Research Topics

Gender intentional crop breeding: from integration to institutional innovation

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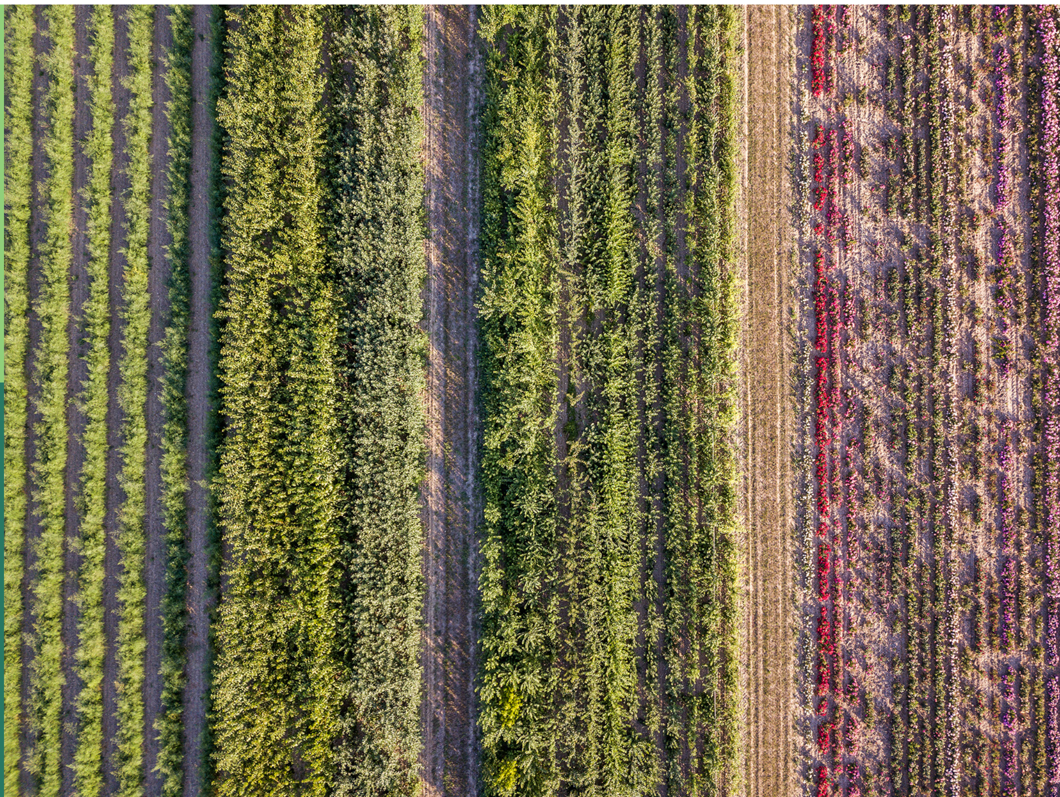

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Gender intentional crop breeding: from integration to institutional innovation

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Editorial: Gender intentional crop breeding: from integration to institutional innovation

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Editorial on the Research Topic
Gender intentional crop breeding: from integration to institutional innovation

Gender-intentional breeding requires research ecosystems and institutions that directly address gender inequality. The kind of institutional innovation needed involves not only reshaping breeding programs' technical goals, objectives, strategies and intended impact, but also introducing new methods and ways of learning, and even new value systems. Two complementary Collections on Gender Intentional Breeding explore these challenges with the shared goal of providing an overview of factors that influence how, when, and why gender research can trigger changes in breeding priorities, processes and institutions. These insights draw on experience from diverse crops, organizations and geographies. This Research Topic, *Gender intentional crop breeding: from integration to institutional innovation* focuses on the contextual issues that determine the effectiveness of the approach. Research Topic One, *Gender Intentional Breeding Case Studies,* consists of case studies documenting experiences with gender-intentional breeding.

Gender-intentional breeding designs and deploys new crop varieties and animal breeds responsive to the needs of poor rural women and men, with the dual aim of improving gender equality and accelerating adoption. This requires breeding programs that recognize users' divergent demands, taking gender differences into account. Meeting these diverse demands requires analysis of whether different user groups, men and women in particular, have different needs and preferences for new plant varieties or animal breeds, and whether addressing these preferences can increase adoption and enhance benefits. Gender-intentional breeding is a subset of client-oriented breeding that sets breeding objectives based on current and anticipated user demand. It includes but is not limited to purely commercial criteria for the acceptability of new varieties or breeds.

The papers emphasize the need for plant breeding to transition from a traditionally supply-driven approach to one that is gender-intentional, demand-led, and participatory. By changing how breeders prioritize traits, varieties selected, and seed strategies developed to actively involve social scientists in decision-making, breeding programs can integrate social and gender considerations into their work. Programs should make sure that the design of new varieties, embodied in breeders' product profiles, takes into account the role of women in food systems and their constraints in accessing seeds and inputs. Several papers conclude that gender-intentional breeding requires integrating gender analysis into breeding objectives from early stages, ensuring that breeding programs consider trait preferences of both men and women in variety design.

Gender-intentional breeding requires new impact assessment metrics that measure breeding success on a broader range of criteria: impact should be based not only on agronomic performance but also on gender-differentiated adoption rates, effects on labor use and drudgery, especially processing ease, and food security. Furthermore, breeding programs should engage in targeted outreach to redress structural barriers that limit women's access to improved varieties. Breeding programs should also seek to influence policy to gain institutional support for women's participation in variety selection, seed multiplication, and dissemination. One key recommendation is to move beyond simple sex-disaggregated approaches and apply intersectional analysis to understand how gender, social, economic, and ecological factors shape trait preferences. Several papers stress the importance of co-developing product profiles with men and women farmers, even within the same household, to ensure that breeding targets reflect real and diverse needs.

The Research Topic highlights the value of novel participatory breeding approaches that involve a representative cross-section of value chain actors, and breeders in joint decision-making. It calls for innovative methods such as crowdsourcing information on varietal preferences to strengthen stakeholder engagement. Structural changes in breeding institutions are also needed, including hiring more women scientists and promoting interdisciplinary collaboration for gender research. The papers identify fostering transdisciplinary teams that combine breeding expertise with gender and social science expertise as one of the most essential transformations required.

Overall, plant breeding must move from a gender-aware to a gender-intentional model, actively working to overcome inequalities in variety adoption and access. This transformation entails cultural change in breeding organizations, so that gender considerations are not peripheral or add-ons but are integral to impactful breeding. Change of this magnitude requires leadership commitment, institutional incentives, and long-term funding, not only to integrate gender concerns but to embed them into lasting and transformative institutional change.

Author contributions

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

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The men who feed the world? Putting masculinities on the agenda for crop breeding research for development

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Science, technology, engineering, and mathematics (STEM) fields that are dominated by men and masculine have historically been shown to lead to poor representation and discrimination of women and gender diverse scientists, managers, and leaders. This in turn negatively impacts inclusive innovation processes and outcomes. We claim that crop breeding is one such field that is undeniably dominated by men, and even masculine, and could therefore harbor the very same dynamics of exclusion. Yet there is a dearth of research systematically investigating how masculinities are performed in the institutions, organizations, cultures, discourses, and practices of crop breeding. In this Perspective piece, we present a theoretically informed hypothesis of crop breeding organizations as representing spaces where masculinities associated with rurality, management, and science and technology come together in ways that may marginalize women and gender diverse individuals, including in intersection with sexuality, race, ethnicity, and disability. In developing this hypothesis, we draw upon theoretical and empirical insights from masculinity studies in rural sociology, management and organization studies, and feminist technoscience studies. We demonstrate how critical men and masculinities studies can help expose masculinities in crop breeding to investigation, discussion, criticism, and change. As we seek to advance equality in and through crop breeding organizations, this framing helps to guide future research with potential to positively impact the culture of crop breeding research.

KEYWORDS

crop breeding, feminist technoscience studies, gender, masculinities, management and organization studies, rural sociology

Introduction

Men and masculinities studies of science, technology, engineering, and mathematics (STEM) have demonstrated the tangible impact of masculinities on women and gender diverse individuals, including in intersection with sexuality, race, ethnicity, and disability. For instance, several studies of physics and engineering show how femininities become denigrated within the masculine cultures and practices of these fields (e.g., McIlwee and Robinson, 1992; Kvande, 1999; Gonsalves, 2014; Francis et al., 2017). Many women experience a seeming incongruence between their gender identity and professional identity (Faulkner, 2007). They are forced to navigate a "dilemma of difference," meaning whether "to construct themselves as more or less different from men, or more or less visible as women" (Kvande, 1999, p. 309). Consequently, women struggle to feel a sense of belonging, which leads to poorer career progression and retention (Faulkner, 2009). Not only does this compromise women's equal status, rights, and opportunities, but also lack of diversity and inclusivity have been shown to negatively impact innovation processes and outcomes (e.g., Østergaard et al., 2011; Beck and Schenker-Wicki, 2014; Hofstra et al., 2020; Jones et al., 2020; Daehn and Croxson, 2021).

In agricultural research and development, studies have shown that women are underrepresented as researchers and in top-level management and leadership (Beintema and Stads, 2017; CGIAR, 2021). For instance, numbers from the World Economic Forum demonstrate that agriculture has the fifth lowest representation of women in leadership positions (28%) among the 19 sectors investigated (World Economic Forum, 2022). In the Consultative Group on International Agricultural Research (CGIAR), women represent 33% of the research workforce and 29% of the senior workforce (which includes management), while 90% of the Director-Generals are men (CGIAR, 2021). Notably, men working in agricultural research organizations have reported a greater sense of fit and comfort, as well as feeling more valued compared to their women colleagues, with men being less likely to quit their jobs in the short and medium-term (CGIAR-IEA, 2017). A recent article further describes the misogyny faced by women leaders in crop breeding organizations (Bentley and Garrett, 2023). Moreover, if agricultural research is anything like other STEM fields, there is also reasons to believe that Black, Indigenous, and People of Color (BIPOC), as well as queer women and disabled women, are particularly exposed to discrimination and marginalization (e.g., Yoder and Mattheis, 2016; McGee and Bentley, 2017; Harrison et al., 2020; Wells and Kommers, 2022).

Various publications and initiatives at the forefront of agricultural research and development have helped draw attention to women's experiences in crop breeding organizations (e.g., Bentley and Verhulst, 2022; De Oliveira Silva et al., 2022; García et al., 2022; Bentley and Garrett, 2023), as well as the need to increase diversity and inclusion in staffing (Wilde, 2012; CGIAR-IEA, 2017; CGIAR System Organization, 2020). However, what has largely been missing from discussions on diversity and inclusion in crop breeding organizations, is the need for a critical analysis of men and masculinities (Sachs, 2023; but do see Resurrección and Elmhirst, 2020, for a discussion on masculinity and epistemic authority in agricultural research), meaning the "historically and socially constructed categories which define legitimate behaviors and identities for men" (Sinclair, 1998, p. 84; see Connell, 1987, 1995).

There are several possible explanations for this conspicuous absence. For one, many feminist researchers and gender specialists find themselves working within organizations dominated by men that discourage critical analysis of men and masculinities. There is often a strong pressure from men in positions of power and privilege to focus on women and "to sanitize sex and gender issues, packing them into more palatable discourses of 'diversity'" (Sinclair, 2000, p. 84). Drawing on her lived experience working as a gender expert, Ferguson (2015) notes that "it is 'okay' to talk about gender as long as nobody has to give anything up or be profoundly challenged about their assumptions, beliefs and behaviors" (p. 392). This relates to a second and closely interrelated argument, namely that men and masculinities remain unmarked and unexamined (Whitehead, 2001). Indeed, part of the power of hegemonic forms of masculinity is that they appear "natural" or "normal" and, thus, taken-for-granted, invisible, unexamined, and undiscussable (Sinclair, 2000). Thus, Hearn (2004) argues that "[m]ost analysis and policy development in research and academia, and often even that which is concerned with gender, continues not to gender men explicitly and not to make explicit men's part in the problem of gender inequalities" (p. 57).

We ask what we might learn from critically examining men and masculinities in crop breeding organizations in order to shed light on the marginalization of women and gender diverse individuals as researchers, managers, and leaders. In exploring this question, we argue that much can be gained by engaging with literature on masculinities in rural sociology, management and organization studies, and feminist technoscience studies. Indeed, we posit that crop breeding organizations represent spaces where masculinities associated with rurality, management, and science and technology merge in complex and, at times, mutually reinforcing ways. In what proceeds, we introduce the field of critical men and masculinities studies, followed by key insights from masculinities studies in each of the respective fields. Accordingly, in this Perspective piece, we demonstrate how critical men and masculinities studies can help expose masculinities to investigation, discussion, criticism, and change (Hearn, 2004). We end with a call for more research on men and masculinities to improve equality in and through crop breeding for development as a field.

Critical men and masculinities studies

Starting in the 1980s, there was a growing interest in men as gendered subjects and masculinities in our understanding of social hierarchies, eventually giving rise to what is today known as critical men and masculinities studies (Pilcher and Whelehan, 2017). The field has largely converged around the idea of "multiple masculinities," meaning an understanding that several masculine identities co-exist in fluid, fragile, and fragmented ways. However, some masculinities become more culturally dominant than others, which is captured in the concept of "hegemonic masculinity" (Connell, 1987; Brittan, 1989; Jeff and David, 1994; Connell, 1995, 2000, 2002; Connell and Messerschmidt, 2005).[1,2] Still, while all men position themselves in relation to hegemonic masculinities, few are able to (or want to) fully enact them, resulting in other forms of masculinities (Connell, 1995). For instance, hegemonic masculinities are more commonly performed by white, middle-class, middle-aged, able-bodied, cisgender, and heterosexual men, while masculinities performed by black, queer, disabled, and lower-class men tend to become subordinate and marginalized. Importantly, studies have demonstrated the harmful impact that both hegemonic and subordinate masculinities can have on men, including higher risks of violence, alcoholism, mental and physical health issues, and so forth

1 This should not be read as saying that hegemonic masculinities are stable across time and place. Rather, they are historically, culturally, and spatially contingent and dynamic.

2 The concept of hegemonic masculinity has been criticized on grounds of being too abstract and ill-defined to be analytically useful (Donaldson, 1993); for becoming a shorthand for a particular set of, often negatively charged, traits and behaviors (e.g., individualism, aggression, and competitiveness) (Collier, 1998; Kerfoot and Whitehead, 1998; Martin, 1998; Jefferson, 2002); and, relatedly, for being over-simplified and for establishing a false dichotomy between hegemonic and non-hegemonic forms of masculinity (Demetriou, 2001). Taking into account several of these critiques, Connell together with Messerschmidt revisited and reworked the concept (Connell and Messerschmidt, 2005).

(Möller-Leimkühler, 2003; Garfield et al., 2008; Cleary, 2012; Shai et al., 2012; Cleary, 2019; Thepsourinthone et al., 2020; Roose et al., 2022).

However, while the pluralization of masculinity emphasizes multiplicity and difference, it is important not to lose sight of men's unities and collective and structural power (Cockburn, 1991; Collinson and Hearn, 1994). Indeed, all men benefit from hegemonic masculinities due to "patriarchal dividend" (Carrigan et al., 1985; Connell, 1995), meaning the advantage that all men gain as a result of women's subordination. Men often position themselves as masculine by situating women as "other" (Pini, 2008; Ellis and Meyer, 2009; Keddie, 2022), and distancing oneself from femininity "becomes a way to claim power" (Ottemo et al., 2021, p. 1020). Acker (1990) contends that "[w]omen's bodies cannot be adapted to hegemonic masculinity; to function at the top of male hierarchies requires that women render irrelevant everything that makes them women" (p. 153). Even if women can perform (aspects of) hegemonic masculinity, they are likely not judged as positively as men, or, indeed judged unfavorably or even penalized (e.g., Cockburn, 1991; Pierce, 1995; Rutherford, 2001; Pini, 2008).[3] Additionally, though hegemonic masculinity builds itself in opposition to femininity, queerness similarly presents a threat to it by undermining the artificial gendered binary on which its assumptions and subjugations rest (Cheng, 1999; Heasley, 2005).

Thus, the concepts of hegemonic and plural masculinities can help shed light on the most culturally dominant forms of masculinity in crop breeding organizations and their effects on women, men, and gender diverse individuals, while simultaneously emphasizing the contradictions and ambivalences men face in creating and sustaining gendered selves. We hypothesize that hegemonic and plural forms of masculinity in crop breeding organization are shaped by rural, managerial, and technoscientific masculinities and their interrelations, as explored in the next sections.

Rural masculinities

Studies in rural sociology have highlighted the culturally defined characteristics of hegemonic masculinities in farming, such as independence, self-reliance, resilience, determination, heroism, physical strength, toughness, ruggedness, and control over nature through manual labor as a means to maximize production (e.g., Bryant, 1999; Liepins, 2000; Peter et al., 2000; Laoire, 2002; Little and Panelli, 2003; Harter, 2004; Ferrell, 2012). Additionally, in line with globalization, industrialization, and neo-liberalization, rural masculinities have become increasingly described in terms of entrepreneurship, managerial skills, business acumen, and technological competence (Brandth, 1995; Bryant, 1999; Laoire, 2002; Little, 2002; Saugeres, 2002; Barlett and Conger, 2004; Kenway et al., 2006; Bell et al., 2015; Anderson, 2020).

Women and their bodies, by contrast, are framed as lacking the physical and technical abilities required to be a "good" farmer, including the lack of an embodied relationship with the land (Saugeres, 2002). The latter point is interesting as it "counters the normative belief that it is femininity rather than masculinity that is most closely associated with nature" (Pini, 2008, p. 21). Queer studies have also produced important critiques of heteronormativity and heterosexism in/of rural spaces, along with theoretical and empirical contributions to our understanding of the intersection of agriculture and queer identities (Gray et al., 2016; Leslie, 2017, 2019; Leslie et al., 2019; Hoffelmeyer, 2020, 2021; Pfammatter and Jongerden, 2023).

While a majority of studies on rural masculinity derive from European and American contexts, several studies have also been conducted on rural masculinities in the "Global South" (Bolt, 2010; Chowdhry, 2014, 2019; Gonda, 2017; Rai, 2020; Kaur, 2022; Ragetlie and Luginaah, 2023). For instance, Twagira (2014) shows how irrigation technology and mechanization introduced by colonial powers in French Soudan (today's Mali) became closely tied to the performance of masculinity. In a more contemporary study, Cole et al. (2015) investigated rural masculinities in Zambia. The authors drew the connection between hegemonic forms of rural masculinity (described above) and the idea of the "big man" in southern African settings, the latter of which "might describe a person who is powerful, chief-like, demands respect, is married (perhaps to multiple women) and head of a household, accumulates wealth through people (e.g., children, spouse), and owns or controls assets such as land, cattle, and farming equipment" (p. 158).

As crop breeders interact with rural masculinities in the field, and may themselves have lived experience in rural settings, an important question worth investigating is how rural masculinities may permeate the research personas and practices of crop breeders? Furthermore, in what ways may heteronormativity and heterosexism in/of agriculture contribute to the marginalization of queer researchers? However, as crop breeders are embedded in organizational and managerial structures, we next explore the potential link between rurality and managerial masculinities.

Managerial masculinities

Since the 1990s, a rich body of work in management and organization studies has foregrounded the ways in which masculine values and assumptions are mutually shaped with the structures, cultures, and practices of organizations, and the ways in which men use managerial masculinities to exercise control over women (and many men) in the workplace (Acker, 1990; Burton, 1991; Cockburn, 1991; Kerfoot and Knights, 1993; Gherardi, 1995, 1996; Collinson and Hearn, 1996; Maier, 1997; Kerfoot and Whitehead, 1998; Gherardi and Poggio, 2001). Queer studies has also been applied to management and organization studies to uncover organizational and managerial heteronormativity and workplace experiences of those who identify as gay, lesbian, bisexual, transgender, and queer (Bendl et al., 2008; Pullen et al., 2017; Rumens, 2017a,b; Rumens et al., 2019).

Kerfoot and Knights (1996, 1998) found that dominant management practices tended to be associated with abstract, rational, calculating, instrumental, controlling, competitive, aggressive, future-oriented, strategic, and, most of all, masculine subjectivities. By contrast, studies have illustrated the tensions that exist between "manager" and "woman" (Marshall, 1984, 1995; Gherardi, 1996; Sinclair, 1998; Blackmore, 1999; Gherardi and Poggio, 2001). These studies demonstrate how women managers have to surveil and manage their gender to align with the orthodoxies of the workplace, such as by adapting (and typically minimizing) their femininities, sexuality, dress, speech, emotions, intelligence, and knowledge.

Scholars of management and organization studies have further sought to define typologies to classify managerial masculinities. In their seminal

3 That does not mean, however, that women cannot or do not perform masculinities (see, e. g., Halberstam, 1998).

work, Collinson and Hearn (1994) created a typology consisting of five (often overlapping) hegemonic forms of managerial masculinity: authoritarianism, careerism, informalism, entrepreneurialism, and paternalism. Scholars such as Bird (2006) and Pini (2008) assert that rural discourses and material conditions are particularly conducive of paternalistic managerial masculinity, which describes a combination of (overt and covert) violence, care, and protection grounded in a familial narrative and the paternal figure who is wise, self-disciplined, authoritative, and benevolent. Indeed, dominant employment relations, decision-making processes, and ownership arrangements in agriculture have historically been paternalistic (Wallace et al., 1994; Bennett, 2004; Price and Evans, 2006; Gibbon et al., 2014). Pini (2008), in her examination of managerial masculinities in farmers' unions and networks, hypothesizes that "the hegemony of paternalism on-farm has spilled over into organizational life" (p. 119), with both managers and farmers being "engaged in battle and require the same traits of aggression, toughness, tenacity and strength" (p. 120). Women, by contrast, "are presented as overly emotional, easily distracted and irrational" (Pini, 2008, p. 120). Thus, Pini (2008) draws the conclusion that "[b] eing a 'real farmer', a 'real agricultural leader' and a 'real man' are often constructed as synonymous" (p. 34).

Still, despite the importance of organizations and management for the (re) production of (certain) men's power and masculinities, we know little of how masculinities are performed in the organizations and managerial structures and practices of agricultural research and development, including crop breeding. Thus, the extent to which and the ways in which paternalistic managerial masculinity, and/or other types of managerial masculinities, pervades in crop breeding research organizations remain unknown, including how these may potentially reinforce heteronormativity. Given that these are technoscientific organizations, however, we can further benefit from insights from feminist technoscience studies.

Technoscientific masculinities

Feminist technoscience studies has helped produce important critiques of the deeply Eurocentric, imperialist, and masculine ideology and philosophy of science (e.g., Harding, 1991; Noble, 1992). Such an ethos promotes a mechanistic worldview, control and mastery over nature, and distance between the observer and the observed (Merchant, 1980; Keller, 1985), and acknowledges white, cisgender, heterosexual, well-educated, and economically privileged men as the most legitimate knowing subject (Haraway, 1997; Harding, 1998). Studies have further shown how male scientists and academics have been depicted, popularized, and celebrated as confident, arrogant, individualistic, self-reliant, heroic, tough, aggressive, and rugged (as well as passionate and sympathetic; Haraway, 1989; Hevly, 1996; Oreskes, 1996; Ong, 2005; Endersby, 2009; Myers, 2010; Ensmenger, 2015; Milam, 2015).

As noted in the introduction to this Perspective, women, femininities, and gender diverse individuals are constructed as being in opposition to science, leading to marginalization and exclusion. Indeed, women have been considered less capable of abstract, rational, and objective thought, which is particularly true for BIPOC (see, e.g., Schiebinger, 2004). This prompts us to ask: what characterizes a "legitimate" or "good" crop breeder and how are these characteristics associated with masculine subjectivities? To what extent and in what ways is the technoscientific culture of crop breeding masculine and heteronormative? How does this culture impact the sense of belonging and, ultimately, retention and progression of women and gender diverse individuals, including in intersection with sexuality, race, ethnicity, and disability?

Toward masculinities studies in/of crop breeding research for development

Crop breeding research organizations can be theorized as spaces where rural, managerial, and technoscientific masculinities interconnect in complex and, at times, mutually reinforcing ways. For instance, we have seen how rural, managerial, and technoscientific hegemonic forms of masculinity share some common themes, including individualism, heroism, toughness, rationality, and control (whether over employees or nature). These masculine performances and interconnections may, in turn, affect the positions and experiences of women and gender diverse individuals in crop breeding research organizations. It is our opinion that to create more equitable, supportive, and enabling environments in crop breeding research organizations, there is a need to transform the masculine organizational and institutional structures, cultures, discourses, and practices. Such a transformation can be assisted by critical men and masculinities studies, which exposes masculinities to investigation, discussion, criticism, and change. We thus call for more scholarly attention and research in this space to improve equality in and through crop breeding for development as a field.

Author contributions

IAT and HAT contributed to the conception of the paper and manuscript revision. IAT wrote the first draft of the manuscript. All authors contributed to the article and approved the submitted version.

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'They think we are delaying their outputs'. The challenges of interdisciplinary research: understanding power dynamics between social and biophysical scientists in international crop breeding teams

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Public sector crop improvement for development programmes aims to produce varieties tailored to the needs of smallholder farmers and their environments. Understanding how social heterogeneity, including gender, drives trait preferences is essential to ensure that crop improvement objectives meet farmers' and stakeholder demands. This requires an interdisciplinary approach, integrating social science knowledge with crop breeding. Although the necessity of interdisciplinary research is recognised and promoted, it is impeded by a multitude of challenges including ontological and epistemological differences, institutional and global hierarchies, disciplinary power relations and struggles for scientific authority. The Agricultural Research for Development (AR4D) sector is marked by entrenched power differentials, including dominance of the biophysical sciences, a historical emphasis on technical solutions which ignores social contexts, and the underrepresentation of women scientists and farmers themselves. Nevertheless, there is limited theoretically informed analysis of power dynamics within AR4D settings. Drawing on qualitative, ethnographic observations of the Feed the Future Innovation Lab for Crop Improvement (ILCI), this article seeks to understand how power affects interdisciplinary research processes. Critical ethnography and power theory is used to analyse power within international crop breeding collaborations and the implications for inclusive knowledge production and research impact. The Powercube is used to examine how visible, hidden and invisible forms of power manifest within local, national, and international relationships across closed, invited and claimed spaces. Our findings suggest that these intersecting power dimensions, which include disciplinary, gendered, institutional and global hierarchies, constrain the contributions that individual researchers can make – particularly social scientists – thereby hindering disciplinary integration. The ILCI case study reveals the complex multi-dimensional dynamics that emerge within agricultural research teams and highlights structural limitations constraining efforts to build socially inclusive and gender-responsive crop improvement programmes. The article contributes to a small but growing literature studying the social construction of agricultural science, and provides insights that can enable interdisciplinary research strategies to more effectively meet the needs of farmers and other stakeholders.

KEYWORDS

power, interdisciplinary research, crop breeding, critical ethnography, AR4D

1. Introduction

Public sector crop breeding that focuses on achieving high yields may contribute to food production and alleviating food shortages, but has been less successful at reducing poverty, hunger and malnutrition (Pingali, 2012). Difficulties meeting the needs of low-income, smallholder producers in marginal environments is partly due to a mismatch between crop improvement goals and farmer realities (Polar et al., 2022), and contributes to low adoption of varieties, particularly in Sub-Saharan Africa (McDougall et al., 2022).

Plant breeding research efforts have been criticised for uneven social and spatial effects (Kingsbury, 2009; Sumberg et al., 2013), leading to a growing emphasis on more equitable and inclusive approaches. It is argued that if breeders overlook traits – such as taste, colour, size, shape – that are important to different end users (for example women), varieties will not be adopted (Walker and Alwang, 2015; Tufan et al., 2018; Ashby and Polar, 2019). This in turn can potentially affect household food insecurity and poverty (Polar et al., 2022). To address this, more inclusive trait prioritisation processes and tools are being developed to understand the range of preferences that matter to different social groups and identities (Orr et al., 2018; Tufan et al., 2018; Ashby and Polar, 2021; Teeken et al., 2021; McDougall et al., 2022). It is assumed that if crop improvement can 'get the traits right', this will result in more desirable and beneficial varieties for a diversity of user groups, leading to increased adoption, improvements in productivity, and reduced poverty and malnutrition. This new orientation also aims to produce varieties that have greater value or success in 'the market'. The rise of demand-led (Persley and Anthony, 2017) and market segmentation and targeting (Donovan et al., 2022) approaches for crop breeding conflates markets, demand and social inclusion (Tarjem, 2022). However, it also expands the requirements of crop improvement programmes, necessitating the inclusion of social scientists to carry out these new agendas.

Historically, crop improvement has been carried out by plant breeders and biophysically trained scientists (i.e. agronomists, plant pathologists and entomologists), with limited input from social sciences (i.e. agricultural economists, rural sociologists, anthropologists, gender specialists and nutritionists). Despite the recent emphasis on multidisciplinary research teams that incorporate social scientists, little is known about how such arrangements work in practice. In particular, there is limited understanding of the realities of designing and implementing socially inclusive research, how collaborations are experienced by researchers, the extent to which disciplinary integration is achieved and how these arrangements influence crop breeding practices and outputs. Critical reflexive analysis of research processes is rarely undertaken, maybe because as a social science domain this is not prioritised within a technologically oriented sector dominated by natural sciences.

Within AR4D, social scientists often struggle to influence the work of biophysical scientists. Social scientists who are women can be 'doubly marginalised' by a lack of respect for their discipline and their status as women (Verma et al., 2010: 272). Qualitative social scientists, again who are often women, are especially challenged as their work is often referred to as 'anecdotal' (Verma et al., 2010: 268). Racial and global hierarchies further contribute, but have largely been ignored and so occupy an 'absent presence' (Pailey, 2019). The 'deeply masculinised' character of modern agriculture, historically shaped by Anglo male scientists (Farhall and Rickards, 2021: 11), can be traced back to colonial models of development; and the separation of public and private spheres and gendered divisions of labour that fostered male dominance of technology (Polar et al., 2021: 80). As a result, 'women and people of colour have had little influence over the directions that agricultural research has taken' (Hassanein, 2000: 52). Research by Marks et al. (2023) suggests that plant science suffers from ongoing underrepresentation of marginalised identities. Due to global disparities, established under imperial colonialism and perpetuated through modern Eurocentric frameworks, researchers in the global South face multiple barriers to participating in plant science, with gender and race intersecting to generate particular constraints for women of colour (Marks et al., 2023).

As plant breeding embarks on a shift towards rapid, data-intensive approaches whilst also attempting to be more socially inclusive, it is necessary to critically assess past experiences and the current research landscape to see what lessons might be learned. This will illuminate 'the dynamics of power that determine what (and whose) ideas and technological solutions prevail' within research domains (Leach et al., 2020: 7). This article attempts to begin 'researching the researchers', with an explicit emphasis on power, to gain a better understanding of the social dynamics of agricultural science, specifically crop improvement, and its implications. We begin with the overarching research question: How does power manifest within multidisciplinary crop improvement collaborations and what are its impacts on integrating knowledge from the social and biophysical sciences? We attempt to answer this question through qualitative, ethnographic research that explores power dynamics through a case study of a multi-country agricultural research for development (AR4D) project, the USAID-funded Innovation Lab for Crop Improvement. While our findings may conform to certain stereotypes of power dynamics within the AR4D sector, and beyond, they reflect the lived experiences and perceptions communicated by our respondents.

Our research framing and data interpretation has been informed by our own experiences as women and socially oriented scientists working in the AR4D sector. Our gender, disciplinary training and experiences guide our perspective on power and our understanding of how power influences individuals, research processes and disciplinary relations. In accordance with feminist theory, we do not consider our experience a 'bias' but rather a strength, giving us insights that improve our analysis and interpretation (Harding, 1991). As white researchers from the global North, we acknowledge that we are writing from positions of privilege. We do not claim to speak on behalf of others but rather act as 'observing participants' (Mostad and Tse, 2018: 54). In this article, we turn our ethnographic gaze to reflect on and question the construction of Western/Northern agricultural knowledge with the aim of facilitating processes that can decentre and decolonise existing power structures.

2. Interdisciplinarity and power: a review of the literature

Interdisciplinary research is widely promoted by donors and research institutions alike (Kelly et al., 2019).[1] It is increasingly recognised that many of the current global challenges 'are invariably 'wicked problems', to which there is no single solution' (Fraser, 2017: 139). This understanding calls for new approaches to science and knowledge production to tackle 'complex and highly interconnected problems' (Fritz and Binder, 2020). This argument assumes that interdisciplinary research 'generates more nuanced and robust understandings of the social and natural world than knowledge emerging from within traditional disciplines, and will lead to more innovative or more holistic solutions' (Frickel et al., 2016). However, the challenges faced in such work are often unacknowledged. Promotion of interdisciplinarity presumes that scientists from different disciplines know how to work together effectively, and ignores inequalities between them.

A growing body of academic literature exploring interdisciplinary endeavours indicates that hierarchies, prejudices, and power asymmetries shape many interdisciplinary interactions (MacMynowski, 2007). As disciplinary collaborations rise in number, it is increasingly apparent that 'how the idea of interdisciplinarity gets put into practice, what form it will take and what goal it will be assigned, depends on the configuration of power between epistemic communities, economic actors and political stakeholders, as well on their interests in, and views on, legitimate science' (Albert and Laberge, 2017). The presence of entrenched disciplinary hierarchies indicates the importance of being 'attentive to power relations and status hierarchies between disciplines and knowledge areas … and struggles for scientific authority' (Frickel et al., 2016: 6).

Studies on how interdisciplinary initiatives work – and do not work – in practice are rare (Freeth and Vilsmaier, 2020: 58). As Callard et al. suggest, 'We still know remarkably little of the mundane detail of what it looks and feels like to labour in an interdisciplinary setting' (2015: 1–2). In particular, the structural conditions, political and power dimensions that influence or hamper such collaborations and, thus, knowledge production are rarely addressed in scientific discourse (Dannecker, 2020: 1). Within the AR4D sector, power dynamics have been analysed between agricultural scientists and farming communities (Cooke and Kothari, 2001), global science and indigenous knowledge (Sillitoe, 1998; Sillitoe, 2007), but there has been limited analysis of power dynamics within research teams themselves. Agricultural anthropologist Todd Crane (2014) argues that to better understand research processes and professional practices of agricultural scientists, they should also be subjected to an analytical lens. He proposes that applied anthropological research should take inspiration from science and technology studies (STS), which takes the social configuration of scientific knowledge production and technology development as its focus (Felt et al., 2017). Crane argues that 'empirical social research on scientists' … will enable better theorization of how and why certain forms of applied agricultural research work (or do not work)' (2014, 47). Analysing the social construction of agricultural science, particularly 'technical practices, social organisation, and institutional norms' (Crane, 2014: 47) may provide a fuller understanding of crop improvement and make interdisciplinary research more effective.

There have been successive attempts to improve disciplinary integration, and make AR4D more demand-driven – from farming systems research to participatory plant breeding (Ludwig et al., 2022). Yet despite four decades of agricultural research institutions initiating such approaches, they have never become mainstream in the technology development cycle (van de Gevel et al., 2020). Retrospective analysis indicates that reversing well-established research models implies shifts in power, authority and control. A review of participatory plant breeding (PPB), for example, concluded that disciplinary power struggles thwarted its success (Ceccarelli and Grando, 2020). It suggested that breeders were resistant to PPB because it rendered technical breeding issues subordinate to social factors. Breeders felt 'they had been expropriated of their science, and scientists (social and gender scientists, anthropologists and socio-economists) … [were seen as] trespassers on 'their' territory' (Ceccarelli and Grando, 2020: 237). As Hilgartner argues 'new paradigms and new technologies have the potential to perturb extant regimes' (Hilgartner, 2017: 19) and are accompanied by struggles for control.

In AR4D settings power dynamics are not confined to struggles between disciplines and 'knowledge regimes', but include gendered, racial, and global hierarchies which overlap and intersect with disciplinary and institutional contexts in complex ways. Research communities, like agrarian communities are heavily stratified by social divisions, including, gender, class and ethnicity (Evans et al., 2020; Taylor, 2021:4). From this perspective, 'forms of social differentiation, based on gender, class, and ethnicity … are not peripheral to the research process but are at its centre' (Ferguson, 1994: 545). In sum, 'interdisciplinarity is entangled in much thicker structures of power than either its promoters or its practitioners are willing to recognise' (Callard and Fitzgerald, 2015: 98).

The role of power in interdisciplinary processes is a nascent research area. Analyses of interdisciplinary power indicate that 'studies have rarely been grounded in explicitly articulated understandings of power' (Fritz and Binder, 2020: 2). Nor have existing studies of disciplinary interactions and institutional environments in an AR4D context referenced power theory (Horton, 1984; Rhoades et al., 1986; Cernea and Kassam, 2006; Verma et al., 2010). Marcus Taylor, writing on the political economy of development, notes that 'although authors are clearly aware that power keenly matters, they often seem reluctant to … [delve] into the kinds of critical theory that seek to systematically engage with such issues' and so 'conceptualisation remains superficial' (Taylor, 2015: 82). One challenge to analysis is that 'power is fluid, dynamic, and difficult to measure' (German et al., 2010: 8). Nevertheless, Knapp et al. (2019) argue that it is imperative for researchers to engage with critical theory, particularly branches of

1 According to the National Academy of Sciences, 'interdisciplinary research (IDR) is a mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialised knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research practice' (2005).

feminist and de-colonial theory which help to understand how power shapes collaborative approaches, how identity influences outlook and positionality, and how different types of knowledge are valued.

Power analysis draws on critical social theory, anthropology, political sociology and feminist theory (Acosta and Petit, 2013). In a review of existing work, Svarstad et al. (2018) distinguish between actor-oriented, Foucauldian post-structuralist and Neo-Marxist approaches. In actor-oriented approaches, actors possess and use power to exercise influence over others. In contrast, Foucault's understanding of power is relational, indicating that power is not 'a privilege that one might possess' but rather operates within a network of relations (Foucault, 1977: 26–27). Power is thus co-produced in social interactions, vested not in individuals but in organisational structures, social rules and shared cultures (Heizmann and Olsson, 2014: 758). Marxist perspectives highlight how human agency is constrained and produced by historically established social structures and exercised through economic domination and exploitation, drawing attention to the control and allocation of resources.

An influential approach to power analysis is the Powercube framework (Gaventa, 2006), informed by Lukes (2005) 'three faces of power' which incorporates actor-oriented, post-structural and Marxist perspectives. The Powercube (Figure 1) identifies three forms of power: visible, hidden and invisible. *Visible* power looks at formal decision-making processes and 'who gets what, when and how'. *Hidden* power, focuses on how certain issues and/or participants are excluded from decision-making including how agendas are set and the unwritten rules embedded in social structures that can directly and indirectly influence decisions and interactions. *Invisible* power, focuses on more subtle or diffuse forms of power. Identifying this form of power involves analysing internalised norms, values, ideas and customs which shape people's perception of their roles and actions, often serving the interests of the more powerful. The Powercube extends analysis beyond the three forms or faces of power to include different levels (local, national and global) and different spaces of power (closed, invited and claimed), thereby providing a framework for identifying the multi-faceted dimensions of power. While the Powercube utilises an image that makes the 'levels', 'spaces' and 'forms' of power seem clear and definitive, this is just a heuristic device. In reality, the various aspects of the cube are intermeshed in complex ways. This makes it important to consider interactions between dimensions, and how they overlap and intersect.

Feminist power theorisations influence and add to this framing by arguing that conceptions of power which remain limited to 'power over', or domination and control, are implicitly masculinist. To provide alternatives, feminist scholars argue for a recognition of power as a capacity to act, which includes the capacity to empower or transform oneself and others. Such approaches utilise alternative concepts – 'power within', 'power to', and 'power with' – that highlight the transformational dimensions of power and possibilities for change (VeneKlasen and Miller, 2002). *Power within* refers to an individual's sense of self-worth, self-knowledge and self-efficacy, including the capacity to imagine alternatives. *Power to* refers to the unique potential of individuals to shape their life worlds and make decisions to achieve goals, which opens up possibilities for action. *Power with* refers to finding common ground and building mutual support, solidarity and collaboration, which can help build bridges between different interests.

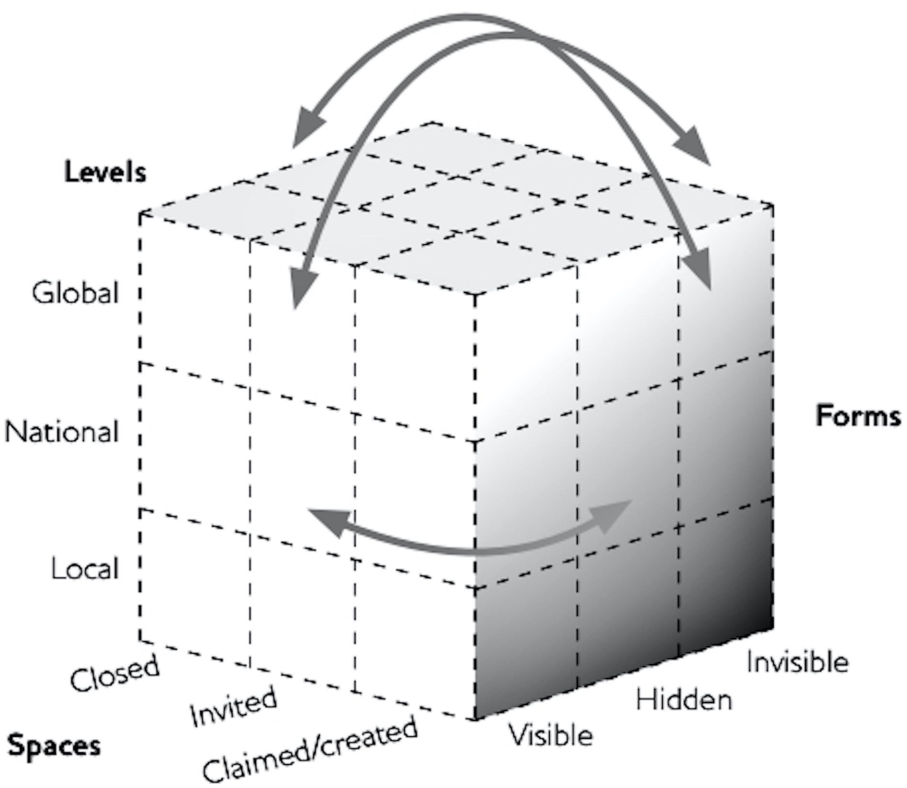

FIGURE 1
The Powercube: the levels, spaces, and forms of power (Gaventa, 2006).

Power through is a recent addition, and refers to the individual power that can be won and lost through relations to others (Galié and Farnworth, 2019). Such conceptions recognise that power is not just negative, coercive or repressive, but can be productive (Gaventa, 2003: 2). These framings have been applied in A4RD, particularly work focusing on gender relations, social exclusion and women's empowerment (Kabeer, 1999, 2000, 2005). Others draw on Rowlands (1995) discussion of intrinsic (power within), instrumental (power to), and collective (power with) (Malapit et al., 2019).

These perspectives offer significant insights and demonstrate that how we perceive and address power depends on our frames of reference, disciplinary lenses, and the methods we use to analyse it (Petit, 2013). The complexity and multi-faceted nature of power dynamics require us to take into account different forms of power; the various actors, institutions, relationships and spaces where it arises; and how dimensions of power intersect. As Svarstad et al. (2018) argue, combining different theoretical perspectives can contribute to richer and more nuanced understanding of how power manifests.

3. Context: the innovation lab for crop improvement

This research is focused on the Feed the Future Innovation Lab for Crop Improvement (ILCI), part of the US Government's efforts to address global hunger, food security and malnutrition. ILCI aims to drive 'bottom-up' strategies in crop improvement by bringing together scientists and stakeholders to co-develop and implement tools, technologies and methods tailored to the needs of specific communities (ILCI, 2021). The overall goal is crop varieties that enhance productivity, growth, resilience and nutrition, while providing equitable benefits to women and youth. The effort is led by a coordinating team at Cornell University, together with other US-based institutions.[2] Research is conducted in collaboration with four 'centers of innovation' (COIs) in Uganda, Costa Rica / Haiti, Malawi and Senegal, with subsidiary teams in affiliated countries including Kenya, Tanzania, Mozambique, Burkina Faso and Niger. COI researchers are largely based within National Agricultural Research Institutes (NARIs) and associated Universities.[3] Research is oriented around a number of themes, referred to as 'objective areas' (OAs). These consist of priority setting, trait discovery, phenomics, genomics, breeding informatics and institutional capacity, with 'cross cutting themes' focusing on gender, youth, nutrition and resilience. OA researchers, mostly from US-based institutions, support COI researchers, mostly based in NARIs in the global South. Both OAs and COIs consist of researchers from a range of biophysical and social science disciplines.

ILCI is described as an interdisciplinary initiative (ILCI, 2021), where working across different biophysical sciences and between biophysical and social sciences are both considered interdisciplinary efforts. By 'forming linkages between previously siloed disciplines' the lab aims to develop approaches that can 'enhance and scale capacity for national breeding programs' (ILCI, 2021). One of the conditions in the call for proposals was the incorporation of social scientists within research teams, to focus on gender, youth and social inclusion and ensure that breeding approaches consider the needs of diverse stakeholders. An ILCI publication (Merchán, 2021: 29) states that while social issues 'are at the centre of why crops are bred in the first place', they are 'often detached from breeding programs'. ILCI is seeking to change this, with a 'multidisciplinary, systems approach' that incorporates 'economists, social scientists and specialists in … gender, youth, nutrition, and inclusion' within 'integrated teams' (Merchán, 2021), to achieve holistic, demand-led crop improvement.

