farm households randomly.

Sample sizes; actual sample size for farm households was determined scientifically, using Cochran's (1963) formula for determining a representative sample for a large population:

TABLE 1 Total number of farmers sampled for gender analysis study.

Malawi		Mozambique		Tanzania	
Region/District	Total sampled	Region/District	Total sampled	Region/District	Total sampled
Northern region		*Nampula province*		*Dodoma region*	
Karonga	91	Rapale	77	Kongwa	40
Mzimba	66	Mogovolas	72	Bahi	40
		Meconta	68		
Central region		*Cabo Delgado province*		*Iringa region*	
Salima	68	Ancuabe	81	Iringa Rural	40
Dedza	73	Chuire	71	Kilolo	40
Southern region		*Zambezia province*		*Morogoro region*	
Mulanje	75	Alto Molocue	74	Kilosa	40
Chikwawa	75			Mvomero	40
Total sampled	448		443		240

$$n = \frac{Z^2 pq}{e^2}$$

where n is the sample size, Z is the chosen Z-score corresponding to the desired confidence level (i.e., 95%), e is the desired level of precision (i.e., 5%), and p is the estimated proportion of an attribute that is present in the population (50% is adopted to obtain maximum sample size), and q is 1-p. This yielded sample size of 385. Taking into consideration for no-responses, the final sample size was 396 per country (66 per district). However, for Malawi and Mozambique the sampled farmers were more than estimated and in Tanzania it was less than estimated (Table 1).

2.5 Qualitative survey design

In line with our gender-sensitive value chain analysis focus as outlined above, qualitative data collection was done at different levels targeting male and female cowpea farmers; lead farmers, community leaders, agro-dealers, extension workers, traders, policymakers, processors, amongst others. The data collection at these levels combined various methods, including, Value Chain Mapping, Key Informant Interviews (KIIs), Focus Group Discussions (FGDs), and Observations.

2.5.1 Cowpea value chain mapping

Value chain mapping with stakeholders was meant to understand and identify main cowpea players and their roles, mapping various segments of the value chain, identifying main products and processes and mapping out preferred cowpea traits within the different nodes of the cowpea value chain. This activity helped the team have a bigger picture of who is involved at each node of the value chains and aided in refining the proposed research approach. This exercise also helped to contextualize and validate the literature review and streamline the research focus of gender assessment in general. The value chain mapping exercise was split into three activities, which were done sequentially as follows:

a. Participatory value chain mapping

This was done together with selected gender group representatives involved in the cowpea value chain at a specific level (i.e., village, community, and district). Specifically, each value chain mapping group ideally was comprised of cowpea farmers/consumers (10 male; 10 female; 5 male youth; 5 female youth), 5 male/5 female (traders and agro-dealers representatives where present), agriculture extension workers and district agriculture officers where present. Some of the activities involved during this process included:

- Preparation of the value chain maps together with the actors present to identify relevant categories for the value chain actors.
- Maps laid out on flip charts by use of a checklist and used to map out actors, activities, flows/relationships, and contexts for cowpea within each context.
- The process of developing the map was iterative until there was consensus on the text and visual narratives about the value chain actors, how they are networked, and how the resources flow between them.

b. Understanding horizontal and vertical value chain integration

Once actors and activities for each value chain were mapped, specific flows/relationships in the cowpea value chain were established. This process assisted in clarifying the linkages further by tracing in what ways the actors, goods/products, or activities are mainly flowing. Are they happening at the same level or at various levels? Thus, the overall aim of this step was to explain vertical/horizontal value chain integration, i.e., the actors (the people), the linkages (the relationships), and the flows (how goods and services move from one actor to another through linkages). This process also assisted the research team to clarify any existing gender differences in terms of actors and activities involved in each node of the cowpea value chain as well as coming up with crude percentage estimates of gendered actors involved at each identified node of the value chain.

c. Identifying gendered barriers and leverage points for change

This last step aimed to ask participants to validate the map, make revisions if necessary, and use it as a boundary object for discussing gendered constraints and opportunities along the value chain. This step was critical as it gave both the research team and the stakeholders involved a snapshot of how a specific value chain operates and aided to either modifying study tools or contextualize some issues further as captured by the value chain map. Through this process, study tools were also further pilot tested in Mozambique before sharing them to the other CICI-ESA countries since the gender sensitive value chain studies were done consecutively within the different counties in question.

The value chain mapping processes were adapted from a *Developing gender-sensitive value chains – a guiding framework* (FAO, 2016) and a gender value chain toolkit by Laven and Verhart (2011).

2.5.2 Focus group discussions

The study had standard focus group guiding figures that were used or modified based on the availability of the groups for each of our study sites as follows: 6 FGDs with farmers (3 adult male/3 adult females), 6 FGD with male and female youth farmers where available; 1 FGD with lead farmers per region/province (not disaggregated by gender, but based on availability), 1 FGD with community leaders per region/province (not disaggregated by gender, but based on availability). Interview guides with semi-structured questions were used to guide discussions and the gathering of appropriate data from these sources. Key focus issues during focus group discussions were: differences between men and women in terms of land ownership, who commonly makes the decision on cowpea production or which varieties to grow in such households and why? criteria that men and women apply when deciding to try or adopt new cowpea varieties, who does what during cowpea production, what cowpea traits/varieties were preferred by each gender group and why, etc.

2.5.3 Key informant interviews and observations

Key Informant interviews with 10–15 agro-dealers, 6 extension workers and at least 3 policymakers were also conducted for all the three countries. Therefore, the research team facilitated participatory and consultative sessions, including individual interviews (IDIs), KIIs and focus group discussion sessions across the study sites.

2.6 Data collected in relation to gender

The gender analysis study focused on the following key issues:

Trait preference data on farmers and consumers were collected according to gender category classified as adult male, adult female, young male and young female. Here, farmers and consumers were asked to indicate the level of importance (on a scale of 4 to 1, denoting, not important, less important, important, very important, in that order) that they attach to a particular trait, the varieties they prefer and their attributes which determine their choice in terms of production or utilization.

Apart from farmers and consumers, we also engaged agro-dealers, traders, and processors. Agro-dealers were engaged to learn on the different inputs stocked related to cowpea production, such as the availability of improved seed, pesticides, agricultural implements and storage materials used in cowpea and whether their main customers are men or female. Traders were also a central focus of this study to understand the movement of cowpea within the value chain, the type of traders (male or female), the kind of cowpea varieties they prefer to buy and whether female and male consumers have different preferences to certain varieties or not. For processors, we focused on the types of varieties processors use and their attributes, their main suppliers, main products and by-products from cowpea processing and the target markets (whether local or export markets) with a gender lens. Throughout the qualitative data collection processes, the research team was also encouraged to record any observations related to the research issues in questions. Table displays an example of country summary for types of data collected based on the methodologies used under this study.

2.7 Data analysis

Data was analyzed separately for each country. Quantitative data was analyzed using SPSS (version 25.0) and STATA (version 17) to generate frequencies, descriptive statistics, cross-tabulations, and chi-square tests. For qualitative data, Kabeer's Social Relations Framework approach was adopted to examine gender dynamics within domains like household, community, state, and markets. This Framework as a gender analytical tool allows an exploration of gender relations from problem conceptualization to analysis of data in different spheres of social enquiry. The framework also emphasizes the subjective meanings of empowerment and the pathways to it, and the need to understand the context-specific and culturally embedded nature of gender relations (Hillenbrand et al., 2014). In this study, this framework was used to frame our overall gender objectives and approach of the comprehensive gender analysis within the cowpea value chain. Thus, by looking at how different concepts such as agency, structure, and discourse influence or are related to specific gendered behaviors or practices. This framework allowed us to take a value chain approach to examine gender dynamics within different domains and spheres as specified above. As such, the social relations between different actors, such as men and women, boys and girls and how these relations shape their access to resources, opportunities, and decision-making powers, were some of the core analyses that took place in all our study sites guided by this framework.

Additionally, content analysis, thematic analysis, grounded theory, and ethnographic analysis were used to identify cowpea value chain actors, their roles, emerging themes and constraints/opportunities related to cowpea value chain and gender (see also, Vaismoradi et al., 2013). In this case, content analysis involved coding and categorizing our qualitative data from the FGDs and KIIs into themes, concepts and categories, based on predefined topics in our interview guide as well as from emergent themes. For example, a theme on 'cowpea trait preference' was further categorized by gender and comparable across gender groups based on both a predefined criteria and the emerging data that was showing differences in preferences between male, female and young cowpea farmers. Similarly, thematic analysis in this study also involved identifying, analyzing, and reporting the patterns or themes that emerge from our data, and relating these themes to our overall research questions. For example, common or recurring issues, such as male farmers' preferences on cowpea traits that had potential market viability could be traced across districts within countries and across all our study sites. This analytical method therefore helped us to generalize patterns of behaviors within and across specific gender groups as shown in our results. Grounded theory being another analytical tool that we used allowed us to further analyze the common

patterns into theoretical assumptions that allowed us to compare and contrast different behaviors of cowpea value chain actors along the value chain. For example, this iterative process allowed us to move across different types of data collected in our study (i.e., quantitative and qualitative) and make comparisons on emerging issues. This process also helped a lot in coming up with specific recommendation of trait preferences for specific gendered groups based on commonalities or differences identified through this iterative process. Finally, ethnographic analysis in this study was further used to understand themes or issues with reference to culture, norms, and practices of the specific gendered groups in our study. Thus, through participatory observation, interaction, and documentation of the behaviors and actions surrounding cowpea production, consumption, marketing and processing amongst others, this method assisted us in describing and interpreting the beliefs, values, roles, norms or behaviors as well as constraints and opportunities related to these issues on specific gendered groups within the cowpea value chain.

3 Results

Figure 2 depicts the gender-sensitive cowpea breeding timeline. The cowpea breeding programs under study in Malawi, Mozambique and Tanzania are relatively recent in terms of developing their own varieties. The current breeding initiative under the Center of Innovation for Crop Improvement for East and Southern Africa (CICI-ESA) was commissioned in 2021 with support from the Feed the Future Innovation Lab for Crop Improvement with a different approach of integrating gender. It had been noted that adoption levels of varieties that were introduced from outside the country and released in the respective countries were low. The gender research activities involved trait preference survey to understand farmers and consumers' preferences for variety traits; cowpea value chain mapping to identify core processes of the chain (e.g., input supplies, production stages, postharvest and marketing stages), the enabling environment (infrastructure and policies, institutions and processes that shape the market environment and regulate the chain), value chain actors (identifying the chain actors, what they do, when and how, where and how the women and youth benefit, the flows of products in the chain, their volumes, values, and value addition at each step), service providers (i.e., input supplies, e.g., seeds, fertilizers), market information (e.g., prices, trends, buyers, suppliers, internal and cross border markets), financial services (e.g., credit, savings) and transport services (e.g., for grain purchasing); focus group discussions with men, women and youth farmers to have a deeper understating of the cowpea preferences; and key informant interviews with extension staff, local leaders, traders, agro dealers, processors to understand tradeoffs and price points.

The gender analysis study output at this early stage was meant to benefit breeders on how they can integrate gendered traits into mainstream breeding so that breeding programs are responsive to the needs of different gender groups so that varieties developed and released are taken up by different end users. Secondary beneficiaries of the gender study will be different end users, primarily farmers, consumers, traders, processors, researchers and policy makers. Lastly, the gender study will also aid in filling a knowledge gap in the literature that exists pertaining inclusive breeding process of improved cowpea varieties, in particular, as well as the broader scholarly debates in inclusive plant breeding more generally.

3.1 Cowpea value chain mapping in Malawi, Mozambique and Tanzania

From the value chain mapping, it was noted that major cowpea players included smallholder farmers (>98%), input suppliers (agro-dealers, government, non-governmental organisations), traders (aggregators), retailers, small scale home based processors and

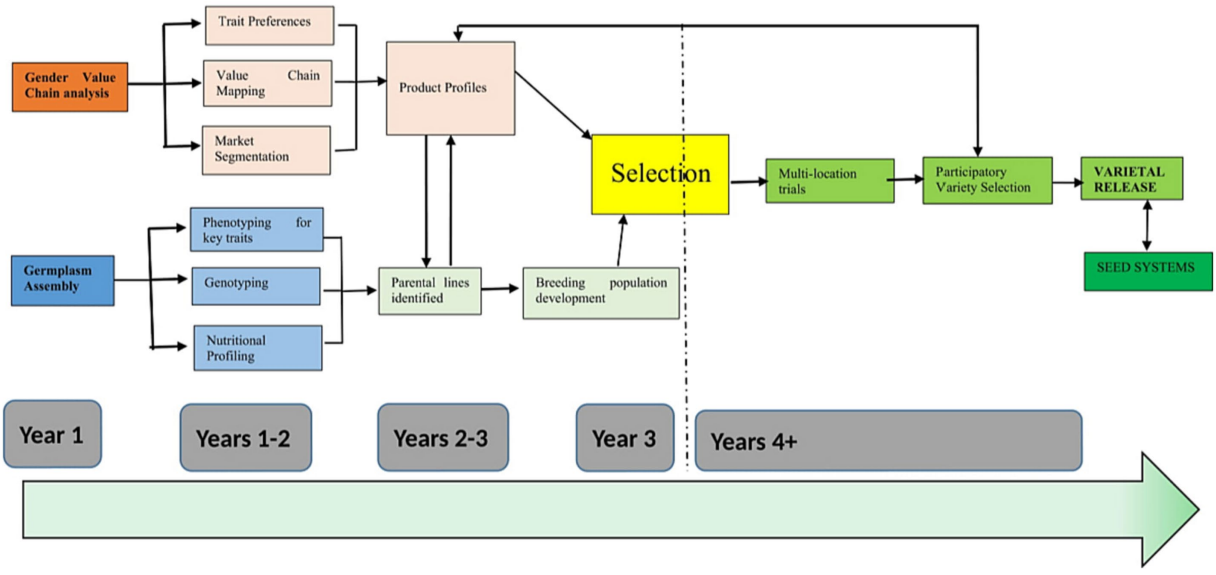

FIGURE 2
CICI-ESA gender sensitive cowpea breeding timeline.

consumers. it was established that more than 75–80% of cowpea producers (the production node), are female farmers, while traders and agro-dealers constitute a range of 70 to 80% of male actors across the cowpea value chain within the sampled districts of the three countries (Figures 3, 4). Most of the cowpea is locally processed in these countries mainly at home into different products such as flour, fried cake (Bagia), soups, roasted, boiled, dried leaves, pulp locally known as *chipere* and 85% of players are females. Most of the cowpea and its products are consumed and utilised locally within these countries with few instances of exports to India, Portugal and other countries.

3.2 Cowpea traits preferences by gender

Tables 2–4 show trait rankings for Malawi, Mozambique and Tanzania, respectively. Overall, the top-ranking traits in order of importance across the countries and gender were; (1) high grain yield, (2) good grain taste, (3) early maturity time, (4) large grain size, (5) good leaf taste, and (6) short cooking time. It was further noted that different gender groups preferred almost similar traits though minor variations were noted in terms of prioritization of these traits. In Malawi, results showed that more adult males prioritised high grain yield, grain taste, field and storage pests' resistance, disease resistance, drought tolerance and *Alectra vogelii* resistance than adult females. Similarly, more adult females prioritised traits such as short cooking time, early maturity, large grain size, leaf taste, leaf yield and grain color than adult males. In Mozambique, a similar trend was observed where a larger proportion of adult males than females preferred high grain yield, early maturity, grain size, drought tolerance, field and storage pests and disease resistance. More adult females than adult male preferred grain taste, short cooking time, leaf taste, leaf yield and grain color. For Tanzania, the proportion of adult females was larger than adult males for all traits.

4 Discussion

The gender study results guided the breeding program in the identification of key priority traits. For example, the breeding program identified high grain yield and quality traits such as fast cooking time, taste and leaf taste as key priority traits for women and youth, while high grain yield, early maturity and pests and disease resistance as key priority traits for men in the three countries. Based on the priority traits, the objectives of the breeding program were realigned to incorporate key priority traits. Furthermore, the gender study helped in market/consumer segmentation which in turn helped in the creation of product profiles for each market segment.

4.1 Gender and breeding for target market(s) or end users

As a breeding program, the attention is on designing and developing specific new varieties to serve the needs and preferences of a specified group of customers with projected uptake of the varieties by different end-users. The ultimate end users of the cowpea varieties are farmers and consumers, both men and women. Farmers produce

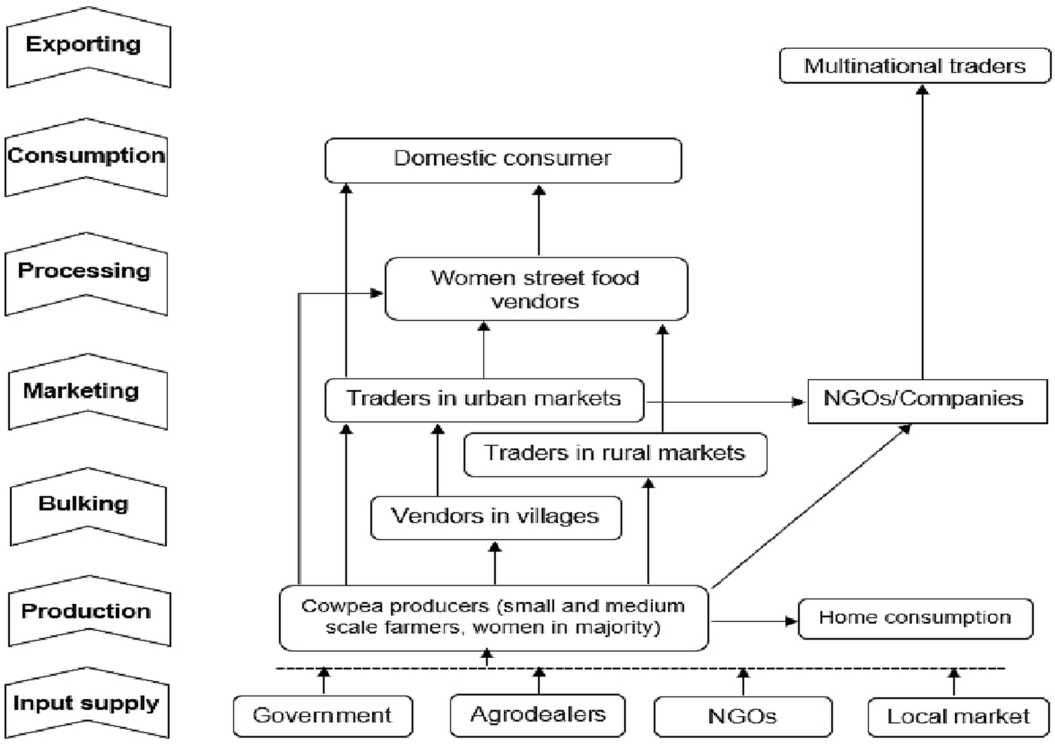

FIGURE 3
Schematic diagram of the cowpea value chain in Malawi from study.

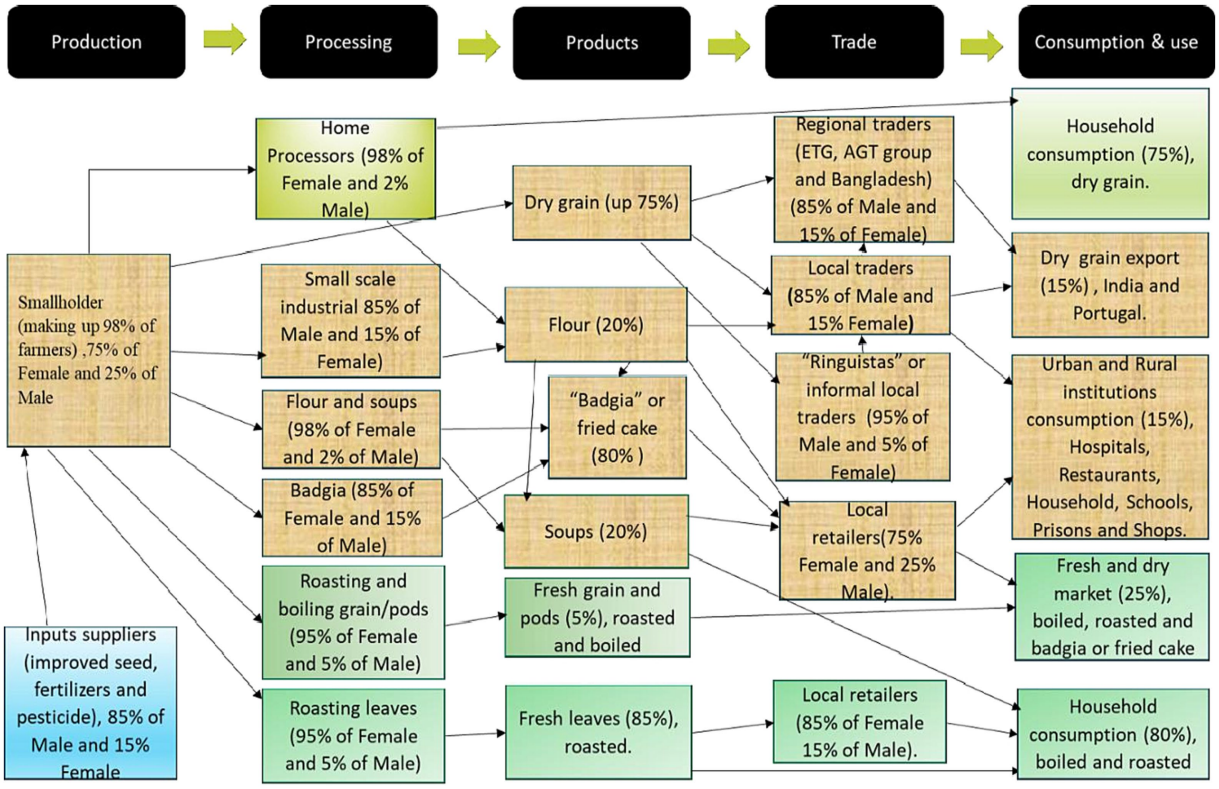

FIGURE 4
Example of a cowpea value chain map generated in Mozambique for the study.

cowpea for both home consumption and sale to the market. As seen from our methodology, we made it a point that our breeding program should be gender inclusive from the onset, starting from the formulation of breeding objectives and trait prioritization, unlike past initiatives, which were not very explicit on the extent of stakeholders' involvement in the breeding cycle. To put this in context, national cowpea breeding programs in Malawi, Mozambique and Tanzania in the past were not actively involved in actual variety development but rather they relied on advanced lines introduced from IITA for national release. Thus, most of these varieties developed were not based on local needs and preferences. Consequently, their uptake and adoption of these varieties was reportedly very low in Malawi (10%), Mozambique (10.9%) and Tanzania (31.3%) (IFPRI, 2020). This underscores for the need of national breeding programs to set their own national breeding objectives anchored on local needs and preferences. Therefore, guided by the need to enhance the uptake of nationally developed varieties, the comprehensive gender-sensitive cowpea value chain analysis resulted in three significant changes in the cowpea breeding pipeline in the three countries which were:

4.1.1 Identification of priority traits

The study revealed that male and female cowpea farmers prioritized traits differently. For example, adult and young male farmers were mainly interested in market-oriented traits such as grain yield, early maturity, taste, pests and disease resistance. Their reasoning was that early maturing varieties would mean having two cycles of crop harvest within the same rainfall period, and they can quickly bring to the market. But this early maturing variety should have good taste since most buyers are local consumers who have such preferences. Obviously, the variety should be high yielding to make more money from small pieces of land. Similarly, women and female youth prioritized high grain yield but quality traits such as fast cooking time, taste and leaf taste were highly important to them. As a breeding program, we currently prioritize these traits with the anticipation of better adoption levels of to-be-developed varieties. The traits being prioritized in the three breeding programs based on the current study were also mentioned by other previous studies (Chiulele et al., 2011; Hella et al., 2013) as traits preferred by farmers in these countries. However, their studies did not consider gender disaggregated preferences.

4.1.2 Designing breeding objectives

Decisions about the targeted breeding objectives take into account information about gender as it has been shown from the study that cowpea is an important crop for both men and women. Even though breeders are mainly responsible for coordinating, facilitating and linking actors and audiences with diverse interests, setting breeding objectives has become a multi-disciplinary exercise involving breeders, gender experts, nutritionists, and socio-economists to deliver varieties that have value on the market. The current breeding objectives are therefore driven by gender dynamics through the inclusion of traits that address the needs of both men and women at national level, such as grain taste, cooking time, maturity and grain size. Due to the overlapping nature of priority traits for male and female cowpea farmers, we aligned our breeding program

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TABLE 2 Ranking of some cowpea traits preferred by farmers and consumers across the six cowpea-producing districts in Malawi.

Trait	Gender	Ranking of cowpea traits in Malawi (%)				Overall rank
		Not important	Less important	Important	Very important	
High grain yield	AF	0.72	0.48	19.32	79.23	
	AM	0.55	1.38	12.4	85.12	1
	FY	2.59	2.59	18.1	76.72	
	MY	2.45	3.67	17.96	75.92	
Fast cooking time	AF	0.48	2.86	18.38	78.04	
	AM	1.15	7.2	29.68	61.67	2
	FY	3.86	4.29	22.32	69.53	
	MY	3.23	8.47	27.42	60.89	
Grain taste	AF	0.5	1.73	30.69	67.08	
	AM	0.55	2.47	25.82	71.15	3
	FY	2.15	6.87	26.61	64.38	
	MY	1.99	7.17	27.49	62.55	
Early maturity period	AF	0.73	7.06	28.47	63.5	
	AM	1.12	5.03	32.68	60.89	4
	FY	4.68	6.38	25.96	62.98	
	MY	3.24	8.5	25.91	62.35	
Large grain size	AF	0.74	6.14	26.29	66.83	
	AM	1.95	8.36	26.18	63.51	5
	FY	5.49	4.22	30.8	59.49	
	MY	2.82	8.47	29.84	58.47	
Leaf taste	AF	0.74	3.96	26.49	68.81	
	AM	1.65	11.54	29.95	56.87	6
	FY	3	8.15	25.32	63.52	
	MY	5.18	9.56	26.69	58.57	
Grain colour	AF	0.97	5.35	25.06	68.61	
	AM	1.7	11.36	27.84	59.09	7
	FY	4.72	5.15	27.9	62.23	
	MY	2.79	9.16	31.08	56.57	
Field pest resistance	AF	3.39	8.23	26.39	61.99	
	AM	2.81	7.02	28.93	61.24	8
	FY	5.15	12.02	22.32	60.09	
	MY	5.24	8.87	24.6	61.29	
Disease resistance	AF	3.4	8.98	25.97	60.92	
	AM	2.56	7.1	26.42	63.35	9
	FY	5.93	10.17	25.42	58.47	
	MY	3.21	10.44	26.1	60.24	
Storage pest resistance	AF	4.14	7.54	31.87	56.45	
	AM	3.91	8.38	28.49	58.94	10
	FY	5.15	9.87	24.03	60.94	
	MY	4.4	8.4	26.4	60.4	
Drought tolerance	AF	7.33	8.56	28.36	55.5	
	AM	6.63	6.91	25.97	59.67	11
	FY	8.58	10.73	18.88	61.37	
	MY	9.2	6	27.2	57.6	

(Continued)

TABLE 2 (Continued)

Trait	Gender	Ranking of cowpea traits in Malawi (%)				Overall rank
		Not important	Less important	Important	Very important	
Leaf yield	AF	0.98	8.78	29.27	60.98	
	AM	2.27	14.45	30.31	52.97	12
	FY	4.72	7.3	27.9	59.66	
	MY	5.6	10.8	28	55.2	
Growth habit	AF	1.95	9.73	30.66	57.42	
	AM	1.69	8.71	32.3	57.02	13
	FY	5.96	9.36	26.81	57.87	
	MY	4.45	12.15	28.34	54.66	
Alectra vogelli resistance	AF	15.35	21.1	10.55	53	
	AM	11.97	21.94	11.11	54.7	14
	FY	16.81	18.97	12.5	51.72	
	MY	13.94	21.12	12.75	52.19	

KEY: AF, adult female; AM, adult male; FY, female youth; MY, male youth.

objectives by incorporating key priority traits that address the needs of both men and women, including the youth within cowpea farming communities. According to Polar et al. (2022) gender-responsive breeding does not mean a program develops varieties specifically for women, but taking on board the needs of both men and women. Though not explicitly stated by farmers, our objectives tend to be more encompassing by including some essential resilience traits into breeding objectives.

4.1.3 Creation of product targets/market segments and specific product profiles

Orr et al. (2018) argued that plant breeding for resource-poor farmers, sellers, and processors requires a marketing approach which among others requires market segmentation and development of breeding product profiles showing trait preferences for end users. From the current study, the majority of cowpea producers and end users are women who are mostly resource constrained. As such, there is always a need to capture information about gender when deciding which market segment or end users to target in terms of variety development. The gender study helped us in market/consumer segmentation which in turn helped to create product profiles for each product target. The current approach in our breeding program is consistent with modern breeding practices where market segmentation and product profile development are integral to an effective plant breeding program (Kimani, 2017; Thiele et al., 2021). Tables 2–4 illustrate how trait ranking by gender and age influenced the overall traits that have contributed to distinct product targets to cater to the differentiated needs of both adult/young females as well as adult/young males.

For instance, the Malawi cowpea breeding program now has designed two product targets, each with a specific product profile, i.e., (1) *Boiled grain* (mostly to cater to income generation needs, and large-scale cowpea farmers – addressing the preferences mostly raised by adult/young males as well as adult females interested to venture into large scale cowpea farming), (2) *Dual purpose* (leaf and grain) – (mostly targeting household and food security needs as well as small scale/local marketing – addressing most of the preferences raised by young/adult females). These differentiated product profiles stem from the extensive data (both qualitative and quantitative), where for instance, the first four preferred ranked traits for adult female farmers were cooking time, grain yield, grain color, and leaf taste, respectively. To also quote:

"…For women, they mostly grow cowpea for home consumption since they can use both its leaves and grain as relish throughout the year… As for men, they might assist their wives in some activities to do with cowpea production because it would help them have food stocks within their household. However, in cases where cowpea fetches higher prices, like the small, seeded ones in our area, you find men being involved more in cultivating such varieties than those that are preferred more for consumption in their homesteads…" (KII with Chiefs in Salima: 01/11/2021).

"…we usually prefer growing local varieties left by our great grandmothers/fathers due to easy access of seeds that are passed from one generation to another – but also because these varieties allow us to consume cowpea leaves and green pods throughout the year. So, we rely on such cowpea varieties in lean times, especially during periods when even finding relish, is not a simple task…" (FGD with Adult females-Karonga: 26/10/2021).

Similarly, Tanzania cowpea breeding program has also developed two product targets with specific product profiles based on their gender analysis study. These product profiles are meant to address cowpea gendered preferences for their farmers. Thus, based on the information on segmentation and gender disaggregated trait preferences in Table 4, Tanzania, like Malawi has developed two product targets to meet the needs of the farmers for boiled grain (targeting income generation and marketing) and dual-purpose cowpea (targeting home consumption and marketing).

For Mozambique, three product targets with specific product profiles have been developed to meet the needs of three market segments. Thus, the first one is for boiled grain with characteristics of short duration, brown colored seeds, large seed, nutritious, drought and disease tolerant for dry grain market targeting both male and female farmers (producers), processors, traders and consumers. The second one targeting both local markets (seed and grain) and

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TABLE 3 Ranking of some cowpea traits preferred by farmers and consumers across the six cowpea-producing districts in Mozambique.

Traits	Gender	Ranking of the cowpea traits (%)				Trait ranking
		Very important	Important	Less important	Not important	
Grain yield	AM	86.33	11.39	0.91	1.37	
	AF	81.74	15.07	1.37	1.83	
	MY	78.44	14.91	4.59	2.06	1
	FY	79.36	13.3	5.05	2.29	
Maturity period	AM	62.24	32.27	2.75	2.75	
	AF	61.24	31.65	2.52	4.59	2
	MY	61.66	26.79	5.31	6.24	
	FY	55.05	22.36	6.73	15.87	
Grain taste	AM	58.22	37.9	1.83	2.05	
	AF	62.93	32.95	1.6	2.52	3
	MY	57.47	34.48	5.06	2.99	
	FY	60.69	32.64	3.68	2.99	
Size of the grain	AM	58.9	29.91	3.88	7.31	
	AF	58.35	30.66	3.2	7.78	4
	MY	58.06	26.73	5.3	9.91	
	FY	57.14	23.49	8.47	10.9	
Leaf taste	AM	50.8	37.3	9.84	2.06	
	AF	55.73	35.09	7.11	2.06	5
	MY	49.66	32.87	10.8	6.67	
	FY	52.87	33.33	7.36	6.44	
Drought tolerance	AM	53.09	17.85	5.72	23.34	
	AF	52.29	17.66	6.19	23.85	5
	MY	52.87	17.01	6.21	23.91	
	FY	50.8	18.16	6.9	24.14	
Field pest resistance	AM	53.65	21.23	3.42	21.69	
	AF	52.86	21.28	3.66	22.2	6
	MY	51.61	20.87	4.59	22.94	
	FY	50.8	21.38	4.37	23.45	
Cooking time	AM	47.2	38.7	5.8	8.3	
	AF	51.96	39.26	1.62	7.16	
	MY	50.23	34.49	6.25	9.03	7
	FY	56.71	31.94	3.47	7.87	
Storage pest resistance	AM	51.26	22.2	5.03	21.51	
	AF	48.39	23.39	5.96	22.25	8
	MY	44.37	20.92	8.05	26.67	
	FY	42.53	21.15	9.2	27.13	
Tolerance to diseases	AM	45.89	23.52	6.62	23.97	
	AF	45.77	22.2	6.86	25.17	9
	MY	47.25	20.64	6.88	25.23	
	FY	46.56	20.87	7.11	25.46	
Grain colour	AM	40.96	36.61	8.47	13.96	
	AF	43.35	33.26	8.49	14.91	10
	MY	37.53	28.44	20.51	13.52	
	FY	41.94	32.53	9.68	15.86	

(Continued)

TABLE 3 (Continued)

Traits	Gender	Ranking of the cowpea traits (%)				Trait ranking
		Very important	Important	Less important	Not important	
Leaf yield	AM	32.11	33.72	9.86	24.31	
	AF	41.51	26.61	9.63	22.25	11
	MY	33.33	28.97	10.34	27.36	
	FY	40.78	23.73	9.22	26.27	
Plant growth habit	AM	25.17	40.96	5.49	28.38	
	AF	23.39	41.51	6.19	28.9	12
	MY	25.06	37.7	7.82	29.43	
	FY	24.83	36.78	9.66	28.74	
Alectra vogelii resistance	AM	19.91	35.24	12.36	32.49	
	AF	18.35	33.26	14.22	34.17	13
	MY	19.35	31.34	14.52	34.79	
	FY	19.59	27.42	17.51	35.48	

KEY: AF, adult female; AM, adult male; FY, female youth; MY, male youth.

international market (grain) is characterized by short duration, brown colored seeds, large seed, nutritious, drought and disease tolerant for dry grain market. The third one characterized by medium duration with brown and/or colored seeds, nutritious, drought and disease tolerant for dual purpose (leaves and dry grain) targets local markets (seed, leaves and grain) and international market (grain) for food and income generation.