The project also attempts to address North–South power dynamics by placing NARIs in the driver's seat. It acknowledges that NARIs play a critical role in the research and development of agricultural products, but are often unable to determine their agendas and visions due to pressures and demands from donors and national governments. In contrast, ILCI intends to make science work for NARIs rather than agendas being imposed from the top down (Tufan, 2020). The emphasis on co-equal relationships, co-creation and partnerships, 'founded on principles of shared dialogue and idea formation' (Merchán, 2021: 29), endeavours to make crop improvement more demand-driven. It is assumed that supporting NARIs to develop and implement localised strategies and approaches will improve the effectiveness of breeding processes and ensure they address national priorities.

Despite these efforts to change the way in which crop improvement processes work, preliminary observations by research coordinators within ILCI suggest that power dynamics within these international, multi-disciplinary crop improvement collaborations inhibit equal voice and decision-making, raising questions about the functionality of such teams and their capacity for generating interdisciplinary outputs (Tufan, 2020).

4. Methods

This article uses ethnographic and qualitative approaches. The first two authors are anthropologists with experience working in interdisciplinary AR4D teams. As researchers' external to the ILCI project, they worked collaboratively with ILCI team members and liaised throughout with the second two authors, an anthropologist and plant scientist, who acted as an advisory team and provided guidance on the approach. Research was conducted over approximately 15 months from October 2021 to December 2022. The first step involved carrying out an extensive review of literature on social science in agriculture, crop improvement and theoretical and practical studies of power, particularly in interdisciplinary contexts. The next step examined and analysed project documents to understand project history and structure. These included the Notice of Funding Opportunity, Request for Applications, COI proposals, annual reports, and the project website. Then, a brief questionnaire was distributed to project members to gather basic information about respondents, to assess how they understood interdisciplinary research and challenges

2 These include Clemson University; Colorado State University; Kansas State University; University of Missouri; Cultural Practice, LLC; RTI.

3 These include National Semi Arid Resources Research Institute (NaSARRI) in Uganda; Instituto Nacional de Innovacion y Transferencia Tecnologia Agropecuaria (INTA) in Costa Rica; and Institut Senegalais de Reserches Agricoles (ISRA) in Senegal; Quisqueya University in Haiti; University of Costa Rica; Lilongwe University of Agriculture and Natural Resources (LUANAR) in Malawi; and Makerere University in Uganda.

faced. A total of 53 members responded. Selected questionnaire respondents were then contacted for follow-up interviews. These Zoom interviews were conducted with 32 project members (16 women and 16 men). Participants were selected based on their position, gender, discipline, and level of experience to ensure a range of perspectives. These included three members of the project management team, nine US-based objective area researchers and 20 COI researchers from each of the four regional 'hubs'. Interview questions focused on a number of key topics namely: individual disciplinary experiences; team dynamics; project communication and decision-making; resources and deliverables; and project leadership. Conversations were framed around interdisciplinary team dynamics rather than an explicit focus on power. We deliberately avoided using the word 'power' in most interviews, due to its negative connotations, such as abuse of power, lack of transparency, and unilateral decision-making (Boni et al., 2009). Instead, we used open questions and neutral language to facilitate discussion. As well as interviews, we observed recordings of project presentations, training sessions and team meetings, internal discussion threads and blog posts, drawing on approaches from institutional and digital ethnography. Once interviews were completed we began to 'code' our notes and interview transcripts to identify patterns using thematic analysis. We drew upon the Powercube and feminist theoretical framings, as well as wider literature, to interpret and structure our findings.

5. Results

5.1. Visible forms of power

Drawing upon the Powercube, we first examined visible power, such as the observable aspects of decision-making. We observed who participates and dominates, and thus whose interests prevail in key decisions. Attention to who prevails also led us to examine who may have little influence despite being present.

The historical development of agricultural science, together with established sectoral norms, has resulted in entrenched hierarchies between the biophysical and social sciences. In the case of crop breeding, biophysical scientists, namely 'breeders', have visible power – or 'power over' – other disciplines. Interviews with respondents conveyed an understanding of the history of this power dimension. One social scientist explained, 'Two or three decades ago, the breeder… would just start breeding based on his own interests or interests of the donors … they would produce varieties that would not be adopted or were not needed by the farmers'. Another commented 'Way back, people just used to go to the field and they did not regard the input of social scientists… a breeder would come up with a variety … but they did not take social and cultural issues into account'. These reflections underline the perceived dominance of crop breeders and lack of input from social scientists or farmers.

Within AR4D, social scientists are often seen as service providers to biophysical researchers and therefore of secondary importance. Several ILCI social scientists explained their primary role as helping to diffuse technology or aid adoption. One respondent said 'When they [breeders] want to diffuse the technology, I have to make surveys and studies and speak about the new technologies they [breeders] want them [farmers] to use.. When they [farmers] accept to use the technology, I do an impact study'. Thus, the main input of social scientists to date has been ex-ante and ex-post studies of crop breeding processes, particularly adoption and impact studies carried out in the aftermath, with limited input to priority-setting and varietal design.

The visible power of the biophysical scientists is apparent in their control over the conceptualisation and framing of project proposals, research questions, budget allocations and methodological approaches. In the ILCI development phase, for example, many of the COI proposals were generated by biophysical scientists. As one COI social scientist commented, 'I was involved in the proposal writing phase but only at the point where the PI had already conceptualised the main breeding ideas of the project … I then had to give my input … from a gender and youth inclusion perspective'. Another respondent commented, 'I think, for most participants, including social sciences was more of an afterthought'. In this sense, proposals were not truly co-produced, suggesting that not all disciplines participated in elaborating project objectives.

Social scientists often have limited decision-making power in the sector. Few social scientists, particularly in NARIs, make it into management positions so have little influence over project design, funding allocation, scientific and institutional practices. Within ILCI, the biophysical sciences, responding to the original USAID request for applications, dominate the project, with 79 researchers affiliated to STEM disciplines compared with 48 social scientists.[4] This pattern extends to project decision-making, with biophysical scientists occupying the majority of leadership roles, giving them greater visible power. The project Director and former Associate Director are both plant scientists, eight out of 12 Objective Areas leads, and seven out of eight Centre of Innovation PIs are trained in biophysical disciplines. Social scientists are the minority in both OAs and COIs, and usually occupy more junior positions. Although project members commented that the social sciences are better represented than in many breeding projects, the predominance of biophysical disciplines is still apparent.[5] The original call for proposals which focused on biophysical tools, technologies and methods for crop improvement is likely to have shaped this imbalance.

Visible power in the AR4D sector generally also has gendered, as well as racial dimensions. Although this is shifting, women continue to be underrepresented. This extends to ILCI, which consists of 81 men, and 46 women scientists. Due to these imbalances, those with visible power in the project tend to be men (nine out of 12 OA leads are men and among COIs, women leaders are often co-leads). The visible power of men was apparent in conversations with respondents. A junior social scientist, for example, referred to people he considered to be 'big names' in the project, all of whom were men. A biophysical scientist commented that project PIs are 'male heavy' and then said 'I am used to being in rooms with 10 men and I am the only woman, which is bad, that should not happen'. There are also perceived racial power imbalances, although few respondents referred to these explicitly. One woman COI scientist said, 'generally there is that segregation where the rest of us, based in Africa, always feel like we are

4 STEM is an umbrella term used to refer to science, technology, engineering and mathematics disciplines.

5 It is also important to note that many social scientists are not trained to go into agricultural research but rather pursue topics that are more oriented towards the focus of their respective disciplines.

second class citizens. We do not have the same voice, or if we propose something it's never really that important… if you propose something in a meeting… and then it [the same idea] comes from somebody in the West suddenly it's like whoa, yeah, that's a really great idea'. This is significant because agricultural technologies and the science that produces them are informed by cultural, social and gender relations, and attendant power dynamics (Harding, 1991; German et al., 2010; Polar et al., 2021).

Cognisant of this, ILCI project leaders have attempted to diversify COI teams by inviting social scientists, and women scientists, into more powerful leadership roles and positions. However, conversations with COI scientists suggest that women with visible power are aware of their gender in ways that men are not.[6] One woman (social scientist) commented, 'there is a gender divide… you still feel a sense of resistance in terms of responses from managers from different teams. With PIs who are male sometimes there is a cultural aspect where females are treated differently, or underestimated. This is not expressed in words, but through their actions. There is a sense that women do not make as much impact and are not respected as much'. Another woman (biophysical scientist) explained 'It is difficult to lead a project, to lead people is challenging… and more so if you are a woman … They [men] may not even give importance to the project because it is a woman who is leading'. This indicates that women experience resistance to their leadership regardless of discipline. Importantly, however, both women cited above are engaged in more 'social' aspects of crop improvement, namely product profiling and cross-cutting themes, suggesting that the resistance they face may be due to the socially oriented research they are leading, and their gender.

5.2. Hidden forms of power

While visible forms of power have been a focus of previous research, less attention has been paid to hidden power within the AR4D sector. This dimension pertains to how powerful actors maintain their power, create barriers to participation, exclude key issues or control agendas behind the scenes.

Although ILCI may be opening up breeding processes by including social scientists and gender experts, control of research and project structures remains in the hands of biophysical scientists. This is evident in project creation processes, with breeders inviting social scientists to participate, creating a sense that biophysical scientists are 'hosts' and social scientists are 'guests'. While social scientists are invited to contribute to trait prioritisation and product profiles, socio-economic data and expertise are only incorporated at certain points. As such, social scientists can only influence or feed into the crop improvement process within certain limits, their input restricted to specific stages or particular areas largely determined by those with biophysical expertise. So, the overall terms of the project are outlined by breeders, who establish the 'rules of the game'.

Forms of hidden power include research practices and modes of working. Within COI teams, several social scientists commented on their role as 'intermediaries' or 'bridges' between breeders and end users (i.e. farmers). To service the sector adequately they are charged with understanding both breeders and farmers. While the onus is on them to do this work, biophysical scientists do not necessarily make similar efforts to understand what social scientists do. It is assumed that social science will fit in to existing processes and structures, rather than redesigning research so there is parity between disciplines.

When speaking about project budgets and timelines respondents revealed that social scientists do not have full control over their work. Budgets are a critical component of proposal writing, constructed during the proposal development phase. Determined largely by COI biophysical scientists, these impact disciplinary budget allocations and working arrangements. One breeder commented 'the project is more of a crop improvement project, so our objectives are more important than other objectives. Even the allocation of funds, we allocate more funds to this major objective of the project compared to other disciplines'. Budgeting carried out by breeders, can reduce the scope of activities and affect the quality of social science work. While budgeting can also constitute a visible form of power, differential funding allocation along disciplinary lines behind the scenes, can also act as a form of hidden power – setting the agenda before social scientists are engaged.

Timelines are another way in which biophysical scientists prioritise certain research processes and objectives. According to the inclusive processes established by the project, trait prioritisation information needs to be collected from target populations. Data is gathered primarily by social scientists who then liaise with breeders. However, gathering such information takes time. As one social scientist explained, 'Dealing with humans is complex. You are collecting profiles and qualitative data on different aspects, and that might take a long time'. However, breeding occurs within specific timeframes, influenced by the seasonal growing cycle and other factors. For breeders to produce results within a three-year project cycle they need to embark on their activities from the outset. Gathering information about traits and developing product profiles can conflict with the demands of breeding cycles. Social scientists from several COI teams reported difficulties in providing breeders with desired information at the start of the project, when it is most useful. One person explained, 'Breeders are frustrated … They think we are delaying their outputs'. Delays have led to tensions around data availability and deliverables, which play into pre-existing disciplinary power dynamics.

Objectives underlying crop improvement also exert power over research processes. For example, breeders' tendency to focus on yield can sideline other criteria that may be sought by men and women farmers. One plant breeder explained, they are mainly concerned with 'the development of varieties that are high yielding … so the breeder is looking at that broad objective, but then within that broad objective there are small, small objectives like nutrition status and gender', suggesting that these 'smaller' objectives are less important. Furthermore, another breeder explained that new approaches incorporating gendered traits (i.e. leaves for fodder) are perceived by some as 'going backwards' in terms of yield, posing a risk that 'developing' countries cannot afford to take. This indicates possible tensions between productivity and social inclusion objectives, with breeders trained in productivist paradigms potentially seeing social inclusion objectives as jeopardising improvements in yield because research led by social scientists may prioritise other traits. Thus,

6 While the role of gender inequality was also mentioned by junior researchers, it did not feature prominently in the interviews perhaps due to the focus on interdisciplinary dynamics.

conflicts may emerge around research conceptualisation and objectives, with different disciplines favouring certain goals, knowledge and outcomes over others. In addition, a focus on producing new varieties as quickly as is feasible, driven by institutional and donor pressures, makes attention to processes of knowledge integration difficult.

5.3. Invisible forms of power

Invisible power refers to the social and political culture which shapes the psychological and ideological boundaries of participation, including internalised beliefs that can result in the marginalisation of certain voices and issues (Gaventa, 2006).

Examining expressions of invisible power revealed a sense of disciplinary inferiority among ILCI social scientists. One researcher said: 'crop improvement screams breeding so if you are a social scientist it's like you are entering a room where you already perceive that you do not belong'. When asked to define interdisciplinary crop breeding, another social scientist said 'interdisciplinarity is when there are social scientists working with *real* scientists', indicating an internalised perception that social scientists are not genuine scientists. This contrasted with a sense of disciplinary confidence in the biophysical sciences. As one biophysical scientist explained, 'early in my career, the plant breeder was the king or queen of the domain, they could do whatever they want, they were all knowing', and mentioned a tendency for biophysical scientists to think they can 'roll over other disciplines'. Such perceptions are not necessarily cultivated within the project space, but originate elsewhere, with one person mentioning having inherited their sense of disciplinary inferiority from their University training. These internalised (and often invisible) attitudes become engrained in scientists during their training, and influence how scientists interact with one another in interdisciplinary settings.

Disciplinary inequities internalised by individual researchers are embedded in (and reinforced by) institutional contexts which valorise so-called objective science. Much of the data about men and women farmers' constraints, preferences and objectives, is qualitative. Such data is often not perceived to be 'scientific' or 'rigorous', further undermining the position of social scientists. In general, as one US-based respondent commented, 'social scientists and economists [in ILCI] face the same kind of challenge, how can we provide value and convince the scientists that what we do is valuable'. This view was reiterated by several respondents who asserted that social scientists have to work hard to demonstrate the usefulness and validity of their contributions. As Douthwaite et al. (2003: 244) comment, AR4D 'largely takes place within an 'invisible college' with positivism as the dominant paradigm, and the biophysical sciences as the dominant discipline'. Due to such internalised scientific norms, social scientists bring less power to interdisciplinary exchanges than biophysical scientists.

Another factor affecting many social scientists in crop breeding teams, is that their academic training does not provide them with experience of working with biophysical scientists – and vice versa. As one social scientist remarked 'this experience is new for me – this is the first time that breeders are asking me to be part of a breeding team'. Developing research approaches at the start of the project cycle is often challenging for social scientists, because, as one respondent commented, in many cases they 'do not always understand the mechanisms of the breeding process'. Whereas breeders have clear research methods and processes, there is a lack of established methods for social scientists' due to their historic lack of involvement in breeding processes. As approaches to collecting socially inclusive data are still being developed, this creates a sense of methodological inferiority, placing social scientists further on the back foot. This may also further reinforce perceptions about the inadequacy of social scientists.

5.4. Closed spaces

Within ILCI, we analysed project processes and structures to identify closed spaces controlled by the most powerful actors. We first considered the project development phase. The initial proposal was formulated by a small group in response to a USAID Notice of Funding Opportunity. During this process, 'big names' and 'established people' were invited by project directors to write certain sections. This was a closed space, described by one respondent as consisting of 'researchers in their fields with a lot of influence'. The majority were men from the global North, affiliated to biophysical disciplines, who had already worked together. People included in this process, and discussions in this space, had considerable influence over the project structure. The group determined how the project was framed, what areas to focus on, assessed COI applications, and many later became 'objective area' leaders.

In analysing these processes, lab structures, and relationships built between scientists around these structures, emerged as another potentially significant 'closed space'. A senior project member explained that another senior scientist on the project 'worked with me [as a postdoc] for a bunch of years, we know each other. We know how we think and we are not afraid to debate things'. This statement reveals a common model in the natural sciences where study and hands-on learning in a laboratory setting led by a disciplinary expert or 'lab leader' is the norm (Latour and Woolgar, 1979). This model is rarely present in the social sciences. After graduating, successful scientists eventually go on to lead their own labs, often in other institutions. Relations between mentors and trainees persist over time, forming local and global scientific networks. These laboratory networks build social capital and propel careers. Lab leaders draw on these networks when developing project proposals, and the researchers they involve often go on to assume prominent positions in project implementation. Pre-existing social relations that develop in such closed spaces can also influence project dynamics and constitute a form of hidden power. For example, in project meetings (which operate as invited spaces) those who already know one another may be more confident to express their views. In addition, these forms of power are often gendered because of the predominance of men in the biophysical sciences.

Interviews indicated that significant internal communication about the project occurred within closed spaces. Members of the management team and project leaders consult with one another, and individual researchers, through one-to-one discussions. Such *ad hoc* and informal communication between individuals can be beneficial as it enables frank exchanges that may not be possible in more open spaces, but it can be another way in which power differentials are manifested. More networked individuals, or those with higher social capital, are more informed than others which can potentially influence how they carry themselves in meeting spaces. Conversations within closed spaces may inform decision-making processes concerning the wider project.

The project framework created by researchers involved in the proposal development stage, seems to have (however unintentionally) created further closed spaces. The core research themes, or 'objective areas', mirror existing academic structures, formulated along disciplinary lines. A significant number of informants suggested that the 'social' objective areas (priority setting and cross cutting themes) mostly work in isolation from the biophysical science domains (genomics, phenomics, breeding informatics). While there is close interaction between priority setting and cross-cutting themes, and between genomics, phenomics and breeding informatics there is limited interaction across these domains. Even 'cross-cutting themes' – which should feed into all areas – is restricted to its own narrow space with limited staff allocation and budget. As such, the structure of the project into silos is contributing to or reinforcing closed spaces rather than challenging them.

The presence of closed spaces prevents disciplinary integration and reinforces existing power dynamics. Organising the project around key 'objective areas' means that different disciplinary groupings can pursue their agendas unhindered by interactions with those they are less familiar with. One respondent commented, 'everyone tends to go where they are most comfortable', and this seems to be mainly along disciplinary lines. This sense of comfort is not necessarily beneficial for interdisciplinarity however, as the friction of disagreement is often necessary to advance ideas. Working in disciplinary silos may be smoother and more comfortable, but it maintains the status quo, rather than facilitating change.

5.5. Invited spaces

Invited spaces are those that facilitate 'participation' and consultation, usually through invitation from authorities within set boundaries. In ILCI, we identified efforts to create spaces and opportunities to encourage interdisciplinary collaboration and integration between biophysical and social scientists.

The earliest example of an invited space, was the project co-creation phase. In this process 11 proposals were selected from over 90 submissions through a tiered review. These groups were invited to take part in a 'co-creation' process of proposal development with assistance from the steering group that had written the original project proposal. From the 11 shortlisted, four proposals were selected. This was in-line with the 'bottom-up' approach intended by the project. Cornell and other US-based researchers helped applicants develop their proposals and ensured they adhered to project (and donor) objectives. This included guiding the focus of certain proposals, advising applicants to merge to form specific COIs, and suggesting the promotion of individuals to more visible leadership roles. While this was an attempt to facilitate more inclusive and interdisciplinary dynamics, it also exemplifies the power of 'donor-researchers', and may have cemented the authority of the 'core group' – mostly male biophysical scientists, including those representing COI institutions.

Another form of invited space was a steering committee, established to break down silos in the project and facilitate communication between objective areas. The committee consisted of people from each project area, with different objective areas selecting their own representatives. As one person explained, 'the senator for phenomics represents their constituency, they come to the meeting, they take their information back to their constituency'. Despite the democratic impetus, and attempt to re-think project structures and modes of working, some perceived this process to be infused with pre-existing power relations. As one respondent commented, they are 'only inviting this core group again … it's not entirely transparent' [referring to the original steering group involved in writing the proposal]. While the committee was an attempt to break down silos, it failed due to a lack of buy-in from established figures and 'only met once or twice' and 'basically did not go anywhere'. Regardless of whether these perceptions are an accurate account, they reflect a perception of status and knowledge hierarchies, and attitudes towards integration.

To address the internally perceived lack of integration, the ILCI management entity tried to introduce incentives, such as providing financial support through an internal application process, to support interdisciplinary collaboration – another form of invited space. Such interventions recognise the scarcity of mechanisms to promote interdisciplinary work within existing academic structures. Indeed, one project member stated 'you have to be disciplinary before you are transdisciplinary to get tenure'. Performance metrics are another factor, as one respondent commented: 'academics are not known for being interdisciplinary, they are not rewarded for that', their rewards are 'publications, self-advancement and getting more funding for your group'. This extends to other institutional contexts, including NARIs where breeders are assessed primarily on the number of varieties they release. Although peer reviewed publications are important, varieties are still the predominant and most prestigious metric. In general, project level incentives to work across silos – in 'invited spaces' that aim to promote disciplinary integration – are not powerful enough to override established institutional structures and incentives.

Ultimately, researchers are unlikely to participate in invited spaces and invest in new ways of working if it risks falling short of the metrics of success instilled by their particular discipline or institution. Integration has a cost, as one respondent said, 'it takes extra time that people do not necessarily have' to learn what other groups do and determine how it applies to their own work. In addition to the time cost, interdisciplinary research can make people feel a sense of inferiority. One respondent mentioned 'interdisciplinary work is challenging, because you might be faced with research topics you know nothing about and that can be very intimidating'. The lack of incentives, compounded by the challenges of interdisciplinary work, hinders attempts at integration.

5.6. Claimed spaces

Claimed spaces are more organic than closed and invited spaces, usually created by less powerful people or groups to shape their own agendas. We are aware of only a few examples of such spaces within the project so far.[7]

7 These spaces are often highly personal and localised, and difficult for detached observers to access.

COI research teams are one instance of a claimed space. Researchers in national institutions described ILCI as a 'bottom-up' initiative where COIs have autonomy to decide what they work on and how, with support from Cornell, which some saw as different to the usual project approach where donors or funding bodies control the agenda. One researcher commented 'they [Cornell] do not have the imperialist point of view I have experienced in other projects. It has been very freeing. I can make mistakes and ask for help'. Another respondent echoed this saying 'it is very different to other projects. Some projects come when everything is already drawn. You cannot change. You just have to implement'. So, although the project is 'led by US universities', and framed by donor agendas, COI institutions have a sense of 'power within' – that they know best the challenges and priorities that concern their *national* contexts. As one researcher commented, 'it's not them telling us what they want us to do … we know our problems, we know our challenges… we can provide the solutions, we just need the support'.

The Innovation Lab model, as it functions within ILCI, seems to play an important role in facilitating communication within and between countries, teams and disciplines. For example, a COI social scientist commented, in reference to the presence of US Universities, 'the involvement of many stakeholders has helped to calm them [the breeders] down. If it was just us it would be too tense'. External input therefore seems to enable scientists from different disciplines, institutional and country contexts to work together. Nevertheless, such statements may be influenced by 'donor-researchers' and 'recipient-researchers' relations, with those receiving support possibly presenting positive accounts due to funding needs.

Organic research collaborations are another potential example of a claimed space. These spaces have emerged largely from individual efforts to cut across project silos, driven partly by a sense of frustration at the lack of integration. As one researcher commented, interdisciplinary research is 'about developing new methods and new tools that cross the disciplines … methods should be melded together'. Efforts to develop integrated approaches tend to be initiated by more junior project members (often women with less visible power) via informal connections. In creating these collaborations, one respondent described looking for someone 'on the same level as me that I can talk to, who is responsive and who is willing to give time'. Such collaborations are an example of 'power with', where individuals organise and act as a group to address common concerns.

An additional claimed space are objective area office hours that enable researchers across COIs and OAs to meet. These are organised by OA leads – usually US-based researchers – to liaise with representatives from COI research teams. Women social scientists participating in priority setting and cross-cutting themes office hours perceived this as a friendly environment where they felt supported and at ease. As one respondent commented, 'the priority setting team tends to be mostly social scientists and we understand each other easily … there is a common language and you feel comfortable'. Such spaces also provide a refuge for social scientists who may be isolated or unsupported within their own institutional or project spaces. As women have not acquired status and influence comparable to their male counterparts, they create their own networks to counter the power of the 'core groups' that dominate the sector. These spaces can be a coping strategy and form of resistance for marginalised researchers.

5.7. Local levels of power

Local levels of power consist of sub-national institutions and associations, including implementing organisations, programmes, and service delivery. With ILCI, we considered implementing structures like field stations and research teams as the local level. Actors include junior researchers, field technicians, support services, administrative staff and those carrying out 'day-to-day' project work. Although they overlap, 'local' dynamics and practices differ from managerial and decision-making processes at the 'national' level, and interdisciplinary power dynamics play out at the local level in specific ways. Within ILCI, certain teams appear to work smoothly, whereas others face challenges due to gendered and disciplinary dynamics, leadership styles and personalities, the nuances of which are difficult to unpack from a distance.

The 'field' emerged as a critical 'space' in terms of power dynamics at the local level, with tensions manifesting around fieldwork, demonstrating how levels and spaces of power overlap and interact. For breeders, 'the field' can refer to research plots or experimental field sites. For social scientists, it can refer to villages or farming communities. COI researchers referred to differential claims over fieldwork, with one social scientist mentioning that breeders in their team asked why they were going to the field, saying 'this is not your business'. Another also referred to breeder's ownership claims over this space, who apparently feel that social scientists are 'going to see their target people who they work with to develop varieties. They [the breeders] ask us what we are doing, why are you going to the field to ask questions?' These comments indicate struggles for control, limited understanding of different disciplinary approaches to fieldwork, and a lack of integration.

Limited knowledge of what scientists from other disciplinary backgrounds do is an important factor influencing relations between researchers at the local level. A COI biophysical scientist commented, 'there's so much work involved in what we do, whereas social scientists can just come up with a survey in three months and they have their results'. Similarly, a COI social scientist said, 'It is very easy for biological sciences … but it is more challenging for social scientists. [We] have to understand farmers and laboratory researchers and what they do'. Another social scientist remarked, 'the practice of science is different than the ideal of science, but you can only understand practice if you go with the people when they are practicing'. They further explained, 'once in a while colleagues who are agronomists follow me during my fieldwork to see what I do. This is always a good experience and we all learn from each other. I wish it could happen more often' – indicating opportunities for change.

The 'field' is also a space where tensions around gender come to the fore. Women can find fieldwork and travel to meetings at short notice challenging, due to childcare and domestic responsibilities. This is not always considered by men on research teams. One COI researcher explained, 'they do not understand that you cannot just up and go because of your children. It frustrates the men who want to do tasks and meet certain deadlines'. The same respondent said 'in my country it is quite common to hear people say ladies should not be part of this [research] because if the husband is sick … [or] if the child is sick she has to take time off'. Such reports indicate that the practice of science is structured to suit a male model. One woman from a COI team mentioned their refusal to go to the field or meetings at short notice, which can be seen as foot dragging or non-compliance

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with dominant norms (*cf.* Scott, 1985). This is also a form of hidden power, and 'power to' – the potential of every person to shape their lifeworld through their actions. However, that women at the local level are resorting to such tactics suggests a lack of appropriate sensitisation for men and women field workers, and a gap in institutional or structural support from the national level.

5.8. National levels of power

The national level includes forms of authority linked to nation-states, including institutions, policies, initiatives. ILCI is led by Cornell University, both a land-grant university and a privately endowed research university and prominent national institution, in collaboration with a number of other US-based universities.[8] Actors at this level are responsible for the strategic decision-making that guides the project and include the ILCI management team, PIs, lab-leaders, and external consultants. While these actors may represent the 'national' level, they are not equally powerful, at least in terms of visible power.

The Feed the Future Innovation Lab model, is based on an implicit assumption of the superiority of US-based knowledge and expertise, reflected in language such as 'top US universities' (Feed the Future, 2022), which is internalised by 'donor recipients'. As one COI researcher said, 'we have a kind of hierarchy. They, the Cornell team, forms the first layer because they are like our superiors, like the experts'. Another commented 'they [Cornell] have a big role to play because they are the ones giving us the funding'. Such hierarchies, based on 'national' reputation, and 'global reach', imbue US institutions with visible *and* hidden forms of power, demonstrating the inter-relatedness of national and global levels of power. As well as creating knowledge hierarchies, such assumptions potentially mean that capacities within national institutions are not considered. For example, one researcher mentioned that COI expertise in participatory research was overlooked – despite a long history of work in this area – due to an assumption that recipient countries lack capacity and require assistance with key research skills and approaches: 'They [Cornell] made assumptions about what their role was, and what our capacities were'. Issues of seniority also came into play, 'I've done this for twenty years… this person three years out of graduate school is telling me that I'm doing it wrong'. Further evidence of these dynamics is demonstrated by US-based researchers describing COI teams as more 'advanced' or more 'nascent' than others, assessments largely based on access to technology, research infrastructure and resources. Although such observations may be accurate on a material level, they may overlook other capacities, implicitly placing COIs on a trajectory from 'least advanced' to 'most advanced'. This points to hierarchical notions underpinning research, and power imbalances between 'donor-researchers' and 'recipient-researchers' and global North and global South (Nshobole, 2021), which permeate the process at every level.

Hierarchies also occur between national institutions. COI research groups comprise a range of national institutions, including NARIs and national universities, varying from country to country, whose interactions are also influenced by power relations. One respondent said there can be 'intellectual hierarchies' between national universities, 'for example when a "mother" university is involved' (meaning a university that provides training to other institutions). Another mentioned that national university scientists often think they are better or more advanced than NARI scientists. They commented that NARI scientists are often 'looked on as technicians', and due to differences in resource endowments 'tend to feel inferior'. All researchers indicated that such perceptions affect the performance of teams. In certain country contexts, these institutional hierarchies are partly a legacy of colonial rule. During the colonial and pre-independence period in Africa, agricultural research institutes, specialising in agricultural science and technology, were separated from universities, focusing on social sciences and humanities. This resulted in a separation between research and education, and a sense that agriculture and technical training was inferior to academic, liberal arts training (Lynam and Mukhwana, 2021). This indicates the importance of understanding the historical origins of relations between actors in the AR4D sector, particularly the colonial foundations of current arrangements (Mdee et al., 2021).

Institutional histories at the national level continue to inform disciplinary relations in the present. Our conversations indicate that many NARIs do not have in-house social science expertise, meaning they need to look to other institutions to provide these skills, or appoint biophysical scientists to do socially oriented research. This can be seen within the ILCI project where biophysical researchers, often women, are allocated to 'cross-cutting themes' work. Such dynamics are supported by observations from wider literature which suggests that in African contexts, often NARI researchers are appointed to 'social science' positions without formal training, which is attributed to difficulties in finding and contracting social scientists with adequate training (Roseboom et al., 2005: 9). It has been suggested that social scientists in global South contexts are often not drawn to agricultural research, for many reasons, including divides between 'pure' and 'applied' work, the perceived lower status of technical and applied work, and the lack of rewards and career progression within agricultural research institutes (Roseboom et al., 2005; Verma et al., 2010). Due to the scarcity of agricultural social scientists those working in the sector are thinly spread across projects, with implications for their work.

5.9. Global levels of power

Global levels of power relate to formal and informal sites of decision-making beyond the nation state, including international institutions, and donors. ILCI is funded by the USAID Feed the Future (FTF) initiative, and 'national' agendas to 'advance US national security and economic prosperity', and 'reduce *global* hunger, poverty and undernutrition'.

International ideas about research and development influence national strategies through donor-funded interventions. From inception, approaches prioritised by USAID influenced the way the ILCI research process was conceptualised and designed. The US Government Global Food Security Research Strategy (2022–2026), published by Feed the Future, prioritises partnerships and innovation, as well as diversity, equity and inclusion. It also emphasises 'convergence research' which entails 'integrating knowledge, methods

8 Clemson University, Colorado State University, Kansas State University, University of Missouri.

and expertise from different disciplines and forming novel frameworks' to 'solve complex and specific societal challenges' (Feed the Future, 2022: 9). Once developed, such concepts, policies and frameworks take on a life of their own and influence modes of thinking and scientific practices. The promotion of ideas and research framings, which are shaped by a 'global epistemic community' (Harris, 2019: 121), demonstrate the 'global' power wielded by donors and funding agencies.

Awareness of donor power is reflected in comments from COI members who perceive certain crop improvement objectives as 'donor' agendas. One COI researcher explained in relation to new crop improvement approaches, 'speaking from the African perspective, donors stress having a wider scope of thinking. You have to consider the end user, you are not just doing it for yourself but for others … you need other disciplines, breeders cannot do it alone'. Another researcher said 'gender is an aspect that I have to admit we have not explored a lot, but it is on our menu of things that we are supposed to do'. These comments suggest a perception that certain agendas, such as interdisciplinarity and 'gender inclusion' are driven by donors. As Polar et al. (2022) note, experiences to date indicate that including gender in breeding design can be a slow process that gains importance only due to donor demands. However, if approaches are not jointly conceptualised and understood there is a danger they will be seen as impositions and researchers may refuse to 'buy in' to the overall agenda. There may also be a sense that interdisciplinarity and inclusivity are just the latest trends, resulting in performative attempts to meet donor requirements rather than meaningful engagement.

Despite the visible emphasis on inclusion and disciplinary integration there is evidence of a degree of 'double speak' by donors. Some ILCI researchers have the impression that the main thrust of the interdisciplinary research has been on 'new technology that cuts across plant science disciplines', with one person stating 'If you look where the money is going, I would say that is the case'. This implicit focus may privilege certain disciplinary agendas and methods and preclude others. Several respondents intimated *ad-hoc* communication with donors through one-to-one conversations or meetings during which certain priorities and expectations are conveyed. Project leaders mentioned that they were 'conscious of what USAID were looking for' during the proposal writing phase and as such the project 'addressed issues around tools' and set boundaries around how far the project was going in terms of what it could feasibly address. Another mentioned, that USAID 'wanted Cornell in the program because they wanted razzle dazzle technology' and that 'the project probably got funded based on USAID perceptions of how good the team would be'. So, although there is an emphasis from FTF on inclusion (which places an emphasis on social science input), there also seems to be a perception of an implicit steer towards tools and technical 'solutions' which is communicated to project leaders in closed spaces. The implicit steering and tacit signals of donor agencies constitute another form of hidden power.

6. Discussion

Drawing on Gaventa's Powercube framing, this research examined how power dynamics shape interdisciplinarity and social science inclusion in ILCI crop improvement teams. Our results have shown how global epistemic communities (i.e. donors) influence research agendas at the national level, even when these efforts are intended to be 'bottom-up'. In turn, hidden forms of power, such as institutional reputations and resource endowments, influence national hierarchies. Researchers working within national institutions at the local level experience invisible forms of power influenced by disciplinary and gender norms. These intersecting expressions of power have implications for research team members, with some 'core groups' having more authority and visible power than others. Our analysis also reveals how different groups and individuals express their power through different strategies and using different means. Feminist power theory has enabled us to identify forms of power where researchers are building alliances across local and national levels through claimed spaces. Many social scientists, especially women, are practicing power 'with' their peers to claim power. Power 'through' can also be seen where social scientists are invited into more powerful roles and positions through interaction with supportive leadership or 'allies' who use their social and structural power to support them (Hattery et al., 2022).

Theoretically informed power analysis can help researchers better understand the ways in which power acts to reinforce dominant paradigms, and to identify actors, entry points and positive forms of power that can be mobilised in favour of desired changes (Acosta and Petit, 2013). In the ILCI context, power is not only held by individual scientists but is produced through interactions between, actors, discourses, institutions, knowledge, practices, in a range of spaces and across multiple levels. Certain individuals may exert greater power than others, but this is gained and exercised through social relations, institutions and resources. In this case, playing the host enables biophysical scientists to 'maintain a [hidden] structure of rights' (Gherardi, 1996: 192), and as guests, social scientists are assigned a position but cannot achieve ownership. 'Successful assertions of power are therefore embedded within wider networks of power that contribute to their success' (Ahlborg and Nightingale, 2018: 388). From this perspective, because power is produced through relations, which themselves are dynamic, there is potential for change – if the right leverage points can be identified.

Explicitly analysing researchers' actions and drivers, and the structures they operate within produces a more accurate picture of how research happens (Crane, 2014). It also avoids essentialising science as a monolith and instead construes it as 'a dynamic and heterogeneous cultural institution of which we are a part and can thus change' (Crane, 2014: 52). Although existing power dynamics may seem entrenched, power analysis can identify areas that have the potential to 'trouble' or 'unsettle' dominant paradigms, and open up new spaces (Ahlborg and Nightingale, 2018: 388). In the ILCI example, this includes proposals, meeting formats, team members, budgets and timelines – all of which play a powerful and often unacknowledged role in configuring disciplinary power relations and interdisciplinary research assemblages, and offer potential avenues for intervention.

Importantly, as Crane (2014: 49) stresses, 'analysis of scientific practice is not meant as a critique of "science," nor … individual scientists', rather it offers insight into barriers to more effective technology production. Here we must emphasise that the prevailing power dynamics with AR4D 'do not come about because [biophysical] scientists are especially power hungry' (Callard and Fitzgerald, 2015: 97). Indeed, inequitable relations are 'rarely, if ever, explicitly endorsed by life scientists' (Callard and Fitzgerald, 2015: 97). Nevertheless, the world views held by biophysical scientists make it difficult for them to recognise the subjective nature of dominant discourses favouring technical approaches and solutions (Verma et al., 2010). Therefore, they may struggle to see that institutional environments and working practices are skewed towards biophysical understandings and practices, and do not facilitate equitable disciplinary exchange (Verma et al., 2010). In addition, rarely do people want to cede power or authority once they have obtained it. Considering this, social scientists may need to work to overcome the 'inferiority complex' that affects social science globally (Brinkmann et al., 2014: 31) in order to assert the value of their contributions and better negotiate positions of influence.

Our analysis of ILCI, and personal experiences, indicate that one way of addressing these dynamics, is the cultivation of allies, thus working with those who exercise visible power (i.e. biophysical scientists) who understand the need to open up and redesign AR4D. As Chambers (2006) argues, working with the more powerful may deliver 'win-win' outcomes. However, building alliances and coalitions requires a recognition that 'such alliances are often themselves filled with power divisions and conflicts' and may require identifying intermediaries who can facilitate and cultivate positive forms of power (Gaventa, 2021: 17). To do this effectively, there needs to be more in-depth understanding of how those exercising power perceive current dynamics, i.e. seeing things from the biophysical point of view, or in anthropological terms, adopting the perspective of the 'other'. This indicates, among other things, the need for further ethnographic work. Conducting such research could help to build understandings and alliances that could shape future collaborative endeavours.

Although working with more powerful members of research hierarchies may be a necessary strategy for change (Chambers, 2006), this does not preclude working with the least powerful to formulate 'bottom-up' empowerment strategies. Just as AR4D social inclusion agendas recognise that certain stakeholder groups may need to be treated differently to overcome barriers – the same may apply to interdisciplinary research teams. The concept of equity acknowledges that not everyone starts from the same place. 'In the context of research teams, equity requires that we elevate specific people to hold as much space as others by providing more responsive support, or even simply more support' (Hattery et al., 2022: 5). Within ILCI, this might mean designing processes and spaces to overcome structural barriers that impede marginalised scientists from shaping research agendas. It also requires acknowledging the 'deep-seated perceptions and experiences of domination and dependency' (Cundill et al., 2018: 4) that exist within multi-country consortia, particularly between 'donor-researchers' and 'recipient-researchers' (Nshobole, 2021), which affect attempts at collaboration and knowledge integration.

In addition, the creation of shared frameworks and objectives is essential. Although research design frameworks will not nullify power inequities, more explicit guidance on interdisciplinary approaches is necessary. As Lyall et al. (2011: 1) point out, 'the sustained development of strategies to help researchers *how* to collaborate effectively and integrate soundly across different domains remains a key research gap'. Such strategies and frameworks require explicit recognition of interactions between different power dimensions in order to build strategies that work across all forms, spaces and levels of the Powercube (Gaventa, 2021). For ILCI this may mean opening up closed spaces such as proposal writing processes, supporting and incentivising claimed spaces that make disciplinary integration happen, whilst acknowledging and interrogating hidden and invisible forms of power such as budgetary processes and scientific norms that valorise certain forms of science over others. Such efforts need to be carried out across all levels to challenge hierarchies.

Furthermore, it is important to revisit the objectives underlying crop improvement to generate a shared understanding of research agendas and priorities. Key assumptions such as the historic emphasis on yield and the current emphasis on social inclusion – and the rationales underlying these – should be interrogated collectively. Such processes may not be smooth, and may entail difficult conversations, but friction is an important part of advancing ideas and developing new frameworks and ways of working. 'Transitioning away from agriculture that is preoccupied with yields and governed by the notion of competitive markets, towards one that aims towards sustainable [and equitable] food security requires different frames, (Acevedo et al., 2021: 122), and these must be developed across disciplinary, gendered and global divides. The friction of engagement is therefore necessary if crop improvement is to become more responsive to the complex social and ecological challenges that face us.

7. Conclusion

Analysing power dynamics within interdisciplinary crop improvement collaborations indicates that successive efforts to make agricultural research more disciplinary and socially inclusive have been thwarted, in part, by entrenched power structures. Visible, hidden and invisible forms of power, operating between spaces and across levels, reinforce positivist scientific paradigms and prevent efforts to open up knowledge production processes. Many of these paradigms are rooted in Western scientific models which have been transposed and imposed, becoming dominant globally. They work in implicit and explicit ways to prevent integration of social science perspectives which threaten established ways of working.

Lessons about the complexities of interdisciplinary power dynamics derived from ILCI researcher experiences highlight possibilities for transformative opportunities – but this is just the first step in what must be an iterative process of change. Insights from this project should inform subsequent phases of research – both for ILCI and wider initiatives. This further indicates the importance of critical reflexive processes and research documentation. Nevertheless, while this study offers a starting point, rather than being conducted from a largely 'outsider observer' perspective, future studies should include a range of 'insiders' from different social positions who can a provide more situated insights. Such processes of reflection should be built into project design and project implementation.

To do AR4D differently, current structures and attendant power dynamics, need to be questioned, challenged and changed. Solutions are not simple or straight-forward. Nevertheless, if such dynamics are not addressed, social sciences will likely continue to play an auxiliary role (Verma et al., 2010). As a result, social inclusion agendas, which strive to address power and politics in order to enhance the voices of the marginalised, will struggle to achieve their goals.

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 humans were approved by University of Arizona Ethics Committee, Tucson, Arizona, United States. 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 because verbal informed consent was obtained from research participants for their anonymised information to be published in this article.

Author contributions

BC, KS, DR and HT contributed to the conception and design of the study. BC and KS conducted data gathering and analysis. BC wrote the first draft of the manuscript. KS, DR and HT wrote and edited sections of the manuscript. All authors contributed to the article and approved the submitted version.

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Crowdsourcing priorities: a new participatory ex-ante framework for crop improvement

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Demand-led approaches to crop breeding involve ranking priorities across different disciplines and stakeholder categories, but the implications of decisions made during varietal development are frequently understood only years later. Breeding teams must work *a priori* to rank crop improvement priorities and product concepts considering the context of the current, and ideally future, environmental, production and market conditions that a variety will be entering upon release. We propose PEEP (Participatory Ex-antE framework for Plant breeding), a new ex-ante framework, as a methodological tool for priority setting in plant breeding. PEEP leverages two elements: the usage of a heterodox methodological approach and the strong emphasis on the participation of knowledge-rich stakeholders. PEEP ranks crop improvement impacts based on a heterogenous set of environmental, social, and economic benefits and it employs a recursive and tailored multi-stakeholder approach to relate crop improvement impacts and product concepts. PEEP builds on the need to engage technical as well as practical knowledge and utilizes a tailored engagement strategy for each knowledge-rich stakeholder involved. The outcome is an assessment that ranks crop improvement impacts and breeding product concepts according to designed set of criteria. PEEP is scalable, gender inclusive, and crop agnostic. The results of PEEP are ex-ante recommendations for breeding teams in National Agriculture Research centers (NARs) and CGIAR centers alike. This methods manuscript describes the theoretical foundations of PEEP and its four phases of implementation.

KEYWORDS
ex-ante framework, priority setting, research priority, research impact, plant breeding

1. Introduction

Crop breeding is a unique field in which the implications and impacts of decisions made during varietal development will be understood only years later when the resulting variety is released to farmers. Breeders make decisions *a priori* that consider both current and, ideally future, environmental, production and market conditions into which a variety will be released. Significant shifts in breeding paradigms, under the banner of "modernization," now position demand or market-led approaches to be non-negotiable (Tarjem et al., 2022). Yet this reorientation and need to respond to complex diversity are at odds with the limited resources most public sector crop breeding for development programs possess. This creates a need for research prioritization within crop breeding programs (Pemsl et al., 2022). A growing body of literature documenting how social differences drive trait and varietal preferences complicates the picture (Fisher and Carr, 2015; Weltzien et al., 2019), asking breeders to understand the priorities that women and men assign to genetically determined traits (Orr et al., 2018). Moreover, demand-led approaches necessitate ranking priorities with an interdisciplinary team, merging needs from different disciplines and experts, such as plant breeders, gender specialists, rural development experts, agricultural economists, and value chain stakeholders (Pemsl et al., 2022). Current demand-led paradigms that focus on triangulating on-farm genetic gains, market responsiveness, and social impacts need priority setting frameworks that link crop improvement priorities, preferred traits and expected impacts. In this methods manuscript, we describe a participatory ex-ante framework for plant breeding priority setting, focusing on crop improvement priorities[1] and product concepts. The framework, called PEEP (Participatory Ex-antE framework for Plant breeding), is developed to relate crop improvement priorities, expected impacts and hypothetical new varieties. The framework centers on the question: when targeting a specific impact, which hypothetical new variety (expressed in the form of a product concept)[2] should be prioritized by breeding programs? Complementing existing participatory breeding approaches, PEEP explores "why" a breeding priority is important and most impactful, in addition to "what" crop improvement priority is top-ranked.

PEEP leverages two tenets to answer this question: a heterodox methodological approach and the engagement of knowledge-rich stakeholders. In contrast to *ex-ante* frameworks built on economic surplus and optimization modeling, PEEP ranks priorities based on a heterogenous set of environmental, social, and economic impacts determined by stakeholders. Furthermore, PEEP employs an iterative and tailored multi-actor approach. Building on the principle of engaging technical as well as practical knowledge, PEEP involves an array of knowledge-rich stakeholders. The outcome is an assessment that ranks crop improvement priorities and breeding product concepts according to a designed set of criteria, co-created with stakeholders and breeding programs. PEEP produces ex-ante recommendations for breeding teams in National Agriculture Research Centers (NARs) and other crop improvement research centers, including CGIAR, using an analysis which is scalable, gender inclusive, and crop agnostic (Mills, 1997). Complementarily, PEEP could also function as a monitoring tool, to align the research agenda of breeding programs to both existing high-level objectives (e.g., 2030 Sustainable Development Goals) and local stakeholders' needs.

Below we describe the theoretical foundations of the framework and its four phases. In section 2, we locate the work in the literature and highlight the novelty of the framework. In section 3 the four phases of the PEEP framework are described. A brief discussion (section 4) on advantages and limitations of PEEP concludes the manuscript. A pilot with the Institute of Environment and Agricultural Research (INERA) in Burkina Faso is underway to test the practicability and reflect on the experience of PEEP, and those results will be published separately.

1 We define "crop improvement priorities" as research priorities in crop improvement. These include research priorities from the domain of breeding, processing, extension and dissemination, cross-cutting themes and climate.

2 Here we use product concept as defined by Rutsaert et al. (2022). Product concepts are brief narrative descriptions, easy to interpret and present. They describe the morphological characteristics of the seed and plant variety, the main grower requirement that the variety addresses and conclude with an additional list of standardized information (e.g., yield potential, fertilizer needs, maturity, grain usage).

2. Background

2.1. Situating PEEP in ex-ante priority frameworks

Crop breeding is a discipline grounded in foresight of future needs of growers, processors and consumers. Setting research and development priorities ex-ante is therefore a necessity to succeed in meeting these demands. We examined the literature around ex-ante research priority setting approaches to situate our work and identify gaps and opportunities for methodological development. To date, different approaches have been developed to support priority setting in international agricultural research programs (Wiebe et al., 2021; Alston et al., 2022). Applications span from CGIAR-level (case studies can be found in Raitzer and Kelley, 2008), to national research prioritization (e.g., EMBRAPA in Brazil as described by Avila et al., 2002). Recently, the use of international agricultural research prioritization exercises has been more sporadic, with less data intensive procedures preferred (Thornton et al., 2018). These alternative methods range from simple qualitative scoring exercises to highly complex simulation models estimating the functional relationship between inputs (research investments) and agricultural outputs while accounting for the underlying uncertainty (see Braunschweig (2000), for an overview of different priority setting methods).

We summarize existing ex-ante priority setting frameworks (Supplementary Table A1) and characterize them along three dimensions of scale of analysis, translation of benefits into dollar values, and sex disaggregation. These three dimensions represent junctions at which ex ante frameworks that are both locally relevant and gender responsive distinguish themselves from more traditional approaches. Most existing frameworks focus on benefits in economic terms, and rarely using sex-disaggregated data (Supplementary Table A1). Country-level assessments are preferred, even though frameworks allowing a flexible scale of analysis (i.e., national and regional) are common.

Guided by an interest to develop a methodology that could be more participatory and engaging for respondents, we further looked at frameworks for their level of participation and engagement with stakeholders. Participation describes the degree at which studies involve a variety of different stakeholders, beyond scientists. Engagement exemplifies the frequency at which stakeholders are involved and if feedback and validation mechanisms are put in place. Studies in the early 1990s guided by economic surplus theory and cost benefit analysis are less participatory and engaging (for a review see Braunschweig, 2000). Recent modeling approaches with heterogeneous agents are also not participatory or engaging (e.g., Endresen et al., 2011; Groot et al., 2012 in Supplementary Table A1). Participatory varietal selection (PVS)-like approaches where alternative research options are validated by non-academic stakeholders (mostly farmers) are more participatory, but the engagement of stakeholders occurs only as an *a-posteriori* consultation with no feedback loop, where priorities from stakeholders are then validated jointly with scientists (e.g., Randolph et al., 2001; Pemsl et al., 2022 in Supplementary Table A1). Crowdsourcing plant breeding methods (e.g., Steinke and van Etten, 2017 in Supplementary Table A1) engage stakeholders in an iterative manner with easy to implement approaches but they include primarily farmers. A rare example of a highly participatory and engaging framework was Blundo-Canto et al. (2020) in Supplementary Table A1, but also highly complex and abstract.

Methodologies currently available for ex-ante research priority setting encompass simple interactive scoring exercises (e.g., participatory ranking scenarios) to complex simulation models estimating the functional relationship between inputs and outputs (e.g., agent-based models; Supplementary Table A1). Allocating research efficiency and selecting the most promising research activities are issues directly tied to the scarcity of resources for plant breeding in development. Therefore, most existing frameworks place an emphasis on economic efficiency and on costs and benefits that can be expressed in monetary values (Braunschweig, 2000). The economic surplus analysis and the cost–benefit analysis are the tools most frequently utilized. Despite being easy to interpret, these two techniques present a few methodological disadvantages. First, they rarely include non-quantifiable and non-marketable outcomes (e.g., the shadow price of gender-related benefits). Second, in these tools, agricultural researchers provide most of the input, and active participation of stakeholders is quite limited. Third, these tools offer a static representation of the commodity market and thus tend to underestimate longitudinal non-linear dynamics which can affect the breeding process (Petsakos et al., 2018). For example, although some implementations allow for an explicit representation of dynamics in production and consumption (HarvestChoice, 1995), economic surplus models able to analyze well-structured foresight scenarios (like those proposed by the Intergovernmental Panel on Climate Change (IPCC) Davis et al., 1987), are frequently complex and data intensive. Lastly, this economic surplus paradigm has raised concerns because externalities, distributional effects, and longer-term impacts all tend to be neglected with a narrow focus on breeding costs and benefits (Dahlberg, 1988).

2.2. What's new? Novelty of PEEP

To develop PEEP, we took inspiration from the systematic, quantitative ex-ante priority assessment undertaken by the CGIAR Research Program on Roots, Tubers and Bananas (RTB) in the period 2012–2014 (Pemsl et al., 2022). PEEP preserves the systematic and quantitative nature of this assessment, while integrating attention to gender and adapting for utility for national level and crop-specific breeding projects. PEEP complements the literature on methods for ex-ante priority assessment in crop breeding through three methodological advancements. First, PEEP is adaptable at the national level, building on the existing work (Mills and Karanja, 1997; Randolph et al., 2001; Singh et al., 2020; Pemsl et al., 2022). Unlike these studies, PEEP leverages the national focus to better consider the relevance of gendered preferences and access to resources, which are context dependent. Second, PEEP is designed to be consultative in all phases, resembling the frameworks of Pemsl et al. (2022) and Steinke and Van Etten (2017). PEEP includes an array of stakeholders beyond scientists, so that crop improvement priorities are set and validated by social and natural scientists as well as practitioners. Here we define practitioners as local actors directly engaged in agricultural production, processing, and marketing and representatives from, e.g., seed companies, agricultural cooperatives, agricultural women's groups, and national or regional policy makers. PEEP is purposively combining multiple participatory tools to ensure that each category of stakeholders is involved through an approach which maximizes participation and engagement. Third, PEEP considers gender dynamics[3] by seeking gender equity in the evaluation of alternative crop improvement priorities, and product concepts. To the best of our knowledge, no existing ex-ante framework thus far deliberately includes gender as a lens of analysis in prioritization.

Each of these three methodological innovations of PEEP has challenges. For example, PEEP requires a heterogenous group of stakeholders with deep contextual knowledge and local impact pathways. This may sometimes lead to conflict between national and local priorities. Establishing a process to reconcile these conflicts is a key component of the PEEP framework. Furthermore, it is particularly challenging to capture the views of the most vulnerable, but often least accessible, populations. PEEP includes nationally representative stakeholders who have an overview of the relative importance of different opportunities and barriers faced by these populations, but a risk remains that the needs of the most vulnerable respondents may still be missed. Finally, integrating a diversity of stakeholders and gender analysis requires additional expertise and creates a further level of complexity. Trade-offs hinge on who might lose or benefit from new varieties.

We leverage the use of heterodox methodological approaches and a strong emphasis on the engagement of knowledge-rich stakeholders to circumvent these challenges. PEEP ranks priorities based on a heterogenous set of benefits without quantifying impacts in terms of economic return (or net present value). Furthermore, in contrast with other scientific domains (e.g., health and medicine) where priority setting and ex-ante analysis are well-established practices and where engagement is actuated through the Delphi method (Linstone and Turoff, 1975), we utilize a less common iterative and tailored multi-stakeholder approach. Built on the principle of engaging technical as well as practice knowledge, PEEP adapts a diverse tool of engagement to each category of knowledge-rich stakeholders. This avoids multiple, highly resourced, and time intensive, rounds of consultation, especially where participants are not familiar with repetitive research-oriented routines.

How is PEEP any different from existing participatory plant breeding efforts? PEEP is interested in the "why" more than in the "what." Linking crop improvement impacts to product concepts, PEEP generates ex-ante impact pathways. These support breeders in justifying the impact of a future variety when the variety is still simply a product concept. Having clarity on which product concept targets the set of crop improvement priorities considered relevant by a heterogenous group of stakeholders assists breeders in (i) justifying the impact of new varieties under development; (ii) ensuring that product

3 We define gender dynamics as the relationships and interactions between and among girls, boys, women, and men. These are informed by sociocultural ideas about gender and the power relationships that define them. Depending upon how they are manifested, gender dynamics can reinforce or challenge existing norms.

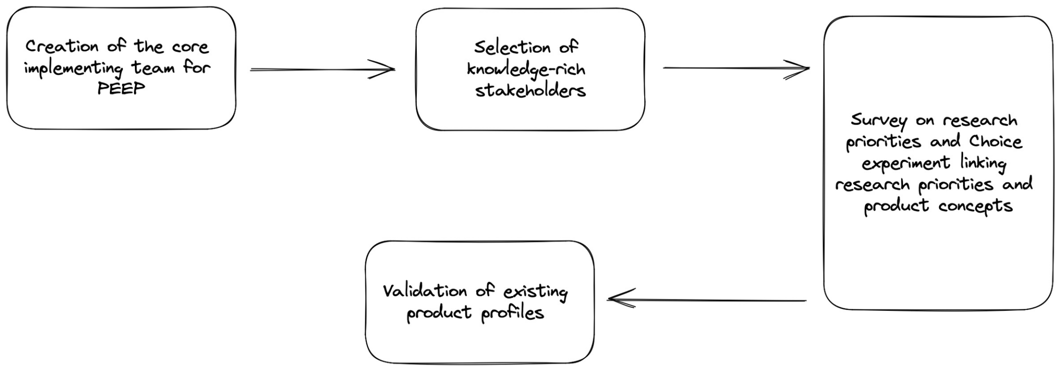

FIGURE 1
Map of the four sequential phases of PEEP.

concepts target priorities and impacts are equitable and fair (iii) justifying the investment made by national and international funders; and, finally, assists breeders in (iv) better marketing of new varieties.

3. Description of the proposed method

PEEP has four sequential phases (Figure 1), detailed in this section.

3.1. Phase 1: creation of core implementing team

In the first phase, the breeding program implementing PEEP must form a core implementing team (hereafter core team). The core team oversees the process development, analyzes the results, and compiles the final assessment report. A set of competencies underlie the selection of individuals for the core team (Box 1) to ensure that the right balance of skills and experience are represented on the team are driving this process. Once assembled, the core team decides the geographical scope of the application (national vs. regional) as well as the target crop. PEEP can accommodate evaluations at the country level or regional level on any crop product concept to be evaluated.

3.2. Phase 2: selection of knowledge-rich stakeholders to form PEEP stakeholders' groups

Assembling a team of stakeholders to engage in the PEEP framework is the second - and possibly most critical - phase of the PEEP methodology. According to their degree of familiarity with the formal (academic) research process, stakeholders are assigned to two groups: (i) group R (Research), and (ii) group P (Practice). The Research group involves any member of a cross-functional breeding team who has technical knowledge of the target crop (see Box 2). Complementarily, the Practice group includes all stakeholders involved into the targeted crop value chain and possess practical knowledge (see Box 2). Engaging the R and P groups with transparency is important, clearly informing each group member about time and resources required to attend the process. For group R, incentives to participate in PEEP might be: (i) contribution to better define national or regional breeding objectives, (ii) the possibility to prioritize gender and climate in the national breeding agenda, (iii) better allocation of resources to crop breeding programs, (iv) possibility to conduct an evaluation which attracts international donors and funding agencies, and (v) networking and round table opportunity for new projects. For group P, incentives might be: (i) steering the breeding work to account for their needs and preferences, (ii) contribute to the development of varieties which are better suited for production and selling purposes, (iii) build social networks with researchers, (iv) tighter links with the local research community, which yield learning opportunities and higher engagement.

Selecting members for the Research group should include consideration of their expertise on the chosen crop, whether they are young researchers or senior leaders, as well as if they are regional or national collaborators working at in-country international centers.

For members of group P, choosing representatives at the national or regional level may be less straightforward. The core team needs to effectively sample a sub-population of producers, traders, processors, consumers, formal and informal agricultural cooperatives, and women's groups. Both at the national and regional level, NARs or CGIAR centers should utilize an informed stratified sampling strategy. If a list of crop producers, processors or traders for each area is available, we highly encourage the core team to use this information to calculate sampling weights

3.3. Phase 3: survey and choice experiment to identify crop improvement priorities

3.3.1. Survey

At the start of phase 3, relevant research priorities are elicited from group R through a large-scale expert survey conducted either online or in person. PEEP provides a generic structured questionnaire as guidance, but the core team adapts and tailors the survey to the crop of reference and specific national context so that it is most useful. Overall, the questions lead respondents to list and explain constraints related to breeding, economic, and gender, as well as climate issues. The questionnaire contains two sections: the first section includes open-ended questions common to all respondents, BOX 1 Set of competencies for the core team

Competencies common to all core team members

Values diversity of perspectives and experience

Seeks representation of social science in research teams and fosters interdisciplinary dialogue

Builds a supportive culture within the working group

Values academic as well as practical knowledge and fosters the exchange of knowledge among experts and stakeholders

Bridges research and development practice

Is open to continuous improvement as a method for improving the research process and its effectiveness

Competencies for breeders, geneticists, pathologists, entomologists, and other members of the breeding team

Demonstrates scientific rigor in the breeding subject of competence

Contributes to breeding scheme design

Contributes actively to developing or improving crop product concepts for the chosen crop in country

Engaged with participatory varietal selection, or participatory plant breeding more broadly

Engaged in the breeding team of the organization and contributes to breeding targets set by the organization

Competencies for gender specialists

Proven foundational gender analysis competencies

Conducts high quality gender research

Interprets and communicates the implications of gender relations as well as gender differences to a multi-disciplinary team at different stages in the research cycle to help the team identify constraints, opportunities, priorities, research outcomes, impacts that need to consider gender

Demonstrate ability to propose and lead a scientific research project addressing social and gender issues

Produces research on social and gender issues suitable for publication

Applies advanced social science concepts and knows how to deepen analysis beyond simple sex-disaggregated comparisons to define implications or outcomes of gender inequality

Makes skillful use of advanced social research design, data collection and analysis techniques to conduct research on strategic gender issues

Leads and champions greater understanding of the relevance of gender to agricultural research

Competencies for climate specialists

Works with climate predictions and meteorological data

Engaged in the use of meteorological data for agriculture

Proposes and conducts research on climate and agriculture

Advocates for including climate in interdisciplinary debates

Integrates climate-smart approaches in plant breeding

Competencies for agricultural economists

Fundamental knowledge of agricultural marketing and economics

Independently conduct of assists researchers in performing economic analysis on a variety of issues related to the agriculture sector

Translates data into written reports/economic analysis, connecting results of analysis to actionable information

Understands how language and culture shape meaning in socioeconomic data collection

Understands basic principles of sampling and controlled comparison in data collection

Has knowledge and experience of different ways to deliver products and services effectively to rural population, to define realistic goals and measurable impacts

Has the skills to independently collect or supervise the collection of reliable social-disaggregated data

Has knowledge and direct experience of ex-post impact assessments, and possibly ex-ante

Has previously engaged actively with participatory varietal selection, or participatory plant breeding

Knowledge of plant product concepts and market segments is a plus, but it is not required

while the second section includes closed questions, tailored to each respondent's competencies. In the second section, respondents are asked to rate the importance of different research priorities using a five-point scale (from "not important" to "very important"). Examples of research priorities are breeding for drought tolerance, improving seed storage, improving traditional processing techniques, developing new products for industrial application, reducing men's and women's health risks of on-farm insecticides use and many more. The first part of phase 3 closely resembles the second step of the RTB ex-ante framework described in Pemsl et al. (2022).

Research priorities are divided into thematic subsets. Each member of the group R will respond solely to the subset of priorities matching their domain of competence. This is done to avoid missing data or including biases in the ranking of research priorities. Data on the personal attributes of the respondents are collected in a third section of the survey.

BOX 2 List of categories in group P and R

Group R (research)

Any member of a cross-functional breeding team, including, e.g.:
Breeders and Geneticists*
Agronomists, pathologists, entomologists, and other members of the breeding team*
Agricultural economists (with expertise in local markets and prices, formal and informal seed systems)*
Gender specialists*
Extensionists, including some with focus on gender
Nutrition specialists (if available)
Climate experts (from National Meteorological Office)*
Food scientists / Food processing experts
Mechanization experts
State or regional policymakers with mandate on agriculture
National policymakers with mandate on agriculture
Non-profit organizations involved in agriculture, development, and gender
Donors – in country and regional missions

Group P (practice)

Producers (social heterogeneity represented, with equal voice to marginalized producers)*
Traders
Processors*
Consumers*
Seed companies
Representatives from farmers agricultural cooperatives and organizations
Representatives from informal and formal agricultural networks
Representatives from women's agricultural groups*
Agro-input dealers
Regulatory bodies for certifying seeds and GM production
Consumers' organizations - including, among others, representatives from women's entrepreneurs' groups and representatives from women's advocate groups

*Non-negotiable members of each group to ensure representative and actionable results.

The following thematic subsets with their appropriate respondent categories are exemplified below:

– Crop Improvement domain, whose research priorities are rated by

  o Breeders and Geneticists
  o Agronomists, pathologists, entomologists and other members of the breeding team

– Processing domain, whose research priorities are rated by

  o Food scientists / Food processing experts
  o Mechanization experts

– Marketing, whose research priorities are rated by

  o Agricultural economists (with expertise in local markets and prices, formal and informal seed systems)
  o Non-profit organizations involved in agriculture, development and gender
  o State or regional level policymakers with mandate on agriculture
  o National policymakers with mandate on agriculture

– Cross-cutting themes, whose research priorities are rated by

  o Gender specialists
  o Extensionists with focus on gender
  o Nutrition specialists (if available)
  o Non-profit organizations involved in agriculture, development and gender
  o Adm2 policymakers (at the state or regional level) with mandate on agriculture
  o National policymakers with mandate on agriculture

– Climate, whose research priorities are rated by

  o Climate experts (from National Meteorological Office)
  o National policymakers with mandate on agriculture

Data on the personal attributes of the respondents are collected in the third section of the survey.

Following the strategy in Pemsl et al. (2022), research priorities in the survey need to conform with the following criteria: (i) the research creates a global public good in the form of a new, adoptable product concept addressing a key constraint or targeting a PEEP opportunity for the crop of reference; (ii) impact would materialize within the 25-year assessment period; and (iii) the research scope is within the NAR or CGIAR center capacity and its mandate, prioritizing the needs of (smallholder) farmers and other vulnerable groups in the country. Furthermore, listed research priorities must be addressable in the next 5–10 years, given the technical and institutional capacity of the breeding programs involved. This helps the group to understand what research can be done, in addition to what is priority, and it gives a sense of possibility that can be acted on.[4] Results from the survey are the first research output of PEEP and represent *per se* an interesting overview of how research priorities are listed and ranked among disciplines.

Overall scores within each thematic domain enable selection of research priorities. The first three[5] top-ranked research priorities in each thematic domain are selected to be included in the choice experiment with group P (see below), for a total of 12 possible research priorities. The domain of crop improvement is excluded because

4 This is analogous to research on traits. If a study presets the list of traits that is asking about, and this is based on traits that they can currently breed for, any priority information is immediately actionable. The utilization of open ended questions would deliver an array of information more detailed on trait preferences, but qualitative data are harder to act on immediately. This is a tension to be aware of.

5 We advise that the list is as complete as possible. However, as the number of combinations in the experiment grow exponentially with the objects to be evaluated (and there are computational limits to consider, to keep the framework as agile as possible), we highly recommend NARs/CGIAR centers having a maximum of 12 research priorities (3 top-ranked priorities for 4 different thematic domains, excluding crop improvement).

priorities in those areas are used to develop the product concepts.[6] The selection of product concepts should consider the scope of the NAR or CGIAR center research activities to ensure a good match of assessed options with the program portfolio. In addition, the core team reviews the final list of research priorities to summarize if and how they are considerate of gendered preferences.

Once the list of crop improvement priorities is ranked by the group R, the core team will develop a list of crop improvement impacts which are directly linked and derived from the priorities selected. For example, if the research priority is "Development of new cowpea varieties which are drought resistant," the corresponding impact will be "Help you deal better with drought while cultivating cowpea." This step ensures that priorities are intelligible for actors of group P and are seen as actionable.

3.3.2. Choice experiment

Once the list of rank crop improvement impacts is assembled, the group P is formally engaged into the PEEP framework. Group P is involved through a crowdsourcing method which closely mimics gamified choice experiments. Gamified choice experiments follow a strict and replicable guideline and provide quantitative results, which can be compared with previous evaluations and the results of alternative methods for priority setting (for an application in the domain of priority setting see the paper of Steinke and Van Etten, 2017).

The choices presented to respondents consist of a set of three product concepts, starting from available end-users' preferences on crop traits and existing product profiles. Here we draw on recent approaches of concept testing to explore motivations behind the choice of one variety over another (Rutsaert et al., 2022). Concept testing entails showing a new product idea through a description or visual material, with the goal to obtain feedback and eventual interest in purchasing the variety. Product concepts are brief narrative descriptions, easy to interpret and present. They describe the morphological characteristics of the seed and plant variety, the main grower requirement that the variety addresses and conclude with an additional list of standardized information (e.g., yield potential, fertilizer needs, maturity, grain usage). Beyond containing the narrative for the product concept, the script includes suggestions on posture, voice tone and other non-verbal instructions to ensure a clear understanding of the product concepts by the stakeholders (Rutsaert et al., 2022). Product concepts are developed by the core team based on existing product profiles, and crop improvement priorities from the survey with group R.

Each product concept is then presented along with the research impacts derived from the survey with group R (see Figure 2). Respondents will be asked "Which of these three new varieties will help you the most to achieve impact A? Which will help you the least?." The three new varieties, presented in the form of product concepts, will be assessed against all 12 impacts (Figure 3 provides an example). Respondents will have the opportunity to declare that the impact is linked with none of the three product concepts proposed (exit strategy). Enumerators will also present research impacts in a random order to each respondent, to ensure that not always the same impacts are presented at last when survey fatigue is at the highest peak (Figure 3).

Once the choice experiment is concluded, the core team utilizes well-established ranking models, especially the Plackett-Luce model, to analyze the data. Calculating the log-worth of each research impact, the core team is able identify which is the product concept with the highest probability of being associated with each impact by the category of group P interviewed.

3.4. Phase 4: validation and feedback

The main result of phase 3 is the prioritization of impacts from crop improvement impacts and how they map to a set of given product concepts. This helps breeders to align their prioritization of product concepts to meet impacts. During this phase, breeders, geneticists, agronomists, pathologists, and other members of the breeding team are responsible for integrating crop improvement impacts. Concretely this means answering two main questions: are existing product concepts able to address the impacts? If not, what information is missing?

A tension might emerge from this validation: on the one hand, the breeding team needs to work with product concepts that are realistic given the technical and institutional capabilities of the NAR or the CGIAR center. On the other hand, the team needs to ensure that previous efforts do not get lost in the name of "*breedability*" of alternatives.

We encourage the ex-ante team to repeat the analysis at every new breeding cycle. If the team perceives that a change in priority might have occurred earlier–due to a new agricultural policy, a climate event, or an expected shock like the Covid-19 pandemic–the ex-ante exercise can be repeated prior to the closing of the breeding cycle.

4. Discussion

We started this methodological work out of necessity. When working with NARS breeding programs to provide support on how to systematically, and most importantly, inclusively set crop breeding priorities, we were unable to identify methods to do so. When we scoured the literature on methods to set crop breeding priorities ex-ante, holistically and inclusively we identified a gap that this methodological work has attempted to fill. We outline in this paper PEEP, a method that provides an answer to a key question for breeding teams: when intending to achieve a specific impact, which product concept should be prioritized for development? To our knowledge there is no other method or approach that seeks to directly engage farmers, and other end users and beneficiaries of crop varieties, to link impacts that are important to them, with options for breeding programs to work on (Brown et al., 2020). In this sense PEEP creates the opportunity for a broader range of stakeholders to "have a say" in crop breeding priority setting. This consultative, if not participatory, underpinning to the work is timely and an important contribution to the field at a time when demand-led breeding is taking center stage. Just as participatory plant breeding can be described as highly client-oriented breeding (Witcombe et al., 2005), we see PEEP as highly client-oriented crop breeding priority

6 Examples of research priorities in the domain of crop improvement are "breeding for high yield," "breeding for biotic stresses," "improving soil fertility," etc.

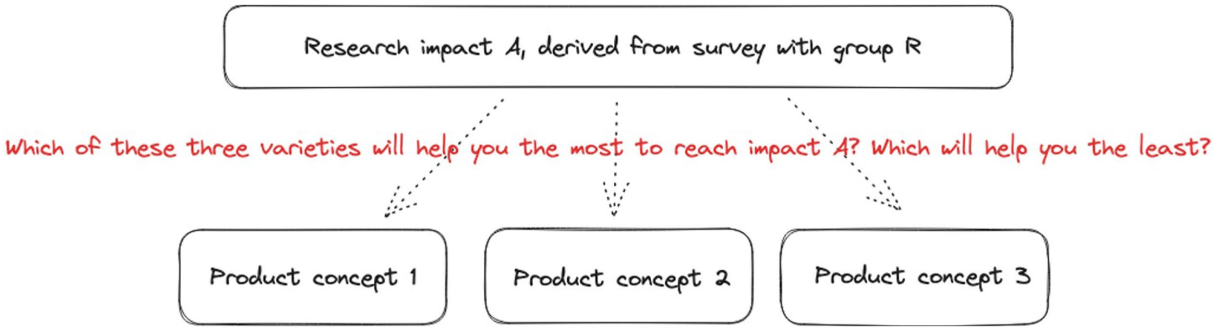

FIGURE 2
Stylized representation of the choice experiment.

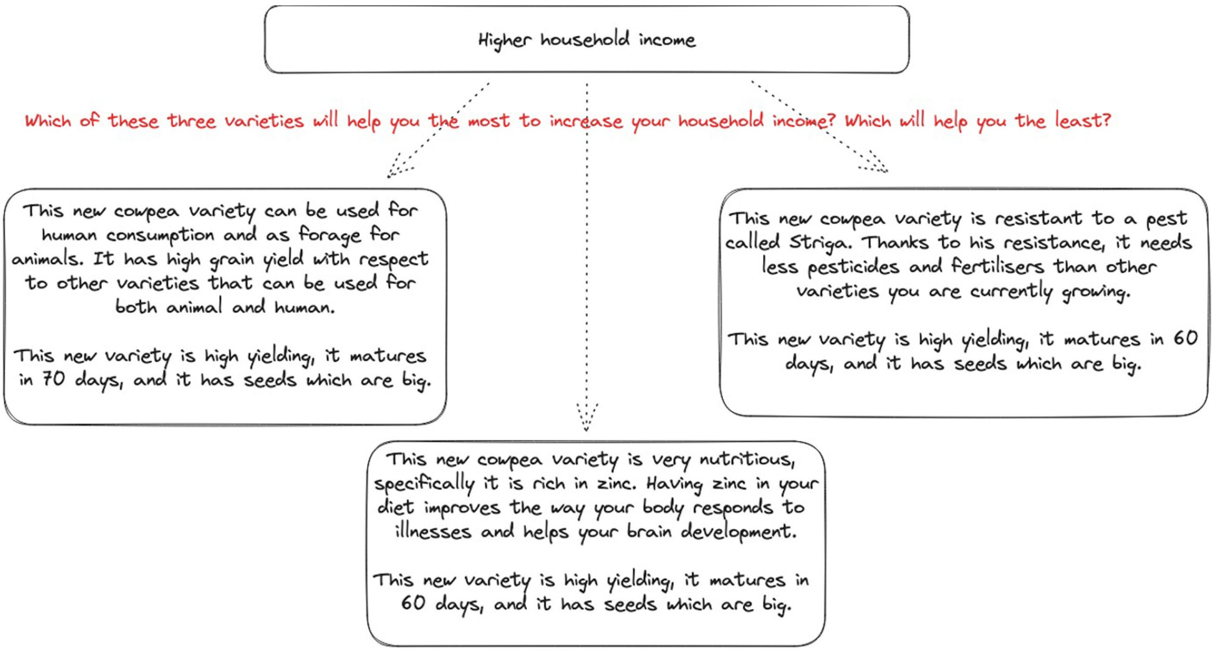

FIGURE 3
Example of the choice experiment.

setting. PEEP is therefore closer to the Blundo-Canto et al. (2020) ex-ante prioritization framework.

Creating meaningful choices of crop varieties can be understood to be a form of empowerment for marginalized farmers (Polar et al., 2021). Using this framing, we place importance on engaging a broad range of socially heterogenous farmers, with emphasis on engaging marginalized women and young farmers in design and implementation of PEEP. This allows the framework to conform with the minimum standard of sex-disaggregation in data collection needed to conduct gender analysis (Doss and Kieran, 2014) and can be adjusted to add layers of socioeconomic data to further enhance analysis. In doing so, PEEP allows breeding programs to observe if targeted impacts are prioritized equally by different actors involved, or if a socially distinct sub-group (e.g., illiterate women or men widows or widowers, single parents) would give different weights to alternative impacts.

Departing from cost–benefit and investment considerations, PEEP leverages methodological approaches typical of heterodox economic disciplines. This entails relaxing assumptions around economic efficiency in favor of non-quantifiable and non-marketable outcomes, produced by rankings elicited from technical and non-technical actors endowed with different types of knowledge and power. In doing so, PEEP contributes to expand the field of priority setting beyond ex-ante investments allocations to include considerations on externalities, distributional effects, and longer-term impacts.

In building a flexible and versatile ex-ante priority setting framework, we aim to demonstrate that national and international research organizations would benefit from systematic and integrated priority assessment cycles that are repeated and constantly adjusted over time, with deliberate learning incorporated into each loop. This will strengthen frameworks and processes, contribute to institutional memory and capacity building, and increase relevance of priority setting for decision making while reducing its costs.

These insights are crucial for the public sector breeding for development, that distinguishes itself by explicitly focusing on social inclusion outcomes, such as gender equality, poverty alleviation and food security as laid out in the sustainable development goals. We expect the framework to guide public crop breeding institutions, such as national agricultural research centers and CGIAR centers. Complementarily, the framework has the potential to be appealing and benefit private breeding programs too. Understanding clients' breeding priorities and expected impacts help private programs to create better products, with higher adoption, profits and return on investment (Ragot et al., 2018).

The framework has limitations. First, it does not account explicitly for trade-offs among crop improvement priorities and impacts. Trade-offs hinge on who might lose or benefit from the breeding process. For example, reduction in yield loss might matter to a farmer but market share by women purchasing a lower-yielding but lower-labor or higher-nutrient crop might matter more to a seed company if it increases sales among women. In aggregating results from the choice experiment, trade-offs and win-lose become less visible to the breeding team. Second, the framework does not plan for a validation step between the survey and the choice experiment: the group P can choose the best and worst combination between impacts and concepts, but, in the current version of the framework, they can neither expand nor modify the set of impacts on which to perform the choice. Piloting the framework will help to mitigate these pitfalls, while possibly highlighting others.

5. Conclusion

There is an increasing need for systematic priority setting to guide resource allocation in international public agricultural research. Effective research prioritization in crop breeding requires an ex-ante evaluation of program activities. The PEEP priority setting ex-ante framework proposes an interdisciplinary, multi-stakeholder and gender-intentional approach to rank crop improvement priorities, impacts and product concepts to perform an ex-ante breeding assessment. While methods and tools within PEEP are not new, taking them to scale and incorporating multiple objectives by analyzing gender, and national/regional benefit allocation represents a substantial advancement over previous efforts. We also experiment with ambitious targeting and stakeholder engagement processes, which help to ground truth the selection of research options, resulting in a high level of stakeholder awareness, and yielding potentially important lessons learned.

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 review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the [patients/participants OR patients/participants legal guardian/next of kin] was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

MO: Conceptualization, Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing. DR: Conceptualization, Funding acquisition, Methodology, Supervision, Writing – review & editing. HT: Conceptualization, Funding acquisition, Methodology, Supervision, Writing – review & editing.

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Conflict of interest

DR is an owner of Cultural Practice, LLC. DR has no direct or indirect conflict of interest with Cornell University, Frontiers, or the organizations involved in or funded by this study.

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

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2023.1265109/full#supplementary-material

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Intra-household discrete choice experiment for trait preferences: a new method

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Crop trait and varietal preferences are socially shaped, varying by gender, experience, and on-farm roles. This drives preference heterogeneity, between households but also within households. Adhering to the common practice of only interviewing the household head as a representative of households, leads to breeding programs collecting trait preferences that do not represent the experiences of other members within that household. This dearth of data on trait preferences of multiple household members could be hindered by the lack of robust and agile methods to collect this data. Here we present a method that explores intra-household differences between husbands and wives in trait preferences through choice experimentation, coupled with questions that capture decision-making, experience and time spent on farm to explore how these drive preferences. Dissecting crop management into three dimensions, we explore what drives intra-household heterogeneity in varietal preferences between husbands and wives, as well as, decision-making, crop experience and time spent working on the crop. We present preliminary results from testing this combined protocol with 270 cowpea growing households (540 respondents) in Senegal. The findings from this work hold promise to inform crop breeding programs on the value of intra-household analysis for trait priority setting, while offering a new method which is applicable by National Agricultural Research Organizations globally.

KEYWORDS

intra-household analysis, Senegal, cowpea, discrete choice experiment, gender

1 Introduction

Breeding programs are becoming more demand-led, yet farmers do not always accept the improved crops developed (see among others, Sheahan and Barrett, 2017; Macours, 2019; Michler et al., 2019; Takahashi et al., 2020). One of the reasons this adoption gap may occur, is that varietal traits tend to be valued differently by different household members (Tufan et al., 2018; Marimo et al., 2020; Maligalig et al., 2021; McEwan et al., 2021; Krishna and Veettil, 2022). This heterogeneity in intra-household preferences is poorly captured by existing crop trait and varietal priority setting practices, with few priority setting studies focusing on intra-household crop and trait choices (Marimo et al., 2020; Occelli et al., 2023).

Members within a household diverge in crop trait preferences when they face different constraints and have varied responsibilities and production goals (Doss, 2001; Teeken et al., 2018; Weltzien et al., 2019). Furthermore, crop management roles at different stages within the crop life cycle are recognized to affect users' acceptability of breeding products (Laborte et al., 2015; Ashby and Polar, 2019). Yet, for setting trait priorities, crop breeding programs frequently collect only the preferences of the household head (or one member of the family) which are implicitly assumed to reflect those of the entire household (Asrat et al., 2010; Pant et al., 2012; Mengistu et al., 2019). The rationale behind this trend is the assumption of the household as a single decision-making unit where there is a shared utility function among family members (Becker, 1965) despite the ample empirical evidence that rejects the unitary household model (Hoddinott and Haddad, 1995; Udry, 1996; Attanasio and Lechene, 2002; Duflo and Udry, 2004). Interviewing only one person, usually the eldest man or the head of household in the family, misses important information about other actors in the household, resulting in only a partial understanding of the adoption process (Joshi et al., 2019). This is true even if women heads of households are interviewed, as their experiences seldom represent the experiences of women who live in male headed households (Doss and Kieran, 2013; Carletto, 2021). As a result, there is a lack of literature on the influence of intra-household preferences on crop decision-making and technology adoption (Gulati, 2016; Maligalig et al., 2017).

As the recognition of the gendered division of labor and knowledge in varietal selection continues to grow (Lope-Alzina, 2007; Teeken et al., 2018; McDougall et al., 2022; Smale et al., 2022), attention should shift toward understanding the influence of intra-household dynamics on trait choices. If household members possess different preferences for crop attributes, then this should be considered by crop breeders when setting breeding objectives. By doing so, breeders can practice more gender-equitable trait and varietal development processes.

The scarcity of intra-household trait preference studies might have roots in the orthodoxy around the unitary household model, but we posit that it is also the lack of standardized data collection methods that exacerbate this persistence. Looking back at 30 years of socio-economic data collection, Doss (2021) describes how feminist economics has been at the forefront of intra-household analysis in socio-economic studies. Many examples testify that intra-household data are increasingly made available: among others, women's empowerment is measured intra-household with the Women's Empowerment in Agriculture Index (WEAI) (Alkire et al., 2013) and the World Bank Living Standard Measurement Surveys – Integrated Surveys on Agriculture (LSMS-ISA) collects plot-level data on who manages the plot. Asset ownership is another topic where intra-household data collection has been impactful (among others, see Deere and Doss, 2006; Doss et al., 2014, 2018). Studies investigating intra-household decision-making are also more numerous: among others, worth citing here Bernard et al. (2019) which uses vignette to describe how within households reasons of production and consumption are made. There is however a dearth of data on intra-household data on trait and varietal preferences from different household's members.

To close the data gap between intra-household analysis and trait preferences, exploration of methods which build on widely known data collection tools, while leveraging best practices from intra-household research are needed. In this study, we propose an intra-household discrete choice experiment method for capturing trait preferences, joining a brief survey module on intra-household decision-making, time use and years of experience in a survey administered to both husbands and wives[1], combined with a standard discrete choice experiment protocol. Dissecting crop management into three dimensions, we explore what drives intra-household heterogeneity in varietal preferences between conjugal couples.

Discrete choice experiments have proven successful in quantifying farmers' preferences and produce results which are tangible for breeders and plant scientists (Anugwa et al., 2022; Miriti et al., 2022). Using a discrete choice experiment framework, bundles of attributes are evaluated. This allows an assessment of how individual choices change when one or more of the attributes varies. Whenever prices are included in a discrete choice experiment, individual choices can be expressed in terms of willingness-to-pay for one attribute rather than another. A large amount of literature has documented agricultural growers' trait preferences using choice experiments, with a particular emphasis on sub-Saharan African countries (among others, see Labarta, 2009; Waldman et al., 2017; Kimathi et al., 2022). Discrete choice experiments present non-negligible drawbacks as method, among others the susceptibility to hypothetical biases and the limitation in the number of traits that can define a crop, without risking decision fatigue with an overwhelming number of choice sets or traits per profile (Burns et al., 2022). However, the use of choice experiments does have two main benefits. First, it does not require longitudinal market data, which are hard to collect and rarely useful in disentangling the effect of each trait on farmers' choices due to correlations between traits (Miriti et al., 2022). Second, choice experiment analyses offer a means through which the nuances of decision-making can be understood by providing insights into implicit trade-offs between different traits (Khanal et al., 2017).

The quantification of trade-offs make discrete choice experiments particularly informative for studying intra-household heterogeneity in trait preferences, but the combination of choice experiments and intra-household methods have not been explored. On one hand, sex-disaggregated data on trait preferences have been collected through choice experiments. For example, Marenya et al. (2021) show that men and women farmers in Kenya have similar preferences for maize traits but showcase different trade-offs between traits. Martey et al. (2022) observe wide dispersion of willingness-to-pay among women cowpea farmers relative to men cowpea farmers in Northern Ghana, with participation in cowpea training contributing to reduce the dispersion of WTP for both men and women (for other examples, see Asrat et al., 2010; Fisher and Carr, 2015; Kassie et al., 2017). However, few studies use choice experiments with an intra-household approach and even fewer do so for crop trait preferences. Intra-household choice experiment

1 If the household is not composed of a head and a single spouse (for example, it is a polygamous household or a household headed by a widow), respondents should be the adult man or woman agricultural decision maker.

methods have been used mainly to explore the acceptance of new agricultural technologies: see Gulati (2016) on rice transplanting technology and Maligalig (2018) on rice improved varieties. Joshi et al. (2019) combine measures of willingness-to-pay with results from the Women's Empowerment in Agriculture Index (WEAI), finding that the respective gender roles of women and men in the family and on the farm are aligned with their preferences for the labor-saving direct-seeded rice technology. Krishna and Veettil (2022) evaluated wheat preferences in 420 households in the central Indian state of Madhya Pradesh. Most women respondents were not actively involved in making decisions related to wheat cultivation, including varietal selection. However, the results indicate that women farmers were open to experimentation with new varieties, a conclusion derived from their positive willingness to pay for improved varietal traits.

Building especially on the work of Joshi et al. (2019) and Krishna and Veettil (2022), we construct an intra-household discrete choice experiment protocol to explore trade-offs and preferences among crop attributes, in relation to decision-making, experience and time spent on farm for conjugal couples. In this paper, we present a description of our method along with preliminary results from a pilot with cowpea growers in Senegal. The choice of cowpea producers in Senegal to test the method itself is a contribution to the literature, due to the scarcity of choice experiments with farmers in the region. The paper is structured as follows: Section 2 describes the method in detail, Section 3 presents preliminary results, and Section 4 discusses findings considering the protocol testing.

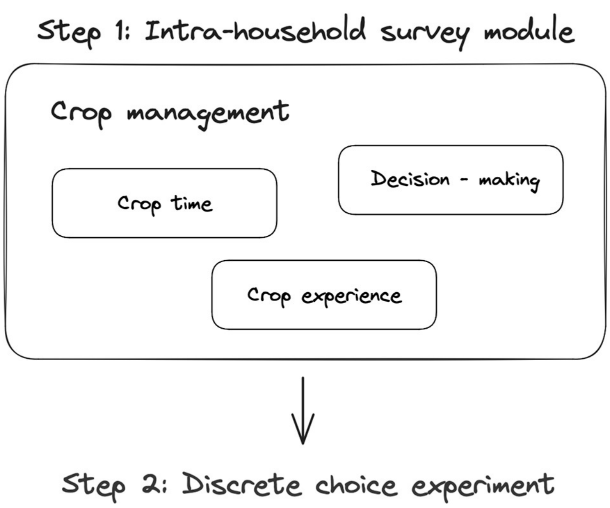

FIGURE 1
The intra-household discrete choice method. Both steps 1 and 2 are administered to spousal couples, or male and female adult decision makers as appropriate.

2 Description of the intra-household discrete choice experiment method

The method has been developed by a team of agricultural economists, breeders and gender specialists affiliated with the Feed the Future Innovation Lab for Crop Improvement, based at Cornell University (US), the Bureau of Macroeconomic Analysis at the Senegalese Institute of Agricultural Research (Senegal) and Cultural Practice, LLC (US). The method comprises a combination of two tools: a brief survey and a streamlined discrete choice experiment (see Appendix I for full tools). We summarize the steps and process in Figure 1, with each step being administered to both spouses within each household producing the crop of interest. For good practice in collecting data from men and women, both tools should be administered separate to the respondents, and where possible by enumerators who identify as the same gender category as the respondent. The method is crop and region – agnostic, but it should be adapted to the crop and region of interest whenever implemented.

2.1 The crop management module

The survey builds on the premise that decision-making dynamics, experience with the crop, and time spent on producing and processing the crop of interest may shape trait preferences within the households. To collect enough information to test this hypothesis, the survey is composed of three modules.

The decision-making module (Section B in Appendix I) investigates who within the household make decisions on the crop of interest, at the pre-harvest, harvest and post-harvest stage. Both household members are asked who within the household makes most of the decisions on crop varieties to be planted, inputs usage, timing of cropping activities, land allocation, intercropping (if practiced) and what to do with the harvested crop. Household members can reply that they perform the activity alone, jointly with their spouses, that their spouses alone are decision-makers, or that other members of the household are making most of the decisions on a specific activity. This module maps decision-making in well-established indices such as the WEAI (Alkire et al., 2013) and it mimics tools used in the literature on intra-household bargaining outcomes and technology preferences (Chiappori et al., 2002; see, among others, Akresh, 2005; Anderson et al., 2017). We are aware of the shortcomings of directly elicited decision-making questions, and the more recent best practice around vignettes as a more effective method (Bernard et al., 2019), however for practicability we have chosen to use the current approach.