Dual purpose product profiles thus target both home consumption needs and income generation by meeting market demands. A similar observation was noted in Senegal where they recommended that breeding programs need to prioritize breeding for dual-purpose cowpea varieties (Mukerjee et al., 2023). This stems from the fact that cowpea is a multipurpose crop and farmers can use it to address different needs ranging from human consumption, livestock feed to environment stewardship (Timko and Singh, 2008; Boukar et al., 2016; Abebe and Alemayehu, 2022). For those product profiles specifically being developed for international markets like the case of Mozambique, they specifically meet demands of male farmers, even thought female farmers also participate in marketing of such varieties at local level.

Across the three countries, we note substantial similarities in terms of trait preferences and prioritization among gender groups. These similarities might be due to similar characteristics among farmers and consumers in terms of farming systems, cowpea utilisation, marketing systems, types of cowpea varieties used (majority use local varieties with similar genetic characteristics). There is also a lot of cross border trades among these countries and perhaps farmers in respective countries produce cowpea targeting cross border markets and this in turn may also explain the apparent similarities in terms of trait preferences. This also implies that a desirable variety developed and released in any of these countries can easily be made available and adopted by farmers among these countries. This is in line with SADC Harmonized Seed Regulatory System (SADC Seed Centre, 2022) in ensuring that farmers have access to more high-quality improved varieties.

4.2 Lessons learned from the gender study

The gender-sensitive cowpea value chain study described here shows that gender analysis is very critical in designing a gender-responsive breeding program that is more likely to benefit both men and women. This study presented both opportunities and challenges to the breeding team. It was a remarkable opportunity to bring together researchers from very different fields and develop a common understanding of how breeding research could be designed and run.

The study brought to light that stakeholder engagement is key in developing product profiles as you reach a consensus on key traits for the breeding program. The trait preference survey revealed that trait ranking differs by gender, meaning that trait prioritization differs among these. This might present a challenge to breeders in terms of developing product profiles and varieties for different market segments with competing interests. Though trait ranking was somewhat different between men and women, it was also observed that the traits preferred were similar, and this kind of like provides a leeway for breeders to design varieties with product profiles that are more encompassing but realistic.

Working in a multi-disciplinary team needs patience and accommodating the procedures and methodological processes from the different fields involved. The Gender Value Chain Analysis being socially based, other uncontrolled factors meant that the breeding timelines had to be delayed due to such unforeseen circumstances. Since breeding protocols in sub-Saharan/resource-constrained countries are usually based on rainfed trials, the breeders had to adjust their timeline expectations based on the limitations faced by social scientists during data collection and analysis processes.

Training (of data collectors/enumerators) is key to successful and accurate data collection. It was noted that some enumerators had challenges in using some of the study tools for data collection. For example, some enumerators found it difficult to conduct choice experiments with farmers and consumers due to their technicalities and complexities. Also, some questions to respondents during the interviews were not properly phrased for the less educated respondents.

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TABLE 4 Ranking of some cowpea traits preferred by farmers and consumers across the six cowpea-producing districts in Tanzania.

Trait	Gender	Ranking of cowpea traits in Tanzania (%)				Trait ranking
		Very important	Important	Less important	Not important	
Grain yield	AM	49.6	33.3	3.3	0.4	
	AF	78.3	19.2	0	0	1
	MY	20	27.9	4.2	1.3	
	FY	23.8	30	1.3	1.7	
Size of grain	AM	31.7	42.5	10	1.7	
	AF	56.3	34.6	5.4	0.8	2
	MY	11.7	27.5	9.2	2.5	
	FY	20.4	28.8	5.4	1.3	
Maturity period	AM	34.6	42.1	5.8	1.7	
	AF	50.8	36.7	7.1	2.1	3
	MY	15	24.2	7.5	2.5	
	FY	19.2	27.5	3.3	2.1	
Grain taste	AM	25.8	47.9	9.6	4.2	
	AF	65	30.8	1.3	0.4	4
	MY	4.2	34.6	13.8	2.9	
	FY	20.8	32.1	3.8	1.7	
Leaves taste	AM	20	35	22.5	7.9	
	AF	53.8	36.3	5.8	1.7	5
	MY	4.2	15.8	24.2	7.5	
	FY	15	35.8	5	2.5	
Cooking time	AM	16.3	37.9	14.6	9.2	
	AF	49.6	39.2	6.7	0.8	6
	MY	3.8	15.4	14.6	7.5	
	FY	20	25	6.3	2.9	
Drought tolerance	AM	19.2	46.7	13.8	2.5	
	AF	33.8	52.5	10.4	0.4	7
	MY	7.9	21.3	14.2	4.2	
	FY	6.7	29.2	10.8	4.2	
Leaf yield	AM	9.6	35	20.4	15	
	AF	37.1	40.4	15.4	2.1	8
	MY	2.9	12.5	17.1	11.3	
	FY	15.4	22.5	7.1	5	
Field pest resistance	AM	17.1	45.4	12.1	3.3	
	AF	30	46.3	17.1	0.8	9
	MY	5.4	22.9	13.8	3.3	
	FY	4.2	27.5	12.1	3.8	
Tolerance to diseases	AM	12.5	41.3	13.3	3.3	
	AF	29.6	37.1	16.7	5.4	10
	MY	4.6	18.3	7.1	9.2	
	FY	7.5	17.9	10	8.8	
Plant growing habit	AM	10.8	44.6	12.1	10.8	
	AF	25.4	53.3	13.3	2.5	11
	MY	5	19.2	12.1	4.6	
	FY	10.4	22.9	10.8	3.8	

(Continued)

TABLE 4 (Continued)

Trait	Gender	Ranking of cowpea traits in Tanzania (%)				Trait ranking
		Very important	Important	Less important	Not important	
Storage pest resistance	AM	14.2	43.8	15	7.5	
	AF	25.8	42.9	17.9	7.9	12
	MY	5.4	19.2	8.8	12.1	
	FY	5.4	21.7	10	10.4	
Grain color	AM	9.2	27.1	25	18.8	
	AF	20.8	48.3	19.2	7.5	13
	MY	4.2	15.8	18.8	9.2	
	FY	10	27.5	10.8	4.2	
Alectra vogelii resistance	AM	0	2.9	2.9	20.8	
	AF	0.4	5.4	4.2	29.2	14
	MY	0.4	3.3	2.9	7.1	
	FY	0	2.1	3.3	9.6	

KEY: AF, adult female; AM, adult male; FY, female youth; MY, male youth.

In terms of the technical team, it may help to accept from the onset that gendered breeding is a continual process. It is, therefore useful to set timed milestones and aim for the best synthesis of data and information within the available time. We found that data analysis and insight generation kept getting better with time. However, once we hit an acceptable threshold of insight to improve on past breeding initiatives substantially, the team decided to move on. Thus, we find that gendered breeding presents an ongoing need and challenge for continual improvements in methods and protocols such that more time, attention and detail are provided for. This also echoes Chambers' (2008) in speaking to the need to start early and proceed methodically with a solid team.

In the same vein, the bringing together of team members from varied technical fields means that a critical success factor is to facilitate the overlap of their technical siloes for meaningful conversations. Brainstorming sessions, idea-sharing sessions, learning workshops, frequent-enough meetings, team building efforts, and other activities are helpful for the team members to begin to understand each other's perspectives, to speak to each other empathetically, get acquainted with resources available to the team as well as, very importantly, to understand their respective and joint roles in the program clearly. The social economist necessarily must understand clearly enough how their input feeds into the ultimate—breeding process. The plant breeder must similarly understand the methods available to the social scientist, including their limitations and correct interpretation of processes and results. This helps the breeder in guiding and inputting into the synthesis of data for market segmentation and product profiling, for example.

4.3 Challenges and study limitations

Considering the breadth and depth of the data collected in the gender-sensitive value chain analysis study, several challenges and limitations must be considered in similar studies conducted towards inclusive breeding ends.

One challenge that confronted our breeding program was the high attrition of social economists. We changed at least two economists before finding a stable substitute. This meant that the substitute had missed an important team-building and project familiarization period at the start of the project. He thus came into a steep learning curve whilst we were heading out for the value chain analysis survey, impeding how much input he could make at the time. For example, he later observed that a cowpea demand study would have been useful; but it was too late by then to incorporate this component in the program's current phase. We plan to incorporate this in successor phases or projects.

Research assistants had difficulty clarifying the names of local cowpea varieties since the names were either given based on use, growth system or how they were introduced in specific areas. As such, most of the local varieties present were named differently within different settings, even if they had similar characteristics.

Most of the research assistants who collected data were either ongoing undergraduates and a few graduate students, a deliberate choice that was made by the research team to build capacities as part of the CICI-ESA project goals. However, this contributed to some study limitations since most of them had difficulties initially employing choice experiments and qualitative data transcription and reporting, despite the team being rigorously trained. Nonetheless, this challenge was rectified through a rigorous data-cleaning process as well as further transcription of audio recordings during the qualitative analysis process.

5 Conclusions and recommendations

Our study was able to identify key cowpea traits that are gender, youth, and resilient inclusive and these have been critical to informing the development of specific cowpea product profiles and market segments. Much as it was a rigorous process, the team recommends that it is a worthwhile and critical process to undertake for any inclusive plant breeding initiative. Plant breeders might not necessarily have to produce specific breeding

lines for each gender group, but they can come up with product profiles that can cater to several needs and differences that are unveiled through a gender-sensitive breeding process.

Being designed as comparative research across three countries, i.e., Malawi, Tanzania and Mozambique, collaborative breeding efforts that are based on a comprehensive value chain analysis allow researchers to map out actors and connections beyond the borders, hence creating an opportunity to map out market demands that can be beneficial for farmers beyond their farming locations.

Having a multidisciplinary team to achieve inclusive breeding agenda pays off in the end. However, there is a need for the team members to be able to embrace the following principles: Shared/ Common Goals, Flexibility; Co-Learning; Co-Creation; Mutual respect and accountability. This is because there should be a realization that all stakeholders participating at each level of the process, are critical to achieving your set goals.

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.

Author contributions

MC: Conceptualization, Funding acquisition, Investigation, Supervision, Writing – original draft. JK-P: Investigation, Methodology, Writing – review & editing, Supervision. DM: Formal analysis, Methodology, Writing – review & editing, Data curation, Investigation. HC: Investigation, Supervision, Writing – review & editing. MT: Investigation, Project administration, Supervision, Writing – review & editing. DB: Investigation, Supervision, Writing – review & editing. JH: Investigation, Supervision, Writing – review & editing. EY: Investigation, Writing – review & editing. NM: Investigation, Writing – review & editing. JK: Project administration, Data curation, Formal analysis, Writing – review & editing.

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Conflict of interest

The 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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Gender mainstreaming in sweetpotato breeding and dissemination in Ghana and Malawi

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Gender responsiveness in breeding programs to meet client and end user preferences for crops is essential. This case study analyzes the implementation experience of gender-responsive breeding and variety dissemination in Malawi and Ghana, focusing on good practices and challenges encountered. In Malawi, a training-of-trainers approach was employed to share knowledge among trained farmers. In Ghana, a research study was conducted to identify gender-based preferences for sweetpotato to define breeding objectives. The participation of social scientists, food scientists, and sweetpotato breeders in the GREAT (Gender Researchers Equipped for Agricultural Transformation) team provided a multidisciplinary perspective, addressing questions and responses in the field. Research efforts were strengthened by focusing on food quality through the establishment of an analytical laboratory for rapid evaluation of nutrition and food quality, including sugars. This helped develop sensory analytical capacity to better understand quality attributes and market segments, guiding breeding and improving market opportunities for women. Breeding outcomes resulting from gender inclusion led to the release of some sweetpotato varieties meeting end user and consumer preferences, as well as adoption of OFSP varieties by men and women. Other good practices for gender inclusion and responsiveness include providing funds for gender-based research and activities, engaging gender specialists and social scientists in trans-disciplinary teams, designing program activities with gender considerations, and incorporating traits in seed multiplication and dissemination decisions. Application of these gender inclusion practices resulted in adoption and development of acceptable sweetpotato varieties.

KEYWORDS

patrilineal, matrilineal, user orientation, awareness creation, value chains, training

1 Introduction

1.1 Why sweetpotato breeding and dissemination efforts paid attention to gender in Ghana and Malawi

Sweetpotato has traditionally been considered as a women's crop grown for food security in Sub-Saharan Africa (SSA). It has been increasing in importance in recent years, and now accounts for 33% of global production, up from 15% in 2009 (Food and Agriculture Organization of the United Nations, 2023). While this was partly due to declining production in China, which is still the largest global producer, both area and yield of sweetpotato have also been increasing across SSA during the same period. The importance of sweetpotato in food and farming systems varies across regions, ranking from among the most important crops in some countries such as Malawi, to having a relatively minor, though regionally important role in others such as Ghana. According to Food and Agriculture Organization of the United Nations (2023), in Malawi, sweetpotato ranks first in production and fourth in production area among crops. In Ghana it ranks twenty-first in production and nineteenth in area. *Per capita* annual production in Malawi is reported to be roughly 402 kg, while in Ghana it is 4.3 kg per person. As others have noted, FAOSTAT data for sweetpotato in SSA are quite unreliable, but they at least provide some point of comparison and may be improving as the crop becomes more mainstream (Andrade et al., 2009; Carey et al., 2021).

Traditionally, across SSA, sweetpotato storage roots have been eaten boiled, fried, or roasted. The predominant and preferred root quality types are staple types with white or yellow flesh, a relatively dry and mealy cooked texture and mild flavor. Sweetpotato tops have also been important as a leafy vegetable or animal feed, varying by region. Sweetpotato, along with other root and tuber crops, was for many years neglected by crop improvement programs since they were not of great commercial interest. However, sweetpotato research and development in SSA has picked up significantly in the last thirty years, driven by recognition of its high production potential, climate resilience, nutritional value, and potential for value addition (Woolfe, 1992; Grüneberg et al., 2015; Mwanga et al., 2017; Low and Thiele, 2020). The demonstration that orange-fleshed sweetpotato (OFSP) can help to combat the serious public health problem of vitamin A deficiency in children under five years old and pregnant and lactating women also contributed significantly to the efforts and have garnered much donor support (Low et al., 2017). These efforts have led to the strengthening of sweetpotato research and extension across SSA, including in Ghana and Malawi, the two countries reported on here.

Sweetpotato value chains have developed both through project interventions, using OFSP as an entry point, and informally, through natural strengthening of local and urban markets for staple-types for traditional uses. These markets provide demand for new varieties, seed delivery systems and services that research and extension programs and other service providers can respond to. Studies and reports by Sugri et al. (2017) and Peters (2015) described and made recommendations about value chains in Ghana. A similar study by van Vugt and Chibwana (2016) described and made recommendations for Malawi. Moyo et al. (2022) present a review of development and use of OFSP puree as an innovative ingredient in baked products, including in Malawi. As products and value chains diversify and strengthen, it is critical for service providers, such as breeding programs to be responsive to the requirements and preferences of the various actors, including women and children.

1.2 Gender relations in Sweetpotato in Ghana and Malawi

Sweetpotato was reported to be a women's crop in the subsistence farming systems of Kenya and Uganda (Mutuura et al., 1992; Bashaasha et al., 1995). In contrast, sweetpotato, while mainly produced for home consumption, was produced by both men and women in Uganda (Abidin, 2004; Ebregt et al., 2004), Malawi (Sindi et al., 2013) and in Ghana (Amengor et al., 2015; Etwire et al., 2018). Amengor et al. (2015) reported that men primarily handle land preparation and planting, while women take charge of weed control, fertilizer application, harvesting, and marketing. Additionally, Adekambi et al. (2020a,b) reported that in northern Ghana, both men and women participate in planting sweetpotato vine cuttings, weeding, and hilling-up the fields. However, men usually sell the roots wholesale, as it is believed that they are better able to negotiate prices with traders and are strong enough to load their sacks of sweetpotatoes onto the trucks as requested by the traders. Women take charge of retail sales in local markets. Late in 2012, a study of the sweetpotato value chain in Nigeria, Ghana, and Burkina Faso noted that much of the sweetpotato in each country was being fried by women for local sale (Peters, 2015). In Ghana and Malawi, as elsewhere, women tend to do the household cooking, so they are highly focused on culinary quality.

In SSA, land tenure can be by matrilineal or patrilineal inheritance. In Malawi, matrilineal kinship is common in Phalombe and Dedza districts where the work described here was implemented. In Ghana, matrilineal kinship is found in the Ashanti Region where sweetpotato is not a major crop, however our project efforts reported here were mainly in patrilineal areas. In matrilineal communities, the land is owned by women or matrilineages and the husbands have a designated residence status. In Phalombe and Dedza in Malawi, a married man moves to his wife's village. These married men are asked to work on the land if the household is engaged in agriculture to feed the family. Women help the men as already mentioned, with men doing some of the heavier tasks. Income is managed by both husband and wife for household needs, including school fees and maintaining the family's house. About a third of the most fertile land is used to grow crops for household needs, whereas another third is used by the husband as he deems fit, and the last third is used by the wife (Sindi et al., 2013).

According to Quaye et al. (2016), in patrilineal communities in Ghana, men control over 80% of agricultural land, and women typically have poor access to land resources and money, and a minor voice in decision-making. The land is usually inherited by sons while daughters go to live with their husbands. The type of crops grown by women, the amount of land farmed, and its productivity are all impacted by women's weak rights over agricultural lands. Additionally, poor markets hamper women's engagement in farming alongside ineffective processing methods. In both patrilineal and matrilineal systems, family lands are kept in trust for posterity and are not transferred. Hence, deliberate efforts are needed to ensure that women as well as men benefit from breeding, variety dissemination and other efforts to improve the lives of all intended beneficiaries of efforts to improve livelihoods and strengthen value chains.

1.3 Context

The organizations and actors described in this paper were core actors in a number of projects in Ghana and Malawi under the Sweetpotato for Profit and Health Initiative (SPHI). The International Potato Center established its regional sweetpotato breeding platform for West Africa at the CSIR-Crops Research Institute in Ghana in 2010. Ghana's national breeding program was chosen because of its strong institutional capacity, including strong support for root and tuber crop research and extension in Ghana at that time from both the World Bank, and the International Fund for Agricultural Development. The national sweetpotato breeding program in Malawi was backstopped from CIP's regional breeding platform for southern Africa in Mozambique. OFSP was a primary, though not exclusive target of the efforts which had the overall aim of repositioning sweetpotato in the food economies of sub-Saharan Africa. Breeders were consistently engaged with these projects in each country and thus were positioned to understand and respond to feedback from all projects. This case study aims to document and analyze efforts to include gender in breeding, variety dissemination and other activities and projects carried out in Malawi and Ghana, drawing primarily on experiences of projects the authors were involved with under the SPHI.

2 Analysis

2.1 Research and other sources of information generated on gender

Prior to 2009, national variety release guidelines across much of Africa already had guidelines stipulating the need to demonstrate "value for cultivation and use (VCU)" (Setimela et al., 2009). This information typically involved the use-of farmer participatory on-farm trials and culinary evaluations, with women heavily engaged in the process of cooking and tasting. In both Ghana and Malawi, one of the earliest variety releases was of an early-maturing, widely adapted, yellow-fleshed farmers' variety, originally from Tanzania, which had high yields and very good culinary quality (Otoo et al., 2000; Moyo et al., 2004). These user-oriented efforts effectively engaged both men and women in breeding assessments, though gender analysis was not an explicit element of the breeding and selection process.

Under the SPHI, starting in 2009, the International Potato Center (CIP) and partners focused on breeding new varieties and strengthening seed systems and value chains through various projects. CIP's projects in sub-Saharan Africa (SSA), prompted by donor priorities, consistently targeted women as key beneficiaries (Abidin et al., 2024; Supplementary Table S1). National research programs, ministries of agriculture, and women's development extension programs were actively engaged in these efforts. The SPHI emphasized the development, dissemination, and use of provitamin A-rich OFSP varieties to help combat micronutrient deficiency, which is a serious public health problem, especially for young children and pregnant and lactating women in much of SSA (Low et al., 2017; Low and Thiele, 2020). These efforts thus sought to combat micronutrient deficiency and improve livelihoods.

Under the SPHI, breeding was supported by the Sweetpotato Action for Security and Health in Africa (SASHA) project which established breeding support platforms in Uganda, Mozambique, and Ghana to backstop regional varietal development and dissemination efforts by national programs. The SASHA multi-disciplinary research team included breeders, seed specialists, postharvest experts, food scientists, and social scientists (economists and gender specialists) to ensure project success. These multi-disciplinary teams interacted regularly, bringing their perspectives and skills to specific project components and team meetings, contributing to the user orientation of breeding efforts and SPHI successes.

During stakeholder consultations and priority-setting exercises for the SASHA project, the critical importance of attention to gender was recognized since women were heavily engaged in smallholder production for household consumption and local sales, and pregnant and lactating women and their young children were the intended primary beneficiaries of efforts to develop and disseminate OFSP. At the breeding platform for West Africa in Ghana, the development of low-sweet, staple-type, varieties was also prioritized since sweetpotato, being sweet, was not considered a staple food, but mainly consumed as a snack. Developing non-sweet types would stimulate new demand for the crop, similar to yam, the regionally important staple (Andrade et al., 2009). Timely access to healthy planting material, postharvest perishability, virus, and weevils were also identified as key constraints along with poor market access. Thus, an integrated approach to breeding, variety dissemination, production and promotion was needed.

Aside from the low-sweet, staple types already mentioned, there was a recognition that consumer-accepted sensory quality attributes were essential, especially for OFSP varieties which were often moister, with lower dry matter content and stronger flavor than the traditional white and yellow-fleshed varieties. Newly introduced OFSP varieties thus ran the risk of consumer rejection. Selection of higher dry matter, drier textured OFSP thus became an important selection criterion. We also recognized that consumer demand can be modified through targeted messaging on health and market opportunities (including new forms of utilization). Planting material dissemination efforts also emphasized use of virus-free, or apparently healthy seed, since timely availability of clean seed is key for high yields (Clark et al., 2012).

The Rooting out Hunger in Malawi with Nutritious OFSP (ROH-OFSP) project took a holistic approach to improving the livelihoods of women while disseminating OFSP, and knowledge on its use and processing (CIP, 2013a,b,c; Abidin, 2014a,b). Strengthening the seed system was critical to ensure adoption. An OFSP variety, Zondeni, released in 2008 was promoted by the project (Chipungu et al., 2010). Links between breeding, seed system, and dissemination efforts in ROH-OFSP used a farmer-centered approach described by Abidin and Carey (2018). The seed system approach involved multiplying and having available true-to-type, healthy planting material at primary sites, and establishing decentralized multiplication sites managed by specialized vine producers (secondary multipliers) or root and vine producers (tertiary multipliers). The approach encouraged commercialization of planting material to generate income. The approach also involved strong partnerships, advocacy and awareness creation, combined with decentralized training on all aspects of production, nutrition, utilization, and strengthening market linkages. A similar approach was used by other projects including Jumpstarting OFSP in West Africa through Diversified Markets in Ghana, Burkina Faso, and Nigeria (Abidin and Carey, 2017), and two projects on development and dissemination of sand storage technology for

preservation of sweetpotato roots for consumption and production of planting material in drought-prone areas.

During the ROH-OFSP project activities in Malawi, a gender specialist assisted to help understand why females were not being reached in the desired numbers during training activities. A study was conducted in 2013 in two districts, Phalombe, and in Chikwawa, with matrilineal and patrilineal communities, respectively. In Ghana, the Gender Responsive Researchers Equipped for Agricultural Transformation (GREAT) project provided an opportunity for a multidisciplinary team involved with the breeding program to be trained on methods to bring a gender lens to the program. The team included a breeder, an economist, and a food scientist. Male and female producers, traders and consumers were surveyed in two farming areas in northern Ghana where CIP projects had been operating. Roles and perceptions of male and female actors, attributes of leading varieties and attributes desired in new varieties were studied. Details of the gender studies in Ghana and Malawi are presented in Supplementary Table S2 and discussed below.

2.2 How attention to gender influenced breeding and seed dissemination efforts

CIP's sweetpotato breeding platform for West Africa was established in 2010 in Kumasi at the CSIR-Crops Research Institute (CSIR-CRI). The CIP program worked with CSIR-CRI in the forest zone and CSIR-Savanna Agricultural Research Institute (CSIR-SARI) in the savannah zone of northern Ghana. Regrettably, CIP support for this platform ended at the end of 2020. Nevertheless, from 2010, breeding dossiers submitted to the National Variety Release Committee included information from multi-locational trials covering major agro-ecologies in Ghana and VCU information generated through farmer and consumer feedback on agronomic, postharvest, gender-differentiated culinary assessments (boiled, fried, pounded) and nutritional attributes. New varieties had superior attributes including improved planting material persistence, early yield, taste, and better shelf-life. Release documents demonstrated the user orientation, identifying user-preferred varieties for release and were also responsive to the potential for promotion of OFSP for health. Seventeen varieties were released between 2012 and 2020 (Ministry of Food and Agriculture, 2019; SARI variety release reports, 2019, 2020, unpublished).

In Ghana, the multi-disciplinary team under the GREAT project reported that male producers tended to focus on agronomic traits such as yield, early maturity (to sell fast), and resistance to drought, weevils, and diseases, while women mostly paid attention to culinary traits such as taste, short cooking time, dry matter content, vitamin A, and use of leaves as vegetables. Men's and women's preferences complemented each other and aligned with predominant roles of men and women in the production system. Men and women farmers wished for varieties which could store for a long time before deteriorating, had good yield, resistance to diseases, and were early maturing. Since the breeding efforts were developing high-yielding sweetpotato varieties with a range of quality attributes, there were no major failings in the breeding effort because of the failure of taking gender into consideration. The preferences of male and female consumers and traders were in general agreement (Bidzakin et al., 2019). However, the predominance in the Northern Region of Apomuden (an OFSP variety released in 2005), and in the Upper East Region of the white-fleshed farmer's variety Obaari indicated the need for strengthening efforts to develop and disseminate new varieties. The GREAT study confirmed work of the Jumpstarting OFSP project from 2014–2017 which improved knowledge on utilization and processing, and sensitization on health benefits of OFSP. The survey results of the Jumpstarting project were published by (Adekambi et al., 2020a,b).

The ROH-OFSP project in Malawi attempted to target women in training on production, nutrition, processing and utilization, aimed at improving knowledge and skills at the farm household level so as to ensure sustained adoption. A training-of-trainers approach was taken with the expectation that trained farmers/agencies should share their knowledge with 5–10 other farmers. As already mentioned, women's attendance was lower than expected. A gender survey in 2013 was carried out to understand why few females attended training events. Similar findings in Chikwawa (with patrilineal kinship) and Phalombe (with matrilineal kinship) suggested that women's low participation was not related to gendered differences in land tenure. Rather, many women were shy to participate in training (CIP, 2013c, p. 14) because of limited formal education and relatively low self-confidence. They trusted their husbands to participate for them with the expectation that they could learn from them later. In worse cases, men forced women to stay at home so they could participate in project activities. It was also found that government extension agents, the project partners, mainly chose men to participate in trainings (Mudege et al., 2017, 2018). These insights helped improve the ROH-OFSP project's efforts to reach women. Emphasis was given to increasing female participation in training and building the capacity to reach both husbands and wives by taking a household approach.

2.3 Methods and approaches: advantages and shortcomings

Partnerships and commitment by national agricultural research and extension services (NARES), and networking stakeholders are important to drive increased consumption, adoption, utilization, availability, and trade of sweetpotato among men and women. However, as illustrated by the trainings in Malawi, special efforts are needed to ensure that more women benefit than is often the case, particularly when commercial opportunities are involved. A recent example highlighting the need for more work to target women in Ghana was provided by a report on adoption and benefits of sweetpotato dissemination efforts by CSIR-CRI and the Ghana Ministry of Food and Agriculture under the West Africa Agricultural Productivity Programme (WAAPP). There was high adoption of improved sweetpotato varieties and production practices, but men benefitted much more than women (Acheampong et al., 2024).

The SASHA breeding platforms were equipped with near infrared reflectance spectrometers to assist with rapid screening of sugars, several minerals and total carotene in raw, freeze-dried sweetpotato roots. This assisted with quality screening of large numbers of early generation clones as part of an accelerated breeding scheme designed to lead to the release of new varieties in 4 or 5 years (Grüneberg et al., 2015). Figure 1 presents the scheme that was used in Ghana, evaluating selections at ecologically distinct CSIR-CRI and CSIR-SARI sites in the north and south of Ghana, and conducting on-farm trials in the

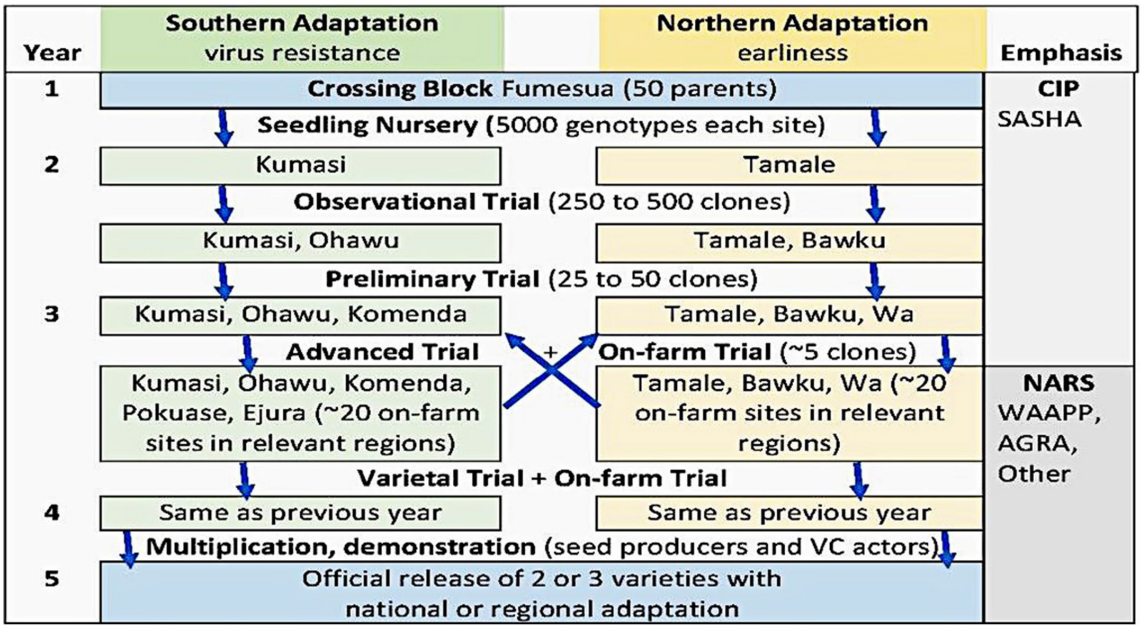

FIGURE 1
Accelerated breeding scheme in Ghana and West Africa with defined environments for population improvement in partnership with NARS.

third and fourth years. At the early stages of selection, traits such as pest and virus resistance, vine vigor, yield and root appearance were of necessity given priority over sensory attributes. Furthermore, sugars in raw sweetpotato roots are not a predictor of the sweetness of cooked roots since starch is hydrolyzed to maltose during cooking (Carey et al., 2019). So, while it was nice to have the ability to rapidly screen for traits such as sugar which is an aspect of culinary quality, it required additional efforts to enable us to predict quality attributes and consumer acceptance in cooked sweetpotato. Thus, the laboratory served as a nucleus for developing the sensory analytical capacity needed to better understand quality attributes and market segments and help guide breeding for different types of products (Dery, 2020; Dery et al., 2020; Ssali et al., 2020).