Decision-making is not the only dimension which determines intra-household trait preferences, with accumulating evidence that experience (often proxied with age and gender) influences crop management decisions within the household (Deressa et al., 2009; Amare et al., 2018). Analogously, time spent working on the plot where the crop of interest is cultivated is also important. Udry (1996) identifies time as a key element to identify the relation between gender and the agricultural production. Pierotti et al. (2022) show how time poverty limits women's role and preferences in farming. In line with these studies, we enrich our survey with a module on crop experience (Section C in Appendix I) and a module on time spent on the plot (Section D in Appendix I), where respondents are asked to list the experience (years engaged in the production of the crop) and the time spent on activities related to the crop production of each household member respectively. These three modules are accompanied by a brief introductory section (Section A in Appendix I), where interviewed household members are asked basic sociodemographic (age, gender, education level, farmers' group membership) and agronomic questions (land under cultivation of the crop of interest and income from the crop). Furthermore, each respondent interviewed is asked to compile a roster of household members, declaring whether they are involved in the production of the crop of interest.

In its entirety, the survey sheds light on the complexity behind crop roles. By eliciting respondents' own and others' perceptions on decision-making, experience and time, the survey highlights not only which household member scores higher in each module, but also the degree of intra-household agreement on crop roles. Furthermore, the interaction between decision-making, crop experience and time, cemented by gender norms, is informative of trait preference heterogeneity within the household.

2.2 The discrete choice experiment

The discrete choice experiment uses pictorial choice sets and asks respondents to choose their preferred choice among a set of predefined options. This part of the method follows closely the established literature on discrete choice experiments (McFadden, 1973, 2001) and it contributes to elicit trade-offs among diverse bundles of traits as the choices proposed to respondents represent different combinations of traits for the crop of interest. Following Kolstad (2011), Ryan et al. (2012), and Wasserman-Olin (2020), we use the discrete choice experiment part of our method also to examine the impact of variations in cowpea attributes on the likelihood of an individual adopting a particular cowpea variety. An example of a choice experiment card is reported in Section E, Appendix I. Since the choice experiment is not gamified, cheap talk and repeated opt-out reminders were given to respondents to mitigate respondents' bias (Tonsor and Shupp, 2011).

To select the traits included in the cards, along with the associated levels, the method proposes a two-step approach. First, a literature review establishes a potential list of traits that are considered relevant by the respondents' category (for example, crop producers). Whenever possible, disaggregated trait preferences based on several dimensions including gender, age and region should be considered. Second, breeders specialized on the crop of interest are consulted to inform which traits the national breeding program is actively prioritizing, ensuring that the choices proposed are appealing to the targeted category of respondents and trait levels align to existing product profiles, and are actionable by breeders.

2.3 Data analysis and synthesis

Once data are collected through the intra-household discrete choice experiment, the method allows to assess the utility of different trait bundles. Researchers can employ any of the discrete choice model suitable for this scope. We find it intuitive to employ coefficients obtained from a mixed logit model and convert them into probabilities of selection compared to the base level bundle. The base level bundle is represented by a combination of traits which are assumed to be the least desirable by a respondent (e.g., low yield, low biomass yield, long maturity, etc.).

Utilizing a mixed logit model enables researchers to relax the assumption that unobserved factors are uncorrelated over alternatives and there is the same variance across all alternatives. In the evaluation of alternative trait combinations, it is highly unlikely that different unobservable respondents' characteristics (such as attitudes, beliefs, risk perceptions) are uncorrelated over trait bundle alternatives. In a similar fashion, it is probable that some trait bundle alternatives are less appealing for the overall sample studied. therefore, the mixed logit model (or random parameter logit) is flexible enough to permit heterogeneity across individuals and time, and it overcomes the limitations of the conditional logit model by allowing for random taste variation, unrestricted substitution patterns, and correction in unobserved factors (Train, 2009). Equation 1 specifies the mixed logit utility function:

$$U_{ij} = \beta_i X_{ij} + \varepsilon_{ij} \tag{1}$$

where β_i is vector of mean attribute utility weights in the sample and σ_i is the vector representing farmer i specific deviation from the mean. X_{ij} are trait bundle alternatives and ε_{ij} is the random error component. β_i ensures that the mixed logit coefficients vary among sampled respondents, generating the heterogeneity exploited by the method to investigate different intra-household probabilities of selection compared to the base level bundle.

By considering the base bundle as the least attractive trait bundle from the respondents' perspective, modifying just one level of the crop attribute significantly enhances the utility and selection probabilities of farmers. More specifically, the probability indicates the likelihood of selecting a specific trait bundle relative to the base bundle. The attribute categories in a trait bundle "b" are dummy variables, taking the value 1 if included and 0 if not. To find the probability of selecting each bundle relative to the base bundle, we transform the ordinal utility calculations into odds following Equation 2.

$$Odds_{\,b} = e^{U_b}$$

$$Prob_{\,b} = \frac{Odds_{\,b}}{Odds_{\,b} + Odds_{\,base}} \tag{2}$$

The probability of selecting a trait bundle relative to the base bundle alternative is a rather straightforward way to synthesize the data collected through the method. However, the method becomes particularly informative if probabilities are disaggregated by socially relevant variables collected through the socio-demographic or crop management modules of the survey. Following Equation 2, probabilities can be segmented by sex, by decision-making, time and knowledge dimensions. Furthermore, they can be segmented by agreement between respondents on responses to each module and question.

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3 Piloting the method with cowpea growers in Senegal

The testing of the method was carried out in the Peanut Basin area, Senegal, in February-March 2023. The area includes six administrative regions (*Louga, Kaolack, Fatick, Diourbel, Thies and Kaffrine*) and it accounts for a sizable portion of the country's land area and population (Beye et al., 2022). We chose to focus on these regions due to their high agricultural productivity, which is critical to the country's economy (Toure and Diakhate, 2020). In these areas, crop production is primarily characterized by cereal-leguminous rotations, with millet, maize, groundnuts, and cowpea being the main crops grown for home consumption (United States Agency for International Development, 2016).

The research team agreed to test the method with households who are engaged in cowpea production for two reasons: first, the study area experienced a decrease in rainfall levels in recent years, leading to environmental degradation and loss of plant cover (Faye and Du, 2021) which his has led to cowpea cultivation becoming a strategic crop choice for farmers in the area due to its drought tolerance compared to other rainfed crops; Second, in Senegal cowpea is commonly grown by both men and women farmers (Guendel, 2009; Smale et al., 2022).

3.1 Sampling and administration of the socio-demographic and crop management modules

In July 2022, the Senegalese Institute of Agricultural Research collected an array of socioeconomic and agronomic data on cowpea producers in the Peanut Basin area. This baseline data provided useful insights on socio-demographic characteristics of cowpea producers in the area, such plot size, number of varieties produced, and top-2 ranked trait preferences by household heads. This information was used to refine the intra-household choice experiment and to guide the sample size calculation.

We used a three-stage sampling technique to select communes/municipalities, villages, and agricultural households to include in the pilot. The number of communes per region was determined by calculating the agricultural weight based on each region's 2017–18 cowpea production values, allowing us to randomly select an average of four communes from each region. Using GIS locations from the 2022 survey, we randomly chose two villages from each selected commune, resulting in a total of 45 villages where we conducted our survey. To focus on intra-household roles and preferences, we interviewed household heads and spouses from monogamous and polygamous agricultural households who produced cowpea. At the village level, we randomly selected six households from a list of cowpea producers in the region, provided by the village chief. Additionally, we chose five households from the list as proxies to replace any original households that were absent or unwilling to participate. The total number of responding households was 270, and we collected data from 540 individuals. Interviews were conducted in the homestead, separately between heads of households and spouses to minimize potential influence in responses and we randomized the order of the interviews in each household. In polygamous households, we interviewed any available spouse who was involved in cowpea production and could provide time, as we found no evidence of any established ranking among the spouses in our study areas.

The survey team consisted of six enumerators (four men, two women) from the Senegalese Institute of Agricultural Research. We initially planned to pair same sex respondents - enumerators, to avoid mistrusts and biases in responses, but during recruitment we encountered difficulties to engage women enumerators. Enumerators were selected for their prior surveying experience and proficiency in local languages, specifically *Wolof,* to effectively communicate with the participants. Before conducting interviews, the enumerators received a week-long training on the method objectives, on the survey and the discrete choice experiment to ensure consistent and clear survey execution and conceptual explanations.

3.2 Design of the discrete choice experiment

To design the discrete choice experiment, we followed the two-step approach previously described. Firstly, we conducted a literature review on traits and attributes for cowpea in Senegal. Our primary list of traits was inspired by the seminal paper by Kitch et al. (1998), which classified each cowpea-related trait into three categories - yield, quality and labor-related. Similarly, the baseline data collection in July 2022 conducted by Senegalese Institute of Agricultural Research in the same area informed the first list of 10 traits to be prioritized in the choice experiment.

However, to reduce the study complexity while maintaining the efficiency of the choice experiment design, we had to further restrict the number of traits. Evidence suggests that farmers make correct choices when presented with fewer attributes in a choice set, as this eliminates the tendency to ignore one or more attributes in the experiment (Hensher and Greene, 2010). Therefore, as a second step in this approach, we consulted two cowpea breeders at the Senegalese Institute of Agricultural Research. We presented them with a list of 10 traits and we co-evaluated which traits would be included in the final experiment design. Following the method, decisions were made according to producers' preferences, the ability to act on the traits by breeding programs, and according to national program priorities for the current and future breeding cycles. For example, grain yield and biomass yield were top ranked by growers in the baseline survey, cowpea breeders were highly interested in growers' trade-off between grain yield and biomass yield as cowpea is regarded as a dual-purpose crop. The relevance of these two traits for both stakeholders' groups and the fact that the national breeding program has the mandate to breed for dual-purpose cowpea in the next breeding cycle ensured that both grain yield and biomass yield were included in the choice experiment. On the contrary, taste was highly ranked by growers, but breeders did not currently have the ability to phenotype their breeding lines for taste (with neither consumer testing nor sensory evaluation). Therefore, despite its importance taste was excluded from the experiment, but noted by breeders as an area in need of methodological development for phenotypic evaluation. The five

TABLE 1 Traits and their levels included in the choice experiment.

Traits	Levels	Description
Grain yield	High/Low	The average grain yield per hectare obtained by cultivating a specific cowpea variety
Biomass yield	High/Low	The average forage yield per hectare obtained by cultivating a specific cowpea variety
Maturity	Short cycle/Long cycle	Length of time between planting and harvesting a cowpea variety
Pod filling	Less seeds per pod/More seeds per pod	The number of seeds per pod produced by a cowpea variety
Seed size	Small/Medium/ Large	The size of harvested grain

TABLE 2 Trait variables included in the utility Equation 3.

Variable	Specifications in Equation 3
Grain yield	Low (base) High (grain yield = 1)
Biomass yield	Low (base) High (biomass yield = 1)
Maturity	Long (base) Short (maturity = 1)
Pod filling	Fewer seeds per pod (base) More seeds per pod (pod filling = 1)
Seed size *which is specified as* Seed size medium Seed size large	Small (base) Medium (seed size = 1) Large (seed size = 1)

final traits were included in the discrete choice experiment are shown in Table 1. We chose to specify the level in a qualitative form (e.g., short and long cycle, instead of providing the exact number of days) since we could not find enough evidence in the literature to quantitatively construct all levels precisely. We completed the design of the choice experiment choosing pictorial representations of the traits selected. For grain yield, biomass yield and seed size we utilized pictures taken at local markets, while maturity and pod filling were exemplified through vignettes. We acknowledge that the representation of pod filling through vignette might be partially misleading for respondents.

We used JMP, a statistical software, to create the choice profiles included in the experiment based on the attributes and levels described in Table 1. A full-factorial design of 192 possible combinations (24 x 3 x 4) was obtained, given that we had 4 attributes with two levels, 1 attribute with three levels, and 1 attribute with four levels. However, since it is impractical to expect farmers to evaluate 192 choices, we used a D-optimal design using the JMP software. A D-optimal design is an algorithmic approach used in choice experiments to maximize the determinant of the information set used in the design of experiments with multiple treatments. It is designed to maximize the differences in attribute levels across alternatives, provide the best subset of all possible combinations and yield data that enables the estimation of parameters with low standard errors (Kimathi et al., 2022). Our generated design had a D-efficiency value of 99.28, indicating a high level of D-optimality (Kuhfeld, 2010). Further, we used a blocking strategy to mitigate the potential impact of presenting too many choice tasks on the respondents' decisions, as this helps to improve response efficiency by reducing the cognitive effort required from each respondent (Hanley et al., 2002; Johnson et al., 2013). A fractional factorial design with 24 choice sets was generated and put into three blocks, each consisting of 8 choice sets. Participants in the choice experiment were randomly assigned to one of the blocks and presented with 8 independent choice sets, with the sequence of the sets randomized within each block. Each choice set depicted a real market situation with two alternatives and an opt-out option, and participants were asked to choose their preferred alternative based on the attribute levels presented. In total, the study gathered 12,960 individual choices (540 farmers × 8 choice sets × 3 alternatives).

3.3 Synthesis of results and segmentation of bundle probability by a socially relevant variable

We estimated respondents' choice utility following Equation 1, including the cowpea traits of the choice experiment (i.e., grain yield, biomass yield, maturity, pod filling, seed size) as explanatory variables. The utility derived by producer i from choosing cowpea bundle j at choice occasion t is shown as:

$$U_{ij\,t} = \alpha_{ijt} + \beta_1 GrainYield_{ijt} + \beta_2 BiomassYield_{ijt} + \beta_3 Maturity_{ijt} + \beta_4 PodFilling_{ijt} + \beta_5 SeedMedium_{ijt} + \beta_6 SeedLarge_{ijt} + \varepsilon_{ijt} \quad (3)$$

The dependent variable is a binary variable defined as 1 if respondent i chooses cowpea alternative j in a choice set t. We encode all traits in the equation using a dummy variable. The base level for each attribute is used as the reference to compare the change in producers' utility. The base level used across all model specifications is low grain yield, low biomass yield, long maturity, fewer seeds per pod, and small seed size (Table 2).

To analyze the utility of the cowpea bundle, we use the coefficients from Equation 3 and transform them into probabilities of selection as compared to the base level. We calculate the utility of the cowpea bundle as:

$$U_b = \beta_1 GrainYield_b + \beta_2 BiomassYield_b + \beta_3 Maturity_b + \beta_4 PodFilling_b + \beta_5 SeedMedium_b + \beta_6 SeedLarge_b \quad (4)$$

where bundle utility b is the sum of the utility for each trait category. The trait categories in bundle b are dummy variables, taking the value 1 if preferred and 0 if not. To find the probability of selecting each bundle relative to the base bundle, we transform the ordinal utility calculations into odds. In this analysis, all probabilities indicate the likelihood of selecting a particular bundle in comparison to the base bundle. We consider the base bundle as a cowpea variety with low grain and biomass yield, long maturity, fewer seeds per pod, and small seed size (the least desirable baseline). To calculate the bundle probabilities, we adapt Equation 2 to our specific case under analysis (Equation 5):

TABLE 3 Mixed logit coefficients from Equation 3.

Variables	Mean		Standard deviation	
	Coefficients	Standard error	Coefficients	Standard error
Grain yield	2.068***	(0.115)	1.569***	(0.120)
Biomass yield	1.318***	(0.0962)	1.365***	(0.120)
Maturity	1.209***	(0.0961)	1.416***	(0.103)
Pod filling	0.507***	(0.0702)	0.884***	(0.107)
Medium seed size	0.378***	(0.0895)	0.0784	(0.210)
Large seed size	0.716***	(0.0930)	−0.775***	(0.139)
Observations	12,960		12,960	
Ll	−2527		−2527	
Aic	5082		5082	
Bic	5187		5187	

Significance level: p-value < 0.01 (***); < 0.05(**); < 0.10 (*).

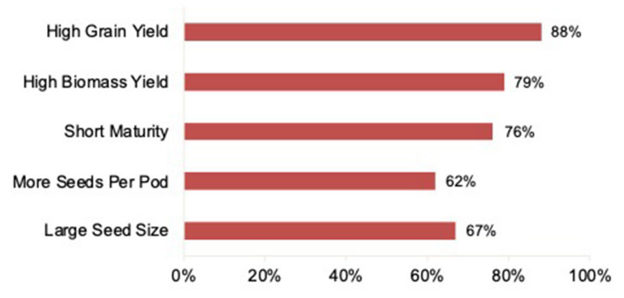

FIGURE 2
Cowpea bundle probability analysis, overall respondents.

$$Odds_b = e^{U_b}$$

$$Prob_b = \frac{Odds_b}{Odds_b + Odds_{base}} \quad (5)$$

As previously specified, the bundle probability analysis can be segmented using socially relevant variables. To showcase the potential of the method, we further synthesized findings from Equation 5 by (i) respondents' sex, (ii) intra-household level of agreement on who decides which variety is to be planted and by (iii) respondents' level of experience in growing cowpea. We first calculated the bundle probability analysis for women and men respondents separately. Secondly, we disaggregated bundle probabilities by the intra-household level of agreement on who decides which cowpea variety is to be planted. Whenever two members of the same household agree on who is the decision-maker for this specific cowpea pre-harvest activity, we consider that household to be in agreement on who decides which cowpea variety is to be planted. Therefore, we calculated the bundle probabilities for those households in agreement on cowpea variety decision-making with respect to households not in agreement. These results are shown in Figure 4B. Finally, we disaggregated by respondents' experience in growing cowpea: we distinguish between those with more than 20 years of experience and those with less. The 20-years cut off has been chosen since it is the mean of the variable distribution.

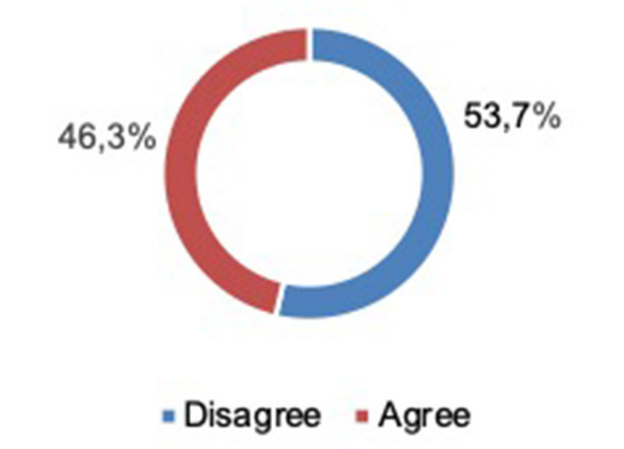

FIGURE 3
Proportion of households in agreement on who decides which cowpea variety is to be purchased.

The three socially relevant variables we showcase in this study are just two of the possible segmentations which our method allows us to compute. The method permits disaggregation either by composite indices aggregating decision-making, time and experience into crop roles or by decision-making, time and experience individually. Furthermore, disaggregation can be made at pre-harvest, harvest and post-harvest stages.

4 Preliminary results showcasing the potential of the method

Mixed logit model coefficients from Equation 3 are shown in Table 3. These coefficients are not disaggregated and represent the influence of independent cowpea attributes on farmers' choice utility and signals their preferences for each trait.

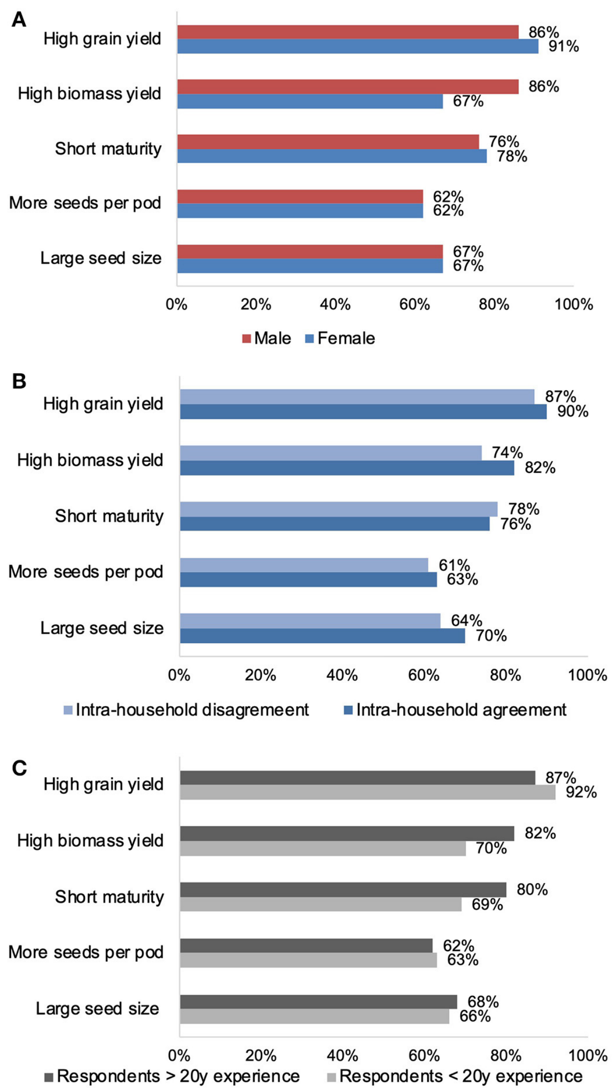

FIGURE 4
Bundle probability analysis by socially relevant variables. **(A)** represents disaggregation by gender, **(B)** shows disaggregation by household agreement, and **(C)** by respondents' years of experience.

Building on coefficients from Table 3, results from the probability analysis are shown in Figure 2. When a trait level is changed compared to the base bundle, the probability analysis shows how much more likely respondents are to choose the new variety. The base level represents the least-attractive bundle from the respondents' perspective, and it has a 50% probability to be chosen over any other bundle. Our findings reveal that respondents, in general, prioritize high grain yield as the most important attribute in cowpea varieties, followed by biomass yield and short maturity. Specifically, when a high grain yield is offered instead of a low grain yield, the likelihood of respondents selecting the new cowpea variety increases from 50% (base bundle) to 88% for the new bundle, with all other traits kept constant. Similarly, when a high biomass yield is offered instead of a low biomass yield, the probability of respondents selecting the new cowpea variety increases from 50 to 79%. Early maturity shows a similar importance, increasing the probability of selecting the new variety from 50 to 76%. More seeds per pod and large seed size do influence the probability of choosing the new variety too, but the effect is smaller compared to other traits in the bundle.

These findings build on those from the choice experiment, and they are interesting *per se* as there are no similar studies currently existing on cowpea in Senegal. However, they do not exploit the entire potential of the intra-household method proposed. To display how the survey can support the segmentation of the findings, we decided to present the probability analysis by respondents' sex, by intra-household level of agreement on who decides which cowpea variety to plant and by experience. In the sample of this pilot, household head respondents are always men while spouses are always women. The proportion of households in agreement regarding who decides on which cowpea variety to purchase is shown in Figure 3.

The figure shows that 53.7% of intra-household respondents disagree on who the major decision maker on the variety to be planted is. Data shows that most disagreements occur when both the household heads and spouses identify themselves as the main decision-makers and choose the *respondent alone* option while answering the "who decides" question on planting cowpea variety. In a smaller number of cases, members identify each other as the main decision-maker (i.e., head identifies spouse or vice versa) and this is still considered a disagreement. Discussions on why these mismatches exist would require a thorough study on gender norms in Senegal and this goes beyond the scope of this methodological paper. We will just say that these discrepancies signal an intra-household heterogeneity which is frequently ignored by crop breeding programs in their priority setting analysis and that this heterogeneity might have implications for seed and marketing as well as adoption. For 53.7% of the households in our sample, the survey question "who decides which cowpea variety to be planted" will have a different answer if asked of the household head or of the spouse. A study not including an intra-household design would have missed this discrepancy, along with others driven by socially relevant variables. To demonstrate how the method is novel in this regard, we go on to regenerate (Figure 2), using responses from the intra-household module.

Figure 4 depicts bundle probability differences for three different segments: men and women respondents (Figure 4A), intra-household agreement on the "who decides" question on planting cowpea variety and intra-household disagreement (Figure 4B) and respondents' experience on growing cowpea (Figure 4C). Findings segmented by gender reveal that the probability of women respondents to select a new cowpea variety is driven predominantly by high grain yield. When a high grain yielding variety is offered, the likelihood of choosing the new cowpea variety increases from 50% (for the base bundle) to 91% for women, and the increase is significantly higher than for men. Conversely, the probability of choosing a new cowpea variety which is more biomass yielding increases to 67% for women and 86% for men.

Figure 4B highlights bundle probabilities differences according to intra-household agreement on who decides which cowpea variety is to be planted. Bundle probabilities do not differ significantly for the three traits of high grain yield, short maturity, and more seeds per pod. For respondents which show intra-household agreement the probability of choosing a new variety which has large seed size is higher than for respondents with intra-household disagreement, but the probability differences are still relatively small (+6%). The narrative is however quite different for high biomass yield: respondents which show intra-household agreement appear to have a probability of choosing a high biomass yielding variety which increases from 50 to 82%, while the one of respondents with intra-household disagreement is at 74%. Finally, Figure 4C depicts bundle probabilities by respondents' years of experience. In this case, differences in trait preferences widen with more experienced respondents preferring short maturity and high biomass yield more than respondents with relatively less experience. The stark difference in bundle probabilities especially on short maturity is very interesting, as it has not been documented previously.

In its entirety, Figure 4 stylizes how the method proposed in this study makes apparent the complexity behind trait preferences. Combining an agile intra-household survey and a streamlined choice experiment, the method gives cross-functional breeding teams the opportunity to quantitatively measure trait preference differences at the intersection between gender, crop roles, decision-making, experience and time.

5 Discussion

Overall, the signs of the two yield coefficients indicate that farmers prefer cowpea varieties with high grain and biomass yields in comparison to low yielding varieties (Table 3). These findings suggests the breeding programs the need to prioritize breeding for dual-purpose varieties in Senegal, as farmers use this crop both for human consumption and animal feed, as biomass yield as a desirable and marketable trait. Looking at the coefficients for the maturity and pod filling traits, respondents exhibit a stronger preference for short maturity compared to long maturity, and for more seeds per pod over fewer seeds per pod. The short rainy season in Senegal might be one of the contributing factors driving the preference for short maturity. Evidence shows that early maturity in crop varieties help coping with short rainy seasons (Abdou, 2021). Furthermore, early maturity in cowpea seems to allow producers to avoid pest and disease infestation that typically occurs at a later stage of cropping seasons (Owusu et al., 2021). More seeds per pod is a trait tied to yield and scholars in the past have considered more seeds per pod also as a labor-saving trait, as it reduces farmers' effort in threshing for a given quantity of cowpea (Kitch et al., 1998). Lastly, respondents seem to prefer cowpea varieties with larger or medium seed sizes over those with smaller seed sizes. In similar studies on preferences across West African countries, cowpea value chain actors have specified their preferences for larger seed size as they believe that consumers in West African regions are ready to pay a premium for such quality (Langyintuo et al., 2003; Mishili et al., 2009; Bolarinwa et al., 2021; Mohammed et al., 2021). The high significance of each trait in Table 3 suggests that each of these traits is generally preferred by respondents. However, in cases when the breeding team is not able to breed for all these traits equally, it is important to investigate trade-offs.

Figure 4 is however the one exemplifying the full potential of the method. The presentation of bundle probabilities segmented by socially-relevant variables is instrumental to study whether intra-household heterogeneity in trait preferences is driven by respondents' roles in crop choice and production. The focus on these roles transcend sex-disaggregation, to include aspects of decision-making, time, and experience on the crop. The proposed method rests on the assumption that a higher intra-household heterogeneity in trait preferences is paired with a higher intra-household heterogeneity in decision-making, experience and time spent. Furthermore, higher intra-household disagreement on crop roles might lead to higher intra-household heterogeneity in trait preferences. The method and the suggested data synthesis via bundle probabilities enable us to test both hypotheses.

For example, short maturity, more seeds per pod and large seeds are traits desirable equally for both women and men. As the Senegalese national breeding program is interested in breeding for dual-purpose cowpea, these intra-household gendered preferences on grain yield and biomass yield hint at the fact that gender entry points should be systematically integrated into the breeding pipeline, to ensure that improved dual-purpose varieties mediate women's and men's needs. However, households showing intra-household agreement present trade-offs between grain yield and biomass yield which are different from households in disagreement. Hypotheses on why this might happen are multiple: households in agreement on who decides which cowpea variety is to be planted might prefer high biomass yielding varieties because the agreement is driven by more discussion within the family and convergence of preferences or, on the contrary, heads' preferences become predominant in pre-harvest choices. Whatever the underlying mechanism, results disaggregated by intra-household agreement raise awareness on the relational nature of trait preferences, with individual choices being shaped by other household members' preferences.

6 Conclusions

This study presents a new method for exploring intra-household trait preferences using choice experimentation. Dissecting intra-household crop roles into three dimensions, we explore what drives intra-household heterogeneity in varietal preferences between gender, decision-making, crop experience and time spent working on the crop. Combining an agile intra-household survey and a streamlined choice experiment, preliminary results from the pilot exemplifies trait differences segmented by a battery of socially relevant variables. Next to findings disaggregated by gender, which contribute to a long-standing stream of literature in priority setting, the method is able to dissect preferences by less investigated – but equally relevant – variables, such respondents' years of experience and the level of intra-household agreement on who decides which variety is to be planted. Similarly, the method can be adjusted to account for other economically relevant variable which play a role in shaping farmers' trait preferences, such as land and input ownership.

The method gives cross-functional breeding teams the opportunity to quantitatively measure trade-offs in trait preferences, considering trait choices an intersection between respondents' gender, crop roles, decision making, experience, and time. By suggesting a method which combines agile and streamlined tools (i.e., a brief intra-household survey and a traditional discrete choice experiment), we supply social scientists within breeding teams with a data collection method which promotes attention to diverse market segments in setting breeding priorities.

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 humans were approved by the Institutional Review Board for Human Participants at Cornell University has granted this study exemption from IRB review according to Cornell IRB policy and under the Department of Health and Human Services Code of Federal Regulations 45CFR46.104(d). For questions related to this application, please contact the IRB office at irbhp@cornell.edu, specifying the protocol number IRB0146740. 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

RM: Data curation, Formal analysis, Investigation, Methodology, Writing – original draft. NF: Conceptualization, Funding acquisition, Investigation, Methodology, Writing – review & editing. MB: Data curation, Investigation, Writing – review & editing. MG: Conceptualization, Funding acquisition, Supervision, Writing – review & editing. DR: Conceptualization, Methodology, Writing – original draft. HT: Conceptualization, Formal analysis, Funding acquisition, Methodology, Writing – original draft. MO: Conceptualization, Formal analysis, Methodology, Visualization, Writing – original draft.

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Conflict of interest

DR is the Director of Cultural Practice, LLC.

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/fsufs.2023.1257076/full#supplementary-material

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Gender mainstreaming in sweetpotato breeding in Uganda: a case study

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Purpose: In Uganda, sweetpotato [*Ipomoea batatas* (L.) Lam] is typically a "woman's crop," grown, processed, stored and also mainly consumed by smallholder farmers for food and income. Farmers value sweetpotato for its early maturity, resilience to stresses, and minimal input requirements. However, productivity remains low despite the effort of breeding programs to introduce new varieties. Low uptake of new varieties is partly attributed to previous focus by breeders on agronomic traits and much less on quality traits and the diverse preferences of men and women in sweetpotato value chains.

Method: To address this gap, breeders, food scientists, and social scientists (including gender specialists) systematically mainstreamed gender into the breeding program. This multidisciplinary approach, grounded in examining gender roles and their relationship with varietal and trait preferences, integrated important traits into product profiles.

Results: Building on earlier efforts of participatory plant breeding and participatory varietal selection, new interventions showed subtle but important gender differences in preferences. For instance, in a study for the RTBFoods project, women prioritized mealiness, sweetness, firmness and non-fibrous boiled roots. These were further subjected to a rigorous gender analysis using the G+ product profile query tool. The breeding pipelines then incorporated these gender-responsive priority quality traits, prompting the development of standard operating procedures to phenotype these traits.

Conclusion: Following an all-inclusive approach coupled with training of multidisciplinary teams involving food scientists, breeders, biochemists, gender specialists and social scientists, integration into participatory variety selection in Uganda enabled accentuation of women and men's trait preferences, contributing to clearer breeding targets. The research has positioned sweetpotato breeding to better respond to the varying needs and preferences of the users.

KEYWORDS

sweetpotato, Uganda, gender mainstreaming, plant breeding, value chain actors

1 Introduction

1.1 Why sweetpotato breeders in Uganda paid attention to gender

In Uganda, sweetpotato [*Ipomoea batatas*, (L) Lam] is typically considered a "woman's crop" grown by smallholder farmers, about 60% of whom are women (Zawedde et al., 2014; Echodu et al., 2019). Farmers value sweetpotato for its early maturity, resilience to biotic and abiotic stresses, and minimal input requirements. Sweetpotato thrives in dry areas with poor soils, so the crop appeals to women who are often allocated marginal lands of the household's farmland. Aside from subsistence production, women also process sweetpotato into secondary products like chips, flour and other value-added products. Women also generate and control income from sale of sweetpotato vines and surplus roots. Women are responsible for household food preparation. As such, they value sweetpotato for bridging the hunger gap since it matures much earlier in the season than the other crops and for its high energy density. Additionally, sweetpotato, especially orange-fleshed type, has a soft texture and sweet taste which appeals to children and is thus useful as a weaning food (Hagenimana et al., 2001). Sweetpotato leaves are increasingly eaten as a vegetable or a relish, contributing micronutrients (Mudege et al., 2017) and diversifying the diets. The crop residues are fed to small animals and ruminants; further endearing sweetpotato to women given their responsibility in animal feeding (Dione et al., 2015).

Breeding efforts have focused on producing new varieties that responded to farmers' needs. By 2016, the Ugandan breeding program had released 22 sweetpotato varieties – both local and improved (Mwanga et al., 2001, 2003, 2007, 2009, 2011, 2016; Grüneberg et al., 2015). The released varieties were selected mainly for yield, weevil resistance, dry matter content, virus resistance and nutrition, especially for vitamin A, with less attention to the gender-differentiated needs of farmers and other value chain actors. Generally, breeders selected for agronomic traits instead of the culinary and processing traits preferred by men and women. For example, the size and shape of sweetpotato roots which largely determine the effort women exert in food preparation were hardly considered. Consequently, released varieties have not been widely adopted, with only 6.9% of the harvest area under improved varieties (Thiele et al., 2021) by women and men partly because their needs were not considered in plant breeding. As a result, farmers, especially women, still rely on landraces whose seed degenerates more quickly compared to improved seed due to pest and diseases infestation (Zawedde et al., 2014; Ogero et al., 2023). Also, Uganda has more than 900 local landraces, which are adapted to the very diverse local production conditions, making it difficult for the improved varieties to replace them (Yada et al., 2010; Labarta et al., 2012). Reliance on landraces is, in part, due to women's limited access to new knowledge, skills and immobility (Puskur et al., 2021). This is compounded by limited access to input and output markets as Katungi et al. (2018) report for similar crops. Women are also expected to commence with cultivating the family land, and only till their own land later in the season. They thus experience time poverty, a challenge that is exacerbated by their triple roles (production, reproduction, caregiving) and contributing to their limited access to improved varieties.

This case study documents the evolution in including gender perspectives in the sweetpotato breeding program in Uganda. It highlights the initial gender gaps, the response to (mostly donor-driven) demands to consider gender in breeding through participatory varietal selection (PVS) and the strong incorporation of gender into the breeding programs through targeted project interventions coupled with gender training. This evolution resulted in greater gender consciousness among breeders, leading to a more gender-responsive breeding program in Uganda.

Elsewhere, breeding programs have endeavored to integrate a gender lens in their plans. In South Africa, the maize breeding programs were ready to incorporate gender responsive traits but lacked guidance on what these specific traits could be because on-farm trials were unable to predict gendered differences in trait preferences. The suggested solution was to review agronomic practices used by female plot managers at advanced stages of the breeding pipeline (Cairns et al., 2022). For beans in Kenya, a combination of gender-disaggregated participatory varietal selection (PVS) and choice experiments identified short cooking time as a "must have" gender-neutral trait (Katungi et al., 2018). So, breeding programs invested in routine evaluation of bean cooking time, using a Mattson cooker. In Tanzania, a gender yield gap was identified where women registered much lower yields than men. This was attributed to their triple roles; exacerbated by limited access to education; technology, training, and minimal land rights (Nchanji et al., 2020). Resultantly, bean breeders were guided to incorporate training on good agricultural practices when introducing new varieties to control selection bias. The Consortium of International Agricultural Research Center (CGIAR) scientists note that promoting socially equitable varieties like nutritionally improved varieties risks creating a yield penalty compared to the best agronomic varieties which could reduce their adoption (Kholová et al., 2021). Therefore, breeders need to work with policy makers to ensure that the yield gap does not affect adoption of such socially advantageous varieties.

This case study is organized as follows. In section 1.2, we delve into the study context and highlight organizations and actors involved, the geographical scope of the breeding program, the size and composition of the breeding team as well as the chief characteristics of target beneficiaries. Section 2 describes the case study methodology while section 3 analyses the evidence of gender integration in sweetpotato breeding in Uganda. Section 4 assesses the approaches, and outcomes of gender integrations in sweetpotato breeding. Section 5, wraps up our discussion of the good practices, lessons learned and recommendations.

1.2 Context

The sweetpotato breeding program in Uganda has evolved over the years (Figure 1). It was established to generate an expanded range of sweetpotato cultivars resistant to the high sweetpotato virus disease (SPVD) and sweetpotato weevil pressures in East and Central Africa, combining nutrition, cooking quality and high yield. More recently, breeding for end-user preference with a gender perspective has come into focus with the increased appreciation of the salient gender needs, roles and responsibilities in sweetpotato cropping systems. End-users in this perspective include seed multipliers, producers, traders, processors, consumers as well as value chain support services.

The International Potato Center (CIP) and the National Crops Resources Research Institute (NaCRRI), an institute of Uganda's National Agriculture Research Organization (NARO), have

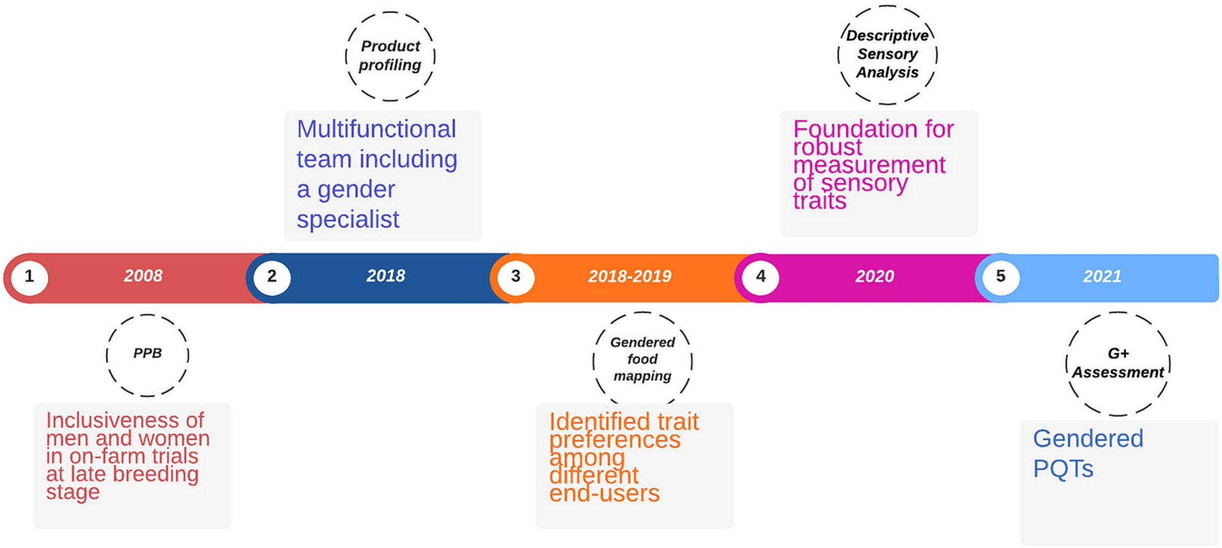

FIGURE 1
Key events and decisions incorporating gender into sweetpotato breeding in Uganda.

collaborated with local and international partners in implementing the various research projects (Figure 2). Local partners included Makerere University, international NGOs (World Vision and Samaritan's Purse), and farmer organizations such as the Soroti Sweetpotato Producers and Processors Association (SOSPPA). Partnerships were formed with international organizations: UK's James Hutton Institute (JHI), Natural Resources Institute (NRI) and AbacusBio, France's Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), Spain's Centro de Investigación y Tecnología Agroalimentaria de Aragón (CITA) as well as other CGIAR centers such as the International Maize and Wheat Improvement Center (CIMMYT). The activities were supported by funding from CGIAR platforms, like the Excellence in Breeding (EiB) which produced the G+ toolkit (Ashby and Polar, 2021; CGIAR, 2021). The CGIAR Research Program on Roots, Tubers and Bananas (RTB) facilitated work on the triadic comparison of technologies (tricot). Other important funding was from The Bill and Melinda Gates Foundation for the RTBfoods and Sweetpotato Genetic Advances and Innovative Seed Systems (SweetGAINS) projects. The United States Agency for International Development (USAID) and United Kingdom's Foreign, Commonwealth and Development Office also supported projects like Development and Delivery of Biofortified Crops at Scale (DDBIO). Over time the sweetpotato program engaged breeders, food scientists, biochemists, gender specialists, social scientists, and data scientists to systematically and holistically understand how to mainstream gender into breeding. These collaborations strengthened the technical and infrastructural capacity, making it possible to address gendered preferences of sweetpotato characteristics. The RTBFoods project, for example, developed methods for measuring sensory traits (e.g., taste, mealiness, firmness) preferences of different consumer segments, thus facilitating gender integration in trait selection (Figure 2).

The geographical coverage of the program stretched across all of Uganda's nine agro-ecological zones with activities in Kabale, Mpigi, Kabarole, Kamuli, Iganga, Busia Mbale, Kumi, Moroto, Lira, Kitgum, Adjumani, Arua, Kamwenge, Luwero and Hoima districts. The breeding program targeted actors across the value chain including sweetpotato farmers (mainly smallholders with <1 acre plot size), small-medium scale processors (mostly women and the youth), traders (mostly female retailers and male wholesalers) and consumers (rural, peri-urban, and urban) (Mayanja et al., 2019).

2 Case study methodology

Step 1. At conception we pooled information on all breeding research projects that tackled inclusiveness of other stakeholders in the breeding process. Each of these projects were reviewed considering: (1) Why the research was conducted, (2) Who comprised the research team, (3) when and how the research was conducted, (4) what the findings of the study were and how they influenced subsequent projects and sweetpotato breeding specifically.

Step 2. A workshop of a transdisciplinary team comprising of three social scientists, two food scientists, two gender specialists and two breeders, was conducted to discuss and document the approaches and lessons learnt during the implementation of the various projects. Insights from this workshop were used to write this case study using the guide developed under the project titled 'Elaboration of case study integrating gender into breeding objectives and decision' (Supplementary material 1).

3 Evidence of gender integration in sweetpotato breeding

3.1 Resources and other sources of information on gender generated

A timeline of gender research in sweetpotato breeding shows that before 1989 breeding was largely biological with little focus on gender

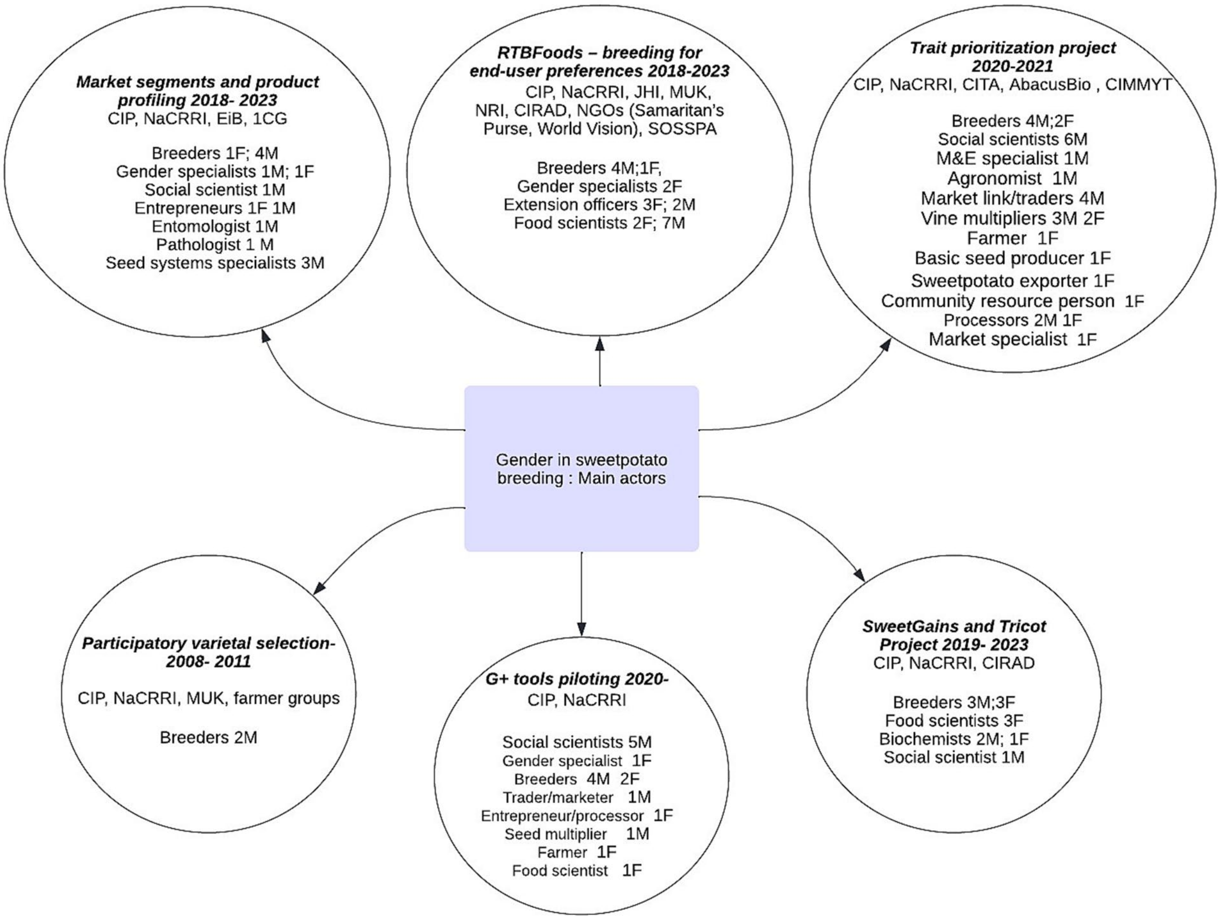

FIGURE 2
Project collaborators and research team composition (F-female and M-male) engaged over time to incorporate gender in sweetpotato breeding in Uganda.