As already mentioned, on-farm trials were an essential element for farmer involvement in variety development and can provide input from consumers and other value chain actors in gender intentional ways. However, they often present challenges with respect to practicality and generating results that are easy to analyze and highly informative. The triadic comparison of technologies (tricot) is a citizen science method that provides a data-driven approach to on-farm and consumer sensory testing (de Sousa et al., 2024). The method uses an incomplete block design which allows individual farmers or consumers to compare varieties (or other technologies) in groups of three, by simply ranking them with regards to characteristics of importance. It is supported by a management and analytical platform that enables easy and highly informative analysis of results of these experiments and which can provide insights on gender, cultural and environmental effects, including generating recommendation domains within a country for the varieties being tested. With partners in Ghana, we used the tricot method to evaluate already released and pre-release selections from the breeding program by large-scale on farm and consumer sensory testing and showed gendered differences in taste preferences for boiled and fried sweetpotatoes (Moyo et al., 2021; Supplementary Poster 1). This new method will require efforts to encourage variety release committees, breeders, and extension partners to adopt this powerful new tool. Resources will be required for capacity development and its routine use, and to engage key actors in providing feedback to the breeding process.

2.4 What in the breeding process changed as a result of learning about gender

Gender sensitivity ensured the participation of relevant actors, including farmers, processors, and consumers, and the inclusion of men and women in evaluations and analysis of results. Selection for high dry matter was an obvious objective aimed at reducing oil absorption on fried OFSP and otherwise improving texture of boiled roots. This resulted in the breeding and release of new, higher dry matter OFSP varieties, such as SARI-Nan, SARI-Jan Low released by CSIR-SARI in Ghana in 2019 and 2020, and in the release of 8 new OFSP varieties in Malawi in 2011 and 2018 (Gatto et al., 2021).

Understanding the needs of and potential market segments for non-sweet and other types of sweetpotato was also very important, particularly since some were skeptical that development of this non-sweet sweetpotato would be useful. Development of sensory lexicons to describe the appearance, texture, flavor and basic taste attributes of fried and boiled sweetpotato roots was a first step. Sweetpotatoes characterized by trained sensory panels could then be evaluated in important sweetpotato production regions and markets by consumers providing their preferences for these varieties. These efforts revealed very different preference clusters differentiated by location, and age of participants, though not so much by gender. It was noteworthy that a preference for the non-sweet (staple-type) sweetpotato was identified in southern Ghana, while sweeter types

were preferred in the north. It was also noteworthy that the higher dry matter, but sweet OFSP, SARI-Nan, was preferred by consumers in each location (Dery, 2020; Dery et al., 2020; Ssali et al., 2020). Such insights are essential for understanding and catering to the needs of these segments, while maintaining a consistent gender focus, to ensure equitable outcomes.

The development of a sand storage technique in Malawi and Ghana provided a tool for ensuring timely availability of planting material and enhancing the dissemination of sweetpotato varieties with a short shelf-life. Short shelf-life, and timely access to planting material are key constraints to increased adoption of sweetpotato (Andrade et al., 2009; Bidzakin et al., 2014). USAID-OFDA-supported projects that developed and disseminated a sand storage technique to extend the shelf-life of harvested sweetpotato roots, to help farm families overcome the constraint of poor seed availability, especially in dryer areas. While reducing postharvest perishability of sweetpotatoes is a breeding priority, this sand storage technique can extend shelf-life of varieties with a shelf life of one to 2 weeks, by several months. In Malawi, during the sand storage development, women farmers helped design a storage pit with steps that made storing and removing sweetpotatoes more convenient than other methods including sandboxes, grain silos, and pits without steps or other methods that had been tried. In both Ghana and Malawi, sand storage enabled women to use household level storage to feed their families or sell, and to sprout roots and quickly produce vines when they need to plant in response to the increasingly variable onset of rains due to climate change (Atuna et al., 2017; Abidin et al., 2018a,b, 2019).

2.5 Breeding and dissemination outcomes and impacts related to gender equity

Developing and promoting diverse varieties of both low and high dry matter sweetpotato, such as CRI-Apomuden, SARI-Nan, SARI-Jan Low, along with a purple-fleshed genotype rich in antioxidants, SARI-Diedi, effectively addressed the diverse requirements of various potential markets and user segments. Varieties with attributes such as high dry matter are often preferred by women sweetpotato fryers (Ssali et al., 2020) and nutrient rich varieties meet the nutritional preferences of both male and female consumers (Bidzakin et al., 2019). Newly released high-yielding yellow and white-fleshed staple varieties, favored by both consumers and processors (women fryers), have also made a significant impact. Additionally, officially released farmer varieties and the landrace, Obaare (CSIR-Nyumingre) have contributed to this dynamic landscape (Bidzakin et al., 2019; Acheampong et al., 2024).

Strengthening the market system through demand-led value chain intervention was the focus of a recent AGRA project in Ghana. This and other investments in Malawi and Ghana reflect the scaling of demand for OFSP emerging from previous efforts. These efforts also stimulated demand for gender-responsive sweetpotato breeding in both countries (Supplementary Table S1). It is essential, however, to continue to foster integrated efforts which intentionally target women beneficiaries through household-based approaches in order to improve both nutrition and incomes, and to encourage the development of feedback loops between breeding programs and the users they exist to serve.

2.6 Adoption and its impacts

The development of improved varieties, strengthened seed systems, promotional activities and value chain support accounted for increased adoption of sweetpotato varieties. The Jumpstarting-OFSP project (2014 to 2017) and the USAID-OFDA sand storage scaling project (2017 to 2018) familiarized women and men in project areas and beyond with the low dry matter OFSP variety Apomuden. The projects created awareness of OFSP utilization and where to buy cleaned planting material. By teaching consumers to fry and bake with sweetpotatoes in local markets, and in school feeding programs, Apomuden found a market niche; paving the way for newer OFSP varieties such as SARI-Jan Low, released by the breeding program. This effort with male and female participants contributed to food security, increased income, nutrition, healthy food systems, and food justice, as locally grown OFSP supplementing wheat-flour for baking has the potential to reduce reliance on imported wheat. This multi-year, multi-project effort created a demand for an OFSP that had previously been rejected because of non-preferred characteristics, opening the door for improved OFSP varieties bred to replace Apomuden (Adekambi et al., 2020a).

In Malawi, the ROH-OFSP project (2010 to 2014) focused on one OFSP variety, Zondeni in the beginning of the project intervention in 2010. It was a local variety, officially released by the National Research Program in 2008. The dry matter is relatively high with good taste, and easily disseminated because men, women, and children liked its taste. Awareness creation combined with information on nutritional value, and potential for generating income through food processing (Abidin, 2010, 2014a) encouraged the adoption of newer high-yielding OFSP varieties, disseminated using similar approaches to the ROH-OFSP project in subsequent projects (Gatto et al., 2023).

3 Discussion

3.1 Good practices

Gender research budgets in projects. Projects in Ghana and Malawi did not have specific operational budgets for gender research related to breeding, seed, or value chains, but were able to allocate these from overall program budgets, drawing on program staff and special programs when needed. For breeding programs, the key is to routinely engage gender specialists and social scientists, or to use appropriate tools, to ensure that input from relevant stakeholders contributes to decisions about product advancement and variety release and dissemination.

Gender considerations in targeting market(s) or end-users. This was driven by overall SPHI objectives of improving the livelihoods of households through improved health and incomes. Since women often prepare food at home, are mothers and primary caretakers of children, or work as food vendors their needs must be targeted. It is necessary, however, to target these users, who can be overlooked in farming systems where men dominate, as was the case for training in Malawi, and is even more the case in northern Ghana where conscious efforts must be made to include women.

Small-scale bakers and vendors of snacks such as *mandazi*, a fried dough in Malawi, and chunk fries in Ghana, are mostly women; they have benefitted extensively from project activities which generated new demand and markets for OFSP (CIP, 2013a). Training in Malawi and Ghana on techniques to reduce oil absorption during frying (e.g.,

parboiling, drying, or coating) also helped women tap into wider markets (Abidin et al., 2015).

Gender and decisions about breeding objectives and the desired impact. All project activities were designed with gender in mind, targeting women also as beneficiaries. Sweetpotatoes are a family crop, thus, men and women should benefit. Breeding and seed systems can be more responsive if they are demand-driven, and oriented toward specific user groups, with feedback loops between breeding programs and beneficiaries. Leaf quality was identified as important to women, but it did not become a specific breeding objective in Ghana or Malawi, because the leaves of most varieties are suitable for eating as a vegetable. A flyer for consumers on how to use sweetpotato leaves as a vegetable or in juice in Ghana and Malawi was published (Abidin, 2016).

Gender and variety design. Desired traits for various uses are selected along with other characteristics required by farmers and other value chain actors. The breeding approach taken by SASHA in Ghana involved making crosses followed by evaluations and selections of clones for traits such as vine vigor, virus, and weevil resistance, root size, root shape, yield, shelf life, etc., in key environments in the North and South (Figure 1). While we could pay attention to quality attributes such as flesh color and dry matter content throughout the selection stages, it was not possible to engage in massive evaluations for processing or culinary attributes at the early selection stages. In Ghana we were interested in different quality types, including non-sweet, staple types, sweeter, high dry matter OFSP, and other flesh and skin colors. We refined these objectives during the time the platform was in operation, improving our understanding of potential market segments in the North and South of the country. As markets for processed products and export pick up, greater attention will be required for smooth, attractive root shapes that are easy to wash, and which are in line with consumer expectations in export markets. A large portion of sweetpotato in West Africa is consumed in the form of chunk fries, mostly processed, and sold by women as a "street food," so breeding programs need to ensure suitability for this use if they are to provide varieties for this massive market (Carey et al., 2021).

Various varieties and advanced selections came through the breeding pipeline, providing high-yielding, culinarily diverse, and accepted genotypes. We used the tricot method for consumer evaluation of advanced selections by men and women of the boiled and fried sweetpotato. These quality assessments were conducted in a market setting and were complemented by on-farm trial evaluations with males and females, so final assessments of acceptability are based on both agronomic and culinary performance (Moyo et al., 2021; Supplementary Poster 1). There was gender differentiation in the ranking of both boiled and fried sweetpotato, with some of the advanced selections emerging as preferred by men and women. Some high dry matter, white- and yellow-fleshed selections were ranked highly by both men and women in boiled and fried forms. Men liked boiled OFSP CRI-Apomuden more than women did, perhaps because of their expectations of its health benefits.

Gender and trait evaluation. Product profiles guided the selection process. These are based on the needs of users, including women. Dry matter levels above 30% are preferred in all genotypes, though the low dry matter content OFSP CRI-Apomuden (under 24%) was successfully disseminated before superior new varieties were available. Dry matter content up to 35% and over is preferred for white- and yellow-fleshed genotypes, though there may be trade-offs if attributes such as appearance and yield are superior. Ultimately, the combination of attributes for growing, cooking, and eating sweetpotato must guide selection decisions, made by men and women end-users comparing experimental genotypes with currently important check varieties of each quality type.

Gender and decisions about on-farm trials. On-farm trials are an essential part of breeding evaluations but have been criticized for not producing easily analyzable data. The development of the tricot citizen science method overcomes this concern, providing informative, statistically-sound analyses based on gender-disaggregated preference ranking by a large number of farmers or consumers. Key factors that contribute to rank differences in preferences in trials are detected using the Plackett-Luce analysis of results (de Sousa et al., 2024). Tricot is a convenient, effective, citizen science method for engaging farmers, processors, and others in the evaluation of technical options, e.g., varieties. The tricot method is not yet routinely used in on-farm trials by the national breeding programs in Ghana and Malawi. However, efforts by CGIAR breeding programs to encourage its adoption are already gaining traction in some national programs. It is essential to ensure adequate budgets for this approach, which has been shown to be more cost effective than traditional approaches to on-farm testing (de Sousa et al., 2024).

Gender and decisions about what types of farmers participate in evaluations. On-farm evaluations typically involve men and women farmers, but any group of end-users can be engaged. Quality or processing assessments can also involve non-farmers. The tricot method allows analyzing environmental influences on crop performance as well as gender preferences.

Gender and decisions about seed multiplication and dissemination. This can be done appropriately, depending on the needs and opportunities, ensuring that required varieties are available for vine multipliers. These efforts should seek to strengthen business opportunities for women to help them in seed or root production and processing businesses, which would stimulate demand for planting material, as implemented successfully by our projects in Malawi and Ghana. There is a continuing need to strengthen the integration of breeding and seed system efforts.

3.2 Lessons

From 2010 through 2019, the SASHA breeding platform in Ghana worked with the national program and many other partners to develop and disseminate varieties. Together with other SPHI projects targeting users' needs, these efforts contributed to improving the livelihoods of many households.

Efforts over the years contributed significantly to our understanding of and our ability to respond to needs in a gender-sensitive fashion. We refined our understanding of attributes required by value chain actors, from farm households to processors and consumers. Studies of consumer market segmentation enabled us to develop an understanding of potential markets for different quality types, including non-sweet, staple-type and sweeter types. The tricot method improved our capacity to understand and respond to users' needs through on-farm trials and consumer taste tests. We hope the use of tricot will gain routine acceptance as a tool for breeding and seed programs. Capacity development and awareness creation efforts stimulated demand for sweetpotato (particularly OFSP) and encouraged processing, farming, and planting material businesses. In Ghana, the breeding program developed

higher-yielding varieties with a range of quality types adapted to the dryer northern environments, and the more humid southern regions of the country. A sustainable program for producing and selling healthy planting material was established at the CSIR-CRI to supply foundation seed to producers, NGO projects, and seed multipliers. Dedication and resources will be needed to continue and to strengthen these efforts.

A new project to empower women in poor areas of northern Ghana is working with CARE-Ghana, and the Ministry of Food and agriculture to use various technologies, including high-yielding new varieties like SARI-Jan Low for vine multiplication, production, and processing (Temesgen and Gyan-Bassaw, 2024). Integrated grassroots projects will allow women to become more active users of the improved varieties, providing feedback to breeders on the need for further improvement. Selection of smooth and regularly shaped roots should be included to increase demand by markets. The unevenly shaped varieties previously released are not attractive nor easy to be cleaned for processing.

In Malawi, the ROH-OFSP project in partnership with the national breeding program and various government and international organizations like the United Nations Food and Agriculture Organization (FAO), non-profit and private-sector actors, laid a strong foundation for continuing dissemination and adoption of sweetpotato, including OFSP. This effort has continued with persistent national, international, and private-sector initiatives, enabling the release and dissemination of several OFSP varieties by the national program. Malawi is a leading producer of sweetpotato in SSA, as a result of the foundational efforts of the ROH-OFSP project and its integrated approach to strengthening seed systems and nutrition education.

The GREAT project, coming towards the end of the breeding and seed dissemination efforts in Ghana, helped confirm traits and varietal preferences of men and women value chain actors in northern Ghana. Women's preferences were largely related to nutritional benefits and culinary use of sweetpotato while men's preferences were predominantly in line with yield and marketability. The interests of men and women were mostly complementary, indicating the importance of ensuring the contributions of both sets of stakeholders during variety evaluations and surveys. The work was conducted in two different regions of northern Ghana with quite different market opportunities, which had a bearing on the varieties being grown, and the responses of men and women in these survey areas.

The participation of a social scientist, a food scientist, and a sweetpotato breeder in the GREAT team provided a multidisciplinary perspective, ensuring that their questions were addressed in the field. All team members participated in the GREAT training, ensuring that the research was gender-responsive. GREAT attached a mentor to each group, to guide the team members through the research. Mentors provided literature, and online meetings, and reviewed research documents.

Our recommendation to breeders interested in impact-oriented, gender-sensitive variety development is to embrace the trans-disciplinary nature of demand-led plant breeding and to use the increasing array of available tools such as defined gender responsive product profiles and tricot. Extension agents and project managers also play a critical role in providing feedback to breeding programs and they should also be brought onto the breeding and dissemination teams to ensure impact. Good communication and cooperation among disciplines and team members is essential. Methods for promoting new products, such as OFSP varieties, must pay attention to diversified market opportunities. Engaging with users will ensure that varieties are developed that can be integrated into equitable and sustainable food economies. Fragmented and sporadic project funding and changing institutional priorities may always present challenges to breeders. However, breeding and seed dissemination programs that serve a large population or important markets will be easier to justify economically in the long run.

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

Ethical approval was not required for the study involving humans in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and the institutional requirements. However, written informed consent was routinely obtained prior to initiation of all surveys reported here.

Author contributions

OU: Writing – original draft. Writing – review & editing. PA: Writing – original draft, Writing – review & editing. ED: Writing – review & editing. JB: Writing – review & editing. NM: Writing – review & editing. ID: Writing – review & editing. ME: Writing – review & editing. EC: Writing – original draft, Writing – review & editing.

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Conflict of interest

The 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.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsoc.2024.1263438/full#supplementary-material

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Increasing sorghum yields for smallholder farmers in Mali: the evolution towards a context-driven, on-farm, gender-responsive sorghum breeding program

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This case study explores a decades long evolution towards a gender-responsive sorghum breeding program in Mali. With known disparities in men and women's access to the resources that improve agricultural productivity and evidence that gender roles and responsibilities shape knowledge and preferences about varieties, there is need for methods that support gender-responsive processes in plant breeding programs. Gender-sensitive and gender-responsive approaches in plant breeding may increase varietal options available to diverse end-users, increase adoption, and limit negative impacts on vulnerable populations. We assess a participatory plant breeding program in Mali to identify determinants of gender-responsive breeding programs. The analysis uses a case study methodology that draws upon project reports, theses, articles, and experiential knowledge to understand how the sorghum breeding program transitioned over time. This case study details (a) more than a decade of sorghum breeding activities and research that led to (b) the inclusion of women in participatory plant breeding, culinary tests, and large-scale participatory selection in on-farm trials, reaching hundreds of women each year and (c) iterative co-learning processes to develop preferred sorghum varieties and increase sorghum yields on men and women's fields. Analyses indicated that collaborations among many institutions on-farm with community actors, research across various disciplines such as agronomy and social sciences, context-specific breeding, and long-term funding were essential to increasing gender sensitivity and responsive in the breeding efforts.

KEYWORDS

gender, participatory plant breeding, sorghum, gender-responsive, seed

1 Introduction

Family run and small-scale agricultural production systems are vital to the food and livelihood sovereignty of rural populations, who produce 80 and 35%, respectively, of the world's food (Lowder et al., 2021). Rural women contribute substantial knowledge and labor towards farming (Doss, 2014), in addition to their responsibilities for the household and childcare and their income generation roles. Despite their significant roles in growing, harvesting, selling, and preparing these crops for family consumption or sale, plant breeding programs have made limited efforts towards positively impacting rural women's livelihood options. Even the understanding and thus inclusion of women's knowledge, preferences, and livelihood strategies has been limited over the past 50 years. Patriarchal tendencies in western science, socio-cultural traditions in rural societies, intersectional-based biases on who holds knowledge, and the corporatization of public breeding, have all contributed to neglecting a potent avenue for increasing agriculture production and well-being of smallholder farm families.

Crop improvement has been extremely successful in homogenous environments, or at least environments where other inputs and management can generate relatively homogenous growing conditions, such as in the Midwest, United States, the Indo-Gangetic Plains, or the fertile Chernozem soils of Ukraine. Selection pressure to generate high-yielding varieties that perform well across homogenous conditions has had less success in stress-prone, less predictable environments (Annicchiarico, 2002) and on the heterogenous small-scale farms (Dawson et al., 2008) that are essential to local and regional food systems. Low adoption rates of improved varieties are due, in part to, their lack of adaptation to the predominant production environments, farmers' limited access and income for purchasing seed and requisite inputs, risk-aversion to new varieties, and exclusion of farmers, especially women, from the trait selection process (Camara et al., 2005; Meijer et al., 2015; Sissoko et al., 2019; Weltzien et al., 2019a; Acevedo et al., 2020; Magnan et al., 2020; Dessalegn et al., 2022). Successful crop improvement that respects food and livelihood sovereignty in these contexts requires a deeper understanding of the intersectional strategies and environmental factors that shape small scale livelihoods.

1.1 Gender in plant breeding

Women farmers face disproportionate obstacles to achieving food security and well-being compared to men. They own less land, have less access to inputs, credit, education, information networks, and resources in households are often allocated unequally. Even in many measures of agricultural productivity gaps, the rectifying of which is purported as a means to improve economic outcomes and well-being, women's livelihood strategies, intentional choices, and the hidden work of reproductive and household care, are often unaccounted for. With known disparities in men and women's access to the resources that improve agricultural productivity (Doss, 2018), including new varieties and seed, and evidence that gender roles and responsibilities shape knowledge and preferences about varieties (Diallo et al., 2018; Weltzien et al., 2019a), processes and methods to create responsive plant breeding programs are needed.

There are efforts in plant breeding to collect gender-sensitive data and understand how and when gender differentiated research on plant traits is necessary. Commonly, trait preference studies use direct ranking (Jinbaani et al., 2023) or choice experiments (Waldman et al., 2014) but these methods give little attention to the social structures and roles and responsibilities within households that shape those preferences (Teeken et al., 2021). Furthermore, a recent review of gender and plant breeding research showed that even when gender-differentiated data were collected for assessing farmers' preferences for plant traits, gender differentiated analyses were rare (Weltzien et al., 2019a). Recent efforts have focused on interdisciplinary research that examines how roles and responsibilities in crop and seed production, processing, cooking, and marketing influences these trait preferences (Diallo et al., 2018; Marimo et al., 2020; Isaacs et al., 2023). Teeken et al. (2021) examined how intersectional identities shaped cassava trait preferences, finding that food product quality traits were more important to food insecure households, and women and men's preferences varied by region, wealth, and household characteristics. Collection of disaggregated data is not enough—having interventions or next steps in research that respond to the challenges discovered in the initial gender analysis and trait preference discovery are essential for meaningful programming that supports women and men in their pursuit of well-being and sustainable agricultural livelihoods. These efforts should also seek to ensure that research and development activities do not increase burdens on women in terms of drudgery, lack of access to new varieties, or through the creation of varieties that shift who is responsible for the production and subsequent profits (Ashby and Polar, 2019). The previous decade's pioneers in gender-responsive plant breeding can provide useful insights for increasing the gender-responsiveness of other plant breeding programs. Here we use a case study to describe the evolution towards a gender-responsive sorghum breeding program in Mali, to address the research question: What are the determinants of gender-responsive breeding programs?

1.2 Setting the stage

Over more than two decades, sorghum breeders, scientists, farmer associations, and practitioners in Mali have created a farmer-driven crop improvement program engaged in participatory plant breeding (PPB) and interdisciplinarity (Rattunde et al., 2021). The objectives of this sorghum breeding team were to characterize an ever-changing production environment, farmer needs, and gender factors related to sorghum, with the purpose of improving food security (Orr et al., 2022) and farmer well-being by increasing the availability and access to preferred, quality sorghum varieties, diverse variety types, and seed. This program transitioned over time from gender-sensitive (men produce sorghum; women are engaged in sorghum production activities) to actively engaging with women and changing programming to respond to a more nuanced, contextual appreciation of the roles and responsibilities of men and women as sorghum producers and actors. We examine this transition in detail to identify determinants of gender-responsive breeding programs.

This case study uses a mixed methods analysis to understand how multiple factors, including personnel, funding, and participatory processes with many partners, led to increasingly gender-responsive

breeding efforts. We present key milestones in the first 15 years of this program, insights into relevant methodologies for future programs, and specific research findings on gender that led to innovations in the breeding program.

1.3 A gender-responsive evaluation framework for long-term participatory plant breeding programs

Efforts towards meaningful inclusion of women in the agricultural development process has had many iterations with varying degrees of alignment with feminist scholarship (Farhall and Rickards, 2021). Nonetheless, recent design and evaluation categories in agricultural research and development, gender-sensitive and gender-responsive, are intended to better operationalize gender-inclusion. Gender-sensitive work recognizes the different needs of women and men (and boys and girls) and acknowledges there are gender power dynamics (UN Women, 2020) while ensuring no-harm such as increased labor or exacerbation of power dynamics in the household. Gender-responsive programming and research calls for understanding the complex interactions of gender and the biophysical environments that shape women and men's needs, priorities, and opportunities (Meinzen-Dick et al., 2011; Mangheni et al., 2021), and respond to them. Programs that are gender-responsive engage with interdisciplinary teams, are intentionally designed to benefit men and women, and consider gender and power relations at the local level as well as within research teams, research and program topics, and institutions (Menghani et al., 2021). Such approaches aim to reduce gender inequities *in situ* (rather than structurally) (Farhall and Rickards, 2021) and use participatory processes that are inclusive and respectful of all stakeholders (UN Women, 2020).

To evaluate the gender-responsiveness of a PPB research and development program, multiple frameworks necessarily come together. Here we briefly examine these disciplinary elements. Evaluations of gender-responsive research and programs have used different parameters. UN Women use two broad categories for evaluations across diverse program types: the first assesses the "degree to which gender and power relationships…change as a result of an intervention" and secondly, it "entails a process that is inclusive, participatory and respectful of all stakeholders," including women's voices and the prevalence of different groups (UN Women, 2020). To test the gender-responsiveness of 14 agricultural research projects, Mangheni et al. (2021) developed a monitoring and evaluation (M&E) framework that considered gender parameters at each stage of research: planning and priority setting, research process, research products, institutional environment, and M&E. This framework lends itself to the research portion of the sorghum program activities but requires amendments for a long-term program that includes capacity building and project-oriented programming.

In ideal PPB programs, all the stages of the crop improvement cycle are in close collaboration between farmers and researchers and there are iterative cycles of discovery, learning, and action through dialogue with farmers, sharing knowledge and characterizing the context, priority setting, planning, and developing seed distribution strategies (Christinck et al., 2005). This participation can take the form of consultation, in which local opinions are asked and research teams make decisions; collaboration, in which priorities are determined together with farmers but project responsibilities remain with the research team; or co-learning, in which farmers and researchers share knowledge, shape priorities, and project responsibilities may be joint (Christinck et al., 2005). Furthermore, farmers and researchers iteratively inform each stage of the breeding cycle, which are: set breeding objectives, generate or assemble new variability for relevant traits, select in segregating populations and experimental lines, test and evaluate experimental varieties, and produce and distribute seed (Christinck et al., 2005). Historically, even with PPB, in which participation is the driving principle, the depth of women's engagement and the response to those findings may be varied. In other words, PPB is not an inherently gender-responsive process. The research components of the iterative cycle of PPB matches, to extent, the research process described by Mangheni et al. (2021). In order to identify determinants of a gender-responsive breeding program, we will use a case study approach analysing the PPB sorghum breeding program in Mali and identifying how and when it transitioned from gender-sensitive to gender-responsive. Finally, we will use these findings to make recommendations for future work and for streamlining the process.

2 Methods and data used

A mixed methods case study review was utilized to analyze when, how, and to what effect gender was integrated into the sorghum breeding program in Mali and to identify critical intervention features that led to a gender-responsive program. An explanatory and descriptive case study approach (Baxter and Jack, 2008) allows for the rich analysis of a process or program in context, using various data sources and exploration of the relationships and communities that shape the phenomenon (Yin, 2003). The process that led towards a gender-responsive program is the unit of analysis (Baxter and Jack, 2008; Miles et al., 2014), in other words we considered the decision-making, research findings, serendipity, and opportunities in the specific context of sorghum breeding in Mali.

The sorghum breeding program that we describe here consisted of the sorghum teams of the Malian Institut d'Economie Rurale (IER) and of the International Crops Research Institute of the Semi-Arid Tropics (ICRISAT), several national non-governmental organizations (NGOs), and farmer cooperatives. The analysis spans from 1997 to 2013, encompassing multiple partners, various funding sources, iterative research objectives, and different stakeholders. This case study focuses on efforts in Mali, although the sorghum team worked with National Agricultural Research Station (NARS) partners in Burkina Faso and Niger as well (vom Brocke et al., 2020). Data for the case study include peer reviewed journal articles, interviews, technical reports, book chapters, dissertations, masters' theses, evidence from informal stakeholder engagement, and grey literature. Documentation from workplans and technical reports provided evidence of how the program responded to research findings over time. We include in-depth descriptions of findings from these resources to fully illustrate the case, to show the subsequent responses to the findings, and because many of these resources are reports or theses that are difficult to access. We also developed a timeline to connect various phases of the program and demonstrate if and how the results of the first learning phase informed the activities of the second implementation phase (Hong et al., 2020). This case study

complements a parallel case study on sorghum in Mali that demonstrated how creating a collaborative framework and local level decision-making opened pathways for resilient farming and food systems (Rattunde et al., 2021). Here, we expand on these learnings to understand how gender research was integrated into the same program.

3 Results

Activities, learning, and partnerships in the evolution to a gender-responsive sorghum breeding program.

3.1 Early agricultural research institutions in Mali

The Sudan-Savanna belt across West Africa is a major rainfed sorghum production area. Sorghum production in West Africa is primarily by small farmers for food security purposes, such as home consumption and sale at local markets. There are few large-scale or commercial operations, and the breeding program targeted the small farm production environment. In 1979, ICRISAT and IER began a bilateral collaboration on sorghum and millet research, and later groundnut, funded by USAID. They have worked in partnership since, with goals of strengthening the national research programs, crop improvement, and cropping systems research (Shetty et al., 1991). Earlier documents indicated that exotic germplasm was used to develop improved varieties but low adoption and interest from farmers pushed activities to on-farm trials to test the varieties under farmer conditions. On-farm results showed low productivity and researchers suggested returning to local germplasm as it was more familiar to the farmers and had sufficient yield (Shetty et al., 1991). The same report indicated that women were largely left out of changes in technologies, crops and productivity and that labor for women and other groups limited their ability to participate effectively in outreach activities and make gains in agricultural productivity (Shetty et al., 1991).

3.2 Production in Malian households

Within a Malinke or Bambara village in Mali, family units are called *du* and are composed of extended family members including a male household head, married sons and their families, and/or brothers, and multiple wives (Smale et al., 2019). The *du* are the unit of agricultural production (UAP). The various family units in the *du* have collective plots in which production decisions and planning are controlled by the male household head (Becker, 1989), with labor contributions from all able members of the extended family. The collective plots are used to produce the household supply of staple crops, such as millets, sorghum, and maize, and cash crops, such as cotton.

Minor family members, including brothers, sons, and wives (unmarried women do not have a right to use land) are allocated plots of land to cultivate each year after the collective fields are allocated (Wooten, 2003). Women are allocated plots last, which generally means they receive the plots that have poorer soil quality. Women are responsible for planting crops that contribute to the sauce for the family meal (Wooten, 2003): mainly cowpea and groundnuts; and they grow cash crops to provide for the ingredients in the sauce. It was not understood until later that most women produced sorghum on their plots too, often in intercrops, as an additional household food security crop. The production of sorghum by women on their own plots only became clear through dedicated partnerships with communities and through gender-sensitive inquiry with social scientists (Van den Broek, 2007). These revelations led to multiple changes in the sorghum breeding program that was already an advanced form of participatory plant breeding (PPB).

3.3 Organizations and actors involved in sorghum breeding

The two institutions leading agricultural research in Mali, ICRISAT-Mali and IER, have had collaborating sorghum breeding programs for many decades. In the late 1990's ICRISAT transferred two plant breeders to Mali who had previously started a participatory plant breeding program in India on millets. One of this pair was a woman, who brought with her awareness of women's roles in agricultural livelihoods from previous work, had a keen sense of engaging with local actors, and had previously engaged with women producers in India. Gender-responsive evaluations have indicated the importance of including female investigators (Meinzen-Dick et al., 2011; Elias and International, 2013) because it is more acceptable, according to certain socio-cultural contexts, for women farmers to engage with other women (Njuguna-Mungai et al., 2016). In addition, the female plant breeder was likely an appealing mentor for aspiring female scientists that later participated in activities. Together, the plant breeders brought with them a philosophy of participatory engagement and partnerships with national research institutes and local actors. This approach led to the development of strong, long-term partnerships with farmer cooperatives, associations, and national NGOs, in addition to strengthening engagement with scientists and technicians at IER. The partnership of IER with ICRISAT led to continuous "learning by doing" and training of many staff in PPB and gender-sensitive processes. Partnerships with farmer organizations like ULPC and AOPP, often organized and maintained by dedicated Malian technicians, and national non-profits such as AMEDD and AMASSA, that work directly with farmers, proved to be a formidable approach to develop a network of communities engaged in the participatory activities. These organizations not only supported in logistics and organizing community activities, but also served as a cultural bridge for scientists and technicians to engage with farmers in a meaningful and reciprocal way.

3.3.1 Key personnel

The two plant breeders hired in 1998 that led the full-scale development of a gender-responsive sorghum breeding program at ICRISAT were supported by technicians (many of them were women), animators, graduate students, and committed staff who were essential for communication and connections within villages. The plant breeders continued to shift the program towards developing and conserving varieties based on local germplasm (guinea race rather than caudatum and kafir races) and in collaboration with farmers. Their appointment, among other things, was based on learnings from

earlier data collected by an agricultural economist in 1995–1996. That dataset showed new varieties developed from exotic cultivars (caudatum race) were poorly adapted to the production environment and unfamiliar to farmers (Yapi et al., 2000) in the region.

Building on the existing bilateral collaboration between IER and ICRISAT, plant breeders worked with the sorghum breeding program at IER; collectively they are all referred to in this paper as the sorghum team. In addition, various graduate students contributed to the program, with added value from visiting social scientists who periodically sought out research opportunities with the sorghum team and who studied the roles and responsibilities of women in sorghum producing households. For example, in 2007 a social scientist did a study that provided the first insight into the quantities of sorghum women were growing on their fields.