(Figure 3). A diagnostics study between 1989 and 1992 by the sweetpotato research team identified the important roles women play across the value chain (Bashaasha et al., 1995; Figure 3, 1). The study highlighted the need to involve end-users in breeding, motivating breeders to introduce participatory plant breeding (PPB) and PVS with groups of women and men farmers in Central Uganda. However, in PPB and PVS (from 2003 to 2011) though the breeders worked closely with farmers in the selection process; little attention was given to urban consumers (Figure 3, 2). Also, some specific reasons behind preferences for the variety were unclear, especially because some traits only appealed to certain actors. For example, across the value chain, only farmers participating in the trial would appreciate a variety's resistance to SPVD (Okello et al., 2022). In 2009, a gender scientist was recruited in the Sweetpotato Action for Security and Wealth in Africa (SASHA) project to support gender mainstreaming in breeding as well as other project components. This contributed to the adoption of a Ugandan bred OFSP variety '*Kabode*' across the borders due to its good eating qualities. Although preferences of men and women processors, producers and consumers were recognized by both CIP and NARO, appropriate tools to allow for refinement and targeting of key traits, market segments, climate uncertainty, changing markets and urbanizing populations and incorporating all the traits in a cultivar remained a challenge. Having identified the important roles of women in the value chain, and recruitment of a gender scientist integration was expected to increase drastically, but this did not happen immediately (Mwanga et al., 2021). This could be attributed to the increased focus on breeding for vitamin A-rich, orange-fleshed sweetpotato (OFSP) in the early 2000's. Consumer education for women and children on the nutritional benefits of OFSP overshadowed considerations of gender relations affecting adoption of new varieties, despite evidence that women played a leading role in decisions to adopt OFSP (Gilligan et al., 2014).

The five- year RTBfoods project (Figure 3, 3b), which started in 2017, introduced a five-step method to develop food product profiles: a detailed description of a food product, including traits for its ingredients, processing suitability and sensory characteristics such as appearance, taste, texture, and aroma. This is only a subset of the target product profile used by breeding programs to describe the mix of basic traits essential to the success of the market variety and value-added traits being targeted in a new product (variety). The objective of developing a food product profile was to identify and rank the most important characteristics by various food chain actors for consideration as breeding targets. Food product profiles identified end-user preferences with a gender perspective (Forsythe et al., 2021). The five steps were: (1) audit of the state of knowledge, (2) gendered food product mapping, (3) participatory processing diagnosis (PPD),

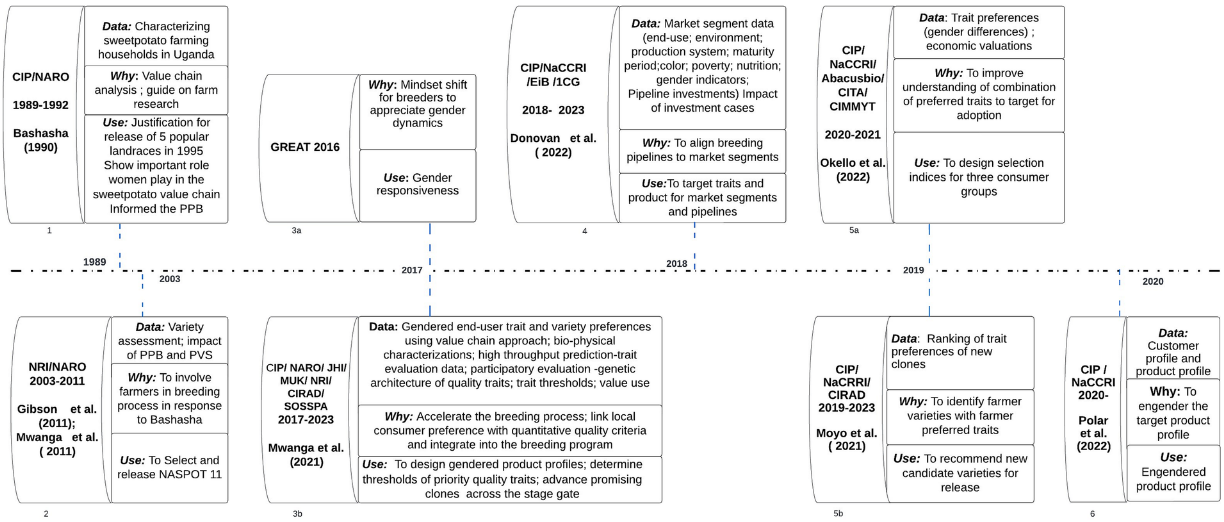

FIGURE 3
Timeline of gendered research activities in sweetpotato breeding.

(4) consumer testing of a selected set of four sweetpotato varieties in rural and urban segments, and (5) triangulation of data with alternative methods for G+ food product profile consolidation. This 5-step method gave a prominent leadership role to the gender researcher and the food scientist. This change was intended to regulate the usually predominant role of the breeder in product design.

Under the same project, the state of knowledge (SoK) output (2018) was led by a gender specialist in collaboration with a food scientist who compiled the desirable characteristics of boiled sweetpotato among men and women end-users, based on a literature review and key informant interviews. These characteristics were probed further in a subsequent study using individual interviews (IIs) and focus group discussions (FGDs) of the gendered food mapping. This was also led by the gender specialist with a team comprising food scientists, agronomists and social scientists. The gendered food mapping identified (1) the most and least preferred sweetpotato varieties, (2) end-user preferences at various product stages: raw, during processing and boiled (Mwanga et al., 2021), and (3) champion processors. The study highlighted socio-cultural aspects of livelihoods, land use and ownership, decision making, control of income in the household and labor, among others.

The PPD was conducted in 2019 and was led by a food scientist working with a gender specialist and a social scientist. A selection of four sweetpotato varieties (including most and least preferred varieties) were used for the PPD. Preferences of women processors were determined for raw roots, at each processing step and the final boiled sweetpotato.

Consumer studies to test boiled sweetpotato varieties in rural and urban areas (2019) were led by a food scientist, working with the gender specialist and social scientist. Respondents were monadically presented with cooked samples of local and improved samples of sweetpotato to evaluate in a randomized order. The study sought to (1) understand preferences of consumers; disaggregated by sex, age, income, education level; and (2) identify eating quality attributes penalized by consumers. This marked the end of the RTBFoods Project gender responsive studies.

In 2017, two more initiatives were introduced. First the Gender Responsive Researchers equipped for Agricultural Transformation (GREAT) program was launched in Uganda. Second, the Excellence in Breeding (EiB) Platform introduced the concept of breeding product profile development (Tawanda Reginold Mashonganyika, 2018). Both these initiatives required convening a multifunctional design team including a gender research specialist. GREAT involved capacity building and hands on research which identified gender differentiated trait preferences in production and marketing (Figure 3, 3a).

The EiB approach identified the market leading varieties (for potential replacement) and proposed 'must-have' and 'value-added' traits, Figure 3, 4. CIP and NARO developed the first sweetpotato product profile with guidance from two gender specialists. Some of the traits put forward included vigorous vine establishment (because women struggled to get planting material) and aroma (most of the new varieties were lacking in characteristic sweetpotato aroma). Nonetheless, these traits were not prioritized in the initial product profile proposed in 2018, as their potential to contribute to the likelihood of replacing the market leading variety was not clearly understood and therefore not appreciated.

The AbacusBio trait prioritization project (Figure 3, 5a), in 2020 and 2021, also contributed to gender responsive sweetpotato breeding. The project was led by a social scientist and involved breeders, a gender scientist, root producers, transporters, retailers, processors, and consumers. It identified three groups of sweetpotato end-users based on categories of trait patterns and direction of preference ranks within each group, i.e., productive output, plant robustness and root quality. There were more women in the root quality group, which gave high preference ranking to dry matter, flesh color, sweetness, skin smoothness and root size. This could be because women are more involved in buying and preparing their household's food, so they pay attention to root quality. A selection index was developed for each group, and this will facilitate breeding for women-preferred traits.

The triangulation and consolidation of the food product profile in 2021 was led by a food scientist with a team that included a gender specialist, social scientists, breeders, traders and processors. The analysis revealed that (1) a large, hard, sweet root with a smooth skin was considered a good raw sweetpotato, which should be easy to peel and non-fibrous and (2) the boiled or steamed sweetpotato should be sweet, firm, mealy, with a characteristic sweetpotato aroma and non-fibrous.

As part of this process gender and livelihoods assessments were conducted for each of the quality traits in the food product profile, using an adapted version of the G+ product profile query tool (Ashby and Polar, 2019, 2021; CGIAR, 2021) (Figure 3, 6). Some traits like 'smooth skin' 'root size', 'sweetness', 'firmness', 'mealiness' and the 'sweetpotato smell', had the potential to increase the commercial value of the sweetpotato crop. This would attract men to dominate the production and trading of the crop, which could cause gender inequalities, which should be addressed during the release and promotion of these varieties. We thus recommended 'amend' or 'proceed with caution' for these traits, and suggested strategies that should accompany release of the varieties to maintain women's active role in sweetpotato markets. As a starting point for deploying the gender-responsive food product profile, five priority quality traits (PQTs) (mealiness, sweetness, firmness, characteristic sweetpotato smell and non-fibrousness) were selected for trait dissection and development of phenotyping protocols (Dufour et al., 2023). A sensory panel was set up and trained to develop a lexicon for descriptive sensory analysis (DSA) as described by Nakitto et al. (2022). Despite being a low-throughput method, DSA enabled the screening of clones for women-preferred quality traits.

Additionally, several proof-of-concept studies identified potential biochemical and biophysical techniques for measuring the gender-responsive PQTs. Spectra and image analysis were explored as high-throughput predictors of the PQTs. The breeding program combined DSA with consumer testing to determine the desirable threshold of these crucial gender-responsive traits. The plot size for the early breeding stages was subsequently increased from 1 m^2 to 10 m^2 to provide enough roots for cooking quality analysis. The trait dictionary was also updated to encompass quality traits.

The Triadic comparisons of technologies (TRICOT) is a crowdsourced citizen science methodology. It involves the distribution of a pool of agricultural technologies in different combinations of three to individual farmers. The farmers use and observe these technologies under farm conditions and rank their performance. TRICOT was piloted to assess consumer perceptions of sweetpotato varieties. The study was conducted by a team led by food scientists and included breeders, biochemists, gender specialists and social scientists in 2020 (Moyo et al., 2021; Figure 3, 5b). Its integration into participatory variety selection enabled accentuation of women and men's trait preferences, contributing to clearer breeding targets. This holistic approach coupled with capacity development gained from the GREAT project and strong institutional support has positioned sweetpotato breeding to better respond to the varying needs and preferences of the users.

3.2 How attention to gender has influenced sweetpotato breeding in Uganda

Several aspects of the breeding program have changed with the shift toward gender-responsiveness. The changes include:

- Definition of markets or end users to be targeted currently includes trait preferences for various end-users across the value chain are now considered
- The breeding objectives have been expanded to include gender responsive PQTs
- Breeding methods have been extended to include tools for medium to high throughput phenotyping of gender responsive PQTs like instrumental texture analysis, artificial intelligence, spectral analysis
- Desirable thresholds (targets) for PQTs were established, e.g., using the established instrumental texture analysis SOP, optimal firmness is indicated by test clones that require a minimum of 3700G force to compress
- Gender-responsive selection index has been developed considering weights for PQTs
- Tricot approach (citizen science) ranking preferences for advanced clones by many consumers/producers has been adopted
- Multi-functional teams have been established for joint decision-making during product advancement, not just the breeder, using a production calendar to ensure data to guide the advancement of clones across the breeding pipeline.

During the research, some opportunities arose that made it feasible to integrate gender trait preferences into breeding. For instance, CIP and NARO implemented projects like RTBfoods and SweetGAINS that aimed at modernizing core breeding operations. These contributed to identifying trait preferences by men and women, supporting the development of phenotyping protocols for priority quality traits and acquiring laboratory equipment to enable high throughput phenotyping PQTs. Sweetpotato research scientists benefited from gender-responsive training by both GREAT and RTBFoods projects. These trainings increased the appreciation for gender research and enabled the team to design more inclusive breeding projects. Also, most of the desirable traits included in the gender-intentional product profile to guide the breeding were available within the germplasm. Cross-institutional partnerships involving CIP, NaCRRI, NaRL, FANEL, JHI, Makerere University and CIRAD expanded access to technical expertise, protocols, and laboratory equipment. The product profile design and the product advancement process benefited from creating multi-functional teams between CIP and NARO. In 2021 the sweetpotato breeding programs at CIP and NARO were assessed by the breeding program assessment tool (BPAT) assessors. The assessment revealed several areas for improvement to drive higher rates of genetic gain and adoption in sweetpotato breeding. This provided justification for institutional support to address changes required for gender-responsive research.

The CIP sweetpotato breeder and gender specialist endeavored to bring different stakeholders on board to implement activities as a team. CIP encouraged breeders to lead the process of integrating gender and incorporating the gender results. This process enabled the breeders to appreciate the need to integrate gender over time. Sweetpotato farmers agreed to participate in the on-farm varietal trials, enabling researchers and breeders to incorporate gender into their work.

Some challenges curtailed the incorporation of gender into the breeding program. In the beginning, most stakeholders, especially the breeders, were reluctant to embrace gender. However, over time they came to appreciate this aspect, because research allowed them to identify specific consumer preferences of men and women. Previously, there had been low adoption of some sweetpotato varieties, like the orange-fleshed ones, and the promoters and researchers hoped that gender research would help to promote OFSP at the community level.

Although the multifunctional team was expected to have sufficient information on gendered trait preferences; unfortunately, there was insufficient data on traits like aroma and vigorous vine establishment to conduct a meaningful assessment. Another issue was how to handle the several traits that were identified during gender analysis, given that only a few could be included in the product profile. Finally, some of the proposed traits (fibrousness and sweetpotato smell) need further assessment. Therefore, either genomic tools or high-throughput phenotyping protocols will have to be developed to support development of varieties.

4 Assessment of approaches and outcomes of gender integration in sweetpotato breeding

4.1 Pros and cons of gender integration approaches

There was a progressive evolution of gender integration in mainstream breeding activities (Table 1). According to the gender mainstreaming continuum (IDRC, 2017), the earliest activities such as PVS and PPB (1992 to 2016) were gender sensitive while more recent activities like the Citizen science (Tricot) and gender food mapping study with RTBfoods (2017 to 2021) had more elements of gender transformative research, given its attempt to rectify past exclusion from breeding by focusing more on women's needs and priorities. For instance, the tricot approach improved inclusivity by allowing more participants to evaluate clones from the breeding program. Participants who were previously hard-to-reach due to mobility and technology access constraints were given an opportunity grow and evaluate new clones and give feedback.

Although the gender food mapping study was gender transformative, the approach required time to build rapport and cohesion among multiple disciplines. All traits prioritized from the findings from the various approaches can be assessed for gender and livelihood assessment using the G+ Product Profile Query tool, enabling robust gender analysis. However, this tool requires evidence to complete which sometimes may be a draw back.

4.2 Changes in breeding process and practice after gender learning

In the multidisciplinary, gendered food mapping study, trade-offs between the disciplines led to omission of some important gender issues at the data collection analysis and inference stages. The study generated a lot of data which needed to be interpreted in a useful way to the breeder. By default, the breeder was designated as the product champion, who was briefed of the findings from various members of the interdisciplinary team. After several iterations, the findings were consolidated for joint conclusions and implications for research and future perspectives.

Gender integration got a breakthrough when the breeders realized how much women affect the choice of sweetpotato varieties grown and how much some sweetpotato traits can make a difference to women's well-being. This is summarized by the CIP sweetpotato breeder in Uganda:

> *"When I got to see how women and sweetpotato were interacting …. I knew that there was no way we were going to succeed without considering traits that women found dear"* Dr. Reuben Ssali, sweetpotato breeder, CIP.

This perspective led to the re-engineering of the PQTs in the breeding pipelines. The larger plot sizes further enhanced this change. The versatility of the crop also was a contributor as explained below:

> *"Sweetpotato is the most versatile RTB crop in terms of utilization, because it can be used in a wide range of end-user products. From food on the table, it can also be processed and used as feed… We need to take care of the needs of end-users including women, men and children …. This is when I felt that this would help get products that can be adapted and adopted and utilized."*- Dr. Bernard Yada, sweetpotato breeder, NACRRI.

In a product advancement meeting led by an economist, breeders equipped participants with basic breeding knowledge. This enabled the interdisciplinary team to integrate social and gender aspects, among other considerations, in the process of selecting varieties to advance for release, as guided by a gender-intentional product profile (Table 2). This interdisciplinary approach allowed for better integration of end-user preferred traits in breeding.

4.3 Breeding outcomes and impacts related to gender equity

The gender-responsive breeding created three varieties: NASPOT 11 which was released in 2010, NASPOT 12 O and NASPOT 13 O released in 2013. These outcomes are mostly attributed to PPB and PVS combining the strengths of farmers and researchers (Gibson et al., 2008; Mwanga et al., 2016). The PPB started in 2003 and three mixed-sex farmer groups in the districts of Luwero, Kiboga and Mpigi participated right from the early stages of breeding. By the third year the participating farmers were already eating the roots and selling them in the fourth year. A comparison between NASPOT 1 (a released variety), NASPOT 11 and Dimbuka (a landrace) by 44 farmers (31 women, 11 men) revealed that NASPOT 11 outperformed the other two on the key agronomic attributes. This accelerated both the breeding process and varietal adoption.

CIP has developed a manual to guide evaluation of sweetpotato trials during PVS. Assessment is sex-disaggregated, where men and women grade traits using color cards for "not acceptable," "more or less acceptable," "clearly acceptable" (Gruneberg et al., 2019). The breeding program worked with 100 farm households for two seasons in five districts (Isingiro, Buyende, Rakai, Oyam and Kabale) for the PVS trials (Mwanga et al., 2016). The breeders intended to recruit equal numbers of males and females, but women were more willing to participate, and they outnumbered men on both the on-farm

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TABLE 1 Evolution of gender integration in breeding activities.

Activity	How gender was incorporated	Advantages	Shortcomings	Adjustments
PVS (farmers selecting segregating materials)	• Before, farmers were considered a homogenous group • Later sex disaggregation was included in social analysis • Farmer-farmer visits and vine exchanges	Contributed to considering end-users' preferences and provided a foundation for further social inclusion	• Not gender sensitive • Analysis and feedback were not sex-disaggregated • Only target farmers	Sex -disaggregated farmer selection Sex and age considered at data analysis
PPB (farmers evaluating segregating material)	• Before, farmers were considered a homogenous group • Later, gender was included in social integration. • Farmer-farmer visits and vine exchanges	Contributed to considering end-users' preferences and was a foundation for further social inclusion and Gender-aware	• Not gender-sensitive • Analysis and feedback not sex-disaggregated • Only target farmers	Sex-disaggregated farmer selection Sex and age considered at data analysis
Choice experiments (AbacusBIO)	• Extensive consultation with gender specialists in design • Socially-inclusive, diverse respondents – intersectional identities • Collected data on gender trait preferences across value chain	• Value chain focus • Economic selection index for advancing genotypes across the value chain • Gender-sensitive	• Untargeted questionnaire • Reporting had limited gender analysis.	Adopted the use of economic selection Indices
Citizen science involving mass volunteer participation in research	• Vines were delivered to households to reduce mobility and access to technology constraints • Farmers allowed to use their own farming and cooking practices • Local languages are used to communicate • Participants received feedback on results from study	• Targets participants with intersecting identities • Enabled participation of previously hard to reach categories • Cost effective • More customized priority setting • Lighter response burdens for participants • Gender responsive	• High initial cost and technical requirements	Started using specialized data tools
Social survey research/value chain analysis/gendered food mapping	• An adapted gender dimensions framework used for the research tool development (Rubin, 2011) • Roots were delivered to local communities • Respondents used their own cooking practices • Interpretation to local language provided	• Some intersectional identities considered • Light response burden • Consumer-targeted priority setting • Complementarity among activities • Promoted inter-disciplinary approach • Elements of gender-transformative research	• Took time to build rapport and cohesion among multiple disciplines	More intersectional identities considered* Deeper gendered analysis on preferred traits* Individual expression facilitated through voting*
Use of G+ Tools for consumer or product profile assessments	• Added an extra layer of gender analysis on PP • G+ PP tool applied to gendered PP to further assess gender responsiveness of identified traits	• Exante assessment of potential gender harm or benefit of a trait • Identification of strategies to accompany traits likely to cause gender disparity • Allows for multi-disciplinary discussions • Allows for shared experience among stakeholders • Final consensual scores after discussion are more rational and informed	• Initially tool difficult and time-consuming to use • Evidence to complete the tool may not exist or may be limited	Used by product design team Gender impact scale still needs to be improved Data analysis at collating results requires improvement

(Continued)

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TABLE 1 (Continued)

Activity	How gender was incorporated	Advantages	Shortcomings	Adjustments
Farmer-managed or small-scale, artisanal seed production (CSPs)	• Women represented in leadership roles • Both husband and wife are included as beneficiaries • Farmer-farmer visits and vine exchanges • Formal registration of commercial seed producers into co-operatives or associations	• Gender-aware • Informs breeders of seed traits relevant to seed producers • Inter-disciplinary activity • Builds business mindset and visibility • Identified market-preferred varieties • Facilitates channels for cleaning materials • Identification of best fit varieties	• High investment costs like irrigation, mini-screenhouses, access to water source excludes women • Registration requirements exclude some social groups	CSPs were empowered when registered as cooperatives

*These adjustments executed for potato and sweetpotato in Mozambique.

trials and the palatability tests. NASPOT 12 O and NASPOT 13 O were outcomes of PVS. The two varieties were reported to have higher storage root and biomass yield, harvest index, and sweetpotato virus disease (SPVD) resistance compared to Dimbuka-Bukulula. However, at first entry into the market, the adoption was pushed by high demand for vines and at this stage men displaced women as the main beneficiaries, as men were attracted by the business opportunity of selling vines. This could have been mitigated by having a defined gender strategy to include men from planning to marketing and avoid displacing women as evidenced elsewhere. In Mozambique, an initiative to commercialize sweetpotato resulted in women retaining dominancy in the roots chain due to inclusive strategies. For example through training and advocacy, men were encouraged to allow their spouses to engage in commercial activities (Mayanja et al., 2022).

5 Discussion

5.1 Good practices

Good practices contributed to the evolution of gender-responsive breeding, notably the progressive change from women vs. men to comparisons between social groups and intersecting identities among value chain actors. This led to a more nuanced approach to discern the different preferences of male and female actors along the value chain, thus widening the scope of inclusivity.

Transition from single to multidisciplinary approach, and later to an interdisciplinary one, led to more integration (Troullaki et al., 2021). This enhanced learning among the various disciplines for a common good. For example, gender specialists obtained a better understanding of biological and food sciences related to breeding from other team members. Capacity development and hands-on support in using new methods and tools allowed the social scientists to improve their understanding of food science and breeding. There was constant hands-on learning by all team members, especially on the cross-functional teams where not only academic disciplines, but other actors in the value chain were included. Interdisciplinary and hierarchical differences were reduced which allowed for mutual respect among disciplines and enabled equal participation in activities. This improved the social relations among team members.

Breeders were directly involved in the tasks of the different disciplines, from study design all the way through to data analysis, which enabled them to appreciate the results of research led by different disciplines. Breeders are now championing the value of working with multidisciplinary teams and integrating gender in routine decision making for the product development pipelines.

As a result, there is more value placed on the data from the PQTs (lab values) and breeders wait for the data even though it takes more time for the output to be delivered. This shows an institutional change resulting in breeders designing projects differently. Teams must be composed differently, and time allocated differently, to allow for more robust product profiling where significant gender-transformative changes are expected to occur.

The RTBfoods project continuously added to the set of existing phenotyping tools (especially for biochemistry and biophysical sciences). The new tools enabled us to quantitatively measure the PQTs, which enabled breeders to include them in the product profile.

TABLE 2 A gender-intentional target product profile for OFSP in East Africa.

Trait type	Trait	Scale	Desirable score	Trait requirement	Improve trait	Thresh-old trait	*Gender score (0–2)
Color	Skin color	1 to 9	2 & 7	Nice to have			1
Flesh type	Flesh color	1 to 9	6, 7 & 8	Essential	Y		1
Processing traits	Optimal cooking time (250 g)	Minutes	20	Essential	y		2
	Boiled sweetpotato uniformity of cooking	0 to 10	10	Nice to have			2
	Raw sweetpotato ease to peel	0 to 10	2	Nice to have			2
Consumption traits	Dry matter content	%	32	Essential		Y	2
	Boiled sweetpotato mealiness	0 to 10	7	Essential	y		2
	Boiled sweetpotato hardness	0 to 10	6	Essential	Y		2
	Boiled sweetpotato sweet	0 to 10	7	Essential	Y		2
Nutritional traits	Beta carotene content	mg/100, DW	20	Nice to have			2
	Iron content	mg/100, DW	3	Nice to have			2
	Zinc content	mg/100, DW	2	Nice to have			1
Yield traits	Storage root yield (rainfed)	t/ha	15	Essential	Y		1
	Roots per plant	Number	3	Nice to have			
	Root size	1 to 9	3	Nice to have			1
	Root shape	1 to 9	2 & 6	Essential	Y		2
	Harvest index	%	40	Essential	Y		1
Agronomic traits	Vine vigor	1 to 9	6		Y		1
	Plant growth habit	1 to 9	>5				0
	Vine yield	t/ha	20	Essential	Y		1
Disease traits	Alternaria resistance	1 to 9	3	Essential	Y		1
	SPVD resistance	1 to 9	3	Essential	Y		1
Insect traits	Sweetpotato weevil damage	1 to 9	3	Essential		Y	1
	Caterpillar resistance	1 to 9	3	Essential		Y	1
Maturity	Early to intermediate (100–130 days)						
Production/multi-plication traits	Vine survival	%	70	Essential		Y	2
Key competitive products	Kabode, Alamura, Terimbere, KENSPOT 4 and NASPOT 8						

*Gender score:
0 = not targeted.
1 = significant (gender-aware or gender-responsive).
2 = principle (gender equality is the main objective of this trait).

5.2 Lessons

Dissection of the traits identified during gender food mapping helped to reveal embedded attributes within what was previously considered as 'dry matter'. As a result, we now assess and measure four traits instead of just dry matter alone (mealiness, firmness, water absorption and optimal cooking time). A combination of methods clearly revealed the important traits, which were identified right from the SoK through to consumer diagnosis. The important traits were then included in the target product profiles.

Applying the G+ Product Profile Query tool (Ashby and Polar, 2021; CGIAR, 2021) as a first step to test the gender responsiveness of traits led to a deeper understanding of the traits. For example, breeders realized that traits like yield and smooth skin could potentially cause gender disparities and displace women in commercial nodes of the value chain. Consequently, mitigation strategies were designed to address these issues at varietal dissemination. For instance, before releasing a new variety we plan to conduct demand-creation trials and prepare information packages targeting female value chain actors to guide marketing, good agronomic and post-harvest handling practices for the new variety.

Among the major challenges faced were the gender data collection gaps. As a result, our first publication (Mwanga et al., 2021) focused mostly on food science with limited depth in gender enquiry. Another obstacle to engendering the sweetpotato product profile is that while sweetpotato flavor is considered highly desirable by women, it is chemically complex and expensive to measure.

5.3 Recommendation

In retrospect, we found that creating a buy-in for all the multidisciplinary team members should have been one of the first steps taken in this investigation. Giving all team members a shared vision would have greatly eased the research. Our future goal is to scale gender integration into other national breeding programs and to extend this process to other areas of the breeding pipelines such as marketing and seed systems.

We recommend that breeding teams elsewhere establish multi-functional teams. An inclusive vison of gender would capture the needs of men and women all along the sweetpotato value chain. This requires understanding how social identities interact to exclude people from certain activities because of their gender. Gender research is a rigorous undertaking that requires expertise, time, money, and adequate preparation. This requires establishing interdisciplinary research teams which are fully engaged for joint decision making throughout the entire product advancement 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

RS, SM, MN, BY, and VP contributed to conception and design of the study. JM and MN organized the schematics and figures. RS, ST, DM, JM, and SM wrote the first draft of the manuscript. IB, DM, BY, JO, RM, and LF wrote sections 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.

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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.2023.1233102/full#supplementary-material

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Data-driven review on gender and rice varietal trait preferences in Bangladesh

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In Bangladesh, farmers adapt to changing conditions through the adoption of improved varieties containing new or combined traits. The diverse varietal adoption decisions among farmers stem from gender-based differences in trait preferences. This review synthesizes existing knowledge to assess the nature, extent, and causes of gendered disparities in rice varietal trait preferences among farmers and consumers in Bangladesh. To enhance the data-driven nature of this review, we not only scrutinized secondary articles (45 documents) and databases but also incorporated and analyzed primary data on varietal adoption and trait preferences. The analysis revealed a pronounced need for rice breeding programs in Bangladesh to integrate both market and climate-smart traits, aligning with gender-specific needs in developing optimal rice product profiles. Analysis of primary data unveiled substantial variations in women and men farmers' varietal trait preferences, influenced by factors like income, access to farming information, household size, land size, and decision-making. Consequently, addressing gender-differentiated trait preferences in the development of improved rice varieties is crucial to curtail farmers' varietal adoption lag in Bangladesh. The findings underscore the necessity of systematic identification and integration of gender-differentiated varietal trait preferences into rice breeding programs. Failure to account for such preferences may disadvantage the gender-responsiveness of developed varieties and limit the anticipated impact. Therefore, understanding the biophysical, social, and cultural dynamics of diverse farmer groups from a gender perspective is imperative for achieving gender-responsive rice variety development in the context of Bangladesh. This process involves identifying key gender concerns for integration into rice breeding programs, ensuring a comprehensive approach to sustainable agriculture.

KEYWORDS

gender, preferences, traits, varietal development, rice variety

1 Introduction

Rice is the staple food for 167 million population of Bangladesh, and the ascent to a rice self-sufficient country was underpinned by a more than three-fold increase in national rice yield over the past four decades (Kabir et al., 2015; Siddique et al., 2018; Kabir et al., 2020). However, the future growth and sustainability of the rice industry are threatened by several challenges like stagnated yields, the inability of new varieties to replace old mega varieties, low (less than 30%) seed replacement rate and varietal adoption lag (Jaim and Hossain, 2009; Hossain et al., 2012; Kabir et al., 2015; Siddique et al., 2018; Kabir et al., 2020). Bangladesh has planned and implemented numerous agricultural policies for rapid transformation of the agricultural sector through swift technological progress. The process started during the 1960s through Green Revolution by diffusing Modern Rice Varieties (MRVs) with corresponding inputs support (Hossain, 1989; Rahman, 2003) to substantially increase rice productivity (Sarkar et al., 2022). However, the diffusion of MRVs went through various cycles, picking up during its inception stage (The late 1960s and 1970s), then slowing down during the mid-1980s and then picking up again during the late 1980s and 1990s due to the policy reforms aimed at liberalization of the procurement and distribution of agricultural inputs and a reduction of import duties on agricultural equipment (Hossain et al., 1990, 1994; Hossain and Akash, 1994; Sarkar et al., 2022). The period-wise cycles of diffusing MRVs during the Green Revolution have been illustrated in Figure 1.

In order to ensure farmers' high adoption of MRVs, each generation of MRVs developed in Bangladesh had considered different varietal trait preferences, i.e., dwarfism – disease resistance – grain quality – high yield – good taste – high market price – shorter duration - stress tolerant, depending on the period and specific context (Hossain and Akash, 1994; Hossain et al., 1994; Jaim and Hossain, 2009; BRRI, 2015; Kabir et al., 2015). With the diffusion of MRVs in Bangladesh, it was projected that farmers' high adoption of MRVs may largely displace traditional varieties and, therefore, varietal diversity would decrease. However, projections were proved erroneous as considerable varietal diversity was found at the farm level (Hossain et al., 2006; Siddique et al., 2018); for instance, a survey report noted 670 rice varieties across Bangladesh – indicating substantial varietal diversity (Tiongco and Hossain, 2015).

In Bangladesh, different rice varieties respond differently to different environmental conditions with varying yields and production risk (Hossain et al., 1990; Joshi and Bauer, 2006; Hossain et al., 2007; Hossain and Barker, 2007; Hossain and Jaim, 2012; Rahman et al., 2020; Al Mamun et al., 2021; Kabir et al., 2021) and to mitigate the risks associated, farmers' adaptation to the changing conditions is made through the adoption of improved varieties with new traits or combination of traits (Kabir et al., 2015; Siddique et al., 2018; Karmakar et al., 2021; Rahman et al., 2023). Thus, rice breeding programs in Bangladesh are designed to develop new rice varieties with traits like high yield, short duration, resistance to pests and diseases, and tolerance to other biotic and abiotic stresses to curtail farmers' adoption lag (Choudhury et al., 1992; Jaim and Hossain, 2009; BRRI, 2015; Hossain et al., 2015; Kabir et al., 2015; Tiongco and Hossain, 2015). However, genetic improvements for these specific traits alone may not be sufficient for new rice varieties to be adopted by different farmer groups as factors like gender may have considerable weight in determining if a variety will be adopted (Weltzien et al., 2020). For instance, from the 87 MRVs developed in the last five decades, only a handful of them (BRRI dhan28, BRRI dhan29, Swarna, and BR11) have become popular among farmers in Bangladesh (Jaim and Hossain, 2009; Siddique et al., 2018). Consequently, in Bangladesh, it takes 15–16 years from the release of a variety to reach its peak of adoption (Jaim and Hossain, 2009; Hossain et al., 2012; Kabir et al., 2020; Karmakar et al., 2021). Therefore, in order to develop gender-responsive varieties and to curtail the varietal adoption lag by farmers in Bangladesh, a deeper understanding on the nature and causes of differing varietal trait preferences by different farmer groups is an essential prerequisite.

Depending on farm duties, production goals and access to resources, varietal trait preferences by different groups, i.e., men, youth males, vulnerable men, women, youth women, and vulnerable women, differ largely (Ahmed, 2014; Weltzien et al., 2020). The sets of traits that men and women farmers prefer are most likely to differ based on their socio-economic status, farming conditions, and their role in the rice value chain. For instance, varietal trait preferences for men in Bangladesh are more focused on rice production and marketing, whereas, for women, the focus is mostly on production use and food security-related traits (Tiongco and Hossain, 2015). So, it is absolutely difficult to say how essential any given varietal trait is for women and men farmers of a social class and agroecology.

Past literature extensively examined the preferences of consumers (Choudhury, 1991; Jaim and Hossain, 2009; Custodio, 2015; Hossain et al., 2015; Cuevas et al., 2016; Custodio et al., 2016a, 2019; Bairagi et al., 2017, 2018; Mottaleb et al., 2017), farmers (Joshi and Bauer, 2006; Hossain et al., 2015; Custodio et al., 2016b; Ynion et al., 2016; Sarkar et al., 2017; Weltzien et al., 2020; Haque et al., 2023), and other value chain actors (Custodio et al., 2016b, 2019; Sarkar et al., 2017), along with an examination of participatory varietal choices (Paris

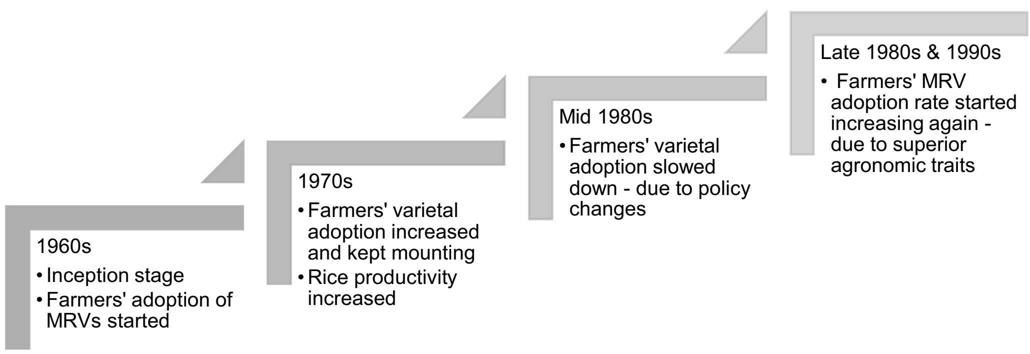

FIGURE 1
Cycles of diffusing MRVs during green revolution in Bangladesh.

TABLE 1 Categorization of reviewed papers based on publication types and research location.

Types of article/publication	Bangladesh	Partially addressed Bangladesh
Gender and varietal trait preferences	–	1
Gender dynamics in rice-based agriculture	10	1
Adoption, diffusion, and impact of modern rice varieties	11	1
Preferences of rice value chain actors	7	6
Rice vision across the globe	6	2

Source: Authors' estimation.

et al., 2005). However, the majority of these studies narrowly focused on the gender perspectives of preferences in the context of rice varietal development. This literature review underscored the absence of gender considerations in rice breeding programs in Bangladesh, emphasizing the need for a more inclusive approach. Integrating gender-differentiated trait preferences into rice varieties is identified as a crucial step to comprehensively address the intricate nuances of varietal characteristics. Therefore, the objective of this review paper is to systematically consolidate existing knowledge and information, with the aim of assessing the nature, extent, and underlying causes of gender-specific variations in rice varietal trait preferences among farmers and consumers in Bangladesh. This review pursues three specific goals: (a) to compile available knowledge documenting gender differences in varietal trait preferences; (b) to comprehensively evaluate the nature, extent, and underlying causes of gendered variations in varietal trait preferences; and (c) to identify and recognize gender-specific aspects that can be integrated into rice breeding programs in Bangladesh.

2 Methodology

This review addresses gender differences in varietal trait preferences through an extensive analysis of pertinent journal articles and secondary documents sourced from Scopus, Web of Science Core Collection, and Google Scholar databases. The search was conducted in February 2023 and employed four distinct categories (Sarker et al., 2023) of search items: (i) exposure keywords (e.g., "Rice," "*Oryza sativa*"); (ii) group of interest terms (e.g., "trait preference*," "preferred trait*," "preferred variety," "varietal preference," "varietal selection," "trait choice," "varietal characteristic"); (iii) outcome of interest terms (e.g., "plant breeding," "variety breeding," "rice breeding," "crop breeding," "crop improvement," "seed system"); and (iv) geographic specifications (e.g., "Bangladesh").

From these searches, a total of 156 articles and associated documents were initially acquired from diverse databases; however, the subsequent removal of duplicates resulted in 89 distinct documents. The criteria for inclusion encompassed original research or reviews that explicitly engaged with varietal trait preferences in the context of rice varieties, seeds, or germplasm. Articles outside the realm of plant breeding and seed systems were excluded. Moreover, geographical limitations confined the search to Bangladesh, and only English-language studies were considered. Acknowledging the potential richness of pertinent literature beyond scholarly sources, supplementary grey literature was also scrutinized.

Ultimately, 45 documents were selected for this review. The categorization of these documents based on publication types and research locations is detailed in Table 1. Notably, a limited number of articles exclusively focused on gender and sex-disaggregated statistics concerning rice varietal trait preferences in Bangladesh. Consequently, this study meticulously curated, tabulated, and graphically presented data from a variety of published works and online resources. To facilitate this, information was collated from a diverse array of sources, spanning media outlets, blogs, research institutes, private and international organizations, policy experts, and newspapers, thereby enhancing comprehension.

In pursuit of a data-driven approach, primary data collected from farmers of different categories from 30 districts across seven divisions of Bangladesh pertaining to varietal adoption and trait preferences, accessed from the 2018 IRRI database, was also subjected to gender-based analysis (IRRI Database, 2018). Descriptive statistics were employed to analyze the primary data. The insights derived from this analysis were subsequently incorporated into the results and discussion section of the review. Notably, like any systematic review, the potential for certain research articles to be excluded due to publication and screening biases cannot be discounted. Consequently, significant effort was expended in scouring reputable databases, websites, and engaging with experts in the field via social media platforms. It is the contention of this study that its efforts substantively contribute to the generation of comprehensive evidence and the identification of key areas of inequity, thereby facilitating the formulation of gender-sensitive breeding policies.

3 Results and discussion

3.1 Nature, extent, and causes of gendered differences in varietal trait preferences

The gender-specific varietal trait preferences reviewed are summarized in this section. The extent to which varietal trait preferences related to value chain actors, gendered roles and responsibilities, and gendered access and mobility provide insights into the nature and causes of gendered differences with regard to varietal trait preferences in Bangladesh.

3.1.1 Consumers' preferences

Consumer's preferences for rice grain in Bangladesh were good taste, white color, slender and fine grains, not sticky, and high-volume expansion (Custodio, 2015), and consumers' perceptions of poor-quality rice in Bangladesh are small and broken grains, rough texture, long cooking time, and too much water requirement for cooking (Custodio et al., 2019). Consumers' preferences regarding rice grain are also varied largely within different regions of Bangladesh. Heterogeneity in rice quality perception is also evident between urban and rural consumers in Dhaka city (Custodio et al., 2019). Consumers' preference for rice according to the process of rice milled is also largely varied across Bangladesh (Jaim and Hossain, 2009). Preferences are largely varied not only among value chain actors of different socioeconomic statuses but also among women with differing empowerment attainment. Table 2 illustrates the historical trends in consumers' preferences for rice quality in Bangladesh.

Consumers' preferences regarding rice grain are also varied largely within different regions of Bangladesh. For instance, producers and producer-*cum*-consumers preferred rice varieties for higher yield, whereas pure consumers preferred varieties on the basis of its tastiness and fineness. The specific grain quality characteristics such as whiteness, broken, shape, amylose (%), aroma, cooking quality, hardness, and chalkiness largely influenced the preferences of both consumers and producers (Hossain et al., 2015). Another study found that 96% of the consumers in Bangladesh bought parboiled rice from the market because of consumption habit (57%), not sticky (15.7%), easily digestible (15.2%), tasty (13.2%), durability (12.2%), and expansion ratio (3.8%) (Jaim and Hossain, 2009). The same study findings noted that the foremost vital quality to consider for good quality rice in Bangladesh is slender rice (42.7%), followed by taste (24.4%) and clean rice (17.0%). Another study noted the top five most preferred rice characteristics in urban Bangladesh as good taste, white, slender, short size, and aromatic grains (Custodio, 2015). Table 3 illustrates the perceptions of consumers on rice quality in Bangladesh.

Findings noted that relatively wealthy consumers are likely to consume more rice than relatively poor consumers, and relatively wealthy consumers tend to be sincere in selecting rice based on grain quality (Cuevas et al., 2016). On a similar note, wealthy households in Bangladesh are more likely to consume fine-grain rice than their counterparts (Mottaleb et al., 2017). However, grain quality can also be superficial and thus can be manipulated by labeling, packaging, and milling. Importantly, the visual appearance of rice grain, such as shape and size, is an important attribute of grain quality that largely affects consumers' decisions to purchase and, therefore, the market price for rice. In addition to size and shape, cooking quality, food value content, and taste also affect the price of rice by influencing consumers' repeated purchasing behavior (Cuevas et al., 2016). In Bangladesh, broken rice normally receives a lower market price, because it is treated as low-quality rice (Cuevas et al., 2016; Mottaleb et al., 2017). After yield, grain type was the second most important factor for farmers when considering the adoption of a new variety because the price of rice is largely influenced and highly associated with the grain type (Custodio et al., 2015, 2016b). Therefore, rice breeding programs must take into account the grain-type preferences of different consumer groups in developing new rice varieties. Without

TABLE 2 Historical trends in consumers' preferences on rice quality in Bangladesh.

Decades			
1980[a]	1990[b]	2000[c]	2010[d]
Parboiled; firm and dry	Parboiled; firm and dry	Firm and dry	High amylose content
High amylose content	High amylose content	High amylose content	Long slender grains; Very fine to fine grains
Slender	Short size medium shaped grains	Medium slender grains; fine grains	High head rice recovery
Short cooking time	–	–	Non-sticky
High head rice recovery	–	–	Tasty
–	–	–	White
–	–	–	Aroma; with fragrance

The grain quality terms used are adopted from IRRI (2015) Rice Knowledge Bank. Source: [a]Choudhury (1991) and Choudhury et al. (1992); [b]Choudhury et al. (1992); [c]Hossain et al. (2015); [d]Custodio et al. (2016a, 2019).

TABLE 3 Consumers' perceptions of rice quality in Bangladesh.

Attribute	Premium quality	Good quality	Low quality
Texture	Non-sticky	Non-sticky	Sticky; becomes too soft if cooked rice is soaked in water overnight
Size and shape	Long; Slender; Very fine to fine	Fine to medium fine; Medium size	Coarse; Bold
Color	White	White but not as white as premium; white even if parboiled	Not very white
Aroma	With fragrance	No bad smell	With bad smell
Purity	–	With 5% impurities	With impurities
Homogeneity	–	With 5% broken grains	Higher % of broken grains
Others	Tasty; Longevity	Tasty; Longevity	Not tasty

Source: Custodio et al. (2016a, 2019).

attaining desirable grain quality that matches end users' preferences, an increase in rice yield may bring less benefit to farmers. Thus, rice breeding programs should focus more on grain quality coupled with traits for high yield, as well as tolerance to biotic and abiotic stresses, that match end users' preferences. If new rice varieties incorporate end users' preferences, this might also benefit rice farmers, as they can accrue extra benefits by catering to consumers' preferences.