3.4 Key activities

The plant breeders implemented various forms of farmer participatory engagement and partnered with academics and practitioners with diverse backgrounds. The iterative learning over the years in collaboration with these partners and the communities led to new approaches and the creation of a gender-sensitive and then gender-responsive breeding program that incorporated various practical innovations to increase relevance to men and women (Figure 1). As the program grew, roughly 300 women per season evaluated on-farm sorghum lines, more than 50 women conducted the cooking trials per season, and at least 100 women per season conducting the sensory evaluations. In addition to the large number of participatory on-farm trials, and the ensuing discussions and observations, a critical entry point was the detailed understanding of farmers' seed management practices and norms that came later (Siart, 2008).

3.5 Description of breeding activities and engagement with men and women sorghum producers

The learning and subsequent shifts (Table 1) that changed how women were engaged in the PPB sorghum program are described below to illustrate the process of becoming a gender-responsive breeding program. The PPB sorghum, started in 1998, provided the foundation for this learning and evolution, and to this day integrates many of the trial types and evaluations detailed below. The program considers farmer and breeder selection criteria on an on-going basis (Christinck et al., 2005); utilizes a Diversified Guinea Race population, and guinea race core collection for the development of hybrids and varieties with increased resilience; and conducts annual on-farm farmer selection of lines and varieties (Christinck et al., 2019; Weltzien et al., 2019b). Many different forms of participatory processes and farmer-led activities were used (Figure 1) and we highlight several below.

3.5.1 Women in selection

The breeding team (IER and ICRISAT) included women farmers in their outreach and engagement early on with the purpose of developing varieties suitable for the whole household. From previous research, the team knew that sorghum was grown on collective family plots in which management decisions were made by the male household head, men and women labored in the fields with specific roles, e.g., weeding was women's task, harvesting was men's task, and that women were responsible for processing sorghum for meals. Thus, they included both men and women in identifying breeding priorities through participatory variety evaluations and over time adjusted these methodologies to (a) include farmers earlier on in the breeding process through farmers' selection among and within segregating lines (Rattunde et al., 2016), (b) re-define breeding priorities based on the expressed visions of farmers on the future development of their production systems, and (c) ensure that women comfortably shared their opinions and observations.

Looking back, it is clear involving women as participants provided some information as to their preferences, but the structure of the group activities may have limited the information they shared. Their engagement in varietal selections did not necessarily lead to the same level of insight as provided by social and gender analysis, nor into social differences that underpin varietal preferences and affect adoption of new varieties. This is similar to a recent evaluation of gender-responsiveness across agricultural research cycles in which the authors found that few projects conducted a complete gender analysis (Mangheni et al., 2021). Still, women were a part of the activities from the beginning and efforts were made to adjust how preferences and information was collected from women that contributed to shifting towards a gender-sensitive program.

In 2003, the sorghum team initiated more extensive field trials to advance multi-location testing of new breeding lines, involve farmers in selection decisions, and understand farmers' selection criteria in more detail. These trials started in 2003 and included 32 entries, e.g., lines or varieties, that were grown in multiple villages across the region for evaluation by men and women. The trials were typically planted in 4 farmer's fields in a village that had sufficient interest and area to support these larger trials. These trials included newly developed breeding lines and experimental hybrids available from the Diversified Guinea populations, the IER selection program, and local checks (Kante et al., 2017). Having farmers evaluate early breeding lines and incorporating their criteria in the selection process shifted the sorghum program towards a partnership with the farmers, and their organizations (vom Brocke et al., 2010). The farmers chose the varieties that would advance in the breeding program, get released, and enter into seed production and dissemination.

Even in the early stages of the program, when it wasn't clear to the team that women produced their own sorghum, women's experience as farmers contributing knowledge and labor in the collective fields was recognized. This recognition extended into the PPB field days, in which methods evolved over the years to ensure women were comfortable and able to contribute their ideas. One way of doing this was to have women technicians from the sorghum team and/or animators in the communities lead the discussions with women separately from men. Another important feature of these activities was awareness of the different levels of literacy in the groups. After recommendations from social scientists, the sorghum team tried different approaches and the methodology evolved such that a female technician accompanied several women in the field, guided them through the different lines, and helped collect their evaluations of each variety by recording the information. Women who could do their own assessments did so. At the end of the field day, the results were

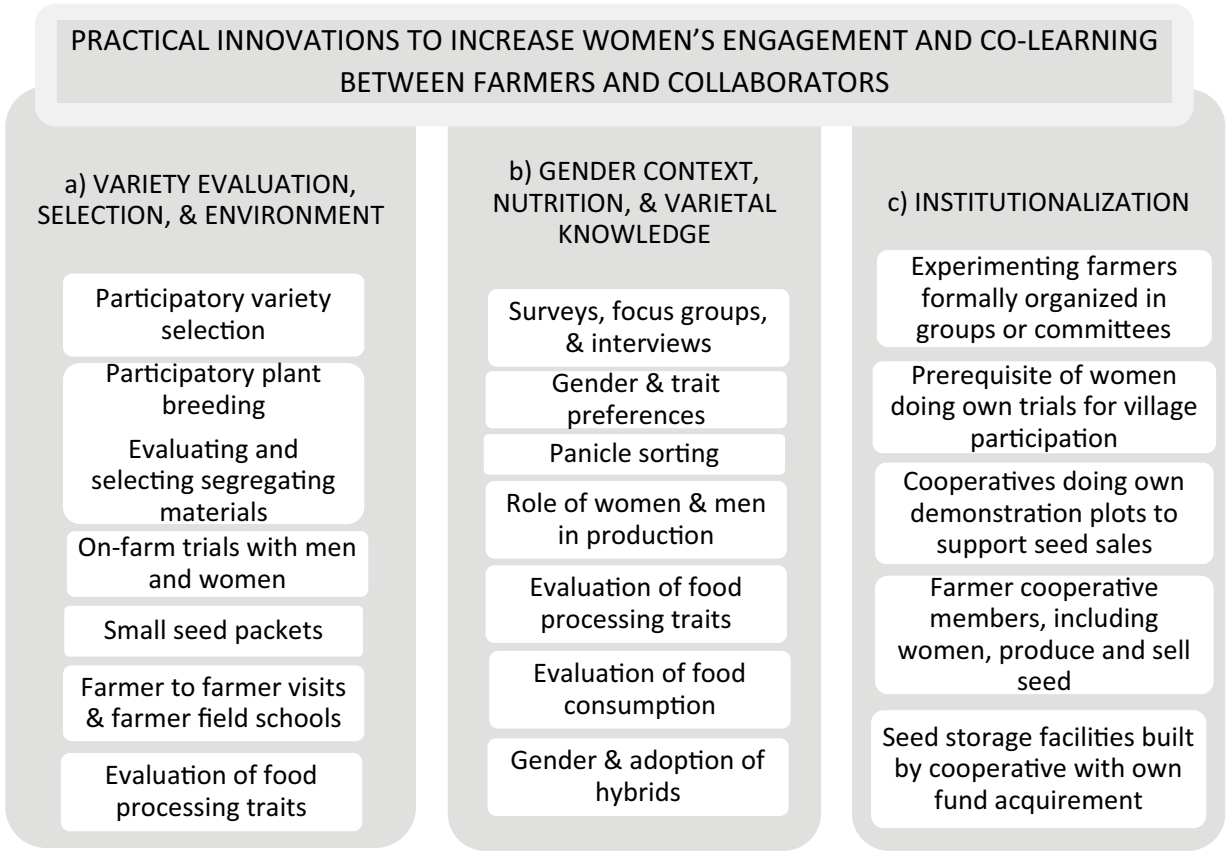

FIGURE 1
Activities used by the sorghum breeding program to engage with farmers through **(A)** biophysical and participatory studies with men and women, **(B)** gender analysis, and **(C)** the methods for institutionalizing local level experimentation and seed production with men and women; and informed by **(A,B)**.

presented back to the plenary of all farmer groups, women contributed to the reflections, and also reflected on the results of the male group.

In 2004, the sorghum team started to formalize participatory, 5-entry on-farm trials with individual farmers. The on-farm trials included entries selected by farmers from the 32-entry trials; the farmers chose 4 varieties to grow in comparison with a local check. The 4 entries were selected based on the results of the 32 entry trials presented to farmer groups during the planning and feedback meetings, held every year in each trial region. Farmers selected entries targeting specific growing conditions, e.g., early sowing dates, fields infested by Striga, intercropping with maize, of low soil fertility. Several sets of such trials were co-designed this way, and village groups of at least 4 farmers chose one of these sets for testing. These 5-entry on-farm trials by individuals allowed the farmers to see how the new varieties (lines) performed in their specific growing environments and they were able to compare performance with their local variety, also by visiting the fields of their group members. It wasn't until later, after understanding the extent that women grew sorghum, that women were specifically included in the 5-entry on-farm trials. Because women grew sorghum mostly as an intercrop in groundnut fields, and thus more space was required, the design was changed, such that women only tested 2 new entries in comparison with their checks. Men farmer groups were given these trials sets only if a group of at least 4 women from their village was interested to conduct their own trials. Male farmers often encouraged their wives to participate.

3.6 Interdisciplinary collaborations over the years

3.6.1 Women's knowledge on grain quality, decortication yield, and culinary attributes

The sorghum team was developing ways to learn more about the grain quality attributes that women, as the processors of the sorghum grain at household level, preferred, starting with the first large scale farmer managed trials, in 2001. Previously, Shetty et al. (1991) evaluated grain quality in the laboratory with detailed observations and analysis of the biochemical attributes important for processing and sensory qualities (Fliedel, 1994). However, these results were not systematically included in selection decisions. Grain quality evaluations moved to the villages, where women could be included, and the whole process of post-harvest management and processing could be considered by the users. Evaluations of grain color, hardness, and other qualities grew into culinary tests conducted in the villages using the varieties (lines) selected from the 32-entry trials. An

TABLE 1 Timeline of gender research and key breeding decisions in the case of PPB with sorghum producers.

Year	Activities and learning	Program response and breeding decisions
Gender-aware stage		
1998–continuous	Identified and examined farmers' selection criteria for sorghum varieties, compared these criteria with the breeder's agronomic observations. Germplasm from local/regional farmers collected. Social survey research not sex-disaggregated Gender-aware approach: Women included as participants in PPB and PVS.	Integrate farmer and breeder criteria into the early stages of the breeding program. Decision to focus breeding program specifically on 900–1,200 mm rainfall environment. Decision to focus on guinea-race germplasm improvement.
1999	Start of 'big trial' with 24 variety trials in Siby and Dioila areas, learning about farmers' seed management practices. Gender-aware approach: Women included as participants in PPB and PVS.	Started the development of breeding lines from "Diversified Guinea Race population," tall and short versions. Breeders leant something about farmers' preferred varieties and trait preferences but not much insight about gender differences.
2001	Breeders expand collaboration to include development partners, such as World Vision.	Breeders initiate collaboration with the IER Food technology Lab on methodology for evaluating processing and sensory grain qualities. Breeders experiment with methodology for fully farmer managed variety trials.
Gender-sensitive stage Definition: programming that recognizes and acknowledges gender power dynamics but does not address these other than try to integrate an understanding into the programming		
2002	Very high demand for test packets for on-farm testing of different varieties; small seed packs made testing feasible for men and women farmers with small plots of land and have unique growing conditions, and provided access to new varietal diversity in the absence.	First sale of 100 g seed packets, from the extension office in Dioila.
2003	Start of 32 entry variety trials, with two plant height groups, as newly developed breeding lines became available from Diversified Guinea populations. Yearly evaluations of 32 entry variety trials in men's fields. Women evaluated same trials separately and in discussion groups, providing new insights into gender differences.	Data on varietal appreciation was always collected from women and men farmers, and presented separately.
2004–now	Start of participatory 5-entry trials with entries selected by farmers from on-farm 32-entry trials from the IER/ICRISAT breeding program: farmers grew 4 varieties and a local check on their farms for evaluations. Greater awareness of need to assess processing traits. Introduction of grain quality assessment and culinary trials.	A standardized protocol for these trials was developed. Specific trial sets targeted specific objectives, and regions; varieties for early or late sowing, for Striga infested fields, for intercropping with maize, etc.
Gender-responsive stage Definition: programming which includes specific action to try and reduce gender inequalities within communities		
2002–2005	Initiated women's assessment of grain, processing, and culinary qualities using cultivars selected from the 32 entry-trials. Learned: the importance of decortication yield, food yield, and the women's skills at evaluating grain visually.	Hired experienced older women regularly to score the seed of selected progenies for grain quality—and throw out the bad ones.
2006	Systematic testing of culinary test method: Validation of decortication and food yield concepts; Different decortication yields of varieties indicated need to consider varietal differences for grain quality on women's work loads.	Continuation of grain quality, processing, and culinary tests. Farmers' local varieties included in tests here forward to provide appropriate reference points for setting targets for major, independent traits.
2007	Master's student in rural sociology studied the production of sorghum in women's fields and assessment of women's potential to engage in the seed supply of sorghum. First realization of the extent that women grew sorghum and how they used it: sold at market for small household goods like salt and maggi for sauce; kept a portion for the lean season; extra meals for younger children. Sorghum production contributed to their food and nutrition security.	Started to participate in Harvest Plus, selection for high Fe because of what they learned about women's use of sorghum for food and nutrition security.

(Continued)

TABLE 1 (Continued)

Year	Activities and learning	Program response and breeding decisions
2008	Another master's thesis in sociology with objectives to gain a better understanding of women's specific sorghum cultivation practices, their role in household resource flows, and the impact of ICRISAT's breeding program on women's sorghum variety choice. Nutrition study evaluating dietary diversity and food frequency to understand role of sorghum in diets, women and children nutritional status, and challenges to food security.	Shifted from 5-variety trials to 3 or 5 variety to accommodate women's smaller field size and production constraints and testing in intercropping situation. Assessment of women's sorghum production constraints, triggering soil analysis of men and women's plots leading to the discovery that women's plots were notably lower in P.
2009–2011	While breeders knew there were problems with low-P soils in the region, they also learned from a soil survey that women's fields were much lower in P	Initiated low-P on-station trials, and targeted breeding for low P adaptation; and eventually low-P progeny tested on-farm.
2011–2012	Changed 3–5 entry trials to include the fertilizer treatment. It was required that at least 4 women test the cultivars, for the village to get trials for the men.	Engaged women more explicitly in seed production, also in hybrid seed production.
2012	Methodology for breeding for low P adaptation published, as a basis for proposing a strategy for including low P adaptation as a trait for improvement into the breeding program. Plant breeding for nutrition-sensitive agriculture (NSA) research initiated to generate and identify varieties with high Fe and Zn particularly for women and children, that were well-adapted to low P fields; partnering with HarvestPlus to develop biofortified varieties.	

interdisciplinary team of nutritionists, breeders, and social scientists developed this culinary test methodology in which the women evaluate the grain quality attributes, decorticate the grain, cook the sorghum into a commonly eaten food, tô, and men and women evaluate the sensory qualities of the tô (taste, color, texture, conservation) (Isaacs et al., 2023). After several years, this method was validated in 2006 across different zones and compared with laboratory tests. Results showed clearly that women had important knowledge about decortication yield and grain quality traits that affected their overall appreciation of a variety (Diallo et al., 2018) and importantly, the amount of food obtainable from a variety (Isaacs et al., 2023). Varieties ranged between 68 and 82% in total "food yield," or the amount of useable flour and grits after the bran was separated out. Among other traits, the color of the final dish (tô), the labor required to process a given variety, the adherence of glumes to the grain, and the grain size were all important factors to women (Isaacs et al., 2023). In response to this new information about processing needs and preferences, the sorghum team hired experienced women sorghum producers to visually score on-station selected progenies for grain quality—and discard the lines that did not meet women's criteria. This ensured that progenies with poor grain quality attributes did not advance in the breeding pipeline. The culinary tests also showed that there are specific thresholds for each grain characteristic, that new varieties have to meet to become adoptable. All culinary tests included a farmer local variety to provide an appropriate reference (Isaacs et al., 2023). The culinary tests with the sorghum team are ongoing, with women preparing the lines or varieties selected from the on-farm trials for evaluation every two years, to ensure that only varieties that meet the minimum standards (thresholds) are released and enter seed production. Varieties with specific processing advantages are also thus identified and get released. The collaboration between food technologists, social scientists and breeders were essential for making these changes to the breeding program.

3.6.2 Social scientists expanded the sorghum team's understanding of women's roles and responsibilities in sorghum production in Mali

A series of social science graduate students interested in conducting their thesis research with the sorghum team added invaluable insights into women's use of sorghum and were pivotal in several breeding endeavors. In each of these cases, the social scientists reached out to the sorghum team because they were interested in conducting applied research in an agricultural context. Most of these connections were spontaneous and not linked to outside funding or the sorghum team's network. These collaborations worked well when the student was embedded in the sorghum program which could then provide advice, logistical support, and feedback. Their research findings were grounded in the local context and provided unique insights that led to shifts in the sorghum breeding program. One of the challenges for the students in sociology programs was that they were expected to produce theses focused on theory rather than applied research.

3.6.2.1 Qualitative research revealed nuances about women's sorghum production

In 2007, a rural sociology master's student studied women's production of sorghum and their potential to engage in the sorghum seed supply (Van den Broek, 2007, 2009). Van den Broek interviewed women in Mandé and Diolia districts to learn about their crop management, access to inputs, labor constraints, field allocations, and how they obtained sorghum seeds. Results varied between the two regions, but generally showed that of the women interviewed, 86% grew sorghum on their own fields, which is similar to other findings of more than 80% (Siart, 2008). The mean and median plot size was 1 ha. This was the first full realization of the extent to which women grew sorghum and how they used it. The evidence also indicated women had more control of the production from the sorghum

produced on their own plots. They primarily sold it to have cash for small household goods like oil, salt, and other ingredients bouillon) for the sauce (especially in Dioila district) and for extra meals for younger children (Mandé). In Mandé the sorghum produced by women was also used to provide additional meals for young children, especially during the lean period before the next harvest, when all family members may have to reduce the number of meals taken (Van den Broek, 2007). Women reported that they also sometimes provide extra meals for men who are doing heavy field work during this time of year (Van den Broek, 2007). The women interviewed said that in the past there was sufficient food, but this was no longer the case and their sorghum production was needed to fulfill daily food needs (Van den Broek, 2007). While they liked millet, sorghum required less work to transform it to flour and gave higher quantities of flour (Van den Broek, 2007). Thus, women's sorghum production on their own fields heavily supplemented their and their children's food and nutritional security, beyond that of the collective fields of the larger family unit.

Another important finding was how women obtained sorghum seed for their own plots. Van den Broek's (2007) research found that women primarily got their seed from their husbands, by either setting aside small amounts of sorghum that was allotted for meals, or it was provided as seed at the time of sowing to them by their husbands. They rarely obtained seeds from the market because it was mixed varieties. Gifts were another source of seed. Thus, women had limited sources of seeds and, as was found soon after, they did not always have varieties adapted to their field conditions. The report concluded that more specific information on women's sorghum needs, and their roles would be required before understanding if improved sorghum varieties and their commercialization could benefit women.

3.6.2.2 PPB, seed, and gender

With this new information related to women planting sorghum, the plant breeders sought to learn more specifically about how and when women were engaging in the ongoing PPB. In 2008, a second master's student collaborated with the sorghum team and investigated women's roles in household resource flows, the impact of the breeding program on women's sorghum variety choice, and other aspects of seed procurement and saving (Donovan, 2010). The purpose was to develop strategic recommendations for the sorghum program to address women's lack of access to improved seed and participation in PPB programs. Donovan (2010) corroborated Van den Broek's work, finding women in Mandé region planted sorghum in intercrops and that 90% of women's seed originated from their husband (68%) or close relative (22%; 8% of which were female) but that 70% then saved that seed for subsequent years. Furthermore, despite the long-term involvement of the sorghum team in the region, surprisingly few women had heard from their husbands about the new varieties or trials. Men involved in the sorghum team's PPB trials did not necessarily share information with their wives. The household roles and resource flows clearly had very defined gender roles and Donovan (2010) concluded the breeding program could not count on indirect transfer of improved varieties to non-participants. Her recommendations included: increasing the participation of women in the farmer field trials because this was the primary point of acquisition of new varieties in this informal seed system; utilizing specific gender analysis tools that target women's preferences and needs directly; organizing women's only trainings for more open dialogue with breeders; and identifying ways to work with non-literate women (Donovan, 2010).

The results of these studies guided developments in the program over the next several years. The first was involvement in HarvestPlus biofortification efforts, with a focus on the selection of high iron and zinc, essential nutrients especially for children and mothers, in sorghum and millets. Second, more research was needed on the soil quality of men and women's fields. Thirdly, "institutionalizing" women's participation in the on-farm variety trials and fourth, more efforts were required to make new varieties more widely accessible by initiating the sale of seed local actors.

3.6.3 Nutrition-sensitive breeding

HarvestPlus was a CGIAR initiative that spanned multiple countries and crops and was focused on traditional breeding to develop and/or identify varieties with naturally high levels of essential nutrients (Bouis and Saltzman, 2017). In the case of Mali, sorghum and millet varieties with high Fe and Zn were the target staple crops considered for biofortification because of their potential impact on children and pregnant women. The McKnight Foundation funded An Bè Jigi ("Hope for all") in Mali from 2006 to 2015 and Helen Keller International (HKI) led the collaboration activities with the sorghum team actors (Bauchspies et al., 2017). The first step, in 2006, was a baseline nutrition study, or quantitative data on food consumption and setting a target level for Fe and Zn biofortification of sorghum (Lugutuah, 2013; Bauchspies et al., 2017). Up to this point, there were no known comprehensive food consumption studies in rural areas of Mali (Smit et al., 2009). Two food consumption studies conducted during the project found cereals (sorghum and millet) provided 69% of total energy intake of children and 75% of intake for mothers (Smit et al., 2009; An Be Jigi, 2010). Cereals provided ±50% of total iron intake, and ± 75% of total zinc intake (An Be Jigi, 2010). Nutritional adequacy ratio for both women and children were low, indicating that there was potential for biofortifying sorghum and millets with Fe and Zn.

This interdisciplinary project wed plant breeding with nutrition and used the strengths of the PPB community networks (Rattunde et al., 2021) to specifically focus on women and children. They identified high Fe and Zn content varieties of millet and sorghum, examined differences in decortication loss for different varieties, explored transformation practices in collective cooking sessions for increased bio-availability including producing whole-grain sorghum flour (Bauchspies et al., 2017), and other activities centered around micronutrient consumption and exclusive breast feeding. Subsequent interviews with 120 women in six villages where the projects were implemented, showed 71% adoption of whole grain processing techniques for children's meals (Bauchspies et al., 2017). At this point, with varietal research and cooking qualities focused on nutritional quality for women and children, it was clear the breeding program was undertaking activities that were gender-responsive by directly selecting lines and varieties that would benefit women and children nutritionally. This long-term funding linked directly with other long-term funding programs from McKnight Foundation, to support uptake and seed dissemination.

3.6.4 Targeted breeding for low P soils

The breeding team knew that there were low-P soils in the region that were problematic. In fact, much of West Africa has soil P content

below a threshold of 7–10 ppm plant available soil P (Bray-1P) content for healthy crop production (Doumbia et al., 1993). ICRISAT specifically tested women's fields for P content in 2011, and found that women's fields had even lower P content on-farm ($N = 207$, mean = 7.4, median = 5.5; soil data collected by ICRISAT, Mali in 2011) (Leiser et al., 2012). In response, they initiated targeted breeding for low-P on-station using genetic variation among the Sudanian zone sorghum varieties and breeding lines to enhance adaptation (Leiser et al., 2012). This eventually included low-P progeny testing on-farm in the context of actual farming systems, in other words, testing within the biophysical-environmental and socio-economic context. They also developed management techniques to overcome yield reduction and risk due to P deficiencies. Douaje, a local sorghum variety collected on a CIRAD mission (Sagnard et al., 2011), turned out to be a favorite among women because it was well-adapted to their low-P soil conditions, and it had high Fe and Zn content (Table 2).

3.7 Institutionalization of farmer centered production of sorghum seed

The inclusion of farmer selection criteria and evaluation of environmental factors led the team to make context-responsive changes to the program that benefitted all farmers, including women. 2008 saw the release of the first sorghum hybrids from the Diversified Guinea Race population and the sorghum team expanded sorghum seed production efforts that had already started with farmer cooperatives. Women's cooperatives in Dioila became seed producers of hybrid sorghum varieties in addition to the men's cooperatives that were producing and selling seed. For all seed cooperatives, women became important seed sellers in their areas and small seed packs were an important intervention. Table 2 highlights several preferred varieties released from the program.

3.8 Hybrid varieties and on-farm trials with women

As a result of insight about women's smaller field size and production constraints, the sorghum team shifted the on-farm entry trials to be 3- or 5-entries, in that 3-entry trials required less land, so that testing the varieties was more of an option for women. These trials were conducted on a yearly basis, whereby women and men were planting 2–4 varieties on their own plots and comparing it with their preferred local variety. In 2010, 344 farmers planted these mini-plots (HOPE Team, 2010).

3.8.1 Women conducting their own plot assessments of sorghum varieties, with fertilizer

By 2011, women and men were engaged in the 32-entry trials, grain quality, and culinary tests (women only), sensory evaluations, selection for low-P adapted progeny, hybrid seed production, and 3–5 entry trials on their own farms. The next step was to systematically test how the hybrid sorghum varieties performed on-farm in comparison with local and improved germplasm, and if there were variations in performance on men and women's plots. Researchers hypothesized these varieties have the potential to increase farmer yields but identification of which variety types and management practices increase yield under diverse production conditions was needed. Understanding whether yield advantages are shown in men's or women's fields (with even lower soil-fertility) was needed to make informed decisions in the breeding program.

The network of farmer cooperatives engaged with the sorghum team to conduct a two-year study of on-farm trials comparing fertilizer practices with different sorghum variety types. 186 farmers from three regions across the Sudan-savannah zone of Mali conducted these trials. Men and women participated, with a total of 1,604 sole sorghum plots analyzed, 609 of which were women's plots. Each

TABLE 2 Outcomes of note from the PPB program and 3–5 trial processes.

Variety	Cultivar type	Notes
Bobodje	Local—The variety was given by a farmer to the sorghum program technician, with the request to include it in the trials.	As a result of the 32 entry trial tests, this variety was released. It has white, hard, big grains. It is still being produced as certified seed by some farmers, because there is demand for it.
Douaje	Local—a local variety collected by a collection mission of CIRAD and IER (Sagnard et al.)	Douaje was found to have the highest Fe and Zn concentration and when women tested it in their low P environments, it was well adapted. A very tall variety, this was the women's variety and most demanded by them. 30% grain yield improvements with the application of wood ash.
Lata	Improved	Very successful variety, derived from diversified Guinea race population and parent to Pablo and Fadda, the most popular hybrids.
Fadda Pablo	Hybrid	Pablo, followed by Fadda, were the most successful hybrids. Caufa and Mona hybrid varieties had high yields but were difficult to produce and when stressed, the glumes did not open, reducing the food yield.
Seguifa Soumba (CIRAD 406)	Improved	Varieties previously released when the trials started but mostly unknown by farmers, especially in Koutiala.
Tieble (CSM 335)	Local—variety collected during the first germplasm collections in the 1980s	This variety was included in the first set of on-farm-trials, and was consistently appreciated by farmers for its yield and grain quality. It was released by IER and ICRISAT. It became the long-term local check variety for all breeding trials for the Sudan Savannah zone in Mali.
Kalosabani (Jacumbe, CSM 63E)	Improved	Extra early maturing selection from a local variety.

farmer chose 2 or 4 varieties (depending on field size) from the larger scale 32-entry trials to test and compare with a locally preferred variety of their choice. The test varieties included hybrid and open pollinated bred-and local varieties with varying plant morphologies. The farmers tested each variety under both their normal practice of no fertilizer and under an intensified practice that included thinning the plants and application of a basal dose of fertilizer (100 kg/ha Di-ammonium Phosphate (DAP)) at sowing and topdressing (50 kg/ha Urea) at 45 days after sowing. Farmers were provided sufficient fertilizer and 50 g of seed of each variety (Isaacs et al., manuscript in preparation; in-depth methods available).

3.8.2 On-farm results

Combined analysis revealed significant yield differences between the variety types and management practices. Practice had the greatest effect on yield, with intensive practice yielding significantly higher across all variety types for everyone. From the Least Square Means analysis, hybrid-varieties exhibited higher yields than the local varieties in intensive practice for women's trials (1,609 vs. 925 kg/ha, respectively) and men's trials (1,262 vs. 989 kg/ha, respectively). In the farmer practice, although the yields and yield differences were reduced, women hybrid varieties still yielded better than women's local varieties (Figure 2). Otherwise, there were no significant differences in any other category for farmer practice (Figure 2).

Women's yields in the intensive management were higher than men's, this may be directly related to invested interest in success, as they seemed more dedicated to the trials and spent a lot of time managing them (personal communication). Plot-to-plot yield comparisons between hybrid and local varieties in individual farmers' trials varied by zone, with a yield gain from hybrids possible for 75% of farmers in Koutiala (especially women) compared with 55–65% of farmers in the other zones (Figure 3).

An additional 392 test plots were planted in intercrops, important for women, over the two years in Mandé. For these plots, there were few differences in variety type yield between hybrids and local varieties, although men saw a yield boost from hybrids when planted in an intensive practice intercrop. Similar to the pure crop, intensive practice yields in an association increased yields by an average of 500 kg/ha.

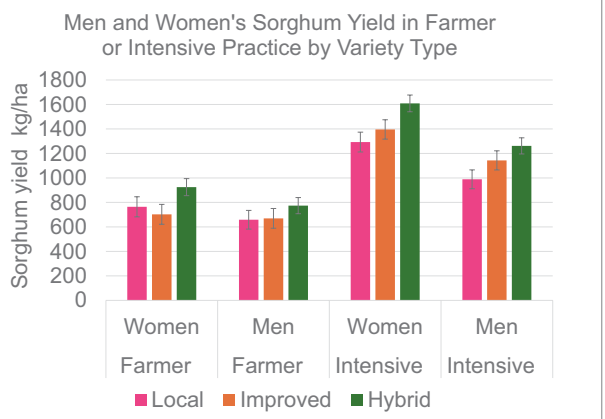

FIGURE 2
Sorghum variety type and management practice mean yields in 2011 and 2012 in Mali. Error bars are standard errors for lsmeans.

The results from this large-scale on-farm study supported the sorghum breeding program strategy of using local germplasm and PPB to generate new hybrid varieties with good adaptation and higher yields for men and women's fields. This superior adaptation of hybrid varieties resulted in women having significant yield gains, even in an intercrop. It also showed that while both men and women may gain from producing hybrid sorghum, there are some environments and conditions in which they are not ideal and improved or local germplasm are better suited. This validated several program strategies including PPB trials each year that engages and exposes diverse farmers to the breeding materials; small seed packs that allow farmers to test new varieties under their own growing conditions with minimal risks (including women's intercrops); diverse variety types available; and activities that support farmer networking to exchange information about different varieties. Finally, the results highlight the importance of fertilizer in improving yields. Although purchase of fertilizer is often out of reach for many farmers, the results showed that if they can access it, men and especially women would maximize the benefit by cultivating hybrid varieties.

4 Discussion

4.1 From gender-sensitive to gender-responsive

The fifteen-year collaboration between ICRISAT and IER sorghum breeding programs in Mali led to improved sorghum production outcomes for both men and women. In the first stage of the program in which women were included as participants in the variety evaluations, the breeding teams were 'gender aware', e.g., aware of gender differences in variety preferences and that improved varieties were not getting traction from farmers. At this stage, no study of gender relations or constraints that underly gender differences in varietal or trait preferences were undertaken.

In the second 'gender-sensitive' stage, breeders realized that sorghum grain quality is important to women. Understanding of trait preferences expanded to include traits that had important implications for the return to women's time invested in grain processing; women were more thoroughly engaged in field and culinary trials and involved in their own discussion groups; but other aspects of gender relations were not investigated systematically. Breeding objectives were more explicitly oriented to address gender-differentiated needs but limited to a post-harvest and culinary perspective.

In the third 'gender-responsive' stage, from 2007 onwards, gender analyses were conducted using methods such as surveys, FGDs, and interviews. In addition, nutrition centered research and breeding was undertaken, focused on women and children's micronutrient deficiencies and methods for increasing Fe and Zn through nutrition field schools. These methods produced data and results that called for breeders' attention because they showed the structural gender inequality that underpinned the different trait preferences—for example, how land was allocated and the quality of that land. This stimulated a cross-disciplinary approach to understanding gendered soil fertility differences. As a result, breeders developed new breeding objectives, including breeding on-station under low P conditions. At this stage, breeding objectives explicitly addressed a structural gender inequality—adaptation to low P availability.

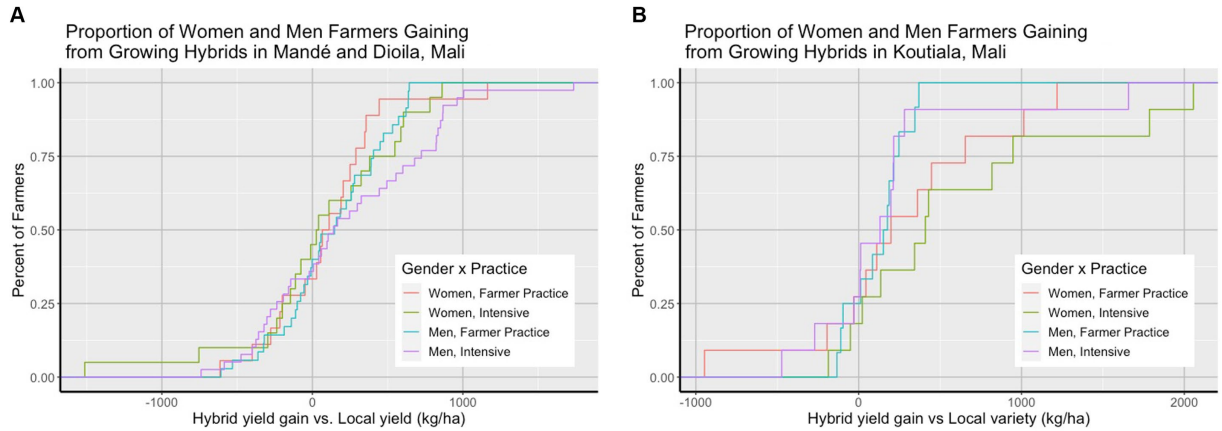

FIGURE 3
Proportion of women and men benefiting from growing sorghum hybrids in **(A)** Mandé and Dioila, and **(B)** Koutiala in 2011 and 2012 in Mali.

Interdisciplinary studies that combined gender analysis with classic agronomic research showed simply focusing on improved varieties and breeding strategies was not sufficient. The two year on-farm trial with men and women not only demonstrated how variable results can be by regional socio-economic differences, but also gender differences in yield that surprisingly, were better for women in several scenarios. Women had the potential to produce as high as men. This suggests gender gaps in productivity may be ameliorated with contextually appropriate resources such as fertilizer and adapted varieties, at least in combination with gender-responsive PPB activities that prioritize local germplasm and farmer selection.

4.1.1 Recognizing and respecting the importance of social scientists

Even with the intentional participatory process the breeding program developed, key factors related to women in sorghum production and household norms would not have been uncovered without the research of social scientists at different junctures. In this case, the breeding program leaders were attuned to the inclusion of women in PPB, but the social scientists had disciplinary theory and methods useful for in-depth inquiry into women's sorghum production and constraints. This interdisciplinary engagement brought new perspectives and skill sets that lent insights into women's involvement in sorghum seed selection and storage, trait preferences, and the breadth of women producing small plots of sorghum. Furthermore, having recognized the significance of gender relations for access to land, the program realized the value of sex-disaggregated analysis of plot fertility, leading to the discovery that women were being allocated plots notably lower in P than plots cultivated by men.

Openness to external researchers, an appreciation of the added insights other disciplines can bring to the table, and close collaboration between actors was essential to the evolution towards gender-responsive breeding. While efforts have been made to increase the role of social and gender studies in biophysical agricultural research and development (Meinzen-Dick et al., 2011; Tufan et al., 2018; van der Burg, 2020), there is still little appreciation for embedding social science research into crop improvement programs, and the depth of training necessary to conduct effective gender and social science research as part of an interdisciplinary team. To ensure gender-sensitive and-responsive research, open-minded teams are required that have a basic understanding and respect the knowledge, methods, and insights that gender and social studies bring (and that *believe* that gender disparities may exist); and vice versa. For example, some engagement with social scientists was less fruitful to the sorghum program because the social scientists were unwilling to engage fully with the sorghum team and create meaningful feedback loops to learn from each other (personal communication), as they saw their role rather as evaluators of the programs and its impacts. Or, applied gender research by graduate students was stymied within their academic units because the work was not appropriately embedded in theory. These theses had to be completely rewritten in order to pass, with the results no longer accessible to the breeding team nor useful to the realities on the ground (Van den Broek, 2007, 2009). This is partially an issue within academia—as western science and funding streams highly value STEM programs, creating hierarchies and doing little to bridge the divides and create shared respect of disciplines. Institutional change is needed in the long-term, and in the short-term, identifying graduate student programs that value applied work and hiring scientists with interdisciplinary sensibilities, and embedding multi-disciplinary teams into crop improvement programs, may be means to overcome these challenges.

4.1.2 Local actors are a cultural bridge between stakeholders

The inclusion of local actors was key to a successful gender-responsive and community engaged breeding program. The team understood the importance of the inclusion of local actors that serve as a cultural bridge between the community, international scientists, and even fellow country people with different backgrounds (urban, status, etc.), language, and cultures. Key personnel with rural experience, community relationships, and technical expertise were the backbone of the program. Key personnel that were women and could comfortably engage with women farmers was essential. One point of reflection is that while researchers and facilitators may be highly educated, they often come from urban backgrounds. This

may cause problems in translation due to lack of knowledge regarding terminology and local agricultural vernacular, lack of experience growing crops, different cultural norms, and class differences. Applied research at the community level requires partnerships with local actors to build trust, to bridge language and cultural translators, and ensure culturally appropriate engagement. Finally, while participatory processes are intended to be inclusive, inherent biases of facilitators and organizers can limit participation of different or disadvantaged groups of people. Only through in-depth, intentional, and contextual discovery appropriate to their targets, can they fulfill this goal.

4.1.3 Long-term funding is essential for sustainable outcomes

Long-term or on-going funding, even in small amounts, was vital to the continuation of projects, to learning, and to the subsequent and meaningful adaptations of the program. Long-term funding supported the full-fledged development of the PPB work, the culinary tests, and nutrition-focused research. Initial funding by the CGIAR Program for Participatory Research and Gender Analysis (PRGA) was critical for initiating the farmer participatory research in Mali and providing opportunities for scientific exchange for the development of methodological approaches. The McKnight Foundation provided funds continuously since 2006 that supported PPB embedded in seed systems work in Mali and they supported the iterative process needed to strengthen farmer organizations to produce and disseminate high quality seed (Donovan, 2010). Long-term projects were also vital to learning and implementing new processes that streamlined selection and screening. For example, co-developing the culinary test over several years with various actors and community feedback helped identify key traits that would then be identified early on and "weeded" out of the breeding pipeline. While it took several years to get the culinary test right, there were valuable outcomes and shortcuts were developed. Knowledgeable women from the villages could sort grain from different varieties in the laboratory to quickly exclude varieties without the right traits. This is an example of streamlining a process after the initial investment in learning the nuances of an issue. Funding with commitment to partnerships with local actors, inclusive of women, helped the program nurture these connections over many years.

5 Conclusion

Gender-responsive plant breeding programs require thoughtful and long-term engagement that enables an iterative process of learning with communities. Our analysis indicated that determinants of a gender-responsive PPB program include engagement and gender analysis at each stage of the breeding cycle; in-depth contextual understanding of men and women's roles and motivations in relationship to the crop; men and women team members that have technical and culturally appropriate gender-sensitivity; collaborative, interdisciplinary teams; equitable opportunities for selecting and testing materials; innovations that respond to findings from gender analyses, such as changing breeding priorities, developing new evaluation criteria, or using small seed packs that are more accessible to certain groups; and technologies appropriate for men and women. Such endeavors require rich partnerships across stakeholders and funding cycles that enable trust-building, co-learning, and the flexibility to modify approaches.

Over the course of a decade, a multi-institution sorghum breeding team in Mali transitioned to a gender-responsive program that worked to understand and meet varietal needs across regions with different resources, market needs, and food traditions. Interdisciplinary engagement provided insights to environmental challenges such as low-P conditions on women's fields, women's sorghum production constraints and preferences, and enabled a nutrition program that increased consumption of whole grain sorghum for children. The gender-responsiveness of the team This willingness to engage with other scientists and directly with farmer stakeholders strengthened the program. It also revealed the complex realities of agricultural production and the nuanced socio-cultural factors that inform farmers decisions. The success of the sorghum team and the varieties that were a product of this work was likely because they embraced this complexity, partnered with the community, and focused on empowering a specific region through interdisciplinary programming and variety development. To be sure, this was possible through long-term funding that allowed for sometimes slower progress including the slow timeline of building meaningful community partnerships and systematic yet relevant and appropriate processes. Funders that also understood these complexities on the ground were vital to this program.

In drawing on lessons from established approaches in the sorghum breeding program in Mali, participatory processes can enable the co-creation of knowledge and new technologies between scientists, farmers, and other actors. Diverse processes including large scale regional trials (based on farmer germplasm) in villages, on-farm trials with hundreds of farmers, participatory variety selection, women led processing and culinary tests, and qualitative research, all contributed to the program's understanding about varietal traits for adaptation in various environments and for diverse actors. It also increased the sorghum breeding programs cultural awareness of traits necessary for processing and cooking and the important role of women in the production of sorghum at the household level and in their own plots.

Globally, there are many initiatives, including private and corporate, aimed at increasing farmer access to improved varieties and ensuring this seed gets to the last mile. While increasing farmer productivity is a highly important goal, ensuring that happens sustainably is also vital to our future. Often, the genetic integrity and diversity of these initiatives are unknown, particularly in the case of patented seed. This case study demonstrates methods to apply a more nuanced and inclusive approach to co-development of improved plant varieties that are environmentally and culturally adapted. Furthermore, by relying on local germplasm to develop a diversified sorghum population, the sorghum team increased the likelihood of farmer adoption and environmental adaptation, and they maintained, if not expanded, the varietal diversity necessary to ensure agricultural resilience in the region.

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.

Author contributions

KI: Conceptualization, Data curation, Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing. EW: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Writing – review & editing, Formal analysis. HS: Data curation, Investigation, Methodology, Writing – review & editing. AD: Investigation, Methodology, Project administration, Resources, Supervision, Writing – review & editing. BD: Data curation, Investigation, Methodology, Validation, Writing – review & editing. MS: Conceptualization, Data curation, Investigation, Methodology, Project administration, Writing – review & editing. KV: Investigation, Methodology, Writing – review & editing. BS: Data curation, Investigation, Methodology, Resources, Writing – review & editing. BN: Validation, Writing – review & editing. FR: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Writing – review & editing.

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Conflict of interest

The 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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A gender-responsive breeding approach to the intensification of sesame (*Sesamum indicum* L.) production in the Maradi region of Niger

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Climatic variability and a decrease in soil fertility have had a detrimental effect on the productivity of the main rainfed crops in Niger (millet, sorghum, and cowpea) and led to a deterioration of the nutritional status and income of the country's farmers. The spatio-temporal variability in rainfall has led rural populations to diversify their farms by integrating sesame (*Sesamum indicum* L.) into their cropping systems because of its low water and fertilizer requirements. Sesame is increasingly becoming a significant source of income for farmers, and it contributes to their food and nutritional security. To boost the production of sesame and facilitate its rapid adoption, our breeding program focused on participatory breeding and varietal selection with the inclusion of gender-specific preferences, from the variety design to the evaluation of new lines on farms. This case study shows that, although women have more experience in sesame cultivation than men, they have less access to production factors such as land. This limited access is especially problematic, as recent trends in land tenure mean that the poorest are no longer able to exploit large areas of cultivable land. It also evidenced that the varietal preferences of sesame growers as well as the mastery of production techniques are a function of the livelihoods and the investment capacity of actors in the value chain. Our study found that men mainly prefer production traits, whereas women have fewer trait preferences, and their preferences tend to be related to marketing and processing. This finding highlights the contrasting roles and responsibilities between men and women in the sesame value chain. Therefore, the inclusion of complementary traits preferred by women and men, provided that they are not negatively correlated with a variety profile, will help meet the full range of needs across the value chain. We recommend the inclusion of gender research in setting breeding goals prior to variety design.

KEYWORDS

sesame, value chain, gender, breeding, strategies, Niger

Introduction

Sesame (*Sesamum indicum* L.) is an annual oilseed crop belonging to the *Pedalliaceae* family. It is cultivated for its seeds, which are rich in oil (50%), protein (23%), vitamins (such as E and B), and amino acids (methionine, cystine, arginine, and leucine). In West Africa, sesame is cultivated across approximately 1,417,115 ha for an annual production

of 941,021 tons (FAO, 2022) in pure stands or in association with cereals (e.g., millet and sorghum).

In Niger, sesame is traditionally an underutilized crop that was produced exclusively by women for self-consumption within the household, often in the form of condiments. Women therefore have a great deal of responsibility in the selection and maintenance of traditional varieties and in decisions on the uses of harvested seed. In recent decades, the demand for sesame seed has risen sharply on the international market, transforming the plant from a neglected crop to a high-value commercial crop. More than 5,600 products derived from sesame have been developed by the processing industry in China (Zhang, 2019). This renewed interest in sesame seeds on the international market has attracted more men to sesame cultivation across large areas. Since men have greater access to production factors (e.g., land and finance) than women, production has predominantly become the work of men, while women, who were once the main producers, have been relegated to the processing and marketing of processed products. Men mainly sell sesame seeds to women on the local market or export the crop to neighboring countries. As such, the role of women has transitioned from that of producers to become the main local processors of sesame seeds.

This transformation is taking place in the context of global climate change and an expanding population that is putting high pressure on the already degraded agricultural lands. It is therefore important for the development of the sesame sector that varietal creation programs take into account for the preferences of all actors involved in the value chain, without forgetting the biotic and abiotic factors dictated by the changing climate.

Until recently, sesame breeding programs have focused on a limited number of traits such as yield, drought tolerance (Diouf et al., 2010; Boureima and Van Damme, 2012; Boureima et al., 2016), and biotic stress. Our limited knowledge of the preferred traits of value chain actors comes from lessons learned during participatory varietal selection (PVS) programs on other crops. Not only are those studies not sesame-specific but they were also conducted in the later stages of the varietal selection process and thus missed opportunities for targeted crop improvement.

In general, and in Niger, in particular, sesame is an orphan crop in that no international agricultural research center has a research mandate for sesame. Consequently, sesame has attracted only limited scientific research to date. Thus, lessons from other crop breeding efforts that used PVS have been an entry point to help us understand the differences that exist between men and women with respect to the preferred agronomic traits of sesame varieties.

Recently bred lines and introduced accessions were evaluated by our team in multi-location trials in farmers' fields by both researchers and sesame farmers (women and men) at all stages of crop development. This study revealed that some traits, such as white seed coat color, were specifically preferred by women for their oil quality. However, our motivation to pay more attention to gender differences in trait preferences derived from the participation of our team (the sesame breeder and the social scientist) in a training course offered by the organization Gender-Responsive Researchers Equipped for Agricultural Transformation (GREAT) in 2021. This experience fundamentally changed the way we approach selection objectives by integrating gendered preferences into the product profile.

The main purpose of this study was to share experiences in terms of the changes induced on the actors involved in a participatory and inclusive selection program while favoring equity in decision-making.

Methods

Contribution to the field statement

The sesame breeding program involves one breeder, one social scientist, and MS and PhD students in the Faculty of Agronomy and Environmental Sciences at the Dan Dicko Dankoulodo University of Maradi, Ali Dan Sofo, Niger. They collaborated with members of two farmers' organizations (FUOPAN SAA in Maradi and FUBI in Zinder region) and one female processors' organization in Tessaoua, in the Maradi region. This collaboration could be related to the selection of participants, and if so, it not only describes but more importantly shows that user representatives have been part of the breeding program. In much of the literature, direct representatives of users have often been left out, and representation of users has been left to social scientists and marketing specialists. Cavicchioli et al. (2023) found that many breeders get concrete feedback directly from users, and those users are even directly part of product advancement, although often not formally recognized. The target beneficiaries are smallholder farmers (both women and men) and processors (predominantly women), as well as traders and the scientific community at national and international levels.

A gender-responsive approach to breeding

In most breeding schemes, the primary goal is to improve the yield of the variety selected to the point that only traits that are directly related to yield are of importance to the breeder. However, since a given crop can be intended for different users and markets, it is important to consider the diversity of end uses for any product that the breeding program produces. We brought together a multidisciplinary and interdisciplinary team to respond to the concerns of the various stakeholders in Niger's sesame sector. In this study, we describe the use of a value chain approach to optimize our sesame breeding program.

In 2012, the predominant belief was that shattering, i.e., the loss of seeds by the opening of the capsules at maturity, was the major constraint to sesame production. In response, a non-shattering sesame line was developed (Boureima, 2012), but this variety was not adopted by both male and female producers for the sole reason that women, who were primarily responsible for the threshing of the capsules, struggled to recover seeds from the capsules because the seeds were tightly retained in the placenta. In contrast, seeds from shattering varieties could simply be recovered by inverting the dried plant so that seeds could flow freely from the capsules.

After the failed adoption of this non-shattering variety, and by taking into account the preferences of women as threshers of the capsules as well as the preferences of sesame producers

(predominantly men), we reoriented our breeding program. Shattering at maturity can cause production losses in the order of 70–80% (Boureima, 2012) and therefore must be considered in the creation of new varieties. We sought to not only produce varieties that are resistant to shattering without being indehiscent to improve sesame yields but also facilitate the threshing of the capsules at harvest by women.

This experience was the trigger to introduce gender-specific preferences to our breeding objectives at all levels, including the methods for evaluating new material on-station or on-farm, variety design, priority traits for the breeding program, criteria to use for evaluating the importance of different traits, and the choice of lines to be advanced to the following generations. Since 2021, our breeding strategy has focused on the development of white sesame seed varieties to satisfy the world market, but these varieties must also display an appropriate level of shattering resistance to avoid seed loss at maturity while still facilitating threshing by women. Our lessons learned in sesame breeding will be broadly applicable because threshing is exclusively done by women across various crops in Niger.

Gender considerations were applied to all methods used in this study and involved all stages of the research (Table 1). This approach allows for consideration of social relations as well as the specific preferences of women and men. We aim to develop the sesame value chain while offering the same opportunities to all stakeholders to be rewarded for their efforts.

The information used in this case study was obtained from two recent studies (Yaou, 2017; Boureima and Yaou, 2019) conducted on station and on the farmers' land with federations of farmers' organizations in two regions of Niger, namely, Maradi and Zinder. The first approach was based on participatory varietal selection conducted from 2016 to 2018, through which 10 sesame varieties were evaluated with the participation of groups of male and female producers at five locations in the Maradi and Zinder regions. The varieties were tested in randomized, complete blocks with four replications at each location. Producers, including men and women, were organized into groups belonging to the federations of farmers' organizations, FUOPAN SAA in Maradi and FUBI in Zinder and were involved in all cultivation operations. The balance between men and women was not taken into account in this study. In addition, the team worked with the farmers' organizations to arrange group visits to assess the attributes of the varieties according to their stage of development (flowering, fruiting, general appearance of the plant, and maturity). Each time, we collate the growers' impressions by asking them to place a branch of a shrub on the most preferred variety across the four repetitions. The parameters monitored by the pilot farmers were the earliness of emergence, the variety that reacted more to the application of fertilizer, comparison between local and improved varieties for agronomic traits, flowering time and duration, attacks by insects and diseases, lodging susceptibility of different varieties, the number of capsules, seed size, the best yield, and the preferred seed color of the varieties.

These exercises were repeated throughout the development cycle and allowed us to form a synthetic compilation of which characteristics were preferred by the producers. During this period, we only focused on the farmers' overall preferred characteristics, regardless of gender. The sole aim was to describe an ideotype variety for a sesame farmer. The selection of participants was done by a focus group with farmers' organizations based on the farmers' experience in sesame cultivation. The *t*-test and chi-square test were carried out on the data collected for continuous and categorical variables, respectively.

In 2021, following the failed attempt to introduce a non-shattering variety that did not meet the expectations of women, and in response to input from GREAT, we reassessed and adopted a new approach based on the inclusion of gender preferences across the entire selection process from the design of the variety to the monitoring and evaluation of the germplasm developed through the PVS. The inclusion of female processors in the evaluation stage was the main shift in the breeding strategy since their knowledge and preferences will have an outsized impact on the sesame value chain. Farmer field schools were conducted across the five locations for demonstration tests and to share the performance of the new lines compared to local sesame varieties.

Results

The male and female producers who were involved in this pilot experiment experienced a modern approach to sesame breeding, including the participation and inclusion of both women and men in decision-making to describe an ideal improved sesame variety. In terms of plant emergence, farmers' observations indicate that the varieties with the highest emergence were the most preferred by both men and women. At the maturity stage, highly branched varieties with a higher number of capsules were more appreciated by both men and women. With respect to fertilizer response, the producers preferred the varieties that were most responsive to fertilizer, irrespective of their gender. Resistance to lodging at the reproductive phase is another characteristic that would be expected for an improved variety. The male producers preferred varieties with larger seeds and sand capsules; however, after threshing the capsules, the white-colored variety was most preferred by the female producers. Details of this study are available in Boureima et al. (2017).

In summary, this participatory evaluation of varieties demonstrated that earliness, number of capsules per plant, large capsules, high branching, and delayed shattering are the major traits preferred by men, whereas the trait preferred by women was the white color of sesame seeds. This information is of great value for us to set our new breeding objectives in the sesame program and highlights the fact that men and women may even have conflicting interests in crop traits.

The second study was a diagnostic survey of 580 rural sesame-producing households in the Maradi region using a structured questionnaire on the varietal preferences of producers (men and women) and processors (women) as well as constraints related to access to production factors. This study was conducted from July to October 2022 by the social scientist and one master's student (for his thesis research) in collaboration with the breeder, and the socioeconomic characteristics of the respondents are given in Table 2. This questionnaire took up a variety of characteristics that were preferred by farmers and processors.

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TABLE 1 All activities of the sesame breeding program currently incorporate gender-specific considerations.

Activity	Description of work
Participatory varietal selection (PVS)	In this study, an evaluation was conducted on village demonstration plots in the communes of Tessaoua and Bandé. The aim was to evaluate selected varieties according to gender-specific trait preferences throughout the selection process and according to the criteria defined by the categories of stakeholders.
Experimenting farmers formally organized in groups or committees or networks to contribute to the breeding program	The experiments were conducted according to a participatory approach through field trials and operations in the form of field schools, farmer exchanges, and a validation workshop for the consequent results. Two farmers' organizations were involved in these experiments.
Social survey research	We conducted social survey research for descriptive statistics on household characteristics (age, gender, education, ownership, partition of agricultural labor, etc.).
Value chain analysis and mapping	The study considered the links in the value chain, mainly selection, production, processing, and marketing. The objective was to understand the role of the different value chain participants, both men and women.
Study of trait preferences	In 2022, for the first time, we conducted a survey on the sesame value chain in the Maradi and Zinder regions to understand the trait preferences of both men and women and to identify gender-related constraints to production factors. The study has a double objective: the first is to understand the preferences of sesame seed producers and processors and to use statistical models to compare and assess preferences by gender. The second objective is to elucidate whether men and women have equitable access to inputs as driving forces to adopt a newly released sesame variety.
Farmer-to-farmer visits and exchanges	Visits to the experiment sites by farmers have the advantage of strengthening their capacity and motivation to adopt novel technologies.
Farmer field school experiments and demonstrations	Farmers' field schools were set up in the villages of Gounaka, Maiguizaoua, and Dadin Sarki. These allowed pilot farmers, including smallholder farmers (men and women), to adopt and master the technical processes of sesame production and for additional farmers to gain interest in the crop.

TABLE 2 The chi-square test on socioeconomic characteristics of respondents to the diagnostic survey of rural sesame-producing households.

	Continuous variables				
	Men		Women		
Characteristics	Mean	SD	Mean	SD	*t*-test
Age (years)	48.20	12.59	50.82	11.38	$t = 0.94$; $p = 0.34$
Household size	13.51	6.36	10.68	8.58	$t = -1.94$; $p = 0.05$
Land size in ha	5.14	4.15	3.18	3.35	$t = -2.15$; $p = 0.03$
Sesame land in ha	1.62	1.28	1.23	0.53	$t = -1.41$; $p = 0.15$
Sesame experience (years)	10.36	6.05	14.27	9.21	$t = 2.77$; $p = 0.005$
Categorical variables					
	Men		Women		*p*
Inheritance	96.12		45.45		***
Rental	3.87		9.10		ns
Gift	0.00		0.00		ns
Purchase	43.8		22.72		*
Renting	3.48		4.54		ns
Pledge	8.90		0.00		ns

Significance is indicated at 5% (*) and 0.1% (***).

The average age was 48 years for men and 51 years for women (Table 2). The number of dependents varied from 14 among households headed by men to 11 among households headed by women. The questionnaire confirmed that women have more experience in sesame cultivation (14 years on average) than men (10 years on average). For production factors such as land, the results showed that, although women and men cultivate similar areas of the sesame crop, women have less access to smaller land areas (3.18 ha) than men (5.14 ha), while farming remains the main activity for all respondents, regardless of gender.

The two major modes of land tenure in the study area are inheritance and purchase. However, according to the results of the analysis, there is significant gender discrimination with regard to these modes of land tenure. Men have significantly more access to land through inheritance (96.12%) and purchase (43.8%) compared to women (45.45 and 22.72%, respectively). The alternatives for

TABLE 3 Synthesis of the case study according to the three trait preference models for some major traits.

Identical preferences	Separate preferences		Overlap
	Men	Women	Red seeds
Yield	Resistance to lodging	High oil content	Delayed dehiscence
Earliness	Several capsules per plant	White seed coat	Several branches
	Resistance to diseases		
	Tolerance of drought		

land tenure are renting, giving, and pledging, which are less frequently practiced but have no significant discrimination based on gender.

Analysis of preferences by gender

The results of the survey revealed that, according to the three models of trait preferences, i.e., identical, separate (or totally discrete), and overlapping, the preferences of women and men are not always identical (Table 3). Men mostly prefer traits that relate to agronomic performance, while women are much more interested in traits that relate to processing. Some traits overlap, such as red varieties, delayed dehiscence of capsules, and number of branches, meaning that even if some preferences are not identical, they are still reported by both men and women. Thus, a breeding program must provide compromise and incorporate the specific needs of women to complement those of men in the variety design to develop an acceptable variety profile. To achieve this goal, we focused on shattering resistance and white seed color while maintaining resistance to lodging. According to the respondents, four sesame derivatives are produced by women in the department of Tessaoua. These are sesame oil, sesame paste used as condiments for cooking, sweet sesame biscuits, and salty sesame biscuits. All these products are sold at the local markets by women and mostly by young girls. The roasted sesame seeds are generally used for home consumption. The money from these activities is usually used by women to support themselves and their families during the lean season. In this study, women's and men's preferences are motivated by the specific task and role they have come to play. They are a function of the livelihoods and investment capacity of actors in the value chain. The sesame value chain creates opportunities for value addition and employment in processing and marketing in rural areas, especially for women.

Discussion

Good practices

By recognizing the importance of gender preferences and prioritizing gender-responsiveness in the breeding program, it has been possible to highlight preferred traits according to the categories of stakeholders throughout the value chain. The success of a breeding program can be evaluated on the basis of public or private utility and, therefore, the feedback from the users of the new variety. This case study demonstrates the importance of a multidisciplinary and interdisciplinary approach to establishing a breeding program that meets the expectations of all beneficiaries. The key elements of this approach include the following.

1. Information about gender is taken into account in decisions about which market(s) or end users the breeding program will target.

The need for gender-disaggregated data provides new, complementary, and actionable information for setting breeding objectives. There is a real need for research dedicated to understanding gender preferences in agriculture. The importance of gender considerations in crop improvement programs has been emphasized in numerous studies (World Bank et al., 2009; Galiè et al., 2017). In our breeding program, a budget for gender will be standard as it is essential for the inclusion of gender in the program to help set our breeding objectives.

Although some traits overlap in terms of preferences between men and women, for some products, there is a clear difference in choice or preference according to gender. Women are mainly processors, but some of them have their own sesame field. In contrast, all men are producers and sellers. Taking these differences into account will make it possible to exploit complementarities to develop a product that is widely appreciated by a full range of stakeholders and end users. However, a related challenge has emerged around goals and expectations. Overall, the focus is on identifying trait preferences. To be of practical value for breeding, a preference should be linked to a usable trait, i.e., specific, quantifiable, and heritable traits that are technically feasible for the breeder to target. Some identified preferences, while still relevant to customers, are not actionable by breeding programs, for example, a high number of capsules and lodging resistance. Varieties with a high number of capsules are susceptible to lodging because of the weight of the capsules.

Gender-specific trait preferences are most useful if used early in the program to help envision a target varietal design and then define breeding objectives. Participatory evaluations with the inclusion of gender specialists, producers, and processors can better refine the selection and achieve a set objective that will increase the chances of adoption of new varieties.

This finding ensures good collaboration between all participants seeking to improve the wellbeing of the population. A gender-based approach, in which producers and processors are the key focal points of all varietal selection, has the merit of establishing mutual trust between researchers and end-users and facilitating the ultimate adoption of improved varieties. The participatory approach developed in this program has enhanced the approach of researchers who currently consider the socioeconomic context, needs, and conditions for accessing resources in their decision-making.

We encourage gender mainstreaming in our sesame breeding program to promote gender equality and the empowerment of women. This consideration is introduced early in the breeding process.

The demonstration plots were managed by pilot producers (women and men) at five locations who have promoted the integration of vulnerable groups (particularly women). All the

achievements have been developed in a collaborative way, contributing to solidarity among community members, which consequently strengthened social cohesion. In accordance with the objectives set by the research team, the availability of improved varieties to producers is expected to influence an extension of the cultivated area and the productivity of sesame in Niger. We have emphasized the training of producers, both men and women, and the inclusion of gender responsiveness for a more efficient and effective evaluation of candidate varieties.

2. Information about gender is taken into account in decisions about what types of farmers should participate in evaluations.

From the PVS experiment, it is evident that a field evaluation of varieties that is undertaken without women is an incomplete study because it ignores a significant portion of the end users, which is likely to reduce the adoption rate and the desired impact of the variety.

In the sesame breeding program, important changes have been observed among both producers and researchers as a result of the participatory and inclusive approach developed through the program's activities. All research questions are formulated according to the real concerns of the stakeholders. The program brings together plant breeders, socioeconomists, environmentalists, agricultural advisory support technicians, farmers' organizations, and students. In this approach, the research protocol is co-constructed and implemented in a real environment using the "field school" concept, with researchers, growers, and students. The main stages involved a participatory gender approach, the results of which provide guidelines for variety development based on stakeholder preferences, followed by a participatory on-site evaluation with growers. Feedback on the results of the participatory approach is provided through an inclusive workshop that includes all actors. This is, for example, comparable to the methodology followed by Forsythe et al. (2021), whose implementation is reflected in the study of Forsythe et al. (2024): The transdisciplinary team worked together from the beginning, participating in activities and exchanging information and carrying out research together regardless of what the dominant discipline was in each activity. This collaboration meant that, apart from having people from the relevant different disciplines involved, which is not a guarantee for success, people actually engage in a meaningful way and on the same level (Page, 2010). This engagement means that participation is also performative and not only deliberative (Richards et al., 2010). It is through the effervescence in a (task) group, created by the act of performing similar activities, that institutions and epistemologies are created (McFeat and Belshaw, 1974; Collins, 2004; Perri 6, 2007) that can be stronger than the interest of the larger institutions that each of the individual people from the different disciplines and backgrounds are part of given their disciplinary schooling, affiliation, and experience. In the case of the sesame breeding program, this could state that this has avoided issues of power dynamics often prevalent in multidisciplinary decision-making (Tarjem I., 2022; Tarjem I. A., 2022; Cullen et al., 2023). This experience has fundamentally changed the way researchers set research objectives in the sesame breeding program by integrating the gender preferences of stakeholders. The participatory approach developed has had the merit of influencing a change in the behavior of researchers, who currently take into account the socioeconomic conditions of stakeholders and their preferences. The approach also enabled researchers, producers, extension agents, and students to work together as equals to achieve research objectives. Finally, it strengthened the strong social relationships between sesame value chain actors.

Summary and lessons learned

This approach to integrating gender responsiveness into the breeding program has yielded the following key reflections and outcomes.

Identification of the specific needs of stakeholders is crucial and should be applied to breeding objectives.

Plant breeding can be planned through a gender-responsive lens to promote the active involvement of farmers at all stages of the breeding program.

Inclusion and consideration of women's preferences are of utmost importance for a breeding program.

Gender mainstreaming can be applied as a strategy for integrating gender concerns into the analysis, formulation, and monitoring of policies, programs, and projects.

Gender inclusion in our breeding program is likely to result in the broad adoption of our newly released varieties.

The development of a win-win relationship between men and women improves socioeconomic development and community resilience strategies.

Implemented on a small scale, the gender-based sesame breeding program in the Maradi region has had a striking effect in terms of supporting community resilience in general and the resilience of the socially disadvantaged groups in particular.

A multidisciplinary team, including breeders and social scientists, is advantageous for a breeding program and can lead to novel solutions.

For those starting out a breeding program, we recommend a team approach to ensure efficient collaboration, with both men and women working together to set breeding objectives.

Further research on gender-responsive breeding is recommended to facilitate greater, more inclusive benefits from new varieties, which could boost prosperity and thereby reduce the migration of women and youth to escape poverty and food insecurity. To favor the adoption of new crop varieties, the breeder needs to ensure these varieties match the target use contexts, which is particularly challenging due to the heterogeneity of socioeconomic and environmental factors among smallholder farmers. For these multidimensional aspects of new variety development, the breeder needs to cooperate with other domains, such as social sciences, to design his breeding pipeline.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical approval was not required for the study involving human participants in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was not required from the participants in accordance with the national legislation and the institutional requirements.

Author contributions

SL: Conceptualization, Formal analysis, Investigation, Methodology, Supervision, Writing – original draft. SB: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft. IS: Formal analysis, Investigation, Methodology, Supervision, Writing – original draft.