There has been significant variance regarding preferences for rice traits among consumers by country, by region, and by country being an importer or exporter (Bairagi et al., 2017). For instance, Bangladeshi rice consumers preferred rice that had great appearance and taste attributes. Conversely, Southeast Asian consumers' first, second, and third choice was more likely to be texture traits, aroma, and appearance, respectively. Also, geographic segmentation significantly affected consumers' decision in choosing preferred rice traits (Bairagi et al., 2017), which must be emphasized in future varietal development programs. In assessing consumers' preferences for extrinsic quality attributes, findings noted that consumers in Bangladesh whose preferred rice trait was aroma were more likely to purchase packaged rice which is consistent with the observation that aromatic rice is usually packaged and its market price is higher (Bairagi et al., 2018). One key aspect to note here is that rice breeding programs must combine both market and climate-smart traits in optimal product profiles while tailored to specific needs. Because if breeders fail to tailor rice varieties based on the demanded trait preferences, other Rice Value Chain (RVC) actors may do so and capture consumer surplus. For example, millers, wholesalers, and exporters can mix varieties to provide different "grades" of texture or double-polish grains to increase slenderness as what is currently done in Bangladesh for the so-called 'Minikit' (further polished version of BRRI dhan28 and BRRI dhan29) rice. Also, failure to incorporate agronomic and stress-tolerance traits, on the other hand, may expose farmers to higher climate and production risks. Therefore, rice breeding programs should consistently incorporate market research on the preferences of different RVC actors. In the long run, market and climate-smart rice breeding will contribute to more efficient, equitable, and sustainable RVCs as a result of better linkages between rice farmers and consumers. The RVC-based recommendations for better varietal adoption by farmers in Bangladesh are as follows;

Recommendations

- Targeting the bio-fortification of Swarna, BR11, BRRI dhan29, and BRRI dhan28 could result in reaching more than half of the rice consumers in Bangladesh with nutrient-dense rice.
- Farmers will accept varieties with nutritional traits only if there is no yield penalty.
- Consumers have a preference for less-parboiled rice.
- Millers, however, go for more polishing to target high-income consumers.
- Nutritional traits must be put into the endosperm for the nutrients to reach consumers.

Source: Hossain et al. (2012).

3.1.2 Farmers' varietal trait preferences

Varietal trait preferences are largely varied among different farmer groups depending on their roles and responsibilities in rice cultivation. Findings noted that farmers in Bangladesh opined high yield (46%), good taste (24%), and lodging resistance (23%) as the top three reasons for choosing rice variety BRRI dhan29 (Hossain et al., 2003a,b, 2006). On the other hand, high yield (28%), good taste (20%), and early maturation (13%) as the top three reasons for choosing BRRI dhan28 (Tiongco and Hossain, 2015). Regarding primary traits in new rice varieties, 96% of farmers in Bangladesh preferred high yield, and as secondary traits, they preferred grain quality, shorter maturity, lodging resistance, and higher milling recovery (Jaim and Hossain, 2009). Other findings noted farmer's rice varietal trait preferences in Bangladesh as yield, tolerance to biotic and abiotic stresses, short duration, and profitability. Farmers usually assess a new variety in terms of a range of attributes, including grain quality, straw yield, and input requirements in addition to yield (Joshi and Bauer, 2006; Haque et al., 2023). Rice grain quality largely influences the farmer's adoption decision of new rice varieties, for instance, due to poor grain quality after cooking, hybrid rice varieties are less preferred in Bangladesh (Mottaleb et al., 2015, 2017). Figure 2 illustrates the results of a varietal adoption study conducted by the International Rice Research Institute (IRRI). Findings noted that farmers' (both male and female) top preferred traits in Bangladesh are high yield, good taste, slender grain, easy to sell, and higher market price.

Figure 3 illustrates that men and women farmers in Bangladesh prefer the same traits, but they rank them differently. To elaborate,

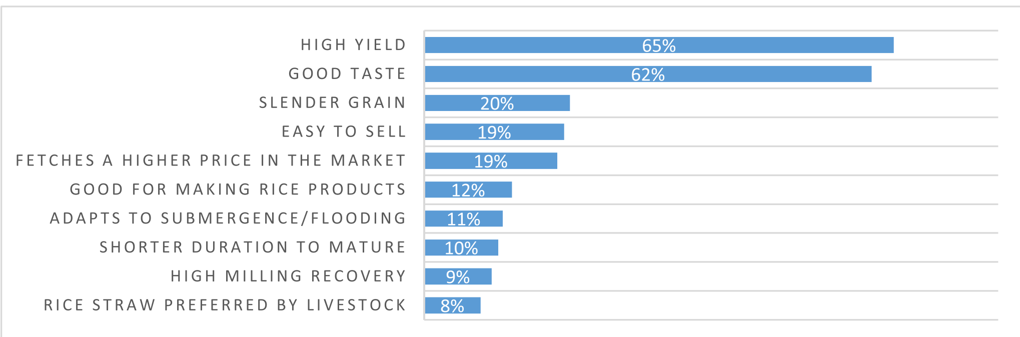

FIGURE 2
Farmer preferred traits (% of responses) in Bangladesh – combined men and women (all varieties). Source: IRRI Database (2018).

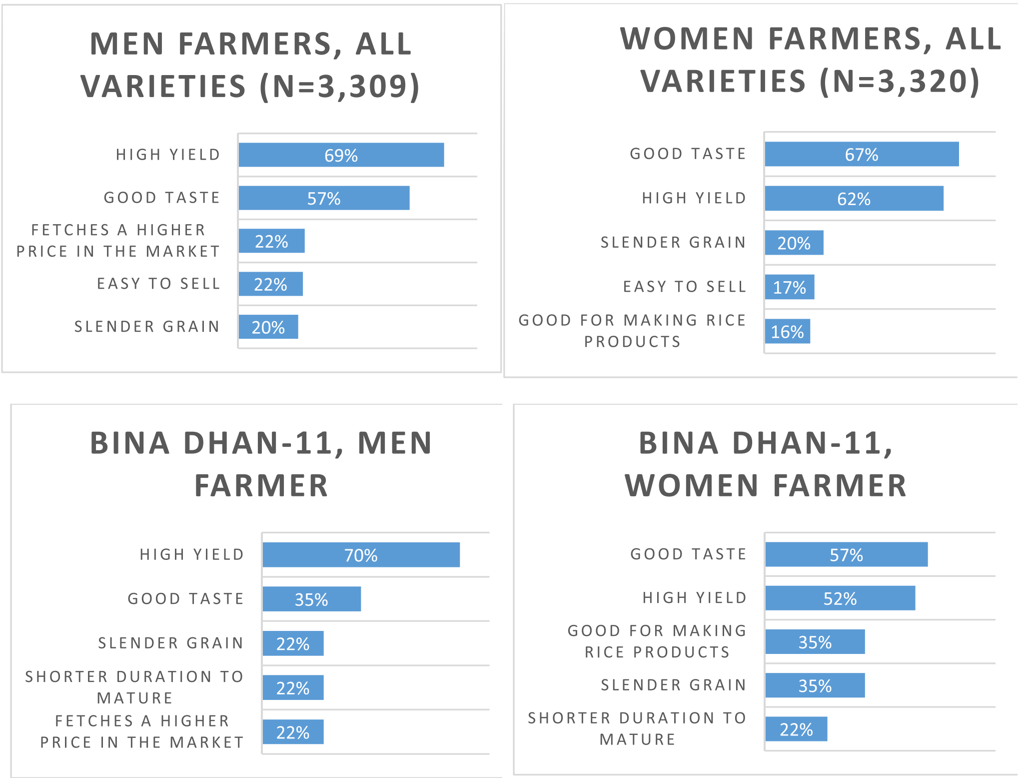

FIGURE 3
Varietal trait preferences by men and women farmers (% of responses) in Bangladesh. Source: IRRI Database (2018).

varietal traits preferred by men farmers seem to be mostly production and market-oriented, whereas traits preferred by women farmers seem to be both production and consumption (good for making rice products) oriented. Similar findings have also been noted for non-stress tolerant rice variety (non-STRV) trait preferences (Figure 4). From Figure 4, traits by both men and women farmers in Bangladesh preferred similar traits for stress tolerant rice varieties (Chowdhury, 2014), and both ranked flood tolerance highly. However, for non-stress-tolerant rice varieties, the findings distinctly reveal significant variations in varietal traits preferred by men and women farmers in Bangladesh. This observation underscores that, in stress ecosystems, farmers, irrespective of gender, prioritize production. Conversely, in favorable ecosystems, male farmers exhibit a stronger emphasis on agronomic traits, while female farmers prioritize traits related to grain quality.

Figure 5 illustrates the differences in varietal trait preferences for men and women farmers by divisions in Bangladesh. Results noted that both men and women farmers have a higher preference for yield and good taste in most divisions. Also, men farmers are more market-oriented in Rajshahi, Dhaka, Khulna, and Barisal divisions, while women are more market-oriented in Rangpur, Dhaka, and Barisal divisions. Both men and women farmers have more focus on the submergence trait in the Barisal division and on the home consumption trait (higher milling recovery) in the Rajshahi division. These results clearly indicate that varietal trait preferences differ not only between men and women but also among farmers of different divisions in Bangladesh.

In addition to these, the study results noted that, using different factors like income groups, farmers' access to farming information, household size, land size, and decision-making on varietal choice, both men and women farmers preferred similar traits with different rankings. The only exception was found in the case of varietal trait preference by religion, where similar traits were preferred by Hindu and Muslim farmers but ranked differently. However, women farmers preferred similar traits and ranked similarly regardless of their religious status. All these results elucidate quite a lot on the nature, extent, and causes of gendered varietal trait preferences in Bangladesh.

Table 4 illustrates the gendered varietal trait preferences in Bangladesh. From Table 4, varietal trait preferences ranked higher by women or men farmers give indications of strong gender specificity. For instance, traditionally, women in Bangladesh are responsible for post-harvest processing and food preparation, which leads to varietal traits related to these activities being preferred more by women than men farmers (Ynion et al., 2016). That's why; women farmers noted trait preferences for a variety, i.e., post-harvest, processing, and consumption aspects that were not mentioned by their counterparts. One key aspect to note here is that women and men farmers in Bangladesh, even within the same agroecology and village, may require different improved traits for cultivating rice under complementary conditions and thus may express different trait preferences for varieties. Hence, attention to incorporating gender-differentiated trait preferences in developing improved varieties can curtail farmers' varietal adoption lag in Bangladesh.

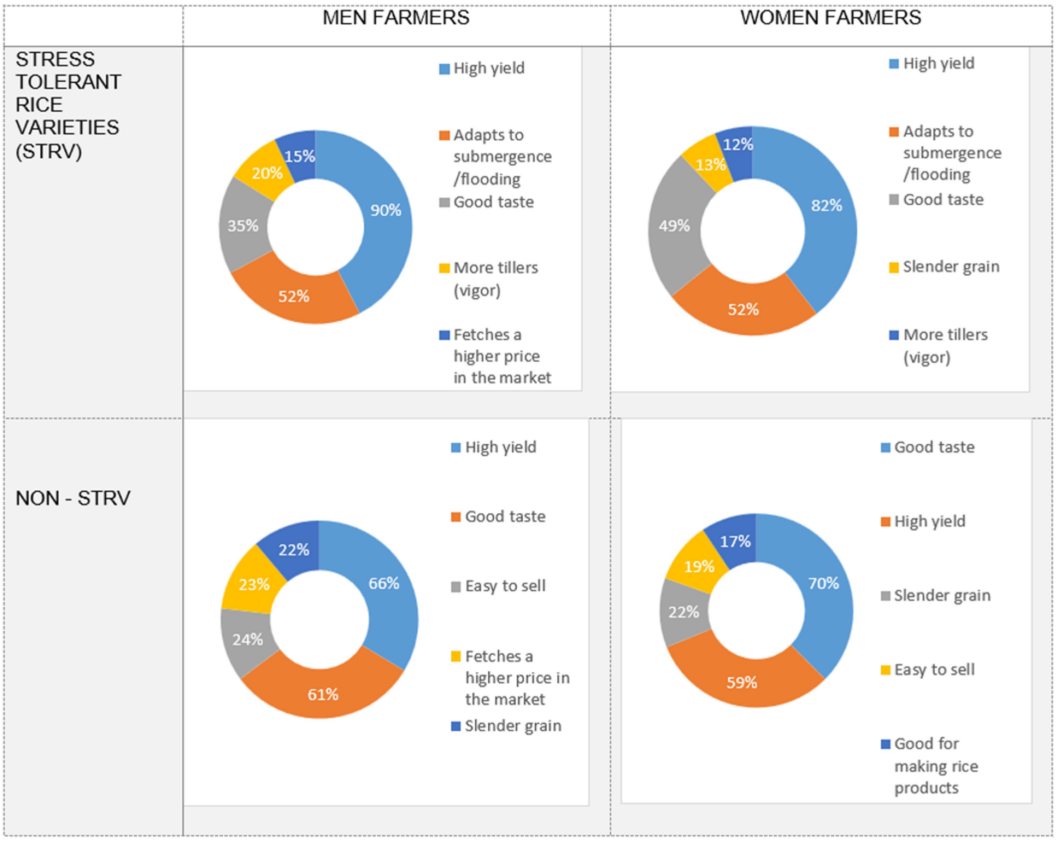

FIGURE 4
Traits preferred by men and women farmers (% of responses) in Bangladesh. Source: IRRI Database (2018).

3.2 Gender and rice breeding programs in Bangladesh

The influence of gender differences on rice farming in Bangladesh is fundamental because men and women have unequal control over and access to productive resources on which rice farming depends largely (Ahmed, 2014; Weltzien et al., 2020). This is particularly the case for smallholder farmers in Bangladesh, where women and men have different roles and responsibilities and where rights and access to productive resources differ significantly (Al-amin et al., 2004). Systematic identification and integration of gender-differentiated varietal trait preferences in designing rice breeding programs in Bangladesh remains unreciprocated. Lack of sensitivity towards gender-differentiated trait preferences by the rice breeding programs can be a disadvantage for gender-responsiveness of the variety developed and can also limit the anticipated impact of newly developed varieties (Weltzien et al., 2020). Hence, understanding the biophysical, social, and cultural environment of different farmer groups from a gender perspective is quintessential to gender-responsive variety development in Bangladesh.

Rice breeding programs in Bangladesh aim to develop new rice varieties incorporating farmer-preferred traits to curtail varietal adoption lag (Choudhury, 1991; Jaim and Hossain, 2009; BRRI, 2015; Hossain et al., 2015; Kabir et al., 2015; Tiongco and Hossain, 2015; Karmakar et al., 2021). However, in Bangladesh, it usually takes 15–16 years from the release of a variety to reach its peak of adoption (Jaim and Hossain, 2009; Kabir et al., 2020). For instance, stress-tolerant along with high market-value rice varieties were promoted in Bangladesh by the Cereal Systems Initiative for South Asia (CSISA) project; however, when monitored, the adoption of such varieties appeared to be very low (Ahmed, 2014). One of the reasons behind such a slow varietal adoption rate can be the conventional varietal development approach (supply-driven) followed by the rice breeders in Bangladesh, in which breeders mostly prefer traits that do not always match the needs of different farmer groups, i.e., men and women (Hossain et al., 2003a,b; Sarkar et al., 2017). In Bangladesh, women farmers' engagement in agriculture has been ever-increasing (Haque et al., 2017; Khan et al., 2017, 2023; Khan, 2019), and their thoughts and perceptions are equally important in developing improved rice varieties. Also, women's knowledge of post-harvest management and cooking quality (Paris et al., 2005; Gurung et al., 2013) are important considerations in developing rice varieties for different agroecologies suffering from both biotic and abiotic stresses. Therefore, the use of the participatory varietal selection (PVS) process may address this issue to a great extent as it involves different farmer groups in the selection of desired breeding lines. Also, the participation of women in the PVS process increases women's decision-making authority in varietal choice, seed acquirement, and crop management (Paris et al., 2005; Gurung et al., 2013).

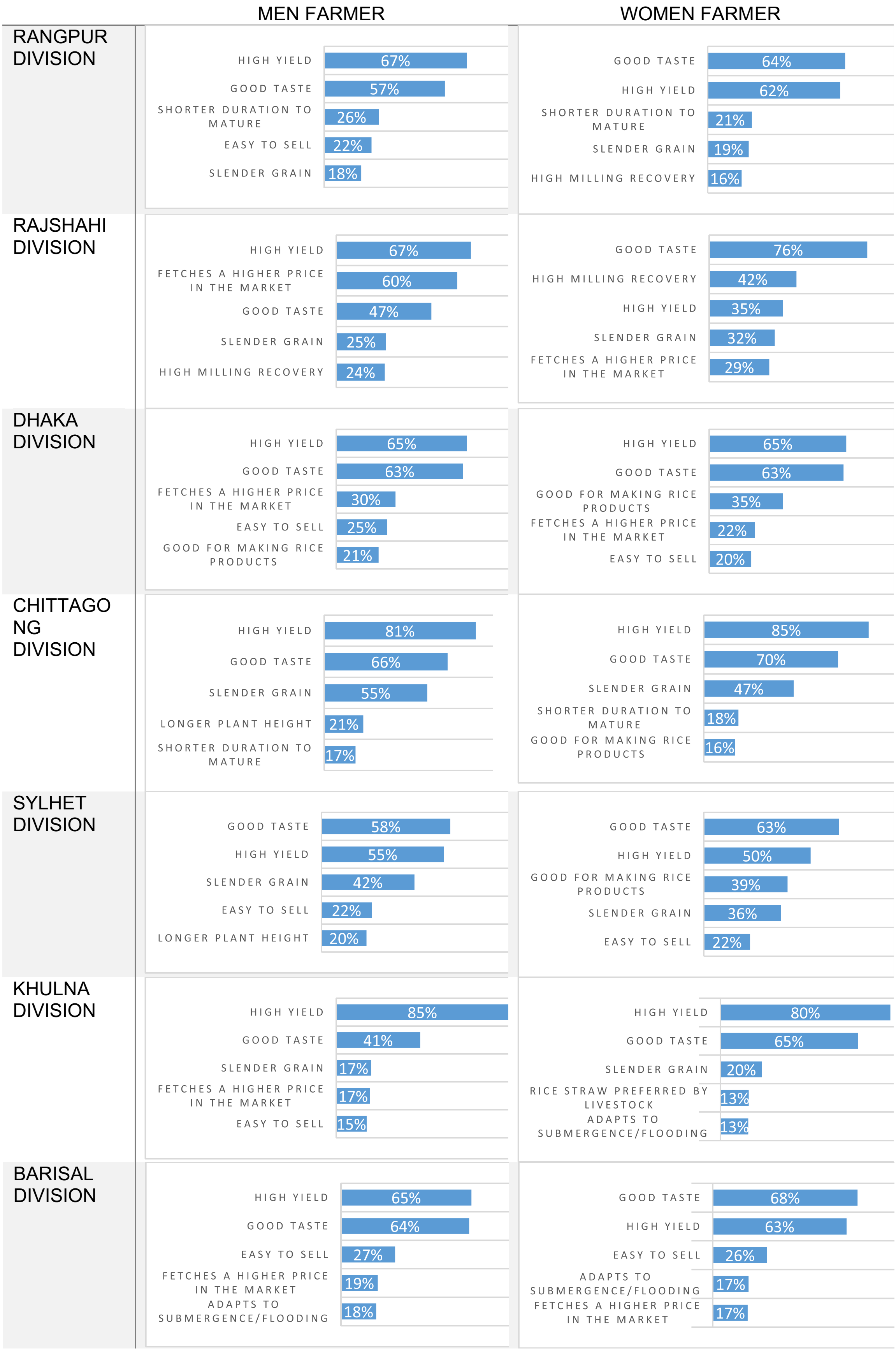

FIGURE 5
Preferred traits by men and women farmers (% of responses) in Bangladesh (by Division). Source: IRRI Database (2018).

TABLE 4 Gendered varietal trait preferences in Bangladesh.

Men		Women	
Rank	Traits	Rank	Traits
1	High yield	1	Good taste
2	Good taste	2	High yield
3	High market price	3	Slender grain
4	Easy to sell	4	Easy to sell
5	Slender grain	5	Good for rice products
6	Shorter duration	6	High market price
7	Adapts to flooding	7	High milling recovery
8	Good for rice products	8	Adapts to flooding
9	More tillers (vigor)	9	Shorter duration
10	High milling recovery	10	Fodder for livestock

The ranking was determined by considering the frequency of responses from the participants. The highest frequency is allocated the first rank, followed by sequential rankings for the remaining frequencies. Authors' estimation based on data from IRRI Database (2018).

TABLE 5 Key gender aspects for integration with rice breeding programs in Bangladesh.

Domains	Determinations	Gender integration
Figure out farmers' criteria for selecting varieties	Modify selection strategies to improve chances for the adoption of newly bred varieties	Women and men can have specific expertise for evaluating certain varietal traits, and their trait priorities can vary
Understand farmers' varietal adoption decisions	Target gender-responsive breeding priorities and assess benefits that different farmer groups may derive	Women farmers can derive benefits from or be negatively impacted by specific types of varietal traits
Characterize consumer demand for specific types of varieties	Based on the developed gender strategy, predict future market opportunities for specific types of varieties	Families with different geography and resource levels can have specific demands; i.e., urban vs. rural consumers [men and women], poor vs. rich, etc.
Recognize patterns of genetic diversity	Gender-focused maintenance of the germplasms	Both women and men farmers can use specific varieties for specific purposes
Identify customers for newly developed varieties	Target gender-focused seed dissemination approach and develop seed marketing strategies accordingly	Target women farmers as customers for specific varieties due to their unique trait preferences or family roles, i.e., bio-fortified crops targeting child nutrition

Source: Adopted from Weltzien et al. (2020).

In addition to gender considerations, it is crucial to recognize the diverse preferences within other demographic groups involved in rice farming. The varietal trait preferences of youth, both male and female, as well as senior citizens and persons with disabilities, constitute significant aspects that merit attention within the rice breeding framework. Understanding their distinct criteria regarding factors such as production ownership, control, and access is essential for a comprehensive analysis of decision-making processes in the rice value chain. Additionally incorporating such trait preference parameters within the rice breeding mechanism is likely to generate new thinking avenues in curtailing farmers' rice varietal adoption lag in the context of Bangladesh. Therefore, rice breeding programs in Bangladesh need to be more mindful in soliciting gender-responsive criteria for developing improved rice varieties. Identified domains and determinations for proper gender integration with rice breeding programs in Bangladesh are illustrated in Table 5.

Gendered differences in production environments may go undetected in typical analyses focusing solely on geographic and biophysical aspects. Thus, rice breeding programs in Bangladesh need to analyze and target different farmer groups, considering sociocultural factors like gender as well as economic and ecological factors. In addition, rice breeding programs in Bangladesh can benefit substantially from gender-focused market analysis, concepts and tools for describing and prioritizing consumer needs, and market demands as a basis for gender-responsive targeting.

4 Concluding insights and recommendations

Many of previous researches were associated with ongoing rice breeding programs, indicating that gendered differentiation with regard to varietal trait preferences has been a concern for rice breeding programs. However, explaining the gender differences in varietal trait preferences for a specific context in Bangladesh was not the primary goal of any research identified for this review. However, few researchers (Al-amin et al., 2004; Haque and Chowdhury, 2006; Jaim and Hossain, 2011; Rahman et al., 2016; Haque et al., 2017; Khan et al., 2017; Khan, 2019) had a primary objective to explain differences in gender relations in the different farming context of Bangladesh. Only one research, Gurung et al. (2013), tried exploring the gender dynamics in changing rice-based agriculture in Bangladesh. In another research, Ahmed (2014), reviewed the gender-related activities under different projects of IRRI since 2000. Consequently, the underlying causes for contrasting gendered varietal trait preferences are not well identified in previous research. In the context of Bangladesh, detailed discussions to understand the varietal trait preferences of women and men for future varietal development programs were rarely used among the articles reviewed. Therefore, analyzing the differences among varieties preferred by women and men, and the specific traits those varieties possess can provide a basis for identifying gender differences. Hence, specifically designed research dedicated to understanding the gender differences in varietal trait preferences is recommended so that the gender-responsive rice breeding program becomes a reality in Bangladesh.

Previous studies on rice grain quality preference in Bangladesh have focused mainly on consumers (Jaim and Hossain, 2009; Bairagi et al., 2017, 2018). However, little has been done to assess grain quality in relation to both farmer and consumer preferences (Hossain et al., 2012, 2015; Sarkar et al., 2017; Haque et al., 2023) in order to infer how grain quality could influence farmers' preference for improved rice varieties and consumers' preference for quality rice grain. In Bangladesh, more research (both qualitative and quantitative) is required to assess the influence of grain quality and other factors affecting farmers, both in men, women and youth, varietal trait preferences for improved rice varieties. It is striking, however, that there is rather scant literature on gender and varietal trait preferences in Bangladesh. Therefore, further research using an interdisciplinary research approach (both qualitative and quantitative) on gendered differences in varietal trait preferences for different farmer groups in Bangladesh will fill a major gap in the literature. More analysis, similar to the analysis done by Tiongco and Hossain (2015), is required in major rice growing regions of Bangladesh to aid the development of improved rice varieties that are more responsive to the needs and preferences of both men and women farmers in Bangladesh.

4.1 Key aspects for gender-responsive rice breeding in Bangladesh

- Develop gender-responsive product profiles: Understanding the differences in women and men farmers' varietal trait preferences can help defining the specific type of variety to be bred by the rice breeding programs in Bangladesh. Developing context-specific gender-responsive rice product profile, with a defined set of targeted attributes that a new variety is expected to meet in order to be successful in the market (Ynion et al., 2016; Sarkar et al., 2017; Ragot et al., 2018) is helpful in this respect. Critical aspects here include recognizing the combination of "must have" traits that need to be above a threshold for acceptability and prioritizing the key varietal traits to be improved. Consumer-preferred quality traits such as processing and cooking attributes are a major group of "must have" traits that women in Bangladesh frequently highlight, and insufficient attention to ensure acceptable levels of these traits risks a lack of farmers' adoption of newly developed varieties. Therefore, gender-responsive product profile development will define the combination of varietal traits needed to respond to the targeted demand of different farmer groups and of different ecologies across Bangladesh.
- Gender-responsive breeding strategy for enhanced genetic gains: One of the most important questions of modern times is whether it is really worth developing a gender-specific variety that meets demand and has benefits for a certain farmer group. The answer is quite simple. We do not need to develop separate varieties, given the fact that in Bangladesh, varietal trait preferences of women and men farmers are based on their differentiated farming and household roles and responsibilities. For instance, men's focus on agronomic traits and women's preferences for qualities for post-harvest processing, cooking, and food security are complementary. The inclusion of such complementary varietal traits that satisfy both women and men farmers' trait preferences in a given variety could be a pre-condition for responding to the full range of varietal desires and needs. Breeding separate varieties for women and men could be necessary only when the traits for their respective objectives differ significantly and involve tradeoffs.
- Complexity of gendered trait prioritization: Based on the evidences of previous discussions, it is clear that varietal trait preferences are quite different for women and men and are equally important for guiding future rice breeding programs in Bangladesh in a gender-responsive manner. However, it is often difficult to generalize or quantify the gendered differences unfailingly. For instance, if breeding programs in Bangladesh opt for the gender-focused comparison of varietal trait preferences, it is more likely to generate a contradictory picture due to numerous socioeconomic characteristics influencing gender roles and responsibilities, shaping their preferences. Generalizations about gender-differentiated varietal trait preferences requires an explanation of how preferences reflect underlying gender differences in assets, markets, information, and risk. This requires reference to a social profile that includes but is not limited to analysis of varietal preference differences between women and men in Bangladesh.
- Ways forward: To learn effectively about the gender differences in farmers' varietal trait preferences, rice breeding programs in Bangladesh must use multiple methods (On-station trial, on-farm trial, participatory varietal selection, individual interviews, focus group discussions, and case studies). In addition, breeders must have joint annual feedback and planning meetings with both women and men farmers to improve knowledge and awareness of overall goals and specific breeding objectives of rice variety development. Breeding programs must also set quotas for variety trials to be conducted by women in their fields, which in turn will give them a direct opportunity to propose their priority traits to use for varietal evaluations. Effective implementation of all these is expected to support gender-responsive trait prioritization by the future rice breeding programs in Bangladesh.

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 authors.

Author contributions

MSK: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Visualization, Writing – original draft. MARS: Investigation, Methodology, Supervision, Visualization, Writing – original draft. MRI: Funding acquisition, Investigation, Supervision, Writing – review & editing. HB: 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.

Publisher's note

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Farmer-preferred traits and variety choices for finger millet in Uganda

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Finger millet is a climate-resilient crop providing food and nutrition security and income In Uganda. However, the current productivity of finger millet in farmers' fields is low and among other factors, this is due to the poor adoption of improved varieties. With this study we aim to identify and profile varietal traits preferred by finger millet farmers and consumers in Uganda. We specifically focus on how these traits vary among women and men in the Ugandan finger millet value chain. We collect data using semi-structured questionnaires among 170 households growing millet in Bushenyi, Lira, and Nwoya districts, and we triangulate questionnaires replies with qualitative information from 11 focus group discussions and 3 key informant interviews. Using descriptive statistics and probit regression models, we find that the majority of the farmers (97%) prefer growing landrace varieties of finger millet compared to only 3% growing improved varieties. The most preferred varieties were Kaguma in Bushenyi, Ajuko Manyige in Nwoya, Kal Atar, and Okello Chiba in Lira. Farmers' choice of variety depends on a combination of traits including agronomic, marketing, and consumption traits. Gender, marital status, education levels, and occupation are the major socio-demographic factors that influence specific preferences related to finger millet variety. This study lays a foundation for designing a gender-responsive finger millet product profile to guide the development and release of new varieties by the finger millet crop improvement program.

KEYWORDS
finger millet, gender dynamics, socio-demographic factors, variety preference, Uganda

1 Introduction

Finger millet is a dominant cereals crop grown in Uganda, both in sub-humid and semi-arid regions due to its ability to grow and perform well even in harsh environments (Wanyera, 2005; Owere et al., 2015; Adikini et al., 2021). It is the third most important cereal after sorghum and maize in terms of area under production covering a total land area of 437,000 hectares (UBOS, 2022). It is grown across the whole country, majorly in the eastern, northern, and western regions of Uganda (UBOS, 2022; Kasule et al., 2023). The crop is primarily grown for its grain, which serves as food, providing over 65% of the carbohydrate requirements and 30% of the daily calorie intake for humans (Gupta et al., 2017). The stover is used for livestock feeding. Finger millet grains are rich in micronutrients, antioxidants, and dietary fiber, which promote health and nutritional well-being (Ojulong et al., 2021; Abioye et al., 2022). The crop is gluten-free making it a premium special diet for people with diabetes and gluten-sensitive consumers (Ojulong et al., 2021). In addition, finger millet has strong cultural roots where it is considered a special meal in all cultural functions like marriage, naming of the children, and celebrating new harvest festivals (Wanyera, 2005).

The demand for finger millet is on the rise both at local and international levels (Gierend et al., 2014; Orr et al., 2016, 2020). This is due to its climate resilience and drought tolerance characteristics; the crop requires less water to complete its growth cycle, making its production more sustainable (FAO, 2019; Choudhary et al., 2023). The crop can withstand high temperatures up to 44°C, at which other cereals like maize and rice cannot grow (Yogeesh et al., 2016; Mwangoe et al., 2022). In addition, the rising population coupled with changing lifestyles, and rapid urbanization create opportunities for the development of diversified millet food products according to taste requirements, and convenience for traditional and modern consumers such as ready-to-eat foods or food for diabetics, hence widening the demand (Orr et al., 2016, 2020). Given the health benefits of millet, private companies are taking up the commercialization of millet-based products. For example, bushera (a non-alcoholic soft drink made from millet) is currently processed and packaged by both small and big companies such as Century Bottling Company in Uganda (Mubiru et al., 2020; Kasule et al., 2023). These types of finger millet products need the development and release of finger millet varieties that have traits for the specific niche market but also ensure sustainable production and productivity to balance supply with demand (Kasule et al., 2023).

Finger millet production is largely done by small-scale farming households with no access to inputs like improved seeds, fertilizers, pesticides, or improved implements (Wanyera, 2005; Adikini et al., 2021). All the production is done at a subsistence scale and purely rain-fed (Adikini et al., 2021). The current average productivity of finger millet at farmer fields is 0.6 t/ha (UBOS, 2022), which is very low compared to 3.5 t/ha obtained on-station. This low yield is a result of several factors including biotic stresses (like finger millet blast disease, parasitic striga weed), abiotic stresses (like drought, erratic rainfall, and declining soil fertility), limited availability and access to quality improved seed by farmers and poor agronomic practices leading to drudgery (Owere et al., 2014; Adikini et al., 2021; Kasule et al., 2023). In addition, finger millet is faced with low adoption of improved varieties and a lack of variety replacement (Owere et al., 2014, 2015). Over 60% of farmers are still using landraces which they recycle every season (Adikini et al., 2021; Kasule et al., 2023). Often, many of these landraces are inferior in yield, not well adapted to emerging climatic effects, and are prone to pests and diseases (Adikini et al., 2021; Kasule et al., 2023). To address the above challenges, over twelve improved finger millet varieties have been released in Uganda (Adikini et al., 2021). Notably, varieties such as SEREMI 2 (U15) and PESE 1 (P224) have been widely adopted by farmers both in Uganda and across East Africa (Kenya and Tanzania) largely because of their attributes like early maturity, big fingers, attractive colors, more tillers, good brew, and bread (Mwema et al., 2017; Orr et al., 2020; Ojulong et al., 2021; Tracyline et al., 2021). Finger millet varieties ENGENY, GULU E, and SERERE 1, released in the early 1970s, had very low adoption largely because of the poor yield (Gierend et al., 2014; Kasule et al., 2023). Similarly, varieties SEREMI 1 and 3 despite having high yield, were not adopted by farmers because they lacked brewing quality and the taste of the bread was poor (Gierend et al., 2014).

Variety adoption is a complex process and any new variety that does not address farmer preferences and production constraints is less likely to be adopted (Kasule et al., 2020). This is simply because farmers are specific in their decision making which can play a role in determining whether a variety or technology can be adopted (Cagley et al., 2009; Weltzien et al., 2019; Sanya et al., 2020). The lack of a systematic breeding process that incorporates traits preferred by farmers has been reported to result in poor performance and low adoption rates of new varieties, by farmers, especially by farmers in marginal environments (Gierend et al., 2014; Acevedo et al., 2020; Mireri et al., 2023). This therefore implies wasted efforts and resources given the years it takes to develop and release a variety. Understanding the trait characteristics preferred by farmers and other stakeholders in the value chain is key in defining product profiles needed to develop new varieties and therefore offers great potential for adoption. Currently, the traits preferred in finger millet varieties by farmers are not well defined, and very scanty information is available which limits the ability of breeders to incorporate such traits.

The research so far conducted on variety preference in finger millet has focused mainly on the preference of the farmers without considering the needs of other value chain actors like consumers (Owere et al., 2014). Although finger millet has long been considered a food security crop (Wanyera, 2005), the monetization of the economy forces farmers to sell part of the crop to satisfy their needs. The implication is that farmers may produce finger millet to suit the needs and preferences of other end users that may be different from theirs. Genetic modification of crops without considering consumer traits can lead to a rejection of new varieties. For example, discoloration of endosperm due to over-expression of ß-carotene is seen as a barrier to adoption for certain food crops (Polycarpe Kayodé et al., 2005). Also, consumers at different nodes have different trait needs. For example, millers prefer grain with good milling characteristics; while brewers desire grain that produces a good malt (Kiprotich et al., 2014). Consumers' quality perception of grains and derived foods needs to be incorporated into breeding programs to successfully enhance the adoption of improved varieties. Information on consumer traits in finger millet is lacking and needs to be identified, documented, and incorporated into product profiles to guide breeders during the breeding process. This will allow the integration of consumer traits at an early stage of variety development.

Variety choices and trait preferences are also influenced by gender (Cagley et al., 2009; Frimpong et al., 2023; Zimba et al., 2023). Studies have shown that trait preferences by men and women farmers may differ, especially when they are faced with different constraints, different roles and responsibilities in production and consumption systems, and different crop production goals (Weltzien et al., 2019; Andiku et al., 2021). Women and men have unequal access to and control over production resources like land which affects their decision on the choice of variety to plant (Weltzien et al., 2019). According to Cagley et al. (2009), farmers in most finger millet growing areas practice a patrilineal system of land ownership and men decide how a given land is used. The size of land and other productive resources will affect the choice of variety grown by women and men. According to Nchanji et al. (2021), most women tend to grow landraces because of their availability, affordability, and accessibility while men tend to adopt and grow improved varieties. Given the limited access to and control over resources by women, studies have also shown that women tend to focus more on food security-related traits like early maturity, multiple harvests, production potential during the full growing season as well as productivity under sub-optimal soil fertility (Christinck and Kaufmann, 2017).

Women are also keen on post-harvest processing and food preparation traits including storability, grain color, and texture (Weltzien et al., 2019; Frimpong et al., 2023). On the other hand, men tend to focus more on production and marketing-related traits (Frimpong et al., 2023; Zimba et al., 2023). Gender differences also affect how crops are utilized in postharvest and food processing and marketing and how these are valued by different consumer groups (Weltzien et al., 2019). Previous studies on other crops like cassava, sweet potato, and banana, indicated that gender differences in needs, access, and roles play a big role in the adoption of improved crop technologies including varieties (Tufan et al., 2018; Sanya et al., 2020, 2023; Polar et al., 2021). Finger millet is not an exemption to this trend; thus, the need to integrate gender in all breeding activities to ensure the needs of the end user are integrated into new varieties.

Therefore, the study was undertaken to identify and profile varietal traits desired by finger millet farmers and consumers and how these traits vary among women and men in the finger millet value chain. This study also dissects how socio-economic characteristics affect the trait preference of finger millet farmers. This information will be used to refine the product profiles and guide a variety development processes, recommendations, and deployment strategies by the Finger Millet Improvement Program in Uganda. Ultimately the new improved variety of finger millet will have the right traits needed by end users and this will increase adoption leading to increased yields, hence, improved food and nutrition security and income among smallholder farmers especially those in climate change-prone areas.

2 Materials and methods

2.1 Description of the study areas

The study was conducted in the Northern and Western regions of Uganda covering three districts, namely Bushenyi located at 0°31’59.99” N and 30°10’60.00″ E (Western Uganda), Nwoya located at 2°38’3.59” N and 32°00’0.00″ E and Lira located at 2°16’26.40″ E (Northern Uganda). The three districts were selected because they are among the leading finger millet-producing areas in Uganda.

2.2 Geospatial maps

The displayed maps were generated using the geographic information system software QGIS version 3.30.[1] Shape file data for the locations of the study area were obtained from the Uganda Bureau of Statistics (2023) spatial data portal. To place the geo-referenced study sites, the Datum of World Geodetic System 1984 (WGS84) was used to maintain consistency in datasets during analysis (Kumar, 1988). The map highlights major sites for growing finger millet in the corresponding agroecological zone (Figures 1, 2). The major nine agroecological zones depicted on the map were derived from a classification system that considers factors such as climate, soil type, vegetation, and socio-economic and cultural characteristics (MAAIF, 2018).

2.3 Study design

The study employed mixed methods research, incorporating both qualitative and quantitative methods to capture the preferred traits for finger millet by the farmers. The study mainly involved both men and women smallholder finger millet farmers in the selected districts.

2.4 Selection of study sites and sampling method

Multistage random sampling was used to arrive at the household level. In the first stage, the selection of regions was based on literature and production statistics data sources (UBOS, 2022). The major finger millet-producing regions were identified as the eastern, western, and northern regions in Uganda. For this study, western and northern regions were selected because little or no information regarding trait preference for these regions exists. Most of the studies so far conducted concentrated in the eastern region (Owere et al., 2014). In the western and northern regions, major finger millet-producing districts were selected based on production statistics. Bushenyi district in Western, and Lira and Nwoya districts in Northern regions were selected. Two finger millet growing sub-counties from each district were selected with the help of district production and marketing officers of the respective districts. A systematic random sampling was used to select 23–40 households per sub-county making a total of 173 households for the quantitative survey (Table 1). The respondents were purposively selected using an interval of five households with the help of local leaders and agricultural extension officers familiar with the area. From each household, one respondent who had experience in finger millet production was selected and interviewed. For households where both the household head and spouse were knowledgeable and actively involved in finger millet production, the household head was selected for interviewing.

2.5 Data collection methods

2.5.1 Quantitative data collection

The quantitative data were collected through a formal survey using semi-structured questionnaires. A total of 8 enumerators (4 women and 4 men) were trained on the designed survey tool. This was done to improve efficiency and accuracy in data collection and clarity in elaborating questions to respondents. The questionnaire was pretested with 10 finger millet farmers in Ongino subcounty in Kumi district who share similar characteristics with farmers in the study

1 https://www.qgis.org/en/site/forusers/download.html

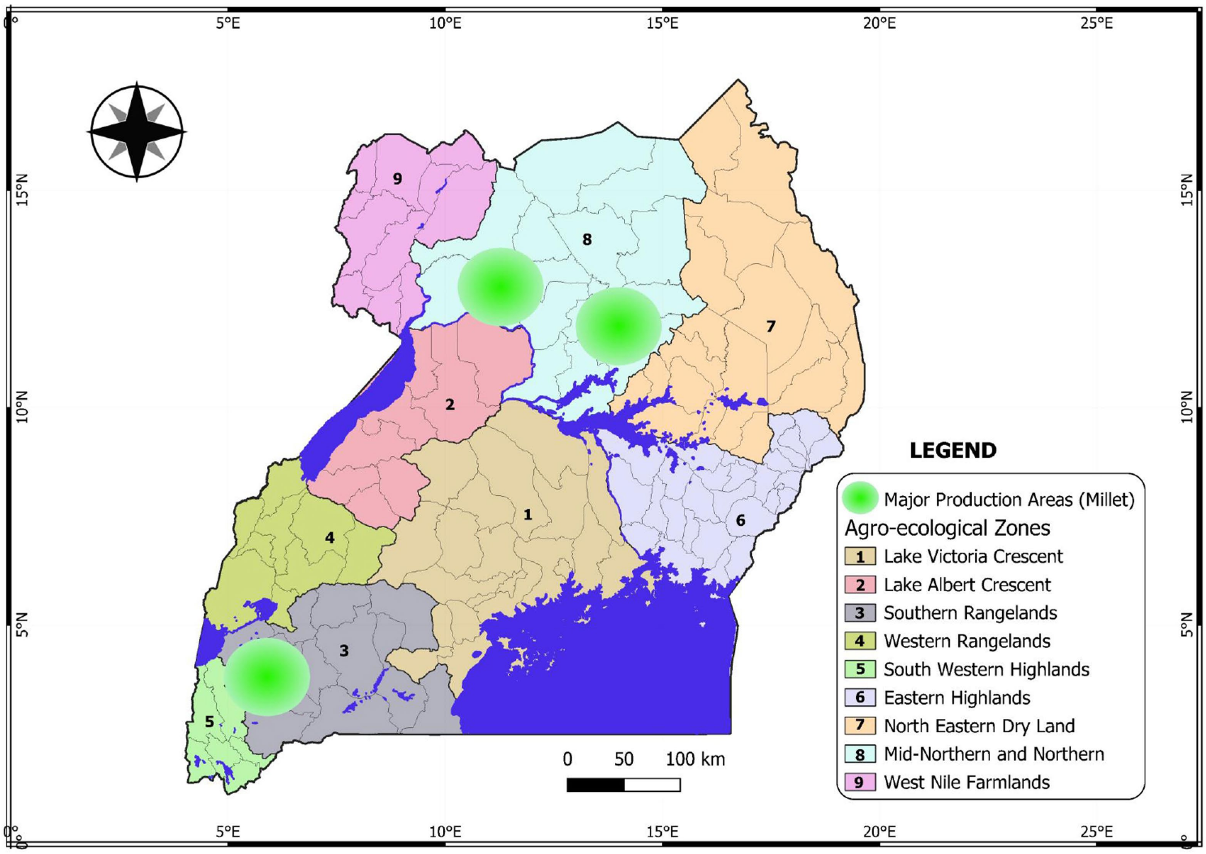

FIGURE 1
Showing a map of Uganda indicating the major finger millet growing areas.

areas and amendments were made to the study tool. Data were collected on the demographic and socioeconomic characteristics of the households, finger millet production system, variety grown, millet trait characteristics preferred by farmers, and socio-economic factors that affect trait preference and consumer sensory attributes. The survey questionnaire was automated using an open data kit (Kobo Collect).

2.5.2 Qualitative data collection

This study also used qualitative research methods to validate the data from the quantitative methods described above. Two methods were used, i.e., Focus Group Discussions (FGDs) and Key Informant interviews (KIIs).

2.5.3 Focus group discussions

FGDs were conducted purposely with farmers to get in-depth sex-disaggregated trait preference information. To guide the discussions, an FGD question guide was developed. The tool was pretested with farmers in finger millet growing districts as described above. Four facilitators (2 females, and 2 males) were identified and trained to conduct the FGDs. In each study district, a total of four (2 women and 2 men only) sex-disaggregated FGDs were conducted. However, the data for one of the men FGD from Bushenyi district was lost hence giving a total of 11 FGDs instead of 12 as earlier planned. Each FGD had 8–12 participants who were selected based on their knowledge of finger millet production with the help of an area extension officer. Before the start of the discussion, the research team (i.e., a facilitator and a note taker) introduced themselves to the participants and the purpose of the research was also properly explained. Consent was sought from all the participants and the guidelines that would guide the discussion were laid out to the participants to ensure proper sharing of ideas. The participation of the participants was voluntary and they were allowed to opt out of the FGD at any time with no penalty. Also, participants' consent to record the interview and take photos was sought. An audio recorder was used to record the discussion. Each participant was assigned a code to avoid others referring to them by their name. During the discussion, every participant was given an equal opportunity to actively share their views. The FGDs centered around finger millet production systems, uses, roles, and responsibilities of men and women in finger millet production, practices used by farmers, and farmers' trait preferences and challenges faced during production.

2.5.4 Key informant interviews

One key informant interview was conducted in each district with the district production and marketing officer who oversees all the extension activities in the district giving a total of three KIIs. Key informant interviews were conducted before household surveys and focus group discussions (FGDs). The information generated guided the development of questionnaires and FGD guides as well as getting a deeper understanding of finger millet production from the perspective of the knowledgeable people in the district. A flexible

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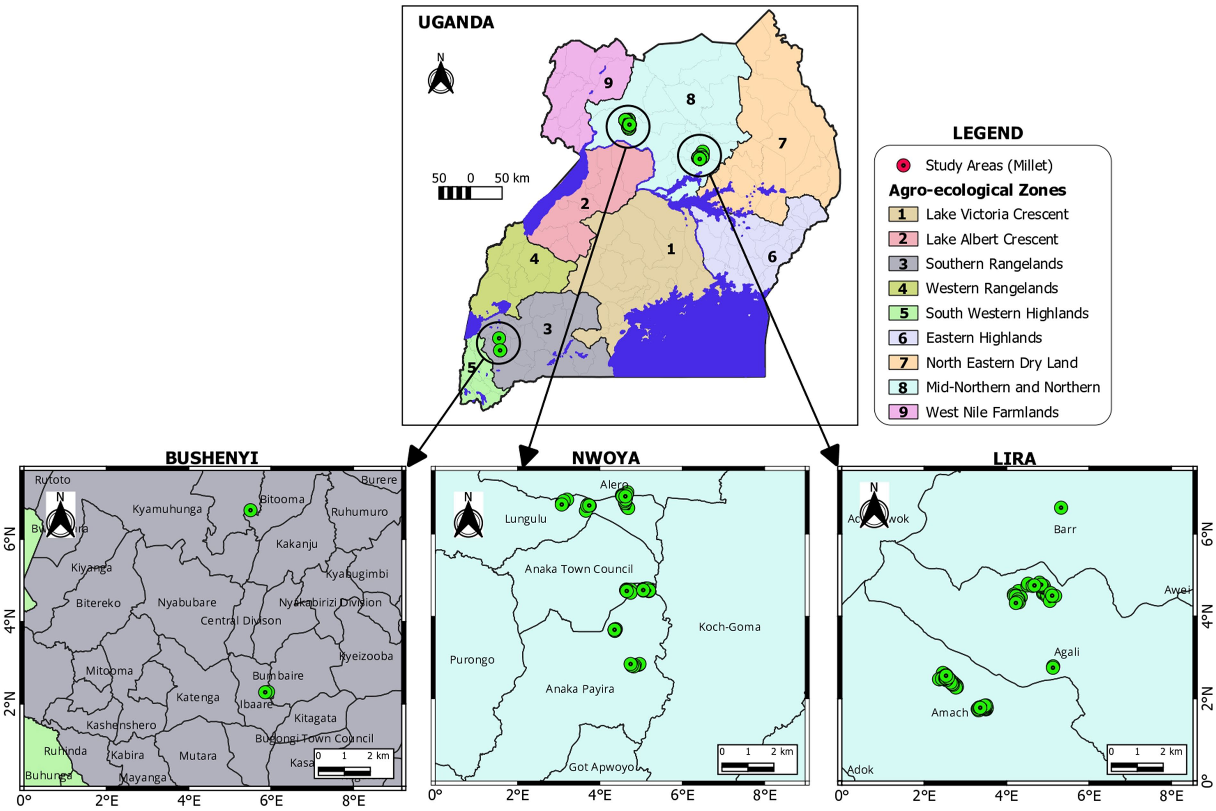

FIGURE 2
Showing the different agro-ecological zones with areas where the study was conducted.

TABLE 1 The number of households sampled per district.

Region	Districts	Sub Counties	Number of households sampled
Northern	Lira	Agali	23
Northern	Lira	Amach	26
Northern	Nwoya	Anaka	26
Northern	Nwoya	Lungulu	29
Western	Bushenyi	Ibaale	40
Western	Bushenyi	Kyamuhunga	29
		Total	173

checklist with open-ended questions was used to interview key informants. This generated information on finger millet production systems, trait preferences, and challenges faced by farmers during finger millet production.

2.6 Data management and analysis

Data from Kobo collect was exported to and cleaned in Excel. Data was coded and analyzed using the statistical package for social scientists (IBM SPSS version 29.0, 2022) using descriptive statistics on both quantitative and qualitative datasets to produce graphs. Multiple response data for varieties and farmer traits were grouped using the multiple response command of SPSS. To analyze relationships between variables; contingency chi-square tests were used to make statistical inferences at a 0.05 level of significance. Finger millet farmer-preferred attributes were subjected to principal component (PC) analysis based on eigenvalues greater than 1.0 by performing multiple response analyses to generate attribute frequencies of respondents which were later used for principal component analysis (PCA). Results were presented as percentages in bar graphs and tables. A *t*-test was performed in SPSS to assess significant differences in preferred traits between male and female respondents.

A Probit regression analysis was performed using the statistical software Stata version 14 to examine the factors influencing farmers' choice of finger millet. Probit regression is a statistical method commonly used to analyze binary outcomes, where the dependent variable can take only two values (in this case, "Choice of the trait" or "No Choice of the trait"). The model helped in understanding the relative importance of different variables in influencing the decision-making of millet farmers. The analysis assumes that the decision-making process follows a latent continuous variable that is not directly observed but can be related to a set of explanatory variables through a cumulative distribution function called the standard normal distribution.

The equation structure of the Probit model can be represented as follows:

$$\Pr(Yi = 1) = \Phi\left(\beta 0 + \beta 1X1i + \beta 2X2i + \ldots + \beta nXni\right)$$

Where:

Pr ($Yi = 1$) is the probability of choosing the trait for the *i*th farmer.

Φ represents the cumulative distribution function of the standard normal distribution.

$\beta 0, \beta 1, \beta 2, \ldots, \beta n$ are the coefficients to be estimated.

$X1i$, $X2i$, …, and Xni are the independent variables for the *i*th farmer.

In this case, the dependent variable (Yi) is the choice of trait for finger millet (either "Choice of trait" or "No Choice of trait"). The independent variables ($X1i$, $X2i$, …, Xni) include sex, education, marital status, farming experience, occupation, and household size. These independent variables were assumed to influence the farmers' decision-making process regarding which millet traits they chose. The Probit regression was performed for eight trait characteristics: big head, big grain size, disease resistance, early maturity, high yielding, high market demand, taste, and drought tolerance. The model's estimation allows you to analyze the relationship between these trait characteristics and the farmers' decision-making process while controlling for the impact of the independent variables on their choices.

For qualitative data, all the audios were transcribed verbatim and all the notes taken during the FGDs were consolidated to ensure that what exactly happened in the field was well documented. Transcripts were cleaned and coded manually to generate themes. After the analysis, both qualitative and quantitative findings were integrated.

3 Results

3.1 Demographic and socio-economic characteristics

The information generated during this study was obtained from farmers who had been cultivating finger millet for a period ranging from 1 to 50 years or more (Figure 3). Bushenyi and Lira districts recorded the longest period of finger millet cultivation in the study area while Nwoya had the shortest period of finger millet cultivation.

In this study, the majority of finger millet farmers own land and others have access to land for growing the crop in the surveyed districts (Figure 4). A few farmers who need extra land for finger millet cultivation, rent 2–3 acres of land to supplement what they own (Figure 4).

The demographic and socio-economic attributes of respondents and their households in each district are summarized in Table 2. Out of the 173 survey respondents, 61.3% were female while 38.7% were men. In study areas, 62.8% of the respondents were in the ages of 26–50 years, with only 12.1% of the respondents below 25 years of age, whereas 25.1% were above 50 years of age. Most respondents were married (monogamous) and significantly ($X^2 = 180.96$, $p = <0.001$) more than the polygamous and widowed. There were no respondents who were single or divorced in the surveyed areas. A majority (56.4%) of the survey respondents achieved at least primary education and were significant ($X^2 = 189.13$, $p = <0.001$). In comparison, 21.3% attained a maximum of secondary education (21.3%), however, 19.4% of the respondents interviewed never went to school for any formal education (Table 2). The differences in the main occupation of the respondents across study sites were significant ($X^2 = 191.6$, $p = <0.001$), with most respondents (86.1%) earning their living on crop farming followed by self-employed or on-farm businesses (5.5%).

3.2 Finger millet production systems

Detailed descriptions of finger millet production systems in surveyed areas are presented in Table 3. The majority (96.9%) of finger millet farmers plant landraces with only 3.1% using improved varieties ($X^2 = 176.9$, $p = <0.001$). The primary purpose (72.5%) of finger millet varieties grown in study areas was for food and income ($p = <0.001$). 23.6% responded that finger millet is cultivated mainly for food home consumption and 3.9% grow finger millet for sale only to obtain income (Table 2). On average, 79.2% allocated 1 acre for sole cultivation of finger millet ($X^2 = 23.3$, $p = 0.003$), followed by 2 acres (15.6%), 3 acres (2.9%), and least on 4 acres (1%) in 2021. A total of 70.1% of the respondents use their home-saved seed ($X^2 = 178.7$, $p = <0.001$). Farmers also access finger millet seed from open markets (22.9%), fellow farmers (4.9%), and least from Non-Government Organizations (NGOs) (Table 3).

3.3 Major finger millet varieties grown and farmers' trait preferences in Uganda

Generally, farmers consider traits like early maturity (271.8%), high yields (231.1%), drought tolerance (229.5%), taste (209.5%), big heads (196.7%), and high market demand (121.3%) across the surveyed areas (Table 4). In Western Uganda (Bushenyi district), early maturity (87%), taste (81.2%), and high yields (79.7%) were the most preferred traits. In northern Uganda, early maturity (93.9%), drought tolerance (79.6%), and high yields (71.4%) were the most preferred traits in Lira district while in Nwoya district attributes like early maturity (90.9%), drought tolerance (81.8%), and high yields (80%) were preferred by farmers (Table 4). The least preferred attributes in all surveyed areas were good brewing characteristics, striga resistance, faster fermentation properties, heavy brew, and small grain size among others.

From the 11 top-ranked desirable finger millet attributes, we assessed their patterns of variation and relative order of importance using principal component analysis (PCA) (Table 5). Each eigenvalue for the first four principal components (PC) was greater than 1.0 and cumulatively contributed to 56.4% of the variation in finger millet attributes among the respondent farmers (Table 5). Scores of PC1, which accounted for 18.7% of the total variation, were correlated to ($r > 0.45$) to pest tolerance (0.71), drought tolerance (0.59), big heads (0.52), disease resistance (0.51), and high market demand (0.47). PC2 explained 16.5% of the total variation with loading scores contributed by taste (0.67), medium plant height (0.53), and drought tolerance (0.51). Scores of PC3 contributed to the variation of 11.5% correlated with attributes such as easy to thresh (0.6), disease resistance (0.53), medium plant height (0.51), and high yields (−0.49) while at PC4, only attributes such as high yields (0.62) and big heads (−0.6) were discriminating contributing to 9.7% of total variation (Table 5).

From the focus group discussions, it was noticed during the discussion that farmers grow several finger millet varieties. In western Uganda, varieties mentioned by farmers included SEREM 2, Mahega, Mbanjura, Kabaragara, Kabumburi, Kabukunguru, Kagume, and Nkodere. In Northern Uganda, some of the varieties mentioned by farmers were Ajuko manyige, Okello chiba, Okama, Kal atar, Todyang, Okama lango, and Agun kibati. The top-ranked varieties grown by farmers in western and northern Uganda and their preferred attributes are presented in Table 6. Farmers identified local landraces as

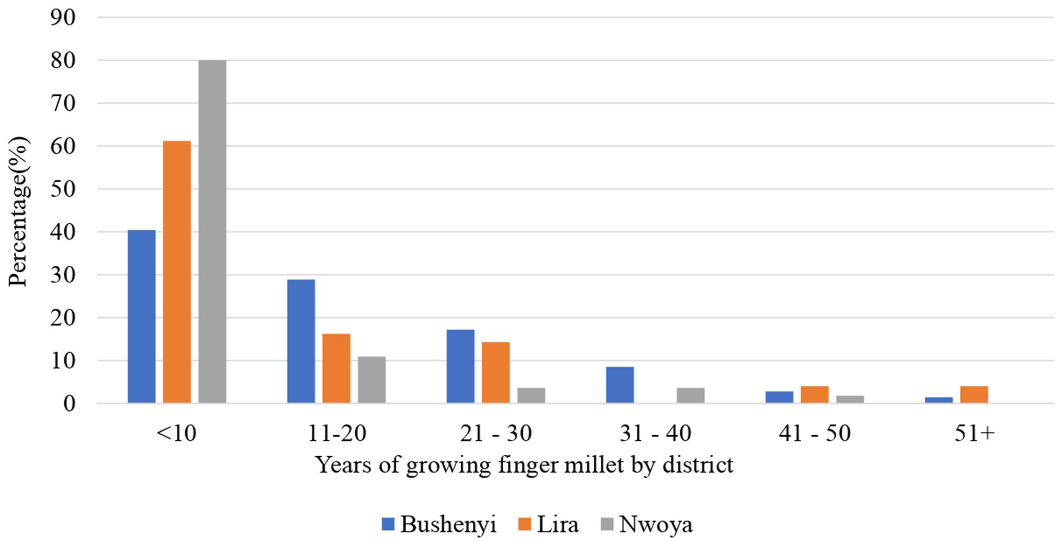

FIGURE 3
Duration of finger millet cultivation by farmers in the study areas.

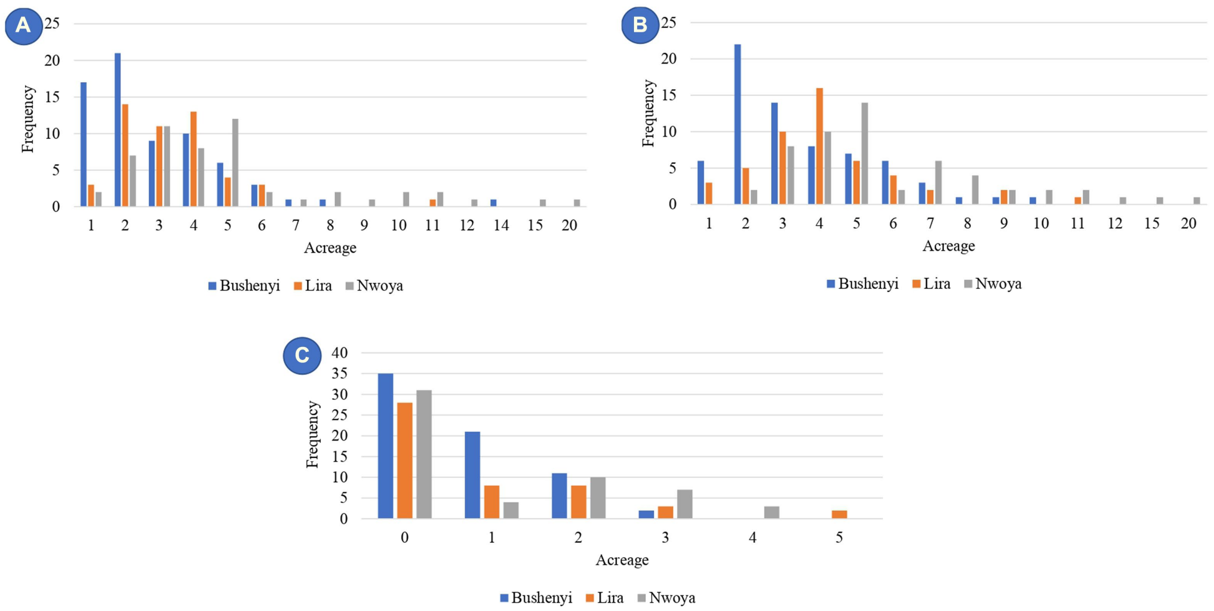

FIGURE 4
Farmer responses about land ownership **(A)**, access to agricultural land **(B)**, and land rented **(C)**.

preferred finger millet varieties by their local names. These were Kagume from the western region and Ajuko Manyige and Kal Atar from the northern region. Farmers highlighted attributes as to why they prefer these varieties for food and porridge, some for both food and making the local brew, while a few were not conducive for food but only alcohol. During focus group discussions, it is therefore understandable why some varieties with non-preferred attributes were rejected by farmers like the Kashema variety in western Uganda. Furthermore, in the same region farmers prefer the variety, Kisansha, because of its soft stem and therefore, easy to harvest. This variety is easy to harvest by hand rather than using a knife, hence less laborious besides other attributes.

3.4 Gender differences in finger millet traits preferred by farmers and consumers

Gender differences in finger millet traits preferred by men and women while growing the crop in Uganda are presented in Table 7. Using a *t*-test, significant variations were observed in preferred

TABLE 2 Socio-demographic characteristics of smallholder finger millet farmers in Western and Northern Uganda.

Variable	Class	Western Uganda	Northern Uganda		Mean	Chi-Square	df	*p*-value
		Bushenyi (*n* = 69)	Lira (*n* = 49)	Nwoya (*n* = 55)				
Sex	Women	52.2	73.5	58.2	61.3	5.55	2	0.06
	Men	47.8	26.5	41.8	38.7			
Age (year)	<25	7.2	16.3	12.7	12.07	4.57	4	0.33
	26–50	62.3	57.1	69.1	62.83			
	>50	30.4	26.5	18.2	25.1			
Marital status	Married (Monogamous)	91.3	83.7	85.5	86.83	180.96	9	<0.001
	Married (Polygamous)	4.3	6.1	12.7	7.70			
	Widowed	4.3	10.2	1.8	5.43			
	Divorced/Separated	0	0	0	0.00			
	Single	0	0	0	0.00			
Education level	No formal education	23.2	22.4	12.7	19.43	189.13	18	<0.001
	Primary level	53.6	61.2	54.5	56.43			
	Secondary (A-Level)	1.4	2	0	1.13			
	Secondary (O-Level)	18.8	14.3	27.3	20.13			
	Tertiary/University	2.9	0	0	0.97			
	Vocational	0	0	5.5	1.83			
Main occupation	Business/self-employed (off-farm)	8.7	4.1	3.6	5.47	191.6	24	<0.001
	Casual laborer	5.8	2	1.8	3.20			
	Civil servant	4.3	0	1.8	2.03			
	Crop farming	73.9	91.8	92.7	86.13			
	Driver	1.4	0	0	0.47			
	Engineer	1.4	0	0	0.47			
	Livestock farming	4.3	2	0	2.10			

traits for only yield ($p = 0.039$). The top five traits preferred by female finger millet farmers were early maturity (92.3%), drought tolerance (73.1%), taste (73%), high yielding (72.1%), and big heads (66.4%). Male finger millet farmers preferred varieties with traits like early maturity (87%), followed by high yielding (85.5%), drought tolerant (79.7%), taste (68.1%), and big heads (63.8%). Both men and women mostly preferred finger millet varieties that are early maturing.

The study also revealed differences between men and women in sensory trait preferences and cooking quality characteristics for finger millet consumption (Table 8). Men (60.9%) showed a stronger preference for good cooking quality compared to women (39.4%) with a statistical significance ($p = 0.006$). However, both men and women largely agreed on the trait of good taste (97.1%). There were no significant differences in other consumer traits like short cooking time, use of little flour to mingle, and making good color when mixed with cassava between men and women. Although a high percentage of men (85.5%) prefer nice aroma compared to women (77.9%), this difference was not statistically significant ($p = 0.21$). Similarly, the cooking quality characteristic 'dough stickiness' shows minimal gender differences (reported by 21.2% women, and 20.3% men) with no significant variation ($p = 0.89$). Both men and women consumers mostly prefer millet with a good taste. Three-quarters of the millet consumers reported good taste and nice aroma as their preferred sensory attributes.

3.5 Probit regression results

3.5.1 Big head trait preference

Among all the socioeconomic factors presented in the model, the results showed that gender, marital status, experience in growing millet, age, and household size did not significantly ($p > 0.05$) influence the preference for big heads among finger millet farmers (Table 9). Education at primary, secondary, and tertiary levels significantly ($p < 0.05$) influenced big head trait preference compared with no education. However, there was a decreasing odds ratio from lower (0.3) to higher education (0.03) for preferring big heads as compared to having no education.

3.5.2 Big grain size

Marital status, experience in growing millet, age, primary and secondary education levels, and household size did not significantly ($p > 0.05$) influence the preference for big grain size among finger millet farmers (Table 9). However, gender and having tertiary education had marginal statistical significance (0.06) in explaining

TABLE 3 The finger millet cropping system of the surveyed households in northern and western Uganda.

Variable	Class	Western Uganda	Northern Uganda		Chi-Square	df	*p*-value
		Bushenyi (*n* = 69)	Lira (*n* = 49)	Nwoya (*n* = 55)			
Variety grown	Improved	5.8	0.0	3.6	176.90	6.00	<0.001
	Local	94.2	100.0	96.4			
Land size where millet was grown in 2021 (acres)	1	92.8	77.6	67.3	23.25	8.00	0.003
	2	2.9	20.4	23.6			
	3	1.4	0.0	7.3			
	4	2.9	0.0	0.0			
	5	0.0	2.0	1.8			
Seed source	Fellow farmers	7.20	2.00	5.5	178.67	12.00	<0.001
	Home saved seed	63.80	75.50	70.9			
	NGOs	4.30	0.00	1.8			
	Open markets	24.60	22.40	21.8			
The main purpose of finger millet grown	Food and income	58.0	79.5	80.0	208.02	12.00	<0.001
	Food	42.0	14.3	14.5			
	Income	0.0	6.1	5.5			

Df, degrees of freedom; NGOs, Non-Government Organizations.

farmers' choice for big grain size trait preference. For instance, being a woman had an odds ratio of 2.056 for choosing millet with a bigger grain size than men. Considering education, having a tertiary education had an odds ratio of 7.104, suggesting that individuals with tertiary education have a significantly higher odds ratio of choosing big grain size than those without education.

3.5.3 Disease resistance

There was a positive association between experience in growing finger millet and the likelihood of preferring disease-resistant traits (odds ratio of 1.02), although the association was not statistically significant ($p > 0.05$) (Table 9). Gender, marital status, and occupation do not appear to have statistically significant ($p > 0.05$) effects on the preference for disease-resistant traits among finger millet farmers. Primary and secondary education had an odds ratio of 0.292 and 0.246 respectively, indicating a lower likelihood of choosing disease-resistance traits than farmers without education, however, their effects were pronounced and statistically significant ($p < 0.05$). The age of farmers had an odds ratio of 0.967, indicating older farmers are less likely to choose disease-resistance traits for millet compared to young farmers and the relationship was statistically significant. Also, household size had an odds ratio of 1.215 and was statistically significant ($p < 0.05$) indicating that higher household size is associated with a higher preference for disease resistant finger millet varieties.

3.5.4 High market demand

Gender, education, and occupation of the farmer had a statistically significant ($p < 0.05$) relationship of choosing high market demand trait (Table 9). Women had approximately 47.6% lower odds of choosing finger millet varieties with high market demand compared to men. However, this association was marginally statistically significant ($p = 0.075$). Individuals having primary education, secondary education, and tertiary education had a lower odds ratio of choosing finger millet with high market demand compared to those with no education even though the differences were statistically significant for primary and secondary education levels at 0.05 and 0.01 levels of significance, respectively. Respondents whose main occupation is agriculture have approximately 141% higher odds of adopting high-market demand finger millet varieties than those with non-agricultural occupations farmers (Table 9).

3.5.5 High-yielding

Experience in growing millet, main occupation, age, and household size did not show significant effects ($p > 0.05$) on preference for high-yielding varieties (Table 9). Gender, marital status, and marginal education levels significantly influenced the preference for finger millet varieties with high-yielding characteristics. Women had approximately 63.2% lower odds of choosing finger millet varieties with high-yielding characteristics compared to men ($p < 0.05$). Also, married farmers were 742% more likely than unmarried farmers to choose high-yielding millet varieties ($p < 0.05$). Having secondary education compared to no education had an odds ratio of 0.226 ($p < 0.05$), indicating that farmers with secondary education are less likely to choose high-yielding millet variety compared to non-educated millet farmers.

3.5.6 Taste

Most of the factors like gender, marital status, experience in growing millet, main occupation, age, household size, and education levels significantly ($p > 0.05$) influenced the preference for finger millet varieties based on taste (Table 9). However, higher education (tertiary) was marginally significant ($p = 0.08$) for the taste trait.

3.5.7 Drought tolerance

Respondents with agriculture as their primary occupation were more likely to choose finger millet varieties that are drought tolerant

TABLE 4 Attributes that farmers put into consideration when selecting finger millet varieties in western and northern Uganda.

Preferred attribute	Bushenyi (%)	Lira (%)	Nwoya (%)	Rank
Early maturing	87	93.9	90.9	1
High yielding	79.7	71.4	80	2
Drought tolerant	68.1	79.6	81.8	3
Taste	81.2	59.2	69.1	4
Big head	62.3	65.3	69.1	5
High market demand	36.2	46.9	38.2	6
Disease resistance	47.8	32.7	29.1	7
Big grain size	24.6	44.9	27.3	8
Pest tolerant	17.4	34.7	36.4	9
Medium height varieties	29	34.7	16.4	10
Easy to thresh	17.4	24.5	29.1	11
Long storability	13	18.4	32.7	12
High flour yield	29	14.3	20	13
Takes long to feel hungry	1.4	20.4	27.3	14
Good bread colour	8.7	16.3	16.4	15
Easy to weed	1.4	20.4	14.5	16
Tall varieties	18.8	6.1	3.6	17
Resistance to birds	4.3	12.2	10.9	18
Lodging tolerance	0	10.2	14.5	19
Easy to grow	1.4	12.2	10.9	20
Red grain color	5.8	6.1	10.9	21
Short height of the variety	0	14.3	7.3	22
High dry matter content	7.2	4.1	5.5	23
Easy to grind	5.8	6.1	1.8	24
Can grow in poor soil	0	10.2	1.8	25
Small grain size	2.9	4.1	1.8	26
Heavy brew	0	2	3.6	27
Ferments fast	1.4	2	1.8	28
Resistance to Striga	2.9	2	0	29
Good brewing characteristics	1.4	0	0	30

TABLE 5 Principal component analysis of major finger millet preferred attributes in surveyed areas in Uganda.

Variables	PC1	PC2	PC3	PC4
Early maturing	0.27	−0.35	0.01	0.25
High yielding	0.19	0.09	−0.49	**0.62**
Drought tolerant	**0.59**	**0.51**	0.1	−0.01
Pest tolerant	**0.71**	−0.25	0.32	−0.03
Taste	0.24	**0.67**	0	0.06
Big head	**0.52**	−0.11	−0.01	**−0.6**
High market demand	**0.47**	0.08	0.1	0.39
Easy to thresh	0.37	−0.31	**0.6**	0.22
Medium height	−0.34	**0.53**	**0.51**	0.09
Disease resistance	**0.51**	−0.03	**−0.53**	−0.16
Big grain size	−0.17	**−0.72**	0.05	0.13
Eigenvalue	2.06	1.82	1.26	1.07
Proportion of variance (%)	18.73	16.51	11.49	9.7
Cumulative variance (%)	18.73	35.25	46.73	56.43

PC, principal component, Boldface values denote high score values indicating the preferred finger millet attributes (>**0.45**).

than non-agricultural occupations respondents (odds ratio of 2.592), and the difference is statistically significant ($p < 0.05$). Women farmers have approximately 51.3% lower odds of choosing finger millet varieties with drought tolerance characteristics compared to men, with a marginally significant ($p = 0.099$) difference, suggesting a potential but not strong relationship (Table 9).

4 Discussion

4.1 Socio-demographic profile of finger millet farmers in Uganda

Finger millet is an ancient crop and this study showed that farmers who participated in the study had been cultivating the crop for periods ranging from 3 years up to over 50 years. This denotes the presence of knowledge of millet production dynamics over the years and increasing awareness of the crop's economic potential and importance hence attributing to the recent surge in finger millet cultivation in the study areas (Owere et al., 2014; Adikini et al., 2021; Kasule et al., 2023). Western Uganda appears to have a longer history and is more established in finger millet cultivation. This is in agreement with other researchers who attributed this long history to the Iron Age and domestication of finger millet which originated from the highlands of western Uganda (Fuller, 2014; Kasule et al., 2023).

Majority of the households in western and northern Uganda growing finger millet owned or had access to 2–3 acres of land. Furthermore, some farmers, despite owning and having access to land, choose to rent more land for finger millet cultivation (UBOS, 2022). This access and ownership of land underscores the importance of land as a resource in finger millet cultivation. Access to more farming land has been shown to improve food and income security among agricultural communities in Uganda (FAO, 2018). The amount of land allocated to finger millet production is less and could be attributed to the customary tenure system of land where women only access land through their husbands who own and make decisions on the land use. Given that the majority of respondents in this study were women (over 60%) compared to men, their response was based on household decisions concerning land ownership. Studies indicated that in a household, women consult their spouses and are more likely to report joint decision-making than men in crop farming (Gebreyohannes et al., 2021).

The predominance of women farmers in finger millet production compared to men in this study confirms earlier studies in Uganda (Owere et al., 2014; Otieno et al., 2021). Similar results were reported in other East African countries like Kenya, where 57% of the farmers producing finger millet were women (Mbinda et al., 2021). Studies in other crops have shown that the predominance of women in agriculture activity is associated with low productivity because women farmers have limited control and access to resources that influence

TABLE 6 Top finger millet varieties grown and their attributes preferred by farmers in western and northern Uganda.

Variety	Use	Preferred attributes	District	Farmers growing the variety (%)	Non-preferred attributes
Ajuko Manyige	Food	Early maturity (3 months), high-yielding, easy-to-grind, tasty bread, can be harvested before it fully matures	Nwoya ($n=55$)	56.4	none recorded
Kal Atar	Food and local brewing	Moderate yield, early maturity, marketable	Lira ($n=49$)	35	none recorded
Okello Chiba	Food and local brewing	Good brown colour, big head, tasty bread, tallness	Lira ($n=49$)	43	susceptible to lodging
Kagume	Food and local brewing	High-yielding, absorbs water, good bread	Bushenyi ($n=69$)	30	Requires fertile soils, liked by birds

TABLE 7 Finger millet traits preferred by men and women while growing the crop in Uganda.

Attributes	Female (%)	Male (%)	*p*-value
Big head	66.4	63.8	0.729
Big grain	35.6	63.8	0.13
Disease resistance	35.6	40.6	0.509
Medium height variety	27.9	24.6	0.638
Early maturing	92.3	87	0.25
Resistance to birds	11.5	4.4	0.101
High yielding	72.1	85.5	0.039
High market demand	36.5	44.9	0.273
Resistance to Striga	1	2.9	0.342
Taste	73	68.1	0.484
Long storability	22.1	18.8	0.606
Easy to thresh	25	20.3	0.475
Lodging tolerance	8.7	5.8	0.488
High flour yield	23.1	20.3	0.667
Easy to weed	12.5	8.7	0.436
Good bread color	11.5	15.9	0.407
Takes long to feel hungry	15.4	14.5	0.873
Ferments fast	2.9	0	0.157
Red color	5.7	8.7	0.461
Pest tolerant	27.9	29	0.876
Drought tolerant	73.1	79.7	0.322
Easy to grind	6.7	1.5	0.107

TABLE 8 Gender differences in sensory and cooking attributes preferred by finger millet consumers in Uganda.

Trait preference	Percentage responses (%)		*p*-value
	Women	Men	
Good taste	97.1	97.1	0.996
Good cooking quality	39.4	60.9	0.006
Short cooking time	51.9	58	0.437
Use little flour to mingle	49	56.5	0.338
Make good color when mixed with Cassava	48.1	58	0.204
Nice aroma	77.9	85.5	0.214
Sticky	21.2	20.3	0.892

production and productivity (Gebreyohannes et al., 2021). In addition, finger millet is a labor-intensive crop and women perform most of the tedious and time-consuming manual activities justifying the low productivity observed at farmer fields. Proper measure to address this gender gap in finger millet is needed to increase crop production and productivity. One of the strategies is the development, testing, and outscaling of labor-saving machinery in the entire production chain as in the case of Nepal (Devkota et al., 2016).

This study found that the majority of finger millet farmers were within the age group of 26–50 years which is considered the most productive age for any agricultural activity in Uganda (Owere et al., 2014; Mwema et al., 2017; Andiku et al., 2021). This age group has productive and energetic farmers who participate in the economy by providing labor and engaging in economic activities, such as trade and decision-making (UBOS, 2022). They are likely to expand finger millet production and adopt the use of inputs like improved seeds, fertilizers, and better agronomy hence increasing productivity and output.

The study also revealed that the majority of the households rely on crop farming as their primary occupation. This is attributed to Uganda's dependence on agriculture for both food and income security. In addition, a great deal of the study respondents were married and this marital status helps to determine the level of participation in decision-making along with the finger millet production and marketing chain (UBOS, 2022). In Uganda, married farmers have better ownership of production resources like land and are likely to adopt new technologies like improved varieties (Doss et al., 2011). Other studies have also found that marital status of the household head has a significant influence on the adoption of improved crop varieties (Atube et al., 2021). The majority of these respondents had significantly lower levels of education up to the primary level. The low level of education among finger millet producers is of concern, especially for the successful introduction of new technologies and dissemination of information. A low level of education has been identified as a significant factor leading to poor adoption of agricultural technologies and access to information in rural and smallholder farming communities (Fadeyi et al., 2022). An

TABLE 9 Socio-economic factors that affect finger millet trait preference.

Variables	Bighead		big grain size		Disease resistance		High market demand		High yielding		Taste		drought tolerance	
	Odds Ratio	*p*-value	Odds Ratio	*p*-value	Odds Ratio	*p*-value	Odds Ratio	*p*-value	Odds Ratio	*p*-value	Odds Ratio	*p*-value	Odds Ratio	*p*-value
Sex (base: male)														
Female	0.686	0.343	2.056	0.064	0.722	0.376	0.524	0.075	0.368	0.029	0.872	0.724	0.487	0.099
Marital status														
Married (base: unmarried)	0.502	0.479	1.329	0.759	1.337	0.754	1.065	0.94	8.42	0.016	0.222	0.2	0.191	0.172
Education (base: no education)														
Primary	0.313	0.041	1.449	0.433	0.292	0.006	0.407	0.04	0.592	0.371	0.443	0.119	0.692	0.49
Secondary	0.072	<0.001	2.091	0.201	0.246	0.013	0.195	0.004	0.226	0.028	0.364	0.106	0.392	0.147
Tertiary	0.033	0.007	7.104	0.061	0.138	0.117	0.123	0.086	0.308	0.361	0.149	0.079	0.281	0.25
Experience in growing millet	0.992	0.67	1.007	0.724	1.016	0.429	0.978	0.232	0.992	0.728	1.012	0.547	0.985	0.478
Main Occupation (Non Agric)														
Occupation_Agric	2.112	0.131	0.986	0.977	2.098	0.163	2.41	0.093	0.88	0.815	0.531	0.255	2.592	0.047
Age of respondent	0.972	0.152	0.999	0.936	0.967	0.063	0.981	0.247	1.01	0.641	0.973	0.143	0.971	0.136
HH size	0.995	0.956	1.058	0.495	1.215	0.02	1.027	0.743	0.95	0.593	0.979	0.803	1.042	0.645
Number of obs	173		173		173		173		173		173		173	
LR chi2(9)	28.64		7.39		21.47		18.16		15.9		10.77		13.76	
Prob > chi2	0.001		0.596		0.011		0.033		0.069		0.292		0.131	
Pseudo R2	0.128		0.034		0.094		0.078		0.086		0.052		0.072	
Log-likelihood	−97.342		−103.701		−103.777		−107.271		−84.382		−98.635		−89.006	

10.3389/fsufs.2024.1282268

innovative approach of technology transfers especially through farmer field schools where farmers learn by seeing and doing needs to be used in promoting improved finger millet varieties to farmers with low levels of education.

4.2 Finger millet production and cropping systems

Results indicate that only a small proportion (3.1%) of the surveyed farmers were growing improved varieties. This is consistent with most adoption studies for different crop varieties that show low use of improved varieties and farmers' continued use of their landraces alongside improved varieties for various reasons (Katungi et al., 2011; Ainembabazi and Mugisha, 2014; Sanya et al., 2020).

The low use of improved finger millet varieties could be attributed to a mismatch between current varietal traits and farmers' preferences thus failure to meet their diverse needs and demands. This could also be explained by the failure of existing seed systems to deliver the improved varieties to farmers since most farmers (>70%) also reported that they were using their home-saved seed. However, most of these landraces preferred by farmers are often low yielding, late maturing, and tall (susceptible to lodging) (Adikini et al., 2021; Kasule et al., 2023). The finger millet breeding programme therefore needs to prioritize farmers' preferences in the breeding process if the use of improved finger millet varieties is to be accelerated. Integration of actors in the seed system chain will also be useful to ensure that the varieties reach the end-users. Additionally, the results showed that over 70% of the farmers grow finger millet for food and income which could be explained by the high market demand of this crop, thus its potential to contribute to better livelihoods of the diverse and vulnerable groups in fragile ecosystems.

4.3 Finger millet varietal and trait preferences across regions and gender

There were variations in finger millet landrace varieties preferred by farmers in different locations as evidenced from this study. During FGD, farmers revealed that they grow more than one finger millet variety in their field to mitigate the risk of loss due to harsh weather. They further revealed that millet varieties serve different purposes such as brewing, food, or for sale. Farmers' preference for local landraces is in agreement with earlier findings that most landraces are well adapted to low-input farming systems and possess essential quality traits (Orr et al., 2016). Among the traits that farmers use for selecting and adopting the varieties, early maturity was ranked first as the most preferred finger millet trait in both western and northern Uganda. Early maturing crop varieties can yield a positive harvest within a short period of planting to protect farmers in case of low rainfall or drought. This means farmers are aware of the climate changes and the marginal environment where this crop is grown. In addition, multiple cropping can be achieved in small piece of land to ensure food and nutrition security given that most finger millet farmers own less than 5 acres of land.

The prioritization of subsequent traits varied across locations. In western Uganda, taste ranked second followed by high yield, drought, and big head probably because finger millet is produced mainly for food purposes. The most preferred variety in this region was land race Kaguma, because of its high yields, good water absorption properties during cooking, and suitability for making good bread as was reported in the focus group discussion. Studies in other crops, such as maize and sorghum, have similarly highlighted the influence of taste, marketability, and agronomic traits in shaping farmers' variety choices and trait preferences (Mwema et al., 2017; Orr et al., 2020; Andiku et al., 2021; Habte et al., 2023). This implies the need for the integration of consumer traits along with agronomic traits during the breeding process. Lack of variety adoption has been linked to poor taste in some of the earlier released finger millet varieties (Gierend et al., 2014).

In northern Uganda, however, drought tolerance was ranked second followed by high-yield, big head, and test. This could be because the region tends to have long drought spells and unpredicted rainfall. Having variety with such traits guarantees food security and mitigates the effect of climate change in the region (Oduori, 2008; FAO, 2019; Kasule et al., 2023). In FGD, it was revealed that farmers in this region particularly in Nwoya district, prefer a landrace variety Ajuko Manyige, because of its early maturity, high yields, and consumer traits like ease of grinding, and flavorful bread production. Similarly, in Lira district, farmers exhibited preferences, for the landrace variety Kal Atar due to its attributes like early maturity, moderate yields, and marketability suitable for both food and local brew, while Okello Chiba stood out for its visual appeal, tallness, sensory qualities making it ideal for local brewing (Wanyera, 2005; Owere et al., 2014).

In terms of gender, more men compared to women prefer high yielding varieties, and this is consistent with the finding by Nchanji et al. (2021) who reported that men tend to adopt and grow better yielding improved varieties while women tend to grow landraces with low yields. This difference in preferences highlights the diverse roles and responsibilities of men and women in agriculture, influencing their distinct criteria for selecting finger millet varieties (Tufan et al., 2018; Weltzien et al., 2019; Sanya et al., 2020, 2023; Marimo et al., 2021; Zimba et al., 2023). Although there was no significant difference in other traits considered during the production of finger millet, it's evident that similar traits are prioritized differently by men and women. In this study, both men and women prioritized early maturity as the most important trait. This could be due to advantages associated with this trait such as rapid maturation, timely harvesting, drought escape, and reducing post-harvest labor demands (Owere et al., 2014; Kasule et al., 2023). In addition, women also prioritized drought tolerance, followed by taste, high yield, and big head while men prefer early maturity, high yield, drought tolerance, test, and big head. This is consistent with earlier reports that women tend to focus more on food security-related traits as well as productivity under sub-optimal soil fertility (Christinck and Kaufmann, 2017) while men tend to focus on overall increase in farm productivity and income generation (Zimba et al., 2023).

Earlier studies have indicated that women tend to focus more on food preparation traits than men (Weltzien et al., 2019; Frimpong et al., 2023). Our finding contradicts this where more men indicated a preference for finger millet with good cooking quality. Discussion with key informants indicated that finger millet is highly valuable food among millet communities with deep cultural rooting for example when a boy marries a woman, the potential of that woman as a good wife is tested by the quality of the first millet bread she will serve the father in-law. Finger millet is used to perform many cultural functions of which men are the leaders of such function and therefore they put keen interest on the quality of the final product which in most cases is the millet bread. However, there were no significant gender differences for traits like short cooking time, stickiness, use of little flour to mingle, nice aroma, and makes a good color when mixed with cassava. This suggests shared values related to convenience, visual appeal, and sensory experiences among female and male consumers and the universal importance of certain sensory and cooking attributes. Overall, it's crucial to acknowledge that these gender-specific preferences are likely influenced by socio-cultural factors, household dynamics, and women's roles in agricultural decision-making (Quisumbing et al., 2014). The observed variations underscore the importance of integrating gender-sensitive approaches in breeding programs and extension services, ensuring that new finger millet improved varieties meet the needs of both female and male farmers and consumers, promoting sustainable and inclusive agriculture.

4.4 Socio-demographic factors that influence finger millet preferences in Uganda

Principal component analysis (PCA) offered a comprehensive understanding of major attributes that guide the decision-making process of finger millet farmers in Uganda. Farmers appeared to weigh in on agronomic (high yields, drought tolerance, pest tolerance, big millet heads, big grain size, plant height, and disease resistance), market-oriented (high market demand), and sensory (taste) traits. Farmer preferential traits from this study are in agreement with reports obtained by Otieno et al. (2021), Kasule et al. (2023), Singh and Vemireddy (2023), who reported similar attributes. Therefore, the Finger Millet Breeding Program in Uganda should not only breed varieties with good agronomic traits but also with sensory and market-oriented traits. Kasule et al. (2020), also reported that farmer varietal adoption and uptake of improved varieties is beyond agronomic and resistance traits in Uganda. Ensuring a balanced set of agronomic, market-oriented, and sensory traits would change farmers' minds from cultivating landraces to improved varieties.

Probit model results revealed that gender, marital status, education levels, and occupation are the major socio-demographic factors that influence specific preferences related to the cultivation of finger millet. Gender-related differences in preferences arise from the different roles and responsibilities within households (Sanya et al., 2023; Zimba et al., 2023). Female farmers prioritized millet varieties with big grain size, taste, and ease of cultivation, differently from their male counterparts who prefer varieties that are high yielding, and drought tolerant. These findings align with previous research which emphasized the importance of recognizing and addressing gender-specific needs in finger millet and other crops (Weltzien et al., 2019; Marimo et al., 2021; Otieno et al., 2021; Frimpong et al., 2023; Zimba et al., 2023).

Marital status is also an important factor in shaping preferences among finger millet farmers in Uganda. Similar results were reported by Acevedo et al. (2020), Andiku et al. (2021), in other cereals. Higher odds associated with high-yielding varieties among married farmers suggest influences related to household dynamics, joint decision-making, or differing priorities based on family structure. Extension workers in Uganda ought to understand household dynamics and marital status to improve finger millet adoption in Uganda. Education levels influence the adoption of finger millet varieties with high market demand, high yields, taste, big heads, and size. Education drives access to information, and awareness of modern agricultural practices, technologies, and improved varieties (Andiku et al., 2021; Mireri et al., 2023). Other researchers also attributed education to influencing finger millet farmers' decision-making (Mbinda et al., 2021; Mireri et al., 2023). Furthermore, the main occupation particularly where a farmer is engaged in crop farming influences the adoption of finger millet that is drought tolerant (Table 9). Farmers actively involved in farming are aware of specific needs and challenges faced while cultivating finger millet like drought and therefore, opt for climate-resilient varieties (Choudhary et al., 2023; Zimba et al., 2023). In addition, age also influences varietal adoption with older farmers less likely to choose disease-resistant finger millet compared to younger farmers. Hence addressing age-related differences is also pivotal in designing interventions that cut across different age groups.

5 Conclusions and recommendations

The information obtained from this study provides valuable insights into the importance of finger millet in Uganda. There is a surge in finger millet cultivation influenced by factors like land access and ownership, age, gender dynamics, and socio-cultural practices. The study also underscores the significance of women in finger millet production. However, despite the potential benefits of improved finger millet varieties, the adoption rate is still very low. Farmers have a preference for traits of finger millet landraces, indicating a need for the breeding program to align with farmer preferences. The observed differences between men and women in terms of their preferences for finger millet traits call for a more gender-responsive and demand-driven finger millet breeding system. The finger millet seed system in the country is also mainly informal with the majority of the farmers using home-saved seeds they recycle from one generation to another. Integrating actors in the seed system chain within the breeding process is likely to create interest and open opportunities for formal millet seed system development thereby ensuring that the improved varieties reach the diverse end-users.