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Conflict of interest

The 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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Trait preferences of sorghum and pearl millet value chain actors in Mali and Burkina Faso: a case for gender- responsive and demand-driven breeding

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Sorghum and pearl millet have adapted to the socioecological environment in the dryland of West Africa and have been the staple crops for many years. Engaging key stakeholders and improving the sorghum and pearl millet breeding process is essential to addressing the evolving demands of end-users and environmental conditions. Unlike most trait preference studies focusing on men and women farmers' trait choices, we examined sorghum and pearl millet key value chain actors (VCA), including producers, processors, traders, and consumers. We identified their preferred traits of varieties that need to be mainstreamed into the breeding pipelines. Drawing on the past efforts and experiences of the sorghum and pearl millet breeding programs from the last 30 years, the study was designed to integrate gender equality in sorghum and pearl millet breeding decisions and traits prioritization in West Africa. This process was implemented in phases, leading to the drafting of gender-responsive and client-oriented product profiles. The paper elicited an understanding of how the roles and interests of sorghum and pearl millet VCA influence their varietal choice and adoption decisions. The study found both differences and similarities in the trait preferences of the men and women VCA. Most women, mainly in the production and processing nodes, prefer varieties with specific food and grain quality traits, while men prioritize grain yield and biotic stress resistance traits. Even though both men's and women's varietal choices align with their roles in production and consumption, grain yield was commonly desired across gender, crop, and value chain segments. The findings revealed that the gendered interest of actors in the crops' value chain determines their choice of variety. Gender responsiveness requires identifying and understanding the needs and choices of the sorghum and millet VCA and mainstreaming these into the breeding pipeline. The approach employed in the study elicits the understanding, roles, and interests of the various actors and how these factors influence men's and women's decisions to adopt a crop variety. All major stakeholders should co-develop product profiles for the variety being developed to enable co-ownership, increase adoption, and improve gender equity in agricultural technology development and deployment.

KEYWORDS

gender, sorghum, millet, value chain, actors

Introduction

Sorghum (*Sorghum bicolor*) and pearl millet (*Pennisetum glaucum*) are significant sources of calories in many countries in Africa and serve as the leading traditional food crops for most households in the dryland tropics of West and Central Africa (WCA). These crops contribute to food, nutrition, and livelihood security. For example, in Burkina Faso, sorghum contributes about 45 percent of all calories from cereals. While there has been a rise in the total consumption of all major cereals during the past 35 years, sorghum and pearl millet use has remained stagnant globally. The per-head consumption of sorghum is high in dryland tropical countries despite the low income derived from its sales and a climate unfavorable to high economic value production (Laudien et al., 2022). For decades, small-scale farmers in West Africa have been using and spreading suitable sorghum and pearl millet varieties through mass selection and sharing of seeds. However, the identification, understanding and engagement of the crops' value chain actors in the breeding improvement process were limited. Hence, there is a need to understand the social structures and other influencing factors for women and men farmers' varietal choice and participation in breeding activities.

The initial progress and focus on developing participatory breeding programs for pearl millet and sorghum is based on the traditional plant breeding program in West and Africa by the colonial governments. These programs were modified after independence and adjusted to suit the countries' priorities and contexts. The primary reason for creating plant breeding programs was to improve yield, increase adoption by farmers, ensure food security, and improve livelihoods. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) breeding objectives were aligned with the national breeding program of the different countries. Over the years, ICRISAT has emphasized the participatory breeding approach in its breeding programs by consulting and engaging farmers in a variety of evaluation processes. In Burkina Faso and Mali, sorghum participatory plant breeding activities started in the 1990s with varietal tests in rural areas funded by the Regional Research Network on Sorghum (ROCARS), but pearl millet participatory plant breeding activities began later. These experiences enabled researchers to gradually develop the participatory selection method (Trouche et al., 2016; Sissoko et al., 2019). ICRISAT and its partners from the national research systems, farmer organizations, donors, and other research-for-development agencies continued working to increase the yield and adoption of improved varieties through participatory plant breeding (PPB) and other approaches to increase genetic gains (Ceccarelli et al., 2009). As a result, the grain qualities of these new varieties have received some attention for home processing and consumption and are the target of fewer systematic efforts (Isaacs et al., 2023).

The average yield of sorghum and pearl millet was below their potential partly because they are produced in marginal environments, which slows the adoption rate of new varieties (Yapi et al., 2000). In the 1990s, the adoption rates of sorghum varieties derived from reselections within landrace varieties were 20%. About 5% of the "second generation" varieties were bred using more exotic germplasm (Yapi et al., 2000). Rattunde et al. (2018) found that the better grain quality of sorghum landrace-derived varieties for food and their suitability to low soil fertility explain their higher adoption by Malian farmers. The gradual involvement of women in PPB increased in the 2000s, as they were mainly involved in varietal acceptability tests for food quality (Rattunde et al., 2018). The participation of women in culinary tests and sensory tests led to the development of the concept of "food yield," which refers to "the total amount of food or the number of meals that can be prepared from the harvest of a particular variety" (Isaacs et al., 2023). This qualitative research methodology enables women to better contribute and participate in the sorghum breeding programs in Burkina Faso and Mali (Diallo et al., 2018; Rattunde et al., 2018; Weltzien et al., 2019). These processes were progressively modified over time to consider gender integration and embed some focus on gender analysis. However, the transition to PPB assumes the involvement of all stakeholders in the breeding processes and decisions without targeting other actors in the crops' value chain. Breeders paid little attention to gender-equitable feedback between them and end-users.

Thus, the development of sorghum and millet varieties calls for a process that fosters and facilitates co-creation, equitable partnerships, and active engagement with all key stakeholders across the value chain (processors, marketers, consumers, and producers or farmers). Sorghum and millet farmers produce mainly for subsistence Coulibaly et al. (2010), taking little or none of their harvest to market. As a result, they have weaker channels to communicate demand for varieties compared to producers of industrialized crops. For instance, farmers explained during field research that Grinkan, a high-yielding sorghum variety, was rejected because when it is processed, it is too soft to make good "*to*," one of the most popular foods in the area. "*To*" made from Grikan is not considered palatable, so the variety has poor market demand locally and nationally. In addition, farmers' varieties are crucial for coping with late rains, drought, poor soils, and insect pests (Rattunde et al., 2018; Huet et al., 2022). Women often have the poorest lands, so their varietal choices can be even more complex. If the breeding program does not understand and consider the intricate social dimensions and systems of diversification (Teeken et al., 2021, p. 1) that help to manage risk, there will be little scope for replacing farmers' traditional varieties.

Therefore, the objective of this paper was to identify and map the sorghum and pearl millet value chain actors, examine the desired traits of the actors, and facilitate how their preferences can inform the co-development of gender-responsive and market-driven sorghum and pearl millet product profiles. Drawing on the past efforts and experiences of the sorghum and pearl millet breeding programs of the last 30 years, the Gender Research Unit at ICRISAT designed a study to integrate gender equality in breeding decisions and prioritization in West and Central Africa. This process was implemented in phases at different times (outlined below in detail), leading up to the findings of this study. The paper presents the experiences and lessons from the approaches taken toward equitable and gender-responsive sorghum and pearl millet breeding programs in WCA, particularly in Mali and Burkina Faso.

Context

Need for gender integration in breeding pipelines

The potential yield of sorghum in Mali ranges from 0.9 tons per hectare (t/ha) to 4 tons. In Burkina, it ranges from 2 t/ha to 4.7 tons (ECOWAS, UEMOA and CILSS et al., 2016). For pearl millet, the potential in Mali ranges from 2 t/ha to 3.7, while it goes from 1.4 to 2 tons in Burkina Faso (ECOWAS, UEMOA and CILSS et al., 2016). In Mali, pearl millet yield was 1.74 t/ha for sorghum and 1.33 t/ha for millet (Huet et al., 2022).

In Burkina Faso, sorghum yield was 0.99 t/ha in 2020, while millet was just 0.81 t/ha (Diarisso et al., 2023). The rising concerns over the low adoption of improved varieties (Smale et al., 2018) and the need for gender integration into agricultural technology development among research for development practitioners and the donor community motivated the conceptualization of this study. This led to an increased interest in gender-focused research and projects with gender well integrated into the design by CGIAR and related research for development organizations. The failure to define the demands of all value chain actors may limit the adoption of improved varieties and other agricultural innovations. End-users, who operate at the different nodes of the sorghum and millet value chains usually men and women, are the major stakeholders of the breeding products but are seldom consulted at various stages of the breeding design process (Sylla et al., 2023). Until recently, men and women value chain actors participated little in the decisions made in breeding activities. Although there is growing awareness of the vital role end-users should play in breeding decision stages, there is limited understanding of who, how, and when to engage men and women in the processes (Yila and Sylla, 2021; Ojwang et al., 2023; Yila et al., 2023). To identify and address the causes of low adoption, social scientists and plant breeding researchers from ICRISAT and the National Agricultural Research System (NARES) partners in West Africa assess the capacity of breeding programs for gender integration and a literature review on gender inclusion in breeding in WCA was conducted. The review found that actors of other segments of the sorghum and pearl millet value chain were not considered in the varietal evaluation process; the breeding programs seldom prioritize gender-specific traits. The low adoption of sorghum and millet in Mali may be because the new varieties did not cater to the specific traits valued by male and female value chain actors outside the production node.

We adopted the "Target, Reach, and Benefit" conceptual framework (Johnson et al., 2018) (Figure 1) for the development of the client-driven breeding decision process, anchored on the fact that when product attributes demanded by end-users are defined and mainstreamed into the breeding product development process, the acceptance and adoption rates are high, otherwise, they remain an unfulfilled wish list (Ragot et al., 2018). The framework presents our conceptual strategy, which informs how the approaches employed contribute to gender equity and inclusion in varietal development. To develop varieties that consider the needs of the end-users, it is vital to define who the end-users are as the first step to considering their demographic and socioeconomic information, different needs, and preferences. Understanding the community norms and social structures, which can influence varietal preferences and adoption decisions, is also essential (see Figures 2, 3).

The Target, Reach, and Benefits framework was adopted in acknowledgment that it is crucial to involve end-users, particularly women and others in the value chain aside from production, in the breeding design process (Angarawai and Yila, 2021). The framework aims to achieve a change in mindset that recognizes all the breeding products' customers, leading to their greater engagement in the breeding decision process and achieving end-user-informed breeding decisions.

Methods

The study followed a stage-wise approach or phased implementation over some time from the Conceptual Phase, which included reviewing the literature, problem identification, and determining the research purpose; the Design and Empirical Phase, which comprises selecting a research design, developing the study procedures, determining the sampling and data Research Topic plan and data Research Topic and analysis; Analytic Phase and Dissemination Phase include analyzing the data and interpreting the results; and communicating the results to the appropriate audience including the stakeholders (outlined in Table 1). Each stage or phase is linked to and a build-up to the next.

Phase 1: to understand the history of PPB and how gender is considered and integrated into the breeding programs in WCA

Both qualitative and quantitative methods were used to collect data from CGIAR and NARES breeders and selected critical partners involved in breeding activities in WCA using three data Research Topic instruments: (1) a literature review on gender and plant participatory breeding since 2000, (2) an individual questionnaire

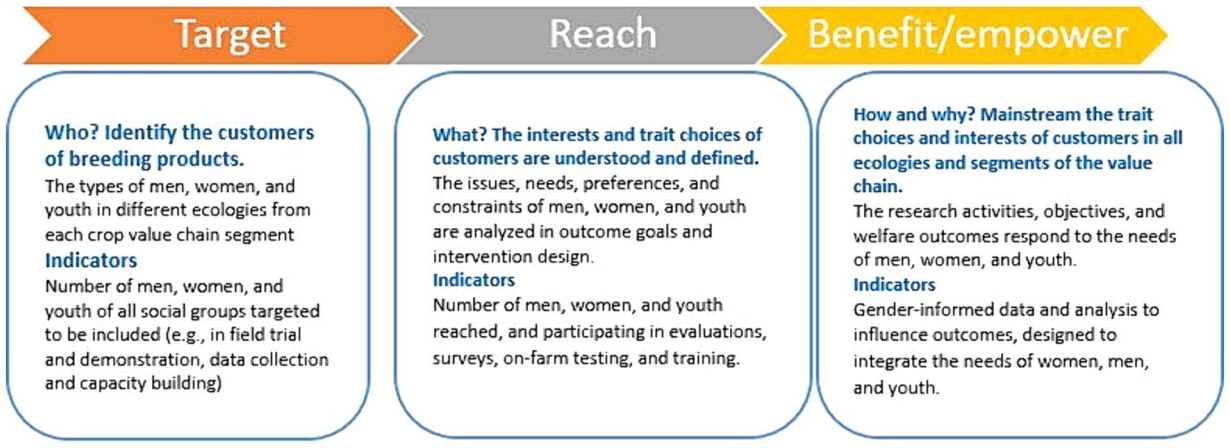

FIGURE 1
The Gender Equity and Inclusion process in varietal development and deployment.

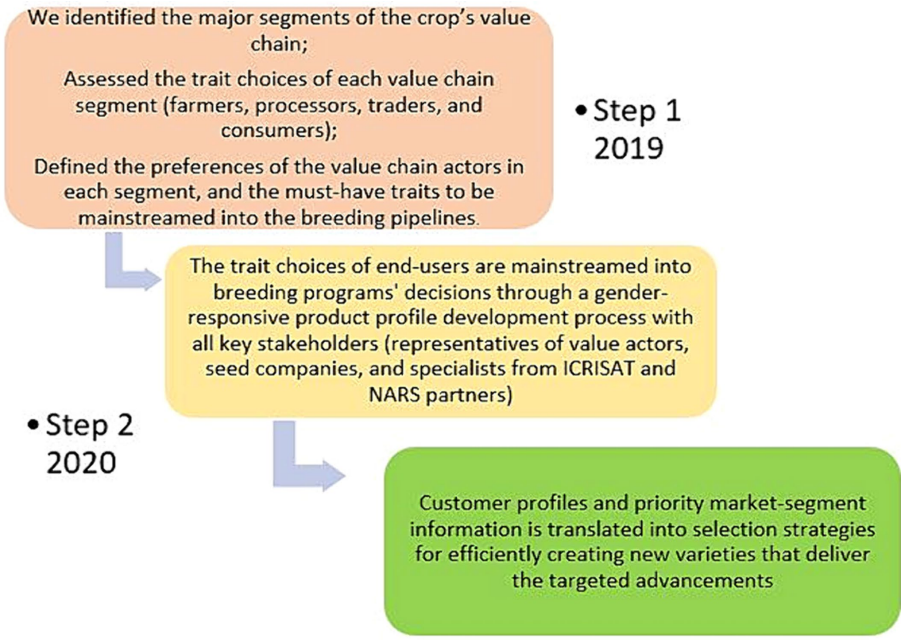

FIGURE 2
Co-development of client-oriented varieties processes.

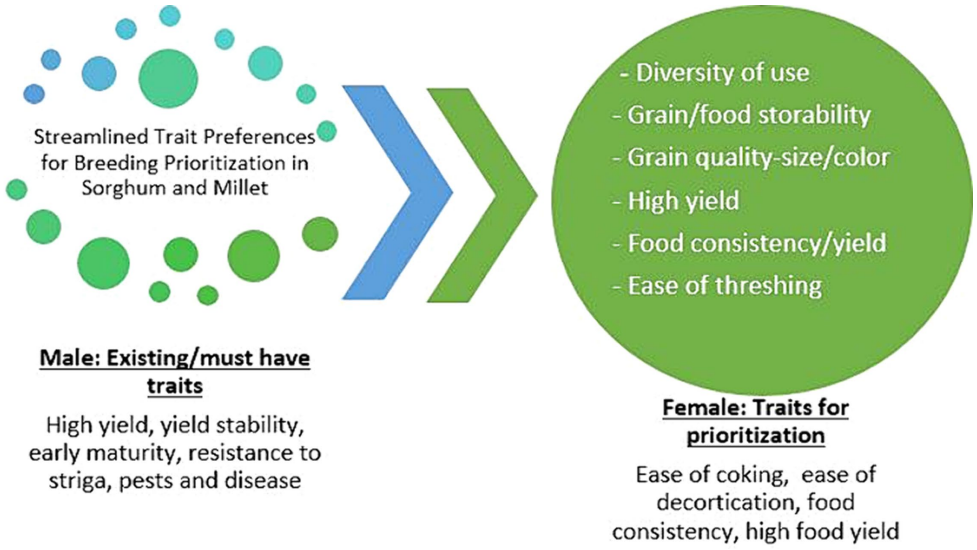

FIGURE 3
Summary of traits preferences for breeding prioritization.

designed to understand the history of PPB, how gender aspects are considered in the breeding programs and at what stage of the breeding cycle, as well as the challenges and opportunities for gender inclusion for breeders. The questionnaire consisted of closed and open-ended questions; (3) Focus group discussions were organized for each crop in the study countries. The individual interviews were conducted with 29 breeders from the national and international research institutes' plant breeding in WCA. Consultations with the breeders revealed that the most critical activities in which gender was considered in breeding activities were participatory varietal selection and seed multiplication (Yila and Njuguna-Mungai, 2019). From the 1990s to 2014, sorghum and pearl millet breeding programs were mostly gender blind, or at best, gender-aware (field notes, 2018).

Phase 2: gender data to inform varietal trait choices

The first phase of this study, led by a postdoctoral fellow, concluded that men and women farmers are not the only end-users

TABLE 1 Methodological phases and processes of the study.

S/No.	Phases/Stages of the study	Period	Objectives	Methodology/ Approach	Key result/Remark/ conclusion
1	Conceptual Phase: Documentation of the history of cereal and legumes PPB in ICRISAT- WCA	2018–2019	Identify areas of presence/absence of gender considerations in the processes and their impacts and implications for the breeding and adoption of varieties. Assess how the breeding programs were conceptualized, implemented, and modified over time with a particular focus on gender analysis and how it influences any decisions, as well as the gender capacity needs of the breeding program.	Individual questionnaires, Focus Group Discussions, and oral histories with NARES and CG Scientists, partners, and others who played critical roles in the development of PPB. Qualitative and quantitative methods involving all ICRISAT breeding programs/ partners as key respondents.	Results from consultations with the breeders showed that farmers are mainly involved in the breeding activities at the participatory varietal selection and seed multiplication stages. The study concluded that men and women farmers are not the only end-users of the breeding products, and their varietal choices may not be homogenous.
2	Empirical Phase: Gender data to inform varietal traits choices	2019–2020	To examine and map the traits desired by actors of the crops' value chain and how these preferences can inform the development of varieties that are not only gender-responsive but also market-driven.	A mixed-method approach was used for data Research Topic and analysis using qualitative and quantitative methods. The data were collected in three phases: reconnaissance survey, (1) survey, (2) key informant interviews (KIIs), and (3) FGDs.	Identifying and understanding the diverse users of crop improvement products and defining the trait choices of the key actors is an approach that is responsive to equity and end-users' needs. This approach elicited an understanding of how the roles and interests of the actors intersect with their gender to influence male and female actors' decisions on adopting a variety.
3	Analytic Phase and Dissemination Phase: Stakeholder feedback and co-development of client-oriented product profiles	2021	Provide the key stakeholders with the findings of the trait preference study and together co-develop and make input into the product development process.	A stakeholder workshop with all key stakeholders (Representatives of value chain actors, seed companies, Breeders, Social Scientists, Gender Specialists, and Food Technologists from ICRISAT and NARES partners) in four West African countries to provide feedback and co-develop a product profile for each crop.	The crop teams, primarily by country, discussed and characterized customers for specific crops and linked groups of customers to the product profiles proposed by ICRISAT-WCA for specific market segments. The product profiles were revised by examining and adding important traits from gender and value chain nodes' perspectives based on insights into existing markets and processing options. Corresponding changes were made to the customer profiles for specific traits, such as nutrition traits, such as vitamin A biofortified millet varieties and sorghum varieties with high flour yield and grain hardness. These are examples of suggested trait prioritization changes.

of the breeding products, and their varietal trait choices may not be homogenous. This led to a second phase that sought to identify and examine the trait preferences of the sorghum and millet value chain actors and how these preferences may inform the development of varieties that are not only gender-responsive but also market-driven. The Gender Research Scientists, a sorghum breeder in ICRISAT and a NARES' millet breeder in Mali, identified the major segments of the sorghum and millet value chain, assessed, and characterized the trait choices of each value chain segment, examined the socioeconomic determinants of their varietal choices, defined the preferences of the value chain actors in each segment, and the must-have traits to be mainstreamed into the breeding pipelines.

A mixed-method approach was used for data Research Topic and analysis, applying qualitative and quantitative methods (Behrman et al., 2014). The data were collected in three stages: (1) reconnaissance survey, (2) survey, (3) key informant interviews (KIIs) and FGDs. A rapid reconnaissance survey (Hildebrand, 1981; Brophy et al., 1991; Butler, 1995) was conducted to gather information and feedback from the field to help identify the major segments of the sorghum and millet value chain in Burkina Faso and Mali and to formulate the questionnaire.

The study used multi-stage sampling to select 1,324 respondents, comprising 598 (45%) women engaged in producing, trading, processing, or consuming pearl millet and sorghum in the major regions in Mali and Burkina Faso where the crops are produced. The districts were purposively selected based on the importance of pearl millet and sorghum production and because they had breeding activities and innovations introduced by research institutes and state extension services.

The regions and districts were also chosen for their social stability and relative safety from terrorist attacks in Burkina Faso and Mali. The study districts in Mali are Dioila (region of Koulikoro), Kati (region of Koulikoro), Kouliala (region of Sikasso), and Tominian (region of Segou). While in Burkina Faso, the study was conducted in the districts of Kombissiri and Manga in the region of Centre-sud; in the districts of Ziniare and Zitenga in the region of Plateau-Central; in the districts of Sabou and Kindi in the region of Centre-Ouest. At the village level, at least 30 respondents were randomly selected for the study, taking care to include men and women. The value chain actors were asked questions about their specific segments. For instance, questions about processing were posed to processors, questions on marketing were asked of grain traders, and so on. Specialization is rudimentary, so some respondents are farmers, traders, and processors. Actors were selected based on their primary activity, where they earned the most income or were primarily engaged. Thus, their involvement in several value chain segments informed many of the actors' trait preferences.

Result and discussion

Demographic and socioeconomic information of respondents in the case study

The 1,324 respondents are farmers, traders, processors, and consumers of pearl millet and sorghum, of which 45% are female (Table 2). Their average age is 44.5. The females are younger (41) than males (48). Respondents from Burkina Faso are slightly older (47 years) than those from Mali (44 years). Most respondents are illiterate (62%), especially women in Burkina Faso (81%). The respondents that identified as producers were (65%), processors (16%), traders (6%) and consumers (12%). In Mali, the respondents who identified as producers were (63), processors (22%), traders (5%), and consumers (10%). In Burkina Faso, 68% of respondents were producers, 11% processors, 7% traders, and 14% consumers. In Mali, 43% of the women sampled were processors (but only 2% were men), and only 3% of the sampled women were traders. A third of women respondents (32%) were pearl millet and sorghum processors in both countries. The female respondents were less represented in farming (47% of women were farmers, vs. 84% of sampled men). Only 4% of the women sampled were traders, but 8% of the men were. Fewer women rarely engage in trade and production because of their low capacity in these nodes and gender roles and social norms that restrict mobility. Women engage more in processing, in which they have expertise and skills that are locally recognized and valued as an activity related to their traditional role in food decision-making and preparation.

Sorghum and pearl millet value chain actors' preference traits in Mali and Burkina Faso

Pearson's chi-squared test is a statistical tool used to determine the differences between two sets of observations that could be due to chance. A value close to 0 is more likely to be statistically significant (not explained by chance) than a value close to 1. Conventionally, 0.05 or lower is statistically significant. This case study used the chi-squared test to see if the difference in trait preferences between men and women could be explained by chance.

Table 3 presents the preferred traits of sorghum value chain actors in Burkina Faso and Mali. High yield is the most preferred trait for male and female farmers in both countries. Yield stability is more critical for farmers in Mali, especially for females. In Mali, almost all male and female farmers desired pest, disease, and weed resistance (including striga), but not in Burkina Faso, where the men especially gave little importance to pest resistance. This may be because men in Burkina Faso have greater access to low-cost pesticides. Men and women farmers value good quality food grain in both countries.

Grain traders of both genders, in both countries, value good grain quality traits. Mali traders said grain color was crucial, while it matters little in Burkina Faso. Nearly all male and female sorghum traders in Mali want good taste, easy threshing, and large grain size traits, but none of this interest traders in Burkina Faso.

In Mali, sorghum processors of both genders prefer food consistency, diverse grain use, easy threshing and grinding, high food yield, grain quality, and food storability traits. In contrast, these traits are much less important for male and female processors in Burkina Faso. This validates the result of the FGDs, which revealed women's explicit knowledge and understanding of specific attributes of grains in a particular variety due to women's reproductive role at home and engagement in the processing segment.

> "For the improved varieties, we appreciate Pablo variety because of the grain size, the white color, and the hardness of the grains. This variety is suitable to be transformed into semolina and flour" (Karangana, mixed FGD, December 2019).

As the need for flour grows in Mali, the establishment of grain mills can modernize the processing sector, boost the earnings of everyone involved in the sorghum supply chain, and provide new opportunities for young people and women in rural and peri-urban areas where opportunities are limited.

Male and female consumers in Mali all value food taste and consistency, grain storability, large grain size, and food yield. However, in Burkina Faso, only food consistency and grain storability mattered to males and females. The differences between the two countries are much more important than those between men and women. Farmers, traders, processors, and consumers in Mali share more commonly desired traits than the actors in Burkina Faso, where respondents only value high yield and good grain quality. Sorghum is highly desired and more consumed as food in Mali, which may explain why traits associated with food and grain quality and products are more preferred than in Burkina Faso.

Table 4 reveals that male and female farmers prefer high-yielding pearl millet, especially in Mali, with no significant difference in gendered preferences in the two countries. More women in Mali preferred yield

TABLE 2 Demographic information.

Characteristics of respondents	Burkina Faso			Mali			Overall		
	Male	Female	Pooled	Male	Female	Pooled	Male	Female	Pooled
	(*n* = 398)	(*n* = 314)	(*N* = 712)	(*n* = 328)	(*n* = 284)	(*N* = 612)	(*n* = 726)	(*n* = 598)	(*N* = 1,324)
Sample sex (%)	56	44	50	54	46	50	55	45	100
Average → age (years)	49	44	47	47	37	42	48	41	44.5
Education (%)									
No → formal education	64	81	73	42	61	52	53	71	62
Adult education	3	2	2	19	11	15	11	7	9
Koranic education	8	1	4	5	5	5	6	3	5
Other	0	1	0	1	1	1	0	1	1
Primary education	20	12	16	20	15	18	20	13	17
Secondary education	5	4	5	7	6	7	6	5	6
Tertiary	64	81	73	6	1	3	35	41	38
Education value chain segment (%)									
Consumption	11	17	14	2	17	10	7	17	12
Trade	9	6	7	8	3	5	8	4	6
Processing	1	21	11	2	43	22	1	32	16
Production	79	57	68	88	37	63	84	47	65
Total	100	100	100	100	100	100	100	100	100

stability. However, both female and male farmers in Mali cared a lot about pest, disease, and weed resistance, while in Burkina Faso, these traits were of much less significance, especially for men, probably because women are traditionally responsible for manual weeding. Drought resistance was much more critical in Mali, especially for women. In Burkina Faso, there was no significant difference between female and male pearl millet producers with respect to drought resistance. All the agronomic traits are more critical in Mali, especially among women farmers.

For grain traders, ease of grinding is essential in Burkina Faso, especially for women. Unlike Burkina Faso, traders in Mali pay much attention to grain color; food consistency is preferred by most traders, especially in Mali. While female and male processors in Mali attach importance to food consistency, food yield, food storability, easy grinding, and grain quality, food consistency is the only trait important to 60% of processors of both genders in Burkina Faso. Consistency of local dishes is essential for traders who sell to discerning consumers. Pearl millet consumers prefer traits such as food yield, grain attractiveness, and good taste, while easy grinding is essential to both female and male consumers in Mali. In Burkina Faso, only food consistency and grain quality are preferred, with no significant gender differences. As with sorghum, the major differences in pearl millet actors' preferences were between the countries, not between men and women.

The study revealed that women along the sorghum and millet value chains were slightly more likely to prefer end-product qualities such as grain quality, storability, food yield, and consistency. In both countries, women and men desire similar qualities in sorghum and pearl millet varieties. A gender-responsive breeding program may find that men and women substantially agree on the traits they want in a crop variety, but this should never be assumed. The specific requirements of men and women must be empirically determined, even if they are found to be similar (Polar et al., 2022).

Phase three: stakeholder feedback and co-development of client-oriented product profiles

This stakeholder feedback workshop aimed to support breeding prioritization that fits the needs of the stakeholders who are the end-users of the breeding products. The findings of the trait preference study conducted in phase 2 were presented to the key stakeholders.

A stakeholder workshop titled "Demand-Driven and Gender-Responsive Product Profile Development for Groundnut, Pearl Millet, and Sorghum in West and Central Africa" was organized from 21 to 24 June 2021. This workshop brought together the crop stakeholders and representatives of the sorghum and millet value chain, including farmer organization representatives, grain traders, processors, seed companies, and seed producer cooperatives, as well as researchers working on crop variety development (social science, gender, food processing, nutrition, and plant breeders). The multi-country and crop stakeholder workshop provided a feedback mechanism for the diverse value chain actors to give their input and co-develop the product profiles.

Workshop organization and output

The workshop was conducted over 4 days in Bamako, Mali. Each day was structured to build on prior discussions. Concepts such as Customer Profiling, Market Segmentation, Gender Responsiveness, and Product Profiling based on the G+ tools (Ashby et al., 2018; Tufan et al., 2018) developed by the CGIAR Gender and Breeding Initiative were reviewed and clarified. In small groups, the participants discussed the criteria for customer segmentation. The overview of results from gender studies conducted in Burkina Faso, Mali, Nigeria, and Ghana was presented by the gender and social scientists who participated in the studies. Participants formed discussion groups per country to

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TABLE 3 Sorghum value chain actors' trait preferences in Mali and Burkina Faso.

Segments		Burkina Faso			Mali	
Farmers	Male (n = 314)	Female (n = 179)	p-value (chi^2)	Male (n = 289)	Female (n = 105)	p-value
High yield	73.4	76.0	ns	91.8	94	ns
Yield stability	23.9	26.3	ns	57.6	66.2	0.03**
Pest and disease resistance	37.4	46.7	0.06	90.9	88.7	ns
Weed resistance	32.8	41.9	0.06*	95.1	91.9	ns
Striga resistance	37.7	46.1	0.09*	88.7	84.9	ns
Grain quality	75.1	83.2	0.05*	80.8	77.5	ns
Grain traders	Male (n = 36)	Female (n = 19)	p-value (chi^2)	Male (n = 26)	Female (n = 9)	p-value (chi^2)
Grain quality	78.7	89.8	0.003***	80.8	70.1	0.0027***
Grain color	17.4	19.2	ns	97.3	93.3	0.032**
Taste	1.0	0.0	ns	98.8	98.9	ns
Easy threshing	16.4	18.6	ns	95.7	96.8	ns
Large grain	2.6	2.4	ns	97	96.5	ns
Processors	Male (n = 4)	Female (n = 66)	p-value (chi^2)	Male (n = 7)	Female (n = 122)	p-value (chi^2)
Food consistency	61.7	62.5	ns	96.0	81	5.987e–09***
Diversity of use	43.6	43.1	ns	92.2	80.8	7.93e–06***
Easy threshing	28.2	27.6	ns	93.0	84.5	0.0012***
Easy grinding	27.9	28.4	ns	97.6	83.5	2.761e–09***
Food/flour yield	12.3	13.4	ns	93.6	78.2	8.919e–05***
Grain quality	53.6	56.9	ns	95.7	86.6	0.0001***
Food storability	39.6	48.7	0.04**	95.1	85.6	ns
Consumers	Male (n = 44)	Female (n = 53)	p-value (chi^2)	Male (n = 7)	Female (n = 48)	p-value (chi^2)
Food/flour yield	17.4	18.2	ns	83.8	71.5	0.000***
Food consistency	73.1	71.4	ns	82	75	0.04**
Food taste	16.9	16.4	ns	89	84.2	0.09*
Large grain size	2.6	3.6	ns	95.7	98.6	0.06*
Grain storability	57.7	62.3	ns	87.2	84.9	ns

Significant at 1%***, 0.5%**, 0.10%*; ns = not significant.

examine the specific, gender-based constraints and inequalities related to unpaid family labor, opportunities for paid work, access to productive resources, and control over agricultural products.

The crop and country teams discussed and characterized customers for specific crops and linked groups of customers to the product profiles proposed by ICRISAT-WCA for specific market segments. Results of the gender studies, as well as the experiences of the different value chain actors present, contributed to these revisions. A second set of discussions, conducted by crop- and country-specific groups, estimated the importance of major crop products. The workshop participants thus contributed significantly to revising the market segments that ICRISAT had proposed. The workshop participants revised the draft product profiles by examining and adding traits of importance from gender and value-chain nodes' perspectives based on insights into existing markets and processing options (Figure 2). Results were shared and discussed, and the next steps were proposed.

The workshop outputs outlined the main definitions for the discussions and summarized the learnings from recent gender studies of trait preferences along the value chains. Most importantly, it assesses and reviews market segmentation and customer profiling for trait demands in new varieties of the three targeted West African crops. Corresponding changes were made to the customer profiles for specific traits like nutrition traits, such as Vitamin A biofortified millet varieties, sorghum varieties with high flour yield, and grain hardness are examples of suggested trait prioritization changes.

Conclusions and implications

In West Africa, cereal breeding programs have focused on understanding the trait preferences of farmers, including gender differences. However, there has been a lack of consideration for the trait preferences of other value chain actors, such as grain traders, processors, and consumers. This study contributed to addressing some of these gaps, provided the foundation for more targeted investigations, and facilitated the understanding of trait preferences among farmers and other value chain actors. The study modeled an inclusive and stakeholder-driven approach to foster a shared

TABLE 4 Pearl millet value chain actors' trait preferences in Mali and Burkina.

Preferences of value chain actors	Burkina Faso			Mali		
Farmers	Male (n = 314)	Female (n = 179)	p-value (ch-2)	Male (n = 289)	Female (n = 105)	p-value (chi^2)
High yield	76.1	76.9	Ns	90.2	95.1	2.132e-06***
Yield stability	27.8	37.2	0.08*	49.4	68.7	0.03**
Disease and pest Resistance	44.9	61.2	0.005***	87.8	91.5	ns
Weed resistance	37.6	53.7	0.005***	92.4	95.1	ns
Striga resistance	41.5	56.2	0.01**	85.1	94.7	0.0001***
Drought resistance	53.4	59.5	Ns	82.9	90.1	0.01**
Grain traders	Male (n = 36)	Female (n = 19)	p-value (ch-2)	Male (n = 26)	Female (n = 9)	p-value (chi^2)
Easy to grind	13.7	17.4	Ns	89.6	94.4	0.04**
Grain color	15.0	23.1	0.07*	95.7	94	ns
Consistency of local dishes	66.7	68.6	Ns	89.0	91.5	ns
Processors	Male (n = 4)	Female (n = 66)	p-value (ch-2)	Male (n = 7)	Female (n = 122)	p-value (chi^2)
Food consistency	59.1	60.8	Ns	97.0	89.1	0.0001***
Food yield	13.9	15.1	ns	95.4	85.2	0.04**
Food storability	40.9	44.1	Ns	95.4	90.8	0.03**
Easy grinding	31.2	32.3	Ns	96.0	92.6	0.09*
Grain quality	49.4	53.2	Ns	95.7	91.9	0.06*
Consumers	Male (n = 44)	Female (n = 53)	p-value (ch-2)	Male (n = 7)	Female (n = 48)	p-value (chi^2)
Food/flour yield	22.6	20.7	Ns	81.3	87.5	0.04**
Grain attractiveness	18.6	21.3	ns	91.8	96.5	0.02**
Grain good taste	19.7	20.1	Ns	84.1	89.4	0.07*
Easy grinding	22.2	26.4	Ns	87.5	92.3	0.07*
Grain quality	51.6	59.2	Ns	86.3	89.1	ns
Food consistency	71.0	71.3	ns	86	83.1	ns

Significant at 1%***, 5%**, 10%*; ns = not significant.

understanding and co-creation of a common vision for the future priorities for sorghum and pearl millet breeding programs. During the stakeholder workshop, interdisciplinary research was encouraged, particularly between the social sciences, gender research, economics, and the biophysical sciences.

The study also aimed to bridge the gap in breeding strategies and processes by considering the preferences and needs of grain traders, processors, and consumers and recognizing how value chain actors' varietal choices are influenced by gender, context, and their role in the value chain activities. Understanding the primary value chain segments helps to reveal how the agricultural system functions and is critical for prioritizing breeding objectives with the product users instead of from the isolation of the laboratory. Gender responsiveness requires not only examining the needs and choices of male and female value chain actors but also targeting and mainstreaming these into the breeding pipeline.

The findings of this study support streamlining the essential trait preferences of sorghum and millet actors and provide valuable insights into the trait preferences of value chain actors in the sorghum and millet industry, with specific attention to the needs and preferences of the female value chain actors. These findings can be used to inform breeding programs, extension services, policy-making, or program strategies to better align the traits of these crops with the needs and preferences of the key stakeholders in the value chain. The study recommends that product profile development should consider the trait preferences of not just male and female farmers but also grain traders, food processors, and consumers by prioritizing their trait preferences such as ease of cooking, ease of decortication, food consistency, and high food yield in setting breeding objectives. Mainstreaming these traits into the existing breeding pipeline will address gender blindness that currently limits the adoption of new varieties. Therefore, studying the connection between non-technical aspects of trait decisions and end users' realities, such as flour or food yield versus grain yield determined by the sociocultural and gender roles of actors involved in a particular value chain, helps determine whether the end users accept or reject breeding the variety.

Moving forward, it is essential to continue conducting similar studies to keep track of evolving preferences and ensure that the sorghum and millet value chain remains responsive to all actors' needs. Doing so can foster a more sustainable and productive value chain for sorghum and millet, benefiting producers and consumers and ensuring gender-equitable feedback between breeders and end-users. Furthermore, continuous collaboration between breeders, farmers, traders, processors, and consumers is needed to streamline

breeding objectives and prioritize trait preferences that lead to developing new sorghum and millet varieties well-suited to local conditions and market demands.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical approval was not required for the studies involving humans because the data Research Topics and methodologies were implemented in phases and the approach did follow the traditional Research Topic methods. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

The reviewer JO declared a shared research partnership group CGIAR with the authors JY and AS to the handling Editor.

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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Examining gendered cassava trait preferences through commercial seed business: a case study of IITA GoSeed and Umudike Seeds in Nigeria

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This study focuses on how, apart from research, commercial seed initiatives and practices aimed at promoting and selling improved varieties also identified gendered trait preferences of cassava users along the value chain. Since 2015, the public cassava breeding program in Nigeria, led by the International Institute of Tropical Agriculture (IITA) in collaboration with the National Root Crops Research Institute (NRCRI), has carried out various research studies to determine the gendered trait preferences by different cassava users along the whole value chain. These studies inform which crop users the cassava breeding programs target, the traits to select, and the definition of product profiles considering gender. The commercial enterprises IITA GoSeed and Umudike Seeds have engaged cassava seed users who validated the findings of the previous studies. The formal cassava seed system in Nigeria is in a nascent stage. Feedback from this system through seed demand and sales is valuable for breeders. Therefore, this study focused on documenting a case study of how IITA GoSeed and Umudike Seeds commercial initiatives, aimed at promoting and selling improved varieties, identified additional gendered user preferences. A total of six key informant interviews were conducted with IITA GoSeed and Umudike staff. Furthermore, reports and sales data shared by the two companies were assessed. We found that traits such as plant architecture that suppresses weed (branched stems with widespread canopy) and food processing suitability were confirmed as important gendered traits while ratooning ability (allowing to cut stems from an existing plant without the plant being affected much) and sweet taste of tubers which can be eaten boiled without elaborate processing are new gendered traits identified by the two companies. IITA GoSeeds and Umudike Seeds identified that the variety TME419 has the highest sales records among men and women, with more recently released varieties gradually becoming more popular, and their branched soil covering or umbrella shape seems to be an important value-added and gendered trait. Notably, women village seed entrepreneurs (VSEs) showed a distinct preference and demand for the varieties Gamechanger and Farmers' Pride, surpassing the demand recorded among men from both companies.

Our findings illustrate that the upcoming commercial seed market demand for different varieties coupled with integrated action research can capture emerging trends among cassava seed and root producers to guide breeding efforts, which is particularly important as breeding is a future investment.

KEYWORDS

breeding, gendered trait preferences, IITA GoSeed, Umudike Seeds, cassava, Nigeria, private seed sector

Introduction

In Nigeria, cassava (*Manihot esculenta* Crantz) is an important staple crop, recognized as a 21st-century crop mostly for smallholder farmers (Food and Agriculture Organization of the United Nations (FAO), 2013). It is propagated vegetatively from stems (stems are therefore considered as cassava "seed") and sold as fresh roots when harvested or processed into different intermediate and final food products such as gari, eba, akpu, lafun, abacha, semolina (a locally made mixture of maize and cassava), and edible starch. These food products are marketed and used for household consumption (Teeken et al., 2018; Wossen et al., 2020). Small landholders who often process cassava into food products produce up to 90% of all the cassava in Nigeria (Ikuemonisan et al., 2020). Women largely dominate the processing of cassava roots into food products (Curran et al., 2009; Walker et al., 2014; Teeken et al., 2018). Some medium and large-scale farmers concentrate on growing improved cassava varieties for starch, high-quality cassava flour, and chips for national and international markets.

Until recently, cassava stems were mostly a by-product of harvested roots exchanged freely or provided as gifts among farmers who plant them in their fields. Such cassava stems are not always considered to be of high quality and may be susceptible to disease or result in lower productivity compared to stems developed specifically for seed. Today, there is much more demand for higher-quality cassava stems than in the past, as farmers wish to establish new fields for increased production to meet the growing demand for cassava roots in Nigeria (Pircher et al., 2022). The purchase of stems is also associated with occurrences such as the destruction of farms in conflicts-prone zones (Olaosebikan et al., 2023) and limited access to good quality stems among farmers, especially women cultivating small plots in communities where cassava is not a major crop. This has created the demand for cassava seed to be sold and influenced the emergence of formal seed marketing opportunities for commercialization within the seed supply chain, specifically for individuals or companies to produce seeds from improved varieties for sale.

Nigerian cassava farmers now specialize in the production and sale of cassava seed. Women and men farmers in need of stems from newly bred cassava varieties patronize these emerging seed businesses. Over the past decade, the Building an Economically Sustainable, Integrated Cassava Seed System (BASICS) project has helped develop the cassava seed system in Nigeria by providing opportunities for individuals and companies to produce and sell newly bred cassava seed (or planting material) for farmers to grow (IITA Cassava Matters, 2021).

Efforts to create a more sustainable cassava seed system have been complemented by research to better understand cassava traits and varietal preferences amongst women and men end-users from different market segments.

The public cassava breeding program at the International Institute of Tropical Agriculture (IITA), in collaboration with the National Root Crops Research Institute (NRCRI), conducted a cassava monitoring survey in Nigeria to assess the adoption of released improved varieties (Wossen et al., 2017a). The program followed up with several mixed-method studies focusing on regional and gendered cassava trait preferences along the value chain and cassava trait preferences that enhance coping with climatic and social stressors in Nigeria (Bentley et al., 2017; Teeken et al., 2018; Ndjouenkeu et al., 2021; Thiele et al., 2021; Madu et al., 2022; Olaosebikan et al., 2022, 2023). These studies identified the distinct needs and preferred cassava traits of women and men value chain actors as one of the reasons for the low adoption rate of some improved cassava varieties (ICVs). This highlighted the need to inclusively integrate crop user preferences into the breeding selection and traits prioritization, especially at the processing and consumption nodes of the cassava value chain where women dominate (Teeken et al., 2018, 2021a,b; Chijioke et al., 2021; Ndjouenkeu et al., 2021; Balogun et al., 2022; Olaosebikan et al., 2023). Breeders considered the limited adoption rate a major challenge for emerging commercial seed enterprises trying to meet the demands for ICV seed. Breeders also realized that establishing a successful formal seed system requires understanding women's and men's roles and their perception of seed quality traits in the mostly informal seed system (Marimo et al., 2021). This informed the improvement of cassava breeding efforts and its transformation toward a more demand-led, resilient, and gender and socially-inclusive approach toward sustainable impact, a major objective of public breeding (CGIAR system organization, 2021; Donovan et al., 2022).

Initiatives to boost cassava productivity and seed access included establishing private seed companies such as IITA GoSeed and Umudike Seeds. Founded in 2019 and 2018, respectively, these companies focus on producing, commercializing, and promoting high-quality early-generation seeds (EGS) for formal seed exchange.

Supported by projects such as BASICS and managed by the CGIAR Research Program on Roots, Tubers, and Bananas (RTB) (2020), IITA GoSeed and Umudike Seeds aim to provide farmers

with affordable, quality-assured seeds. They play a crucial role in distributing EGS cassava, ensuring improved varieties bred by IITA, NRCRI, and other CGIAR Centers reach a wide network of seed entrepreneurs, cooperatives, NGOs, and agro-industries, thus enhancing the formal seed system in Nigeria.

To date, there has been a shortage of empirical evidence regarding the impact of the establishment of such commercial cassava seed enterprises on the generation of valuable feedback and gender-specific insights derived from their operational endeavors in Nigeria. Therefore, this case study focused on IITA GoSeed and Umudike Seeds activities and their engagement with commercial and small-scale seed producers to investigate valuable feedback on gendered variety and seed preferences. The case study highlights how these two seed companies have contributed to cassava breeding by identifying and prioritizing gendered trait preferences along the whole value chain, from farmers to consumers (McDougall et al., 2022; Polar et al., 2022).

Consequently, this study had the following objectives:

1. Undertake a general assessment of the gendered trait preferences among men and women farmers in Nigeria.
2. Identify the gender-inclusive feedback received through the business operations of IITA GoSeed and Umudike Seeds and assess the impact of such feedback on cassava breeding in Nigeria.
3. Assess the gendered preferences of the newly bred and released cassava varieties produced, promoted, and sold by IITA GoSeed and Umudike Seeds.

Methodology, materials, and methods

Study design and setting/context

A case study design was adopted to examine gendered cassava trait preferences identified through commercial seed businesses in Nigeria. Case studies are empirical inquiries that research contemporary issues within their real-life contexts by using one or multiple cases in a setting that can be a bounded system (Yin, 2013; Creswell, 2014). The multiple case study approach allows the researcher to focus on one issue but selects multiple cases to illustrate the issue that can be purposefully sampled from one site or several sites (Creswell, 2014). In a case study design, multiple data sources are used that result from detailed, in-depth data collection (Creswell, 2014). We, therefore, utilized a multiple case study approach by conducting key informant interviews and a review and analysis of secondary datasets with case study participants purposively selected from IITA GoSeed and Umudike seeds in Nigeria. These two enterprises were selected because of their close relationship to the breeding program, which, through research, has already identified many gendered crop user trait preferences.

IITA GoSeed and Umudike seeds companies

As part of the cassava breeding initiative, two private seed companies, namely IITA GoSeed and Umudike Seeds, were set up. They both aim to produce, commercialize, and promote ICVs, focusing on formal seed exchange channels for high-quality breeder and foundation/early generation seeds (EGS). IITA GoSeed and Umudike Seeds were founded in 2019 and 2018, respectively, with the responsibility of producing, promoting, and selling certified early-generation seeds of the improved crop varieties bred by IITA and NRCRI, other CGIAR Centers, and the cooperating NARS (Legg et al., 2022). IITA GoSeed was established with support from the BASICS project, managed by the CGIAR Research Program on Root Tubers and Bananas (CRP-RTB) (Wossen et al., 2020; Legg et al., 2022). Umudike Seeds is a private seed company established by the National Root Crop Research Institute as part of its sustainability strategy for BASICS to promote the development of the formal root and tuber crop seed system in Nigeria. The BASICS project aimed to give farmers access to affordable, quality-assured seeds. NRCRI, with its affiliated seed company, Umudike Seeds, also institutionalized this formal seed exchange of improved cassava varieties for wider reach among cassava growers (Legg et al., 2022) in Nigeria. These IITA and NRCRI-affiliated seed companies are Nigeria's primary producers of EGS cassava. Early generation seed production and distribution are the primary means of disseminating ICVs into the formal seed system and are supervised by the National Agricultural Seeds Council (NASC) (2022), the seed regulatory authority in Nigeria. Both seed companies were created to produce and supply EGS to a community of seed entrepreneurs comprising individuals, farmer groups, cooperatives, NGOs, and cassava agro-industries with an affordable, quality-assured seed of varieties in demand by local food and processor markets (Bentley et al., 2020; Legg et al., 2022).

Methods of data collection and sampling techniques

We employed both primary and secondary data, which comprised quantitative and qualitative data sets. First, we conducted a review of previous studies conducted by IITA and national partners, such as NRCRI, over the past decade. These studies were undertaken to examine cassava trait preferences at each node of the cassava value chain. They focused on understanding the trait preferences of cassava value chain actors, associated gender roles, constraints, and opportunities to improve cassava breeding and meet the needs of end users. Most of these studies were implemented by an transdisciplinary team comprising cassava breeders, social and gender scientists, agricultural economists, anthropologists, extension/rural sociologists, and food scientists in IITA-Nigeria and NARS partner (NRCRI). These studies were conducted under various projects such as HarvestPlus, NextGen Cassava, BASICS, RTBFoods, and the Cassava Monitoring Survey (CMS) in collaboration with the CGIAR Research Program on Roots, Tubers, and Bananas. These studies focused on understanding the trait preferences of cassava value chain actors, associated gender roles, constraints, and opportunities to improve cassava breeding and meet the needs of end users.

Second, we conducted key informant interviews (KIIs) with IITA GoSeed and Umudike Seeds staff who were involved in the implementation of both companies' activities to better understand

TABLE 1 Exploring gender-specific studies (2015 to 2024); a closer look at embedded traits.

Traits evaluated	CMS study (2015-2017)	GPR (2021)	IITA Go Seed/Umudike Seeds (2017-2022)	Nextgen PVS*and Survey (2017)	RTB Foods (2018-2022)	Stem sellers study (2023)	Tricot (2019-2023)
Farmer trait preferences	Yes	No	Yes	Yes	Yes	Yes	Yes
Processor trait preferences	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Food consumer preferences	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Specific preferences of stem sellers	No	Yes	Yes	No	Yes	Yes	Yes
Farmers' land quality	No	No	No	Yes	No	No	Yes
Access to production, processing, and marketing inputs	Yes	No	No	No	Yes	No	Yes
Plant architecture for seed	No	No	Yes	Yes	No	Yes	Yes

PVS, Participatory Variety Selection; RTB, Roots, Tubers, and Bananas foods focused research (through the RTB foods project) including participatory processing and consumer testing; Tricot, triadic comparison of technologies; GPR, Ground Penetrating Radar study on root bulking. *These included mother-baby trial and tricot approaches.

the feedback they got on cassava seed traits of interest to women and men producers, sellers, farmers, and processors. A total of six key informants—three women and three men—participated in the study. For Umudike Seeds, these included the director of research of NRCRI, the general manager of Umudike Seeds, and the Seed Manager. For IITA GoSeed, we spoke to the cassava seed systems specialist, IITA research supervisor, and senior research supervisor. The KIIs were held between June and September 2023 using the developed interview guide. All KIIs were interactive discussions conducted virtually and in person and lasted about one and a half hour per person. In addition, an analysis of sales and unpublished annual reports shared by the two seed companies was done to identify gendered trends in ICV seed demands (Table 1). Figure 1 shows the different gender research initiatives and studies conducted within the IITA/NRCRI cassava breeding program to evaluate women's and men's preferences and its contributions to releasing ICVs for IITA GoSeed and Umudike Seeds formal system activities.

Data processing and analysis

Quantitative data was analyzed descriptively. The qualitative data from the notes was organized and analyzed using content analysis. Excerpts from these interviews have been quoted here to complement the explanations of the quantitative results and discussions.

Results

The findings from the review of studies undertaken by cassava breeding in Nigeria evaluating different gender-sensitive categories of trait preferences are illustrated in Table 1. In the CMS study, trait preferences of cassava value chain actors were categorized into four groups: (1) production traits: early bulking/maturity, high yield (big root size), pest and disease resistance; (2) consumption traits: product taste, good palatability/pound ability, smoothness, fiber content, white color; (3) processing traits: ease of peeling, product final quality (gari/fufu quality); and (4) marketing traits: white color, high market demand (Bentley et al., 2017; Wossen et al., 2017a). Another survey focused on gendered preferred traits of farmers and processors in two major cassava production regions of southwest and southeast Nigeria found that high yield, root size, early maturity, and dry matter content of cassava were desirable traits across the regions (Teeken et al., 2018). Specifically, men in the southwest prioritized cassava flesh color and agronomic traits (suppress weeds, canopy formation, and plant appearance on the field). Notably, although both women and men prioritized processing and food product quality traits, women tended to prioritize these traits more than men. A clear gendered preference was observed for early maturity and the ability to enhance profit (marketability), which were among the desirable traits identified in the study. Due to users' preferences for improved cassava varieties with early bulking roots and stem longevity (Wossen et al., 2017a; Teeken et al., 2018; Olaosebikan et al., 2023), one study used ground penetrating radar (GPR) to determine the early bulking of recently released varieties, along with processors' preferences for food products (Agbona et al., 2021). The experiment included three harvesting dates and an evaluation of gari quality by women processors. Women's preferences were based on the quality of the food product of the early bulking roots evaluated. IITA GoSeed proposed adding the assessment of stem longevity to this experiment at each of the harvesting dates. This was the first time stem longevity was systematically studied using recently released farmers' varieties.

A further participatory study showed that cassava food product (gari, fufu) qualities such as bulk density, swelling capacity, and water absorption capacity were also preferred (Teeken et al., 2021a). In cooperation with the Nextgen cassava project, the transdisciplinary RTB Foods Project further specified cassava root traits. It gave insights into processing, food product quality, and

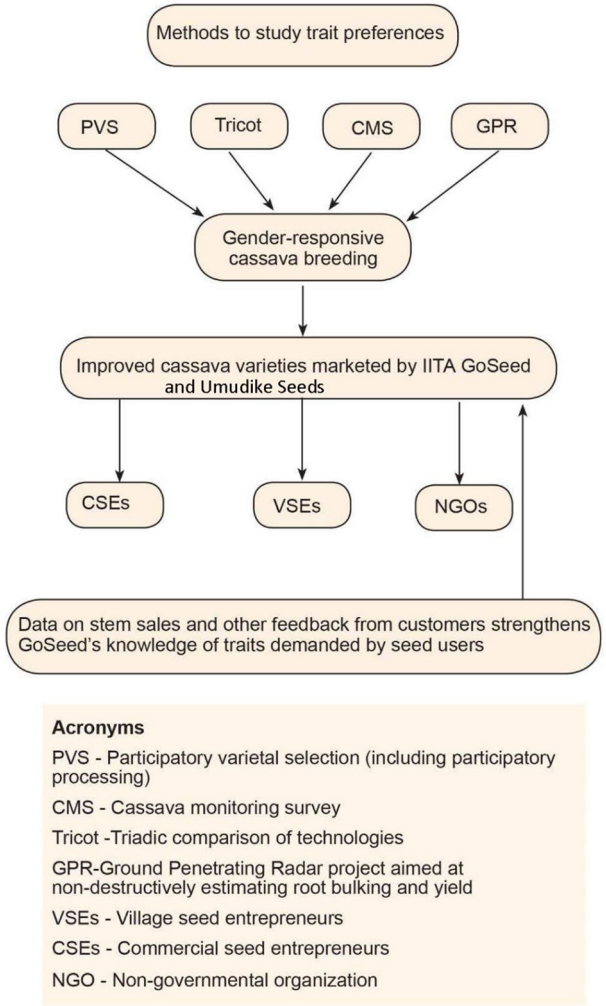

FIGURE 1
Studies on cassava trait preferences informing gender-responsive cassava breeding.

traits preferred by farmers, processors, marketers, and consumers. Traits associated with drudgery or productivity-related traits such as ease of peeling, toasting time, cassava root flesh color brightness/shininess along with food product textural properties were highlighted (Chijioke et al., 2021; Ndjouenkeu et al., 2021; Teeken et al., 2021a,b; Alamu et al., 2023; Bouniol et al., 2023; Olaosebikan et al., 2023; Bello et al., 2024). Teeken et al. (2021b) also revealed how other social dimensions intersect with gender and determine trait preferences: gender differences among poor households increased, and women prioritized food quality traits more. Further, women in food-insecure households prioritized these quality traits more.

Owoade (2023) found that women and men stem sellers indicated their preferences for plant type in relation to cassava stem architecture based on weed control ability, easy stem conveyance (carrying them on their head), and reduced stem wastage during cutting. Good canopy cover was often associated with a branched cassava stem and was considered a weed-suppressing trait: a vigorous branched canopy can shade the ground, thus reducing farmers' attention and expenses on weed control and field maintenance. Some stem sellers in Imo (southeast), especially women, cultivated and preferred cassava that branched at a height between 0.5 to 1.5 meters. Women in the southeast region have control over the choice of varieties they cultivate because few men are involved in cassava cultivation. Rather, the men invest more in yams and other more lucrative businesses. However, in (south-south) Akwa-Ibom, both men and women are involved in household farming and the cassava stem business, and they prefer an erect (straight or unbranched stems) pattern. In (north-central) Benue State, seed producers prefer erect cassava stems that are easier to transport. Stem sellers believe that with erect stems, less stem material is wasted during stem preparation for bundling. For medium-scale farmers, the erect stems are preferred for those who can afford some level of mechanization. In addition, varieties with erect stem patterns can be planted closer together because they take up less space in the field, and when their stems are arranged in vehicles, they take up less space, thus reducing the cost of transportation. Furthermore, this study showed that stem sellers adopted and sold seeds known to be suitable for processing into good quality food products, and the good color of the food product was highlighted (Owoade, 2023).

The cassava breeding program also adopted participatory processing of contrasting varieties using the mother-baby trial approach (Teeken et al., 2021a). It indicated clear varietal differences between product quality as evaluated by experienced processors, especially with regards to eba and fufu color and texture. This informed the release of the variety *Game Changer*. To scale up this approach to be more representative, a new citizen science on-farm participatory variety evaluation method (tricot-triadic comparison of technologies) was carried out with 30 varieties. Farmers and processors were involved in the participatory evaluation. The tricot included a socially and gender-inclusive sampling of 320 farmers and processors who evaluated field trials on their farms at different time points from planting to processing into food products (van Etten et al., 2020; de Sousa et al., 2024). This research showed the variety chosen by the participants was largely determined not only by agronomic characteristics such as yield and dry matter but also by processing and food product quality. It also informed the release of two varieties, *Baba 70* and *Obasanjo 2,* as they were particularly liked by women farmers who processed the varieties themselves rather than giving them to someone else to process (Teeken et al., 2023). These varieties combined excellent agronomic characteristics, including good weed competitive ability with post-harvest processing and food quality, specifically, the color and texture of the food products. Women's preferences benefit the whole cassava value chain because most cassava is processed and marketed by women. Polar et al. (2022) illustrate how all these activities changed Nigeria's largest cassava product profile: fermented granulated and paste products.

Gender inclusion on the business operations of IITA GoSeed and Umudike Seeds

BASICS created a formal cassava seed system in Nigeria involving the production of early-generation seed (breeder seed, foundation seed, and commercial seed). Both companies (IITA GoSeed and Umudike Seeds) worked with other seed

companies/seed producers under BASICS II (2020–2025) to produce released varieties. It was a shared effort of IITA and NRCRI to meet the demand for certified seed (Wossen et al., 2020). This case study documentation references the three seed classes in compliance with the National Seed Standards in Nigeria as developed by the NASC. Breeder and foundation seeds are referred to as early generation seeds (EGS) belonging to the first and second levels of seed class; the certified variety is the third class; and all three classes are approved for sale by NASC. The breeder seed is the first class of seeds developed by breeders with high genetic purity and high integrity of vegetative propagating material under the authorized breeder's control. The foundation seed is the first generation of seed produced from breeder seeds. Registered seed companies/producers usually produce foundation seed. The commercial seed is a certified progeny from the foundation seed (IITA, 2020).

The objective of BASIC II is to consolidate and expand the seed production activities that started under BASICS I. It includes partners such as Mennonite Economic Development Associates (MEDA) (2016), NASC-Nigerian seed certification agency, NRCRI and its affiliated Umudike Seeds, Catholic Relief Services (CRS), and Sahel Consulting Agriculture and Nutrition Limited. Under BASICS I, much of the cassava seeds were produced by VSEs (village seed entrepreneurs), who were often smallholders and could grow whatever varieties they wanted (Bentley et al., 2020). Another category of farmers (outgrowers) was selected through advertisements on social media (Twitter, Instagram, and Facebook) and was not specifically chosen from the existing VSEs. One of the key requirements for selection was that outgrowers had to have a farm of at least five hectares. GoSeed gave the individual outgrowers free stems of improved varieties to plant on a minimum of five hectares and agreed to buy back the harvested stems. The outgrowers were responsible for the cultivation and maintenance of the farm. Only four women were registered as outgrowers, along with 60 men. Because outgrowers were chosen based on their interest and access to the required acres of land and other resources, GoSeed's minimum 5-hectare requirement per person prevented many interested women from participating in the program and producing seeds (Legg et al., 2022). In addition, the digital platform designed to support cassava seed producers (Seed Tracker) required a smartphone to link seed production datasets with other seed value chain actors (www.seedtracker.org/cassava), which many resource-poor women did not have. Hence, women were mostly excluded as outgrower participants. Out of the small number women who initially participated in the outgrowers scheme with GoSeed, only one woman was able to continue working with IITA GoSeed due to different capacities and capabilities that influenced their contribution to the scale-out processes. This woman owned 40 hectares of cassava land in Benue State (personal communication, GoSeed specialist, manager, and principal officer). Very few women could become outgrowers, as they were often constrained by poor access to land and capital, combined with insecurity created by attacks from herders who deliberately allowed their cattle to graze and destroy cassava fields.

To be more inclusive and address the gap in women's participation in the outgrowers scheme/initiatives, cluster and cooperative farming managed by a group lead was encouraged among women. The aim was for them to form an outgrowers/seed producer group with a minimum land requirement of five hectares as set by NASC. This strategy involved forming clusters of cooperative farming involving several interested smallholder women with combined land acres fulfilling NASC requirements to acquire certified documents. A similar outgrower model was introduced in Akwa-Ibom. Most of the GoSeed outgrowers were wealthier men who had access to land resources and, to a lesser extent, women managing cooperative farming and cluster farming to gain larger farm access. The NASC, as a partner in the BASICS project, worked with the VSEs to involve village women as seed producers and customers, to give them a voice in deciding which new varieties were adopted, and to create a more guaranteed source of seed for the improved varieties they wanted; however, the core responsibility of NASC in the project was to ensure the development of regulatory standards and usher all categories of stems producers into the formal seed sector. NASC was also made responsible for developing sustainable strategies for field/seed inspections and certification to ensure continuity after the project ends. Although most of the improved varieties performed better than the local varieties cultivated by the VSEs in terms of yield, the women still kept their preferred local varieties, which had some unique food product quality. This is why breeders wish to evaluate the quality profile of the local preferred varieties to inform breeding food product profiles.

Profiles of released and promoted cassava varieties and their attributes according to IITA GoSeed and Umudike Seeds

The following characterization of promoted varieties under this section is obtained from IITA GoSeed and Umudike Seeds staff based on conversations with the company's personnel and the IITA GoSeed and Umudike Seeds sales data and feedback; it, therefore, represents the point of view of both companies.

Most processors preferred the variety TME419, a landrace sourced from Togo and released in Nigeria (IITA Genebank, n.d.; Ezui et al., 2017; Wossen et al., 2017b; Dixon et al., n.d.) because of its important traits: erect plants with robust stems (meaning that they can still sprout in the field after a period of drought) having good yield and high dry matter (minimal water in the roots) while providing good food product yield and quality. TME419, among other recently released varieties, has traits that both men and women prefer. Women are motivated to sell seeds of new varieties with high market demand to generate income in addition to growing and processing cassava, corresponding with the findings by Owoade (2023). TME419 is a disease and pest-resistant variety with good vigor. It yields more than 25 tons per hectare (Owoseni et al., 2021) and produces high-quality staple foods such as gari, fufu, semolina, etc. It also has good to medium poundable qualities (suitable for boiling and eating) and high starch content, which is ideal for domestic and industrial production. This makes it a real multipurpose variety. Multipurpose use was also identified as one of the most important crop user-preferred traits in the study by

TABLE 2 Officially released profiles of varieties with attributes influencing men's and women's preferences according to feedback from GoSeed and Umudike Seeds, with regards to the maintenance of these varieties by sellers (Source: compiled information from IITA (2020), IITA Cassava Matters (2021), and NAGRAB catalog of crop varieties released and registered in Nigeria, 2022).

Varieties	Clone name	Year of release	Attributes and traits driving stem buyers' demand	Regional preferences (Wossen et al., 2017a; Teeken et al., 2018)	Gender preferences
Poundable	TMEB693	2020	Disease resistance, drought tolerant, grows in sandy-loam soil, with 32.0(t/ha) yield, mealy. Erect architecture. Dry matter of 38.5%, starch (40.3%). Demanded for its handy long root sizes, it targets fresh market consumption and has a mealy texture with a sweet taste.	Southwest and north-central	Men/women
Dixon	IITA-TMS-IBA980581	2005	Disease resistance, grows in sandy-loam soil, with 35.0(t/ha) yield. Erect architecture, stable dry matter of 35.0%, starch>38.0%. It is demanded for its bigger root sizes, which are excellent for granulated and paste product quality.	Southwest and southeast	Men/women
FineFace	IITA-TMS-IBA980505	2005	Disease resistance, grows in sandy-loam soil, with 34.0. (t/ha) yield. Compact architecture, early branching at 1 meter. Dry matter 35.0%, starch > 35.0%. It is mainly demanded for its robust root sizes, good paste product quality, and preferred color and texture.	Southeast, southwest, south-south, and north-central	Men
Game Changer	TMS13F1160P0004	2020	Disease resistance, grows in sandy-loam soil, with an average yield of 38.2(t/ha). Compact architecture, early branching at 1 meter. Dry matter of 42.0%, starch (32.9%). It is mainly demanded because of its multipurpose qualities, such as being excellent in processed household foods, e.g., gari and fufu, paste products, and industrial production.	Southeast, southwest, south-south, and north-central	Men/women
Farmers' pride	IITA-TMS-IBA961632	2006	Disease resistance, grows in sandy-loam soil, with 35. (t/ha) yield. Exhibits both compact/erect architecture, with early branching at 1 meter. Dry matter of 39.0%, starch > 35.0%. It is excellent in processed gari and fufu quality with the preferred color and texture.	Southeast, southwest, south-south, and north-central	Men/women
Ayaya	CR36-5	2012	Disease resistance, grows in sandy-loam soil, with 35.0(t/ha) yield. Erect architecture, stable dry matter of 40.0%, starch>38.0%. It is excellent in processed gari and fufu quality with the preferred color and texture.	Southeast, southwest, south-south, and north-central	Men/women
TME419	TMEB419	2005	Disease resistance, grows in sandy-loam soil, with 36.0(t/ha) yield. Erect architecture, stable dry matter of 40.0%, starch>38.0%. It is excellent for intercropping and has very good starch content for local and industrial products, e.g., starch and flour.	Southeast, southwest, south-south, and north-central	Men/women
Obasanjo-2	TMS13F1343P0022	2020	Disease resistance, grows in loam and sandy-loam soil, with 38.7(t/ha) yield. Umbrella, top branching architecture, over 1 meter high. Dry matter of 40.7%, starch(28.6%). It is mainly demanded for its robust root sizes and excellent flour and starch production.	Southeast, southwest, south-south, and north-central	Men
Baba 70	IITA-TMS-IBA000070	2020	Disease resistance, grows in loam and sandy-loam soil, with 37.5(t/ha) yield. Compact architecture, early bulking, dry matter of 38.5%, starch is 28.0%. Excellent in processed gari and fufu quality with preferred color and texture.	Southeast, southwest, south-south, and north-central	Men/women
UMUCASS 36 and Sunshine (Yellow roots)	IITA-TMS-IBA011368 and IITA-TMS-IBA070593	2011 and 2014	Disease resistance, grows in loam and sandy-loam soil, with 30.0(t/ha) yield, medium branching architecture, $\leq$ 1 meter high. Dry matter of 30.1%, with moderate starch content. It is mainly demanded for its high beta carotenoid content, excellent in processed yellow gari and other bio-fortified food products	Southeast, south-south, and north-central.	Men/women

Ndjouenkeu et al. (2021). Its suitability for domestic and industrial purposes makes it relevant to both men and women.