Most finger millet farmers in the western and northern regions of Uganda are women with limited access to improved technology and low levels of education. Therefore, an innovative approach to technology transfers especially through farmer field schools where farmers learn by seeing and doing needs to be emphasized in promoting improved finger millet varieties to such farmers. In addition, labor-saving machineries need to be customized and promoted to address drudgery along the finger millet value chain to encourage more women, men, and youth to engage in production, thereby ensuring sustainable food, nutrition, and income security among smallholder farmers.

Farmers take into consideration agronomic, sensory, and cooking traits like early maturity, high yields, drought tolerance, taste, and good cooking quality among others while selecting finger millet varieties. However, in this study, limited information was obtained concerning sensory traits and cooking characteristics of finger millet. There is a need to conduct extensive processing and acceptability studies (consumer studies) to explore and discover the sensory traits and cooking quality characteristics that influence end-user selection of finger millet varieties. The study also revealed gender-based differences in trait preferences, emphasizing the need for gender-inclusive finger millet breeding in Uganda. Socio-demographic factors including gender, marital status, education levels, and main occupation influence farmer preference for finger millet varieties. Recognizing and accommodating these factors is crucial for promoting the adoption of improved varieties. This study lays the foundation for informed interventions, emphasizing the necessity of a comprehensive approach to further promote finger millet cultivation in Uganda.

6 Policy implications

Moving forward, this study provide insight for crop improvement teams to define and refine customer-oriented and market-driven product profiles for finger millet breeding programs. Robust efforts are necessary to design a holistic strategy and effective campaign for reaching out to farmers and end users to popularize the available released finger millet varieties and their traits to enhance adoption. Small seed pack models, seed fares, massive radio campaigns, and strengthened partnerships in the agricultural sector are part of the proposed approaches. Challenges of poor seed systems for finger millet could be addressed using the Local Seed Business (LSBs) approach to ensure that seeds are made available in the different communities.

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 this research was authorized by the National Agricultural Research Organization (NARO) which by its mandate follows scientific and ethical processes while conducting research. Informed consent was obtained from all the participants involved in the study and they provided their written informed consent to participate in this study. 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

SH: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. FK: Bibliography, Data curation, Formal analysis, Visualization, Software, Writing – review & editing. IM: Data curation, Writing – review & editing. MB: Supervision, Writing – review & editing. HN: Conceptualization, Writing – review & editing. LS: Conceptualization, Methodology, Validation, Writing – review & editing. DR: Conceptualization, Data curation, Methodology, Supervision, Validation, Visualization, Writing – review & editing. MO: Conceptualization, Data curation, Methodology, Supervision, Validation, Visualization, Writing – review & editing. SA: Funding acquisition, Project administration, Resources, Supervision, Writing – review & editing.

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Conflict of interest

DR was employed by Cultural Practice, LLC.

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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Breaking ground: transformative partnerships for inclusive bean breeding in Zimbabwe

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Common bean is often considered a woman's crop because they play important roles from production to marketing. However, breeding programs often focus on farmers without adequate attention to the interconnectedness between gender and other socioeconomic variables and how they influence varietal and trait preferences of other value chain actors. This study analyzed gendered differences in bean production and trade, implications of socioeconomic conditions on bean production and marketing, and the role of partnerships in closing gender gaps in the bean value chain in Zimbabwe. The results obtained from the analysis of survey data collected from 131 farmers and 18 trades revealed beans as a dual-purpose crop for male and female farmers and traders. Varietal and trait preferences were the same for both male and female farmers and traders but were prioritized differently. While female farmers prioritized cooking time, men farmers prioritized biofortification and market traits. Whereas male traders equally preferred price, color, and appearance, female traders prioritized price over color and appearance. Poverty and marital statuses of respondents influenced the number of varieties preferred by male and female farmers. We found that the effectiveness of partnerships in closing gender gaps in marketing is variety specific. While having partners closed the gender gaps in the marketing of the NUA45 variety, such partnerships did not have the same effect on closing gender gaps in the marketing of Cherry, Gloria, and other varieties. The results show that considering socioeconomic characteristics of actors and partnerships can reduce gender disparities in the bean value chain. Therefore, breeding programs should recognize the interconnectedness between socioeconomic variables and gender when developing breeding products.

KEYWORDS

inclusive innovation, trait preferences, varietal choice, common bean, trade-off, gender-responsive breeding, partnerships, value chain

1 Introduction

Common bean (*Phaseolus vulgaris* L.) is considered a multipurpose crop due to its role in food security, nutrition, income, and sustainable production systems. The major bean producers in Eastern and Southern Africa are primarily smallholder farmers who often utilize family labor because of the small landholding and face several challenges, including low access to improved bean varieties, unreliable markets, price fluctuations, limited access to capital, input resources, and low grain yield. These constraints are not equally perceived by men and women because of socioeconomic disparities, despite the crop being considered a women crop (Ingutia and Sumelius, 2022).

Similarly in other countries in sub-Saharan Africa, common bean in Zimbabwe is also considered a women crop. Mutari et al. (2021a,b) estimate that 60% of women participate in the bean value chain across the country. However, their participation is mostly limited to the production and post-harvest and processing stages, whereas men dominate the lucrative nodes of the value chain, including processing and exports (Nchanji et al., 2022a,b). Low level of women participation in the lucrative stages of the value chain is a major concern, especially in the post-2000 period, when Zimbabwe is experiencing decline in agricultural productivity. Women under representation in the bean value chain is further compounded by declining trend in bean production since 2004 due to climate change, pests and diseases, low use of improved technologies, and economic instability and land reforms (Katungi et al., 2017; Foti et al., 2020; Mutari et al., 2021a,b). For instance, limited availability of improved local breed varieties compels farmers to grow low-yielding, disease susceptible, and stress intolerant varieties, resulting in low yields and low-quality grain (Mutari et al., 2021a,b). These constraints disproportionately affect women who play a critical role in common bean production and food environment (Okello, 2018).

There has been an increasing focus on Zimbabwean common bean value chain in response to the constraints experienced by farmers in the last decade. Plant breeding and scaling programs through private and public sector collaborations have increasingly focused on contributing to nutrition security and equality through biofortification, gender-responsive, and demand-led bean breeding and scaling programs. These interventions have resulted in the introduction of improved biofortified bean varieties that promise to challenge gender and nutritional disparities (Zozo et al., 2021). Examples of biofortified and market-demanded varieties released in the past decade are NUA 45, Cherry, Gloria, and Sweet Violet in 2016 (Akesson et al., 2016).

Increased adoption and bean productivity were expected to increase grain availability and reduce imported grain (Mutari et al., 2021a,b). However, the adoption of newly released bean varieties is not a straightforward process as it involves the interaction between several factors (e.g., gender, access to resources, socioeconomic context, and partnerships) which need to be considered during cultivar development (Foti et al., 2020). Breeding programs should recognize and consider sources of gender differences in varietal and trait preferences and determine how to integrate them to minimize trade-off of technology adoption. This is because male and female farmers might have identical or different trait preferences which may influence gender differences in technology adoption (Ashby and Polar, 2021). Even when preferences are identical, prioritization may differ by gender or change according to ecological, social, and economic or market circumstances (Mutari et al., 2021a,b; Phiri et al., 2022). Thus, the understanding men and women's trait preferences and role of socioeconomic and institutional factors that shape preferences is crucial in developing bean cultivars that will bridge gender gaps and increase bean productivity in Zimbabwe (Anja et al., 2017; Mutari et al., 2021a,b).

Partnerships in the broader value chain—bean breeding, production, and marketing—ensure that product profiles respond to market demand. Therefore, partnerships are vital to support inclusive development (Aseete et al., 2023). These partnerships include both collaborations between breeders and value chain actors from variety development to scaling of new bean cultivars. However, plant breeding programs in Zimbabwe tend to emphasize farmers' trait preferences without adequately focusing on downstream actors, such as traders and processors. Consequently, breeding programs do not adequately ensure that bean products benefit other factors in the value chain beyond the farming community (Ragot et al., 2018). Therefore, studying gendered trait preferences and the role of partnerships in the broader bean value chain—encompassing breeding, production, and marketing—is crucial for several reasons, including ensuring demand-led breeding, promoting inclusive development, addressing farmers' and other downstream factors' needs, and facilitating scaling of innovations.

This study acknowledges interconnectedness between gender and other socioeconomic variables, how they influence varietal and trait preferences of farmers and traders, and how partnerships in the bean value chain can close existing gender gaps. The novelty study is the focus on how gender and socioeconomic variables can form the basis for creating equitable partnerships in bean breeding, production, and trade for inclusive benefits. It contributes to understanding how gender gap in bean value chain could be minimized through partnerships that are built on user and technographic viewpoints, thereby integrating gender considerations into breeding programs. Thus, the study answered three research questions: (1) What are the gendered differences and choice in bean production and trade?, (2) What are implications for and influence on bean production and marketing of male and female farmers?, and (3) Are partnerships in bean production bridging gender gaps in bean production and marketing?

2 Theoretical framework

Innovations in agriculture often perceived to be only technologies or practices that farmers adopt to increase the performance of farm enterprises or address production constraints. However, innovations in agriculture are not merely physical objects but encompass the entire process of technology adoption. Technological change is a complex, multi-component process that involves not just biophysical resources but also invisible innovations that could be interactions, agency, and capabilities of multiple actors involved in the development and dissemination of technologies (Glover et al., 2019). Thus, we use the concept of inclusive innovation as a theoretical basis to highlight gender-sensitive breeding in Zimbabwe.

Innovation is a process of change where new knowledge, skills, social arrangements, or solutions are applied to address diverse challenges in society (Stenberg, 2017). It offers solutions to social issues, such as income inequality and food insecurity. Inclusivity is defined as a system that does not "leave behind" any factor based on gender, ethnic origin, disability, or social status (Phiri et al., 2022). Inclusive innovation is one type of innovation that meets people's needs by involving everyone without discrimination. As a result, inclusive innovation mitigates social constraints such as income inequality and food and nutritional insecurity (Rip and Rip, 2018).

Inclusive innovation aims to achieve socially desirable outcomes such as equality alongside its economic objectives. The concept advocates supporting innovations that address societal challenges and needs, especially of excluded groups (Opola et al., 2021). Inclusivity also focuses on increasing the participation of socially excluded, disadvantaged, and under-represented groups in innovation pipelines. In addition, inclusive innovation aims to contribute to the promotion of technological progress in low-productivity sectors, ensuring that the benefits of innovation are equally distributed. Opola et al. (2021) identified three narratives that define an inclusive innovation concept: bottom of the pyramid, grassroots, and political economy. We draw upon these distinct narratives to provide a comprehensive framework for investigating interconnectedness between gender and other socioeconomic variables in influencing varietal and trait preferences in the bean value chain in Zimbabwe.

The bottom of the pyramid narrative emphasizes the untapped potential of low-income markets, such as smallholder male and female farmers. It argues that innovations can be scaled to benefit marginalized communities when their unique needs, priorities, challenges, and opportunities are understood (Opola et al., 2021). In the context of bean breeding and the entire value chain, the bottom of the pyramid narrative helps in understanding how new varieties can be made accessible and beneficial to smallholder farmers, traders, and other downstream actors. The grassroot innovation narrative focuses on the agency of local communities in technological change. According to Glover et al. (2019), it aligns with the concept of 'affordances,' highlighting the resources and opportunities that local environments offer for functional interaction with new bean varieties. In the context of this study, functional interaction or opportunities could be contract farming and partnerships at different nodes of the value chain. The political economy narrative provides a critical lens on the structural factors (e.g., socioeconomic characteristics) that systematically influence opportunities and behavioral factors in the bean value chain. According to Glover et al. (2019), this narrative resonates with discussion on "dispositions" and "responses," emphasizing the evolving behavior of bean value chain factors as they engage with new technologies.

3 Materials and methods

3.1 Study area

Zimbabwe consists of five major agro-ecological zones that are typically linked to the country's topography. Agro-ecological regions 1 and 2 are suitable for various agricultural activities including maize, bean, tobacco, and horticultural crops. Agro-ecological region 3 is characterized by semi-intensive farming; 39% of the farming systems are smallholder-based, and receive 650–800 mm of rainfall annually, while agro-ecological regions 4 and 5 experience lower rainfall (maximum 600 mm annually) and higher temperatures. The study was conducted in three provinces of Zimbabwe: Manicaland, Masvingo, and Midlands (Figure 1). Manicaland is part of natural regions 1 and 2. Masvingo is in agro-ecological zones 4 and 5, while Midlands is located in zone 4. Manicaland has diverse farming systems due to relatively good rainfall and fertile soils. Compared with Manicaland and Midland, Masvingo is known for livestock farming, particularly cattle and goats. Farmers in Masvingo use improved crop varieties and irrigation to sustain agricultural production as an adaptation to lower rainfall and higher temperatures. Midlands is known for its mixed farming system, including both crop production under drip irrigation and livestock rearing, due to minimal and uncertain rainfall.

The primary constraints to future food security across these provinces are the reliability and volume of seasonal rainfall, particularly in the semi-arid regions. Adoption of climate-smart improved technologies is emphasized as a crucial strategy to mitigating the effects of climate change. Crop suitability assessments in the three provinces indicated that legume production can help the realization of climate action agenda and contribute to food security. Various organizations, ranging from governmental bodies to NGOs and private entities, are involved in research, community development, and the dissemination of agricultural technologies, contributing to climate change adaptation and food security. For instance, collaborations between national and international research organizations through regional alliances have spearheaded the development of biofortified bean varieties that have been disseminated by the extension system in Midlands, Masvingo, and Manicaland.

3.2 Sampling design

Using multi-stage sampling procedure, three provinces and four districts were purposively selected because they were intervention areas of improved common bean variety dissemination programs of PABRA and the Department of Research and Specialist Services of Zimbabwe. Nyanga, Mutasa, and Chimanimani districts in Manicaland province, Shurugwi and Kwekwe districts in Midlands province, and Masvingo district in Masvingo province were selected. This was followed by a purposive selection of farmer groups. It involved the use of extension officers who provided lists of farmers in different farmer groups. The sampling frame comprised 655 farmers, the total number of farmers that were consolidated from the lists provided by extension officer. The sampling involved systematic random sampling after every 5th farmer. Applying a sample size calculation for finite populations, 243 farmers were included. However, due to logistical challenges amidst COVID-19 pandemic, the sampling procedure consisted of the sample size of 131 farmers (52 men and 79 women). Traders were also purposive selected, depending on their availability, which resulted in a sample size of 18 farmers (6 men and 12 women). Initially, the study was designed to conduct a comprehensive survey, targeting grain traders and processors in the three provinces. The unforeseen challenges posed by COVID-19 restrictions, including market closures, and prevented face-to-face administration with traders as intended. The data collection tool was shared with traders electronically. On the other hand, COVID-19 restrictions prevented sampling of processors as earlier mentioned in the study.

3.3 Data collection and analysis

The study used semi-structured questionnaires to collect data from sampled male and female farmers and traders. The sampling unit was male and female farmers involved in bean production. Farmers were selected based on their specific roles and involvement in bean production, irrespective of their position in households. The farmer questionnaire collected household socioeconomic characteristics, farm characteristics, bean production, varietal and trait preferences,

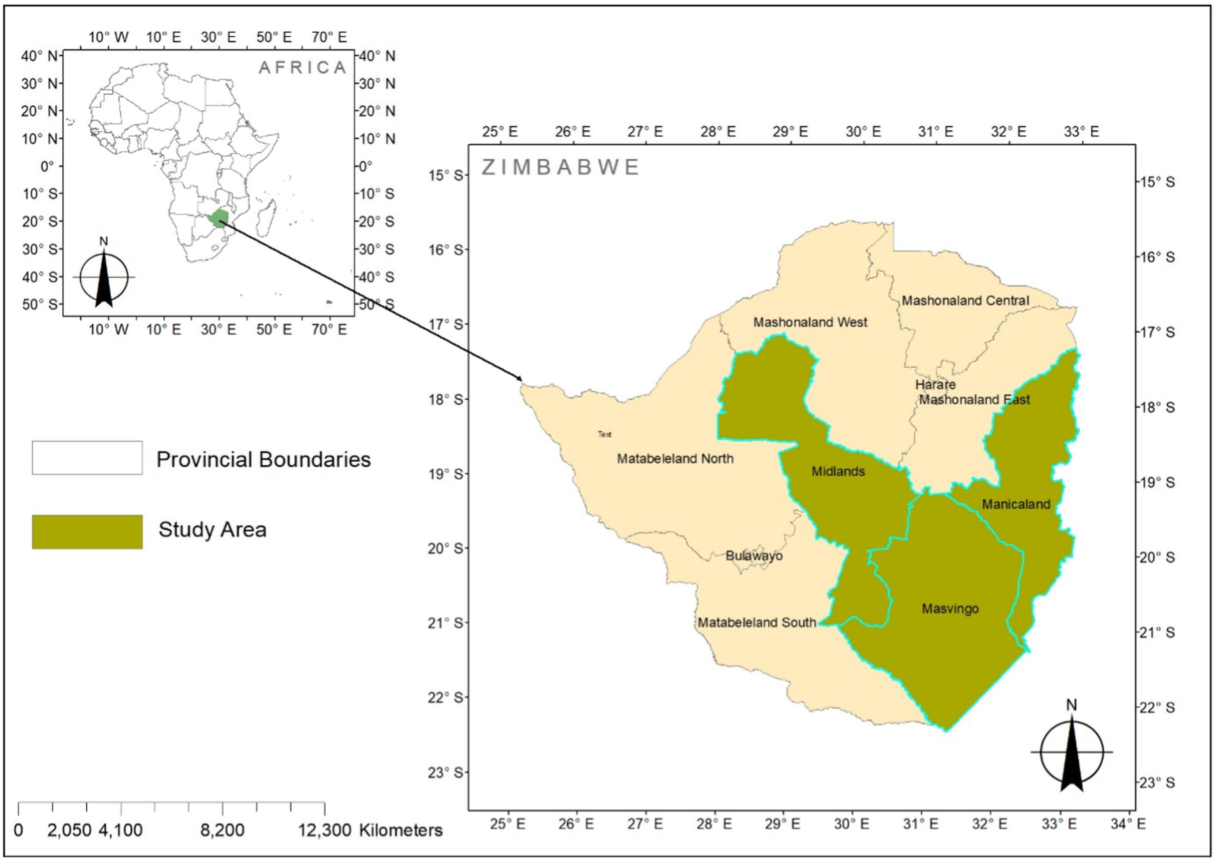

FIGURE 1
Map of the study area.

and bean production partnership or arrangements. The trader questionnaire was programmed for digital data collection due to COVID-19 containment measures that restricted movement. Therefore, the free online survey tool, https://freeonlinesurveys.com/s/EsOG2nln#/0, was used to collect data from 6 male and 12 female traders. Trader survey involved telephone interviews by trained extension officers who recorded the responses in the free online survey tool. The data collected from traders included bean products, varietal and trait preference for grains, partnership, and bean business characteristics. The collected data reflected the diverse experiences and needs of farmers and traders, irrespective of their gender, social status, or role in the bean value chain, which aligns with the inclusive innovation framework.

The collected data were analyzed using Stata version 18. The analysis involved measures of central tendency, mean and standard deviations, proportions, frequencies, and percentages. Test of significance—chi-square test of independence, Fisher's exact test, and sample *t*-test—was used to test for systematic differences between responses provided by farmers. Tests for significance differences were not performed on trader responses due to small sample sizes. Cross-tabulation of results allowed comparison of men and women responses and contributed to the understanding of how gendered differences were associated with varietal and trait preferences. This ensured that analytical approach aligned with the theoretical emphasis on gender-sensitive breeding practices in Zimbabwe.

4 Results

4.1 Sociodemographic characteristics of producers and traders

As shown in Table 1, the analysis shows the results of sociodemographic and farm characteristics of producers who participated in the study. In total, 60% of the respondents were women and 40% were men, suggesting the dominant role of women in bean production in Zimbabwe. The average age of the respondent was 49 years for women and 48 years for men, and this shows that most common bean farmers are adult with the involvement of a few youths. The majority of the respondents were married (68% women and 86% men), 27% women and 4% men were widowed, and 5% women and 10% men were single. Most of the respondents achieved a secondary education or higher (60% women and 77% men), 35% women and 24% men had primary education, and 5% women had no formal education. Literacy levels are important in acquiring agricultural knowledge and information for both men and women; thus, the results indicate that there is a high possibility for the respondents to acquire knowledge on improved bean varieties.

In total, 47% women and 40% men had household income of less than 40,000 Zimbabwean dollars, 33% had an income ranging between 40,000 and 100,0000 Zimbabwean dollars, and only 3% had

TABLE 1 Sociodemographic and farm characteristics of producers by gender.

Variable	Total (N = 131)	Women (n = 79)	Men (n = 52)	p-value
Gender of respondent (%)		60.31	39.69	
Average age or respondent in years	49.04	49.25	48.71	0.830
	(14.06)	(13.47)	(15.02)	
Respondent's marital status (%)				0.001
Married	75.57	68.35	86.54	
Single	6.87	5.06	9.62	
Widowed	17.56	26.58	3.85	
Education level (%)				0.071
No formal education	3.08	5.06	0.00	
Primary	30.77	35.44	23.53	
Secondary or higher	66.15	59.49	76.47	
Average household size	5.66	5.62	5.72	0.787
	(2.03)	(1.92)	(2.22)	
Household income level (%)				0.304
< 40,000	44.62	47.44	40.38	
40,000–100,000	33.08	28.21	40.38	
100,001–150,000	11.54	12.82	9.62	
150,001–250,000	7.69	6.41	9.62	
> 250,000	3.08	5.13	0.00	
Average land area	1.34	0.90	1.67	0.169
	(0.28)	(0.29)	(0.28)	0.85
Partners in bean production (%)	26.72	29.11	23.08	0.445

Standard deviation provided in parentheses.

an income above 250,000 Zimbabwean dollars. The landholding for men and women was 1.67 acres and 0.90 acres, respectively. Approximately 23% of men and 29% of women reported that they received support from partners, such as seed companies, government, and NGOs.

Table 2 shows sociodemographic and business characteristics of traders. Overall, 67% of traders were women and 33% were men. Women traders had higher educational attainment (secondary or higher), and higher percentage of them performed as agro dealers than men. There was an equal number of male and female bean aggregators, while more men (67%) than women (42%) performed as retailers. Nonetheless, more men than women operated formal and commercial enterprises, suggesting differences in nature of businesses operated by male and female traders. The gender differences in bean trade are also revealed by higher trading capacity (2.5 MT) per month of men-owned business which is twice the monthly bean volumes traded by women. The operational capacity of male trader is also higher than female traders as shown by higher number of male and female employees hired by male traders. Moreover, bean trading is more profitable for men ($6,850 *per annum*) than women ($3,843 *per annum*), as shown in Table 2. The analysis of type of bean product revealed that the percentage of women who traded bean grain (92%) was higher than the percentage of men (67%). While one-third of men traded canned beans, only 8% of women reported trading canned beans.

4.2 Objectives of bean production and varietal preferences

The results in Table 3 indicate that NUA45 was the most produced and traded bean variety as reported by 57 and 31% of farmers and traders. Gloria and Cherry were the second and third most produced and traded bean varieties by both men and women. Furthermore, most respondents engaged in bean production and trade with an objective of achieving both food and income, regardless of gender and varietal preferences.

Respondents were then asked to state traits of the most preferred bean variety—NUA45 (Table 4). The p-value of 0.000 indicates that there are statistically significant differences in the overall preferences between women and men. Biofortification trait was highly preferred by both women (43%) and men (46%), suggesting that this trait is significantly important for both genders. Early maturing was similarly important for both women (37%) and men (32%). More women (46%) preferred NUA45 because of cooking time compared with 32.43% men.

Trader trait preferences for bean varieties are presented in Table 5. The results also revealed that men and women preferred same traits albeit with differences in prioritization. Quality and market price were preferred by 100% of the female traders compared with 83% of male traders. The appearance was also highly important for both genders (83%). However, some gender disparities in the consistency of cooked

TABLE 2 Business characteristics of traders by gender.

	Total	Women (n = 12)	Men (6)	p-value
Gender of owner (%)		66.67	33.33	
Education level (%)				0.443
No formal education	33.33	25.00	50.00	
Primary	5.56	8.33	0.00	
Secondary	27.78	33.33	16.67	
College and higher	33.34	33.33	33.33	
Type of trader (%)				0.796
Aggregator	16.67	16.67	16.67	
Agro-dealer	33.33	41.67	16.67	
Retailer	50.00	41.67	66.67	
Level of business (%)				0.083
Commercial	22.22	8.33	50.00	
Semi-commercial	77.78	91.67	50.00	
Nature of business				0.638
Formal	55.56	50.00	66.67	
Informal	44.44	50.00	33.33	
Type of product (%)				0.245
Grain	83.33	91.67	66.67	
Canned beans	16.67	8.33	33.33	
Number of women employees	2.00	1.42	3.17	0.223
Number of male employees	1.61	1.17	2.50	0.116
Annual profit from bean trading (US$)	4,845.56	3,843.33	6,850.00	0.040
Monthly bean trading capacity (kgs)	1,699.00	1,267.00	2,563.00	0.007

meal and fast cooking were observed. More men (33.33% for consistency and 66.67% for fast cooking) prioritize these traits compared with women (16.67 and 41.67%, respectively).

4.3 Implications of socioeconomic conditions on varietal preferences

The results presented in Table 6 indicate that variety preferences for men and women differed by poverty status. NUA45 appears to be the most preferred bean variety, which is grown by both poor (women 60%, men 59%) and non-poor (women 68%, men 73%) farmers. Among non-poor farmers, men showed a preference for Cherry and other varieties, while women primarily opted for Gloria and Cherry. Interestingly, poor farmers, irrespective of their gender, exhibited greater diversity in their planting choices, growing up to five different varieties compared with three varieties planted by non-poor farmers.

Table 7 presents a detailed disaggregation of bean varieties preferred by farmers by marital status and gender. Married farmers of both genders (women: 68%, men: 83%) compared with those who are not married (women: 32%, men: 18%) preferred NUA45. Similarly, Cherry was popular among married individuals (women: 72.73%, men: 83%) than those not married (women: 27%, men: 17%). All married men (100%) and 73% of married women preferred Gloria. Other varieties (Ngonda, Sweet Violet, Willian) were predominantly grown by married individuals (women: 80%, men: 94%) compared with those who were unmarried (women: 20%, men: 6%). While there are observable trends in the data, statistical tests for differences in male and female farmers' preferred bean varieties by marital status indicated no significant differences.

As shown in Table 8, the results of land allocation to bean varieties indicate that men allocated larger land areas to NUA45, Cherry, and other bean varieties than women albeit not significantly different. In contrast, women allocated larger land area to Gloria than men. As shown in Table 8, the absence of significant differences in land allocation by men and women reflects similar findings of no statistically significant variation in bean variety preferences by marital status and gender, as shown in Table 7.

4.4 Implications of socioeconomic conditions on bean marketing

Table 9 presents the bean varieties that are preferred for marketing by farmers, which is disaggregated by gender. Both women (77.03%) and men (75.61%) showed almost equal preference for marketing NUA45. The proportion of women who preferred other bean varieties (Sweet Violet, William, and Ngoda) with an objective of selling was

TABLE 3 Objectives of bean production and trade differentiated by bean varieties and gender.

Actor	Variety		Food	Sale	Both	p-value
Producer	NUA45	Total (n = 112) – 56.85%	1.79	32.14	66.07	0.191
		Women (n = 71)	1.41	26.76	71.83	
		Men (n = 41)	2.44	41.46	56.10	
	Gloria	Total (n = 25) – 12.69%	4.00	8.00	88.00	0.653
		Women (n = 20)	5.00	10.00	85.00	
		Men (n = 5)	0.00	0.00	100.00	
	Cherry	Total (n = 19) – 9.64%	10.53	31.58	57.89	0.913
		Women (n = 12)	8.33	33.33	58.33	
		Men (n = 7)	14.29	28.57	57.14	
	Other	Total (n = 41) – 20.81%	2.44	24.39	73.17	0.177
		Women (n = 26)	0.00	19.23	80.77	
		Men (n = 15)	6.67	33.33	60.00	
Trader						
		Total (n = 13) –30.95%	7.69	23.08	69.23	0.169
		Women (n = 9)	0.00	33.33	66.67	
	NUA 45	Men (n = 4)	25.00	0.00	75.00	
		Total (n = 11) – 26.19%	9.09	45.45	45.45	0.357
		Women (n = 6)	0.00	66.67	33.33	
	Gloria	Men (n = 5)	20.00	0.00	80.00	
		Total (n = 10) – 23.81%	0.00	20.00	80.00	0.595
		Women (n = 6)	0.00	33.33	66.67	
	Cherry	Men (n = 4)	0.00	0.00	100.00	
		Total (n = 8) – 19.05%	12.5	12.50	75.00	0.667
		Women (n = 3)	0.00	0.00	100.00	
	Other	Men (n = 5)	20.00	20.00	60.00	

more than double that of men, but this difference was not statistically significant ($p = 0.109$). In addition, a higher percentage of men preferred Cherry and Gloria for marketing compared with women.

As shown in Table 10, variety preferred by farmers for marketing was disaggregated by poverty status and gender. Non-poor women preferred for marketing of all four varieties, while non-poor men only preferred to sell NUA45. Poor farmers (earning less than 100,000 Zimbabwean dollars ($265.7) per months), regardless of gender, preferred to sell all bean varieties in the market. A higher proportion of poor women preferred selling other varieties than poor men. In contrast, higher percentages of poor men preferred selling NUA45, Cherry, and Gloria than poor women. The Zimbabwean government policy on biofortification of industrial products has led to an increase in utilization of NUA45 in the industries. As shown in Table 11, most of the unmarried women prefer selling NUA45, Gloria, and other varieties than their men counterparts. In contrast, higher percentages of married men prefer NUA45, cherry, and Gloria than unmarried women farmers. More married women prefer other varieties than married men. However, comparison between poverty (Table 10) and marital status (Table 11) is generally not statistically significant, indicating that differences in farmers' preferences for marketing of bean varieties do not vary based on marital status or gender.

4.5 Partnerships and closing gender gaps

Table 12 presents the percentages of farmers and traders with bean production and marketing partners, respectively, disaggregated by gender. In total, 26% of the sampled farmers engaged in partnerships for bean production. When analyzed by gender, 29% of female farmers had bean production partners compared with 23.08% of male farmers. Although women were slightly more likely than men to engage in partnerships for bean production, the absence of a statistically significant difference ($p = 0.779$) between the percentages of female and male farmers with bean production partners suggest that gender is not a determining factor in men and women engagements with service providers in the bean value chain. Even so, men had three production partners (seed company, government, and NGO) while women had two production partners (seed company and government). Table 12 also shows that 72% of traders had partners in bean marketing, albeit with no significant difference by gender [women (57%), men (90%)]. Approximately

TABLE 4 Traits of most preferred bean variety (NUA45) by producers disaggregated by gender.

	Total		Women		Men		
	Freq	Percent	Freq	Percent	Freq	Percent	p-value
Biofortified	44	43.14	27	42.86	17	45.95	0.000
Cooking time	43	42.16	29	46.03	12	32.43	
Early maturing	35	34.31	23	36.51	12	32.43	
Yields	24	23.53	18	28.57	6	16.22	
Price	13	12.75	7	11.11	6	16.22	
Number of pods	11	10.78	8	12.7	3	8.11	
Pest resistance	11	10.78	8	12.7	3	8.11	
Grain weight	8	7.84	5	7.94	3	8.11	
Seed quality	7	6.86	4	6.35	3	8.11	
Grain size	6	5.88	5	7.94	1	2.7	
Seed size	5	4.9	2	3.17	3	8.11	
Market demand	5	4.9			5	13.51	
Grain colour	4	3.92	3	4.76	1	2.7	
Taste	4	3.92	3	4.76	1	2.7	
Fertilizer requirement	2	1.96	1	1.59	1	2.7	
Ease of threshing	1	0.98			1	2.7	
Seed availability	1	0.98			1	2.7	

TABLE 5 Traits of most preferred by traders disaggregated by gender.

	Pooled		Women		Men		
	Freq	Percent	Freq	Percent	Freq	Percent	p-value
Baking quality	17	94.44	12	100.00	5	83.33	0.085
Market price	17	94.44	12	100.00	5	83.33	
Appearance	15	83.33	10	83.33	5	83.33	
Colour	15	83.33	10	83.33	5	83.33	
Grain size	10	55.56	6	50.00	4	66.67	
Fast cooking	9	50.00	5	41.67	4	66.67	
Nutritional value	7	38.89	6	50.00	1	16.67	
Uniformity of size	7	38.89	3	25.00	4	66.67	
Texture	5	27.78	2	16.67	3	50.00	
Consistency of cooked meal	4	22.22	2	16.67	2	33.33	
Weight of grain	3	16.67	1	8.33	2	33.33	
Flatulence	2	11.12	1	8.33	1	16.67	
Stays whole	2	11.11	2	16.67			

43% of female traders had no partners compared with only 10% of male traders. Higher percentages of male traders had farmers (40%) and financial institutions (40%) as partners in bean marketing compared with female traders. In contrast, more female traders (14%) than male traders (10%) had processors as partners. For the NUA45 variety, partnerships appear to almost equalize market participation between women and men (Figure 2). However, for other bean varieties such as Cherry and Gloria, partnerships did not yield similar positive outcomes in closing gender disparities in marketing.

5 Discussion

Common bean is often considered a women's crop in sub-Saharan Africa because women are typically more involved in production for

TABLE 6 Preference of bean varieties differentiated by poverty status and gender.

	Poverty			Non-poor			Poor		
	Non-poor	poor	*p*-value	Women	Men	*p*-value	Women	Men	*p*-value
NUA45	83.33	83.02	0.968	89.47	80.00	0.592	90.00	76.19	0.095
Gloria	20.00	22.64	0.758	26.32	0.00	0.098	28.33	14.29	0.075
Cherry	13.33	12.26	0.876	15.79	10.00	0.667	13.33	11.9	0.831
Other (sweet)	23.33	32.08	0.357	21.05	30.00	0.593	35.00	30.95	0.670

TABLE 7 Bean varieties preferred by farmers differentiated by marital status and gender.

		Women		Men		
Variety	Variable	Freq.	Percent	Freq.	Percent	*p*-value
NUA45	Not married	23	32.39	7	17.50	0.120
	Married	48	67.61	33	82.50	
Cherry	Not married	3	27.27	1	16.67	0.555
	Married	8	72.73	5	83.33	
Gloria	Not married	6	27.27	0		0.289
	Married	16	72.73	6	100.00	
Other	Not married	5	20.00	1	6.25	0.376
	Married	20	80.00	15	93.75	

TABLE 8 Acres of land under bean production differentiated by gender.

Variety	Women	Men	*p*-value
NUA45	3.97	5.05	0.582
Cherry	6.26	14.10	0.334
Gloria	3.81	3.61	0.966
Other	3.70	5.22	0.660

TABLE 9 Bean variety preference for marketing disaggregated by gender.

	Women		Men		
Variety	Freq	Percent	Freq	Percent	*p*-value
NUA45	57	77.03	31	75.61	0.864
Cherry	4	36.36	5	71.43	0.335
Gloria	17	77.27	6	85.71	0.545
Other	14	53.85	4	25.00	0.109

subsistence purposes. However, the results presented in this study depict common bean as a dual-purpose crop as shown by higher percentage of male and female producers and traders who prefer the varieties for both food and income, according to Nakazi et al. (2017). The results suggest that traders are only trading locally supplied grain because what they prefer exactly matches what is produced. Alternatively, farmer's preferences are driven by what is demanded in the market. A higher percentage of male producers prefers NUA45 for income/sale than women, suggesting that men are more market-driven in their preference for NUA45. In contrast, female traders prefer trading NUA45 and Cherry for income than male traders, who prefer Gloria for income generation than female traders.

The results show that men and women prefer the same traits, but prioritization of the traits differs. Women preferences and prioritization of cooking time over other traits could be because it saves time for other activities or fuel/wood which women are mostly responsible for collecting (Nchanji et al., 2021). Higher preferences for market traits (market demand and price) among men than women could be because men are responsible for most household purchases (Siri et al., 2020), explaining why a higher percentage of men responded that they prefer NUA 45 for sale/income. Women play important roles in post-harvest activities, such as threshing, winnowing, and sorting (Nakazi et al., 2017). Then, the expectation was that female farmers would prefer labor and time-saving innovations. However, this is not the case in our study as none of female respondents mentioned post-harvest traits as preferred traits. Instead, a few male producers mentioned ease of threshing as one of the preferred traits. This result suggests possible trade-off with women not minding technologies that cause drudgery as long as they reduce cooking time, contribute to household food and nutrition security (biofortification, earliness, high-yielding, and resistant to biotic stress).

Both male and female traders mostly preferred the same traits in the same order. The first four traits of most preferred bean varieties by traders are market price, color, appearance, and grain size. Traders always purchase what the consumers want. For most of the local food crops like beans, traits such grain size stand out among the most important for consumers purchase decisions (Kuntashula et al., 2012) while for traders the bigger the grain size the less quantity placed in a bag and more money in the pocket.

TABLE 10 Bean variety preference for marketing disaggregated by poverty status and gender.

	Non-poor					Poor				
	Women		Men			Women		Men		
	Freq.	Percent	Freq.	Percent	*p*-value	Freq.	Freq.	Percent	Freq.	*p*-value
NUA45	16	94.12	7	87.5	0.547	41	71.93	24	72.73	0.568
Cherry	2	66.67	0		0.500	2	25	5	83.33	0.103
Gloria	5	100				12	70.59	6	85.71	0.629
Other	1	25	0		0.571	13	59.09	4	48.57	0.164

TABLE 11 Bean variety preference for marketing disaggregated by marital status and gender.

	Not married					Married				
	Women		Men			Women		Men		
Variety	Freq.	Percent	Freq.	Percent	*p*-value	Freq.	Percent	Freq.	Percent	*p*-value
NUA45	21	91.30	4	57.14	0.068	36	70.59	27	79.41	0.452
Cherry	0		1	100	0.250	4	50.00	4	66.67	0.627
Gloria	5	83.33				12	75.00	6	85.71	0.508
Other	3	60.00	0		0.50	11	52.38	4	26.67	0.176

The finding that common bean serves as dual purpose crop highlights the need for breeding programs in Zimbabwe, to focus on developing cultivars that cater for both subsistence and market needs of bean producers. Specifically, breeding programs should target traits that enhance productivity and marketability and those that directly impact household food security and nutritional quality. Example of productivity and marketability traits that could be considered are yield, pest and disease resistance, and grain size and appearance. Biofortification and short cooking time could be considered as critical traits for ensuring food security and nutritional quality. Second, men prioritization of market-oriented traits and women preferences for time-saving traits underscore the need for a gender-responsive breeding approach. Women trait preferences provide an opportunity for common bean breeders to focus on developing biofortified and high-yielding bean varieties that reduce cooking time and drudgery. Lastly, the low prioritization of post-harvest traits by women, despite their significant contribution to bean production, underlines possible trade-off, confronting women when selecting varieties to produce (Ashby and Polar, 2021). This provides an opportunity for innovations (e.g., bean threshers) that ease post-harvest activities without compromising women's preferred traits.

Poor farmers, regardless of gender, preferred many varieties than non-poor farmers. NUA45 was preferred by both poor and non-poor farmers due to its availability and awareness creation as a nutritional panacea to malnutrition in the country. Non-poor farmers are mostly market-oriented as they prefer varieties that fetch profits possibly because of higher food security status compared with poor households. These findings align with the concept that crop variety selection is responsive to changes in income, with income variations leading to diverse choices (Nakazi et al., 2017). Non-poor farmers have a better access to resources, knowledge, and access to mechanization equipment. They may also have higher knowledge about the latest farming techniques than poor farmers. These factors may incentivize them to engage in markets compared with poor farmers (Nchanji et al., 2021). Furthermore, the result showed that married men are likely to have a large portfolio (diverse) of preferred bean varieties than married women. This could be linked to possible influence of gender norms or differences in access to information or knowledge about availability of bean varieties, leading to differing preferences for bean varieties between men and women (Nchanji et al., 2021).

There were also gender differences in land allocation to bean production. The results could suggest possible differences in constraints to men and women access to resources or the importance or prioritization traits. Men's preferences for NUA45 and Cherry, attributed to their marketing, along with gender disparities in access to land, may explain why the allocated larger sizes of land allocated to bean production than women. In contrast, female farmers allocated more land to Gloria than NUA45 and Cherry possibly because of their preference for the color trait as earlier reported by Nchanji et al. (2021). Furthermore, the results show that marital status had an impact on market participation of male and female farmers. Unmarried and married women and men sold all the varieties, while unmarried men only planted varieties, they considered profitable varieties—NUA45 and Cherry.

Three implications can be drawn from the findings on relationship between socioeconomic variables and preferences for bean varieties. First, higher preference of NUA45 by both poor and non-poor is a further testament for developing and promoting nutritional and market-oriented varieties. This would address the food security and nutritional needs of poorer households and cater to the market-oriented strategies of non-poor farmers. Additionally, bean breeding programs in

TABLE 12 Contract farming and production partners disaggregated by gender.

	Total		Women		Men		
Partner	Freq	Percent	Freq	Percent	Freq	Percent	*p*-value
Producers							0.779
Seed company	19	13.97	16	20.25	3	5.77	
Government	12	8.82	7	8.86	5	9.62	
NGO	4	2.94			4	7.69	
None	101	74.27	56	70.89	40	76.92	
Traders							0.145
Farmers	9	36.00	4	28.57	4	40.00	
Financial institutions	6	24.00	2	14.29	4	40.00	
Processor	3	12.00	2	14.29	1	10.00	
None	7	28.00	6	42.86	1	10.00	

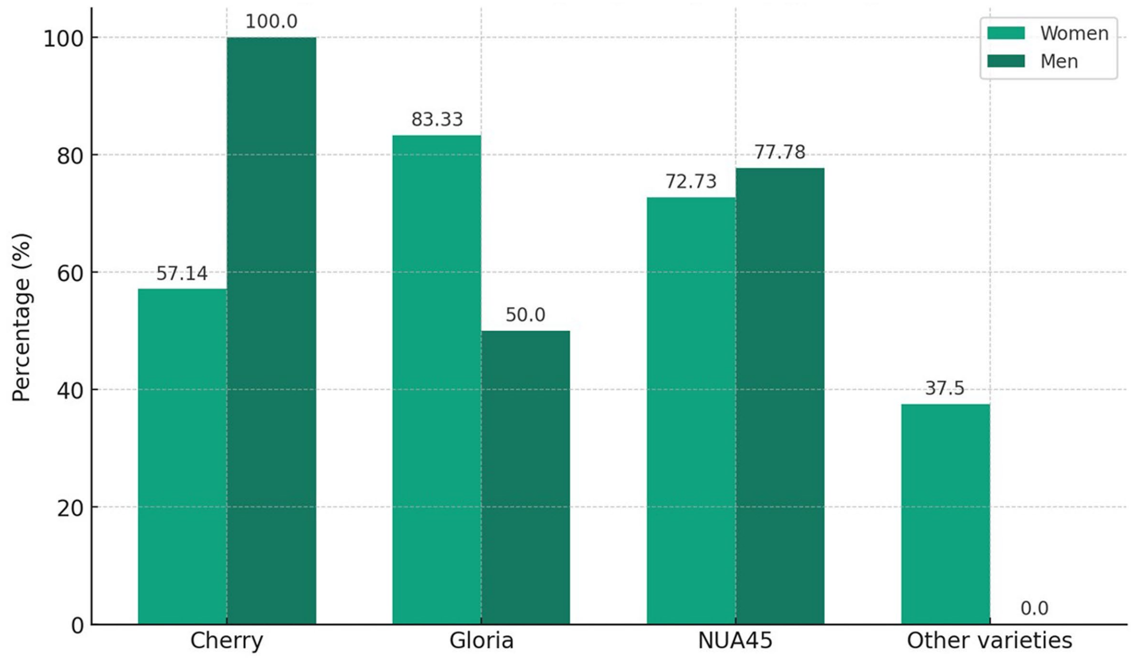

FIGURE 2
Distribution of market participation by variety type and gender.

Zimbabwe should incorporate socioeconomic diversity in breeding strategies to respond for varying levels of access to resources, knowledge, and market engagement between poor and non-poor farmers and women and men. For instance, design of less-input intensive, high productivity, and market appealing bean varieties would cater for needs and targets of both poor and non-poor farmers. Breeding programs should also consider gender and intersectional elements such as poverty and marital status when designing bean varieties to ensure that the breeding process prioritizes traits that are specifically valued by women and men while minimizing trade-off.

Furthermore, the study found that male producers had three partners (seed company, government, and NGOs) while women producers had two partners (seed company and government) that supported bean production. Seed company is the most frequently mentioned partner for women and government is the most frequently mentioned partner for men producers. The type of relations/partnership is possibly limited to already developed seed and dissemination of information about already developed bean technologies via government and NGO extension. Unlike producers, higher percentages of traders have trading partners. Gender disparities were clear with higher percentage of male traders, indicating financial institutions as partners compared with women. This aligns with the bottom of the pyramid narrative that argues that some factors exclude resource-poor factors in value chains (Opola et al., 2021). Women had lower operational capacity and profitability, therefore their bean trading enterprise offered weak business case for financial lenders. It is also consistent with political economy argument for inclusive innovation where male traders can easily access/own collateral-to-secure financial assistance than women (Saha, 2016). As