Farmer's Pride and Game Changer are particularly sold to women VSEs by both IITA GoSeed and Umudike Seeds, which evidences gender inclusion in selecting these varieties and has provided both seed companies with positive feedback from men and women in southwest and southeast Nigeria. Farmers named the varieties "Game Changer" and "Farmer's Pride" themselves after experiencing high yields. Farmers were proud of these varieties, which were established rapidly after planting and could withstand strong winds without falling, even though the plants were tall (IITA, 2020). Table 2 lists both companies' varieties and their attributes. Poundable (TMEB 693), a landrace sourced from farmers in Ghana (Rabbi et al., 2015), was released in Nigeria for its suitability for boiling and pounding without elaborate labor and firewood demand for processing. Farmers often prefer cassava varieties that can simply be boiled and pounded as a cheaper substitute for yam. The variety grows vigorously high, with good canopy formation and stems that are easy to transport to market. The Dixon variety has red petioles with a typical erect pattern. It is resistant to drought and retains its leaves without withering, even at the peak of the dry season. It grows on sandy-loam soil and is good for food products such as gari and fufu. It also provides edible leaves for cassava soup. Women processors appreciate the Dixon variety because it is easy to peel and yields more than local varieties. The Fine Face variety is preferred due to its yield and exceptional morphological appearance of leaves and stem color during growth. It forms a good canopy, reduces expenses on weed management, and supports mechanization.

Understanding the demand trend of varieties is important for their success in the market. The four main varieties in demand at Umudike Seeds are Game Changer, TME 419, Dixon, and Yellow Roots (IBA070593 and IBA011368). Each of these varieties has unique characteristics that cater to the specific needs and preferences of farmers and consumers, as already outlined. Game Changer and TME 419 are particularly popular due to their high starch content, high dry matter and high dry matter stability, and robust growth of roots. These traits make them desirable for farmers looking to maximize their yields and produce high-quality roots for successive processing. The high starch content is important for various applications, such as food processing and industrial use. Additionally, the robust growth of roots ensures better nutrient uptake and overall plant health, leading to improved yields. The Dixon and Yellow Roots varieties also offer advantages that appeal to different customer segments. These responses from different customer segments on specific traits and characteristics of each variety allow Umudike Seeds company to tailor their marketing strategies and production focus to meet the diverse needs of their customers more effectively. The variety named Ayaya (meaning "beautiful") was released in 2020 because the roots could remain in the ground for many months after it had matured; the plant ratooned well and had erect, multiple sprouts within a plot, and formed a canopy to assist weed control. Improved varieties such as Farmer's Pride and Obasanjo-2 have spreading canopies and were selected by women to reduce weeding expenses (IITA, 2020). These varieties have a high, stable starch content and are suitable for mechanized farming systems. With these, seed producers target the industrial processing of cassava into flour and starch.

Seed companies' stem sales report outcomes with VSE and impact on breeding

IITA GoSeed and Umudike Seeds reported brisk sales for TME419, which provides good food product yield and thus limits drudgery during processing (Figures 3A, B). Forsythe et al. (2016), Teeken et al. (2021a), Bouniol et al. (2023), and Bello et al. (2024) have also noted the importance of this gendered trait. IITA GoSeed and Umudike Seeds noticed the strong market demand for certain other traits as well, e.g., umbrella shape (branching at a height of about 1.5 meters), broad canopy, good ratooning ability (stalks that sprout after cut-back), straight plants (allowing easy stem transportation), roots that store well in the ground, facilitating staggered piece meal harvesting based on demand preferred by men and women, and root-rot resistance. The seed companies communicated these qualities to the breeding unit to include in future varieties development and trait prioritization. The seed companies' sales data in 2022 suggest that TME419 is an important prolific variety in Nigeria. It has to be noted that sales do not fully represent demand, as sales are often influenced by what is available. GoSeed staff indicated that the demand for improved varieties was often greater than what could be supplied, and buyers end up purchasing a second-choice variety. IITA Go Seed sometimes bought seeds from other seed producers if their supply could not meet the demand. Figures 2A, B show high seed sales of TME419 to VSEs by IITA GoSeed and Umudike Seeds, respectively. The higher preference or sale of TME 419 can be attributed to more awareness and length of years of diffusions, as one of the earliest improved varieties released since 2005, ahead of Poundable, Game Changer, Baba-70, Obasanjo2, which were released in 2020. The other varieties are starting to compete with TME419 due to demand from customers who ordered improved early-generation seeds. Based on the feedback from men and women on these varieties, there has been rapid production to meet the demand. The supply capacity for each variety, estimated based on the hectares grown for seed production (Supplementary data file and Figure 4), was most often higher than the sales.

Due to the popularity and repeated demand of TME419, relatively newer varieties, such as Ayaya, Game Changer, Farmer's Pride, and Dixon, are expected to compete successfully with this well-known variety, as they also have traits that the value chain demands (Table 2). Figures 2A, B show that Game Changer and Farmer's Pride seem to be more popular among women, contrary to TME419, which is sold more to men than women SVEs. This indicates a comparative advantage of these varieties, such as the umbrella-shaped architecture and leaf retention, that improve weed competitiveness, as well as higher dry matter and dry matter stability combined with good food product quality and processability (Bello et al., 2024; Olaosebikan et al., 2024).

Early Generation Seed trends at Umudike Seeds provide valuable insights into the demand patterns for different varieties of cassava seeds over three years: 2021 and 2022 (2023 only partial)

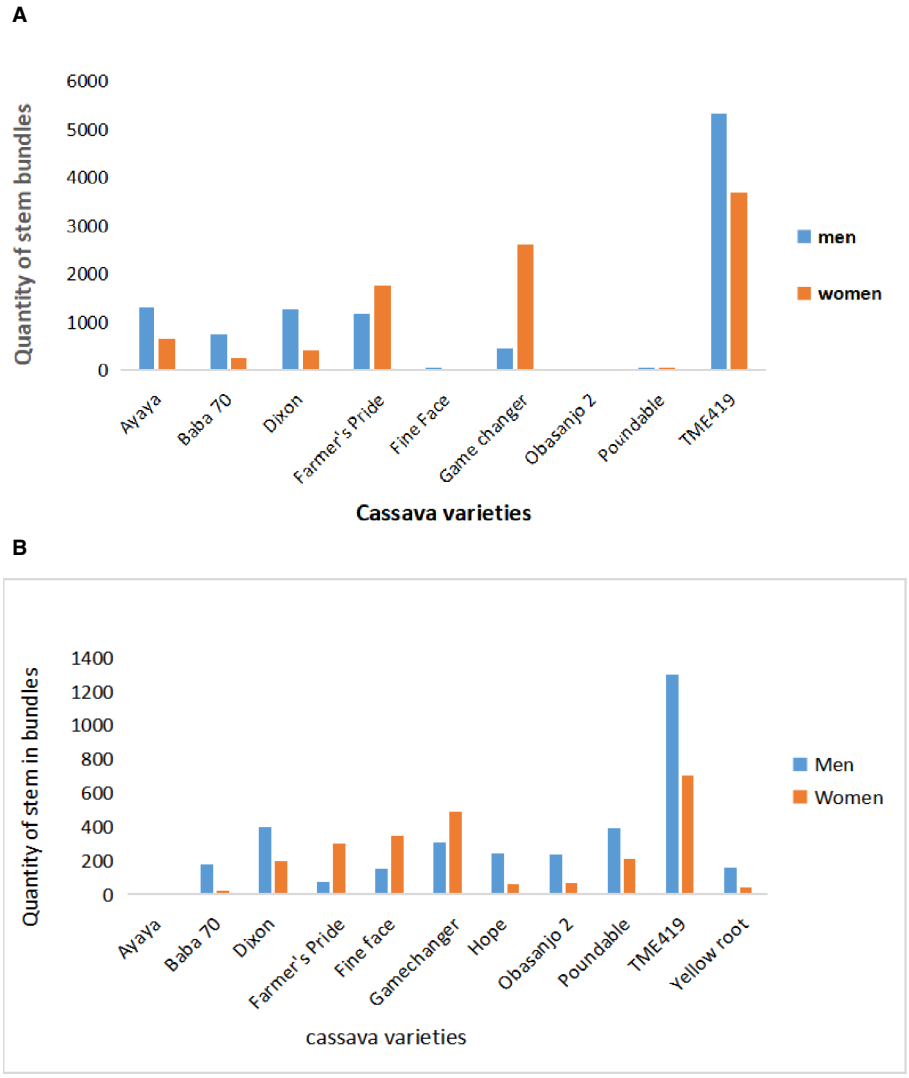

FIGURE 2
(A) IITA GoSeed 2021–2022 sales to women and men village seed entrepreneurs (VSEs) (source: report IITA GoSeed 2021 and 2022). **(B)** Umudike Seeds 2021–2022 sales to women and men village seed entrepreneurs (VSEs) (source: data: Umudike Seeds 2021 and 2022 unpublished).

in the southeast and southwest regions. The demand for the Poundable variety (with a very limited supply and thus limited sales in Figure 3A indicates its popularity among farmers. This suggests that poundable cassava seeds are preferred for cultivation due to their added value of being boilable and poundable in a region where poundable varieties have almost been forgotten and mostly associated with varieties that were grown there before but have vanished, combined with reasonable yield disease resistance, or other desirable traits. Rabbi et al. (2015) selected Poundable (TMEB 693), a landrace from Ghana with special culinary potential, which can be boiled and eaten and has moderate yield. The variety is more resilient to diseases and pests than the older fresh market varieties with similar characteristics. Some farmers and hired laborers in eastern, southern, and western Nigeria were reported to prefer sweet cassava varieties that can be boiled despite their lower yield (Nweke et al., 1994). Women prefer Poundable because of its fresh consumption qualities such as softness and mealiness with a sweet taste; it can be fed to children and to farm laborers after roasting or cooking as a substitute for yam, which is more expensive. Based on this, breeders promoted and encouraged cassava buyers, seed companies, and community seed producers to grow and sell certified Poundable seeds as a variety that could be used in the fresh produce market. The variety has promising potential to reduce hunger among children from displaced households in conflict-prone zones (Olaosebikan et al., 2023). This is because it can be consumed without laborious processing that is required for the dominant bitter varieties in the southern half of Nigeria (Nweke et al., 1994).

However, contrary to GoSeed, there was no demand for Ayaya in 2021–2022 but more so for Yellow Root cassava varieties (UMUCASS 36 and Sunshine). This is because Umudike Seeds is located in a region where men and women prefer consumption of gari with a yellow color appearance (usually achieved by adding palm oil). The Yellow Root varieties target elevated levels of carotenoids for dietary improvement and economizing on palm oil. The demand for Yellow Roots is

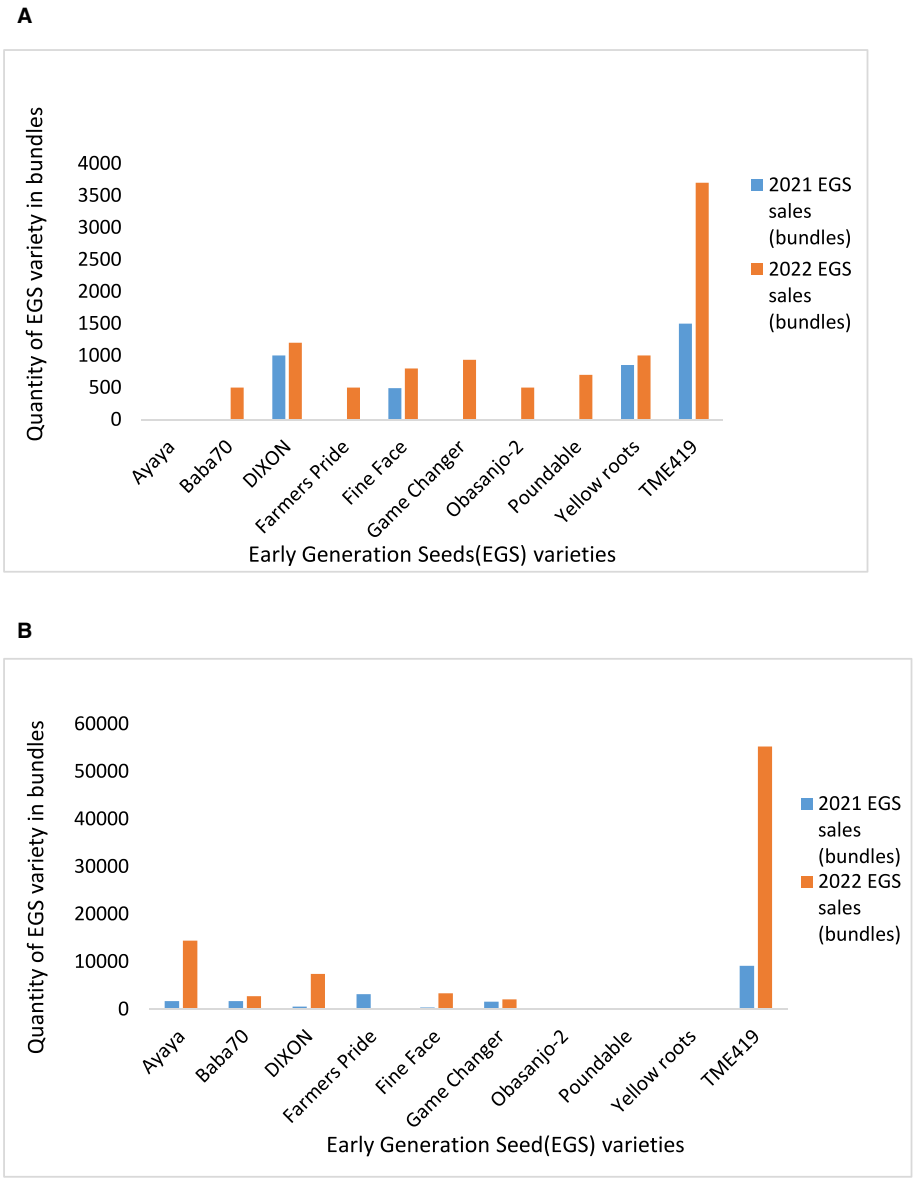

FIGURE 3
(A) Cassava seed sales from Umudike Seeds across 2021–2022 (source: report Umudike Seeds 2021, 2022 unpublished). **(B)** Cassava seed sales from IITA GoSeed across 2021–2022 (source: report IITA GoSeed 2021, 2022 unpublished).

a great motivation for biofortification in breeding programs for sustainable food security and improving nutrition. Some outgrowers who demand Yellow Roots target buyers' demand for high-yielding varieties tailored toward the robust root, high starch, and dry matter. Introducing a Poundable Yellow Root would further increase nutrition and food security impact because more elaborate processing and longer storage time under high temperatures are related to the loss of the carotenoids (Bechoff et al., 2015).

For IITA GoSeed, the demand for some of the newer varieties is growing consistently, while the sales of Poundable, Obasanjo-2, and Yellow Roots are very low (Figure 4).

"A drop in the demand for the Poundable variety is associated with the limited and specific market niche. However, the broad acceptability of Poundable among men and women, plus the variety's yield, improves farmers' food security and livelihoods. IITA GoSeed is located where cassava is demanded as industrial starch, high-quality flour dry chips, etc., while Poundable is intended for the fresh market. Therefore, with the sensitization on Poundable for demand being a released variety, called for re-multiplication on a larger scale while other varieties in surplus are pushed out for supply on cassava demand to avoid unnecessarily running out of certain varietal seed production" KII GoSeed Staff.

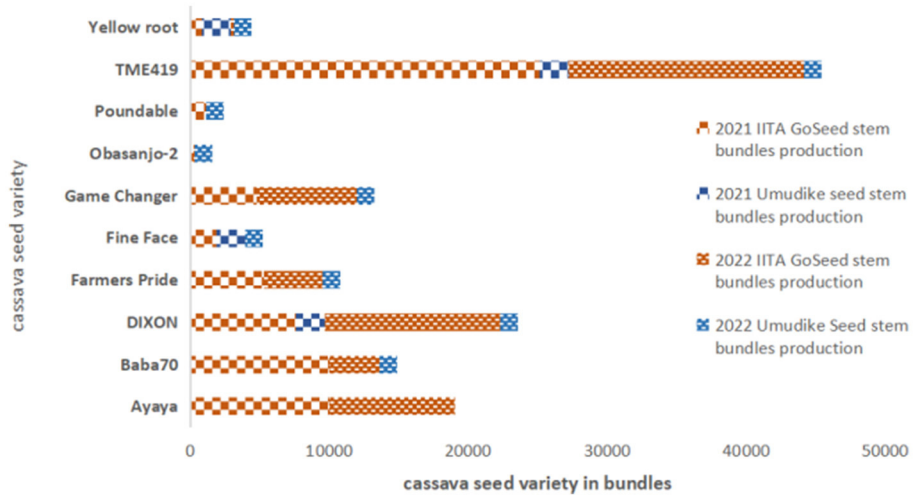

FIGURE 4
2021–2022 IITA GoSeed and Umudike Seeds estimated seed production based on the hectares grown and harvested bundles after seed multiplication (source: IITA GoSeed 2021 and 2022 unpublished).

The production of Poundable seeds has rapidly increased to meet specific demand in Niger state (northern region), where boiled cassava is referred to as *rogo*. Obasanjo-2 was among the varieties chosen after crop user preference studies based on high yield, suitability for gari, fufu product quality, and starch quality content. However, Fine Face performed rather low on food product quality in our processing and food product quality evaluation with women processors (Teeken et al., 2021a). This was also confirmed by a staff at IITA cassava breeding charged with making fufu and gari-eba from late-stage breeding products (Personal communication Rachael Ukpebor) especially when processing includes longer fermentation as practiced in the southwest.

Table 3 illustrates the increasing demand for breeder and foundation seeds for some newly released varieties, while commercial seeds are licensed to seed grower companies. Therefore, EGS producer companies rarely sell commercial seeds. It has to be noted that in relation to Supplementary data file and Figure 4, sales figures were influenced by the availability of the seed varieties rather than accurately reflecting the demand for each variety. The increase in sales with time is partly a result of this (Table 3 and Figures 3A, B). This suggests that IITA GoSeed and Umudike seeds are sister institutes having individual control over sales of EGS varieties (foundation or breeder seeds) that respond to meet market demand when they receive a prior financial commitment on a specific seed variety to make available sufficient quantities of seed of that variety. Otherwise, the available varieties in production are pushed to meet the demand requests. Figure 4 and Table 3 illustrate how IITA GoSeed and Umudike Seeds EGS production and IITA GoSeed seed sales have worked through other seed grower companies as the surfaces cultivated by these other seed grower companies are not included in the total production estimates. This suggests a form of economic benefit to the village seed producers to sustainably produce high-quality cassava stems, enhancing their livelihood and contributing to local economic growth. In seed request and demand, an approach of taking seed stems from certified seed producers is usually applied to answer seed requests whenever IITA GoSeed has no production for such a demanded variety.

Seed supply of high-quality products provides substantial new income-generating opportunities for farmers. The production process ensures that high-quality seed materials follow the certification process guide. Under standard certification of commercial seed systems production of quality assurance, a hectare of cassava multiplication field is established using stem cuttings of 20–25 cm planted at 1 m inter-row spacing by 0.5 m intra-row spacing to produce 20,000 stands of cassava stems. A vigorous stake with a minimum diameter of 2 cm and a minimum of 5 to 7 cassava nodes is recommended to guarantee a high sprouting rate, even if other buds are damaged during cutting and movement. About 400 bundles of cassava are harvested from one hectare. A bundle consists of 50 stems of 1 meter length. Stems are harvested (ratooned) more than once for eight months. The noticeable demand for TME419 in 2022 suggests its importance and acceptance in the market over time. Understanding the reasons behind the fluctuating demand for other varieties such as Game Changer and Dixon can provide insights into changing farmer preferences or market dynamics. The general increase in demand from 2021 to 2022 indicates growth in the cassava seed market. This could be due to factors such as increased awareness, promotional activities, improved seed quality, or favorable weather conditions to facilitate several planting times in one year. While the 2023 data is incomplete, the emerging demand patterns hint at shifting preferences or market forces.

Discussion

Effective practices to assess gender preferences in cassava seed demand

As partly illustrated in Figures 2A, B, assessing varieties and traits of relevance to women and men requires value chain and gender-disaggregated data to focus on varieties that will be demanded by seed enterprises. Focusing on the value chain and

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TABLE 3 Sales of bundles (50 stems) of early generation and certified seed sales from IITA GoSeed fields (source: report IITA GoSeed 2021, 2022 and partly 2023 unpublished).

Variety	Commercial seed @ 400 naira per bundle	Foundation seeds @1,000 naira per bundle	Breeder seeds @ 1,200 naira per bundle	Year
Ayaya	-	1,395	263	2021
Baba70	-	950	708	2021
Dixon	-	415	100	2021
Farmer's Pride	-	1,887	1,258	2021
Fine face	-	350	-	2021
Game Changer	1,080	50	1,483	2021
Obasanjo-2	-	-	209	2021
Poundable	-	50	40	2021
TME419	-	7,725	1,354	2021
Ayaya	-	13,020	1,400	2022
Baba70	-	-	2,700	2022
Dixon	-	7,000	400	2022
Farmer's Pride	-	-	-	2022
Fine face	-	-	3,300	2022
Game Changer	-	1,025	1,000	2022
Obasanjo-2	-	-	-	2022
Poundable	-	-	-	2022
TME419	4,190	54,020	1,200	2022
Varieties	**Commercial seed @ 800 naira per bundle**	**Foundation seeds @1,000 naira per bundle**	**Breeder seeds @ 1,500 naira per bundle**	**Year**
Ayaya	.	200	0	2023
Babe 70	.	200	0	2023
Dixon	.	450	50	2023
Farmer's Pride	.	300	74	2023
Fine Face	.	560	40	2023
Game Changer	.	780	20	2023
Hope	.	300	0	2023
Obasanjo- 2	.	300	0	2023
Poundable	.	600	0	2023
Yellow Roots	.	200	0	2023
TME 419	208	1,767	25	2023

gender disaggregated data enhances the potential of the cassava breeders not only to limit their focus to production attributes but also to consider processing, consumption, and marketing attributes to address the needs of the different actors in the cassava value chain. Due to gender-inclusive research implemented by the cassava breeding program, recently released varieties have been selected to include prioritized gender-essential/must-have traits, mainly based on late-stage evaluations with users. Social science research brings ideas from men and women in the different market segments to breeders, which makes it easier to understand the specific needs and preferences of both men and women, leading to increased use of new varieties.

Apart from the extensive social and gender science research related to a variety of trait preferences carried out by IITA and NRCRI, the IITA GoSeed and Umudike Seeds activities have also allowed for concrete, gender-responsive feedback from users that made both seed companies more customer-conscious, inclusive and user-focused. It is therefore recommended to integrate social science and gender action research into IITA GoSeed and Umudike Seeds operations. Giving more attention to meeting

users' needs and preferences is also an important consideration that can help cassava breeders to increase income, health, and food security (Bechoff et al., 2017). The inclusion of crop users themselves, instead of only market specialists and social scientists, to represent them, has given breeders accurate information about traits preferred by end-users and confirmed and added to what was already identified by the social and gender research within Nigerian cassava breeding. This contributes to the release process of improved cassava varieties during the variety release process and stakeholders' decision process, such as product advancement meetings (Madu et al., 2024). While direct consultation with users seems common, there is however a notable lack of documentation among breeders on involving users as stakeholders in product advancement meetings (Cavicchioli et al., 2023). Including crop users as stakeholders, in addition to social scientists and market specialists, has been identified as a crucial need in further developing a scalable transdisciplinary management system for cassava breeding in Africa (Egesi et al., 2024).

Seed business activities must play a role in research to provide feedback to drive the selection of new commercial varieties. This is important within the context of an emerging seed business in which farmers look for specific outstanding varieties with valuable traits that are not easily obtainable from friends or neighbors and for which they are willing to pay as part of an upcoming, more formal seed system. To further increase research impact and effectiveness, the business of IITA GoSeed and Umudike Seeds constitute excellent platforms for social science, participatory, and transdisciplinary action research. This can help strengthen and generate social/gender inclusive market segmentation and thus breeding investment cases in relation to the One CGIAR social impact areas (Donovan et al., 2022).

Trait importance and gendered considerations

The finding that weed resistance and branching stem traits are important gendered traits, underscores the significance of these characteristics in cassava root productivity and stem enterprises. A branching stem can contribute to reduced weed suppression and improved root yield and can be ratooned. These traits align with previous research findings and highlight the need for continued emphasis on developing cassava varieties with these attributes to support farmers, especially women farmers and processors.

Cassava varieties that are suitable for food processing are crucial, especially in regions where cassava food products such as gari-eba and fufu are staples and consumed daily. Traits such as easy to peel, fast toasting, retaining color, and facilitating ease of processing can significantly impact the efficiency and sustainability of cassava-based food systems. Gender-inclusive research recognizes these traits as vital contributors to addressing community food security and nutrition challenges.

The identification of ratooning ability as a new trait is pertinent. Ratooning replaces new, missing, or destroyed cassava field plots or for stem sales to generate more income and food security. Understanding its importance, particularly from a gender, social, and climatic resilience perspective (Olaosebikan et al., 2023), can guide efforts to develop and promote resilient cassava varieties. The demand for sweet/mealy/poundable cassava varieties that only require boiling and thus minimal processing for consumption is an important consumer preference in an environment where bitter varieties dominate (Nweke et al., 1994) and that require labor and resource-intensive processing. This preference aligns with the need for convenience and efficiency in food preparation, especially in women's roles within households. Gender-aware research can guide breeding focus on sweet cassava varieties that cater to these preferences.

The limited seed demand for Poundable from GoSeed, the company that mainly serves the southwest region of Nigeria, reflects the small fresh market niche segment. Furthermore, Poundable cassava is important in research as a continual parent line introgressed into biofortified cassava to create Poundable biofortified cassava retaining more of its carotenoids when consumed boiled or pounded. Usually, Poundable varieties are cultivated on small portions of land for culinary purposes to substitute yam. IITA GoSeed and Umudike Seeds would benefit from an adoption and diffusion study with regard to these varieties. The increasing sales of Game Changer and Farmers' Pride, especially among women, reflect the suitability of these varieties for women and reflects the gender integration in selecting Game Changer for variety release, while tricot citizen science participatory variety selection however shows the popularity of Baba-70 among women (Teeken et al., 2023).

These gendered cassava seed traits and preferences underscore the importance of gender-inclusive research in informing cassava breeding with regard to customer and product profiling and trait prioritization. This importance goes beyond serving women's needs but benefits the whole value chain as many women set various quality standards because men and women sell their cassava to women processors. By recognizing and addressing the specific needs and preferences of both men and women farmers, processors, consumers, and stem sellers, more sustainable and resilient cassava-based agrifood systems that benefit cassava value chain actors and other stakeholders can be developed.

Conclusion

Since their inception, IITA GoSeed and Umudike Seeds, through their activities and engagement with seed producers/entrepreneurs, appear to have received gender-specific feedback validating and complimenting findings of the previous studies on preferred traits of crop users. On-farm social science assessments combined with food science research help to improve the acceptability of new varieties requiring a transdisciplinary breeding approach. Conducting comparative evaluation of different crop varieties through on-farm testing under farmer's conditions has provided valuable insights. This approach involves using an incomplete block design with each block containing only three varieties. Each block is evaluated by an individual citizen scientist' farmer within their own field (tricot approach). This method is currently being piloted together with the Nigerian variety release committee as a better and more inclusive way to do

on-farm testing for variety release. It allows for additional feedback from farmers and processors and ensures the systematic integration of on-farm data with breeding data. In this pilot, in consultation with the Nigerian variety release committee, cassava breeding has now included customers of IITA GoSeed and Umudike Seeds as participants to connect closer to the upcoming commercial seed system.

The tricot approach can also be integrated into GoSeed, Umudike Seeds, and other seed enterprises to get systematic commercial feedback from users regarding already released new-generation seeds. The combination of action research around tricot and the activities of commercial companies might well be the way to empower and integrate users within the breeding process. One possibility could be to execute tricot with farmers as a breeding trial in which on-farm testing for variety release as well as already released varieties are nested. This approach could make the on-farm testing even more multifunctional and cost-effective by creating win-win situations between farmers, processors, breeders and the private seed sector. It can also simultaneously help identify opportunities for social impact, as currently prioritized within public breeding (CGIAR system organization, 2021). The key lies in carefully choosing the tricot participants. Breeders, working together with the private sector and possibly supported by humanitarian NGOs and NARS, can put a tricot in place combining advanced material and already released commercial and farmer-preferred varieties as benchmarks. The data from the best-advanced clones can then be presented for variety release without having to do another on-farm testing specifically with these candidates. At the same time, the trial can provide feedback to the breeding program on a wider set of advanced clones as well as performance data on the commercial varieties. These measures would be very relevant for the private sector, not only with regards to the performance data but also because they will have disseminated their commercial seed to many farmers which is an excellent marketing strategy. This approach could further integrate breeding practice, research, and the socially embedded practices of stem selling and buying, cassava production, processing and consumption along the cassava food chain.

Data availability statement

All the data used in this article are provided in the article itself and in the Supplementary files.

Author contributions

DO: Conceptualization, Data curation, Investigation, Writing – original draft, Writing – review & editing, Formal analysis. OO: Conceptualization, Formal analysis, Validation, Writing – original draft, Writing – review & editing. AB: Conceptualization, Formal analysis, Validation, Writing – original draft, Writing – review & editing. PK: Supervision, Validation, Writing – review & editing. EP: Supervision, Validation, Writing – review & editing. RO: Methodology, Writing – review & editing. TM: Supervision, Validation, Writing – review & editing. ED-O: Supervision, Validation, Writing – review & editing. BO: Formal analysis, Validation, Writing – review & editing. NE: Formal analysis, Validation, Writing – review & editing. JO: Supervision, Validation, Writing – review & editing. CA: Formal analysis, Validation, Writing – review & editing. JB: Writing – original draft, Visualisation, Formal analysis, Supervision, Validation, Writing – review & editing. ML: Validation, Writing – review & editing. OA: Validation, Writing – review & editing. SC: Validation, Writing – review & editing. BT: Conceptualization, Supervision, Validation, Writing – original draft, Writing – review & editing.

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Conflict of interest

CA was employed by Umudike Seeds.

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.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsoc.2024.1258723/full#supplementary-material

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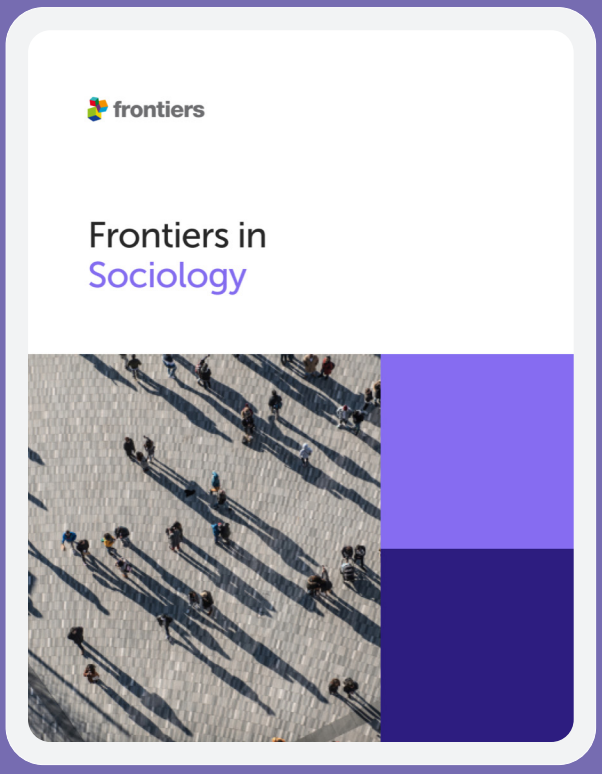

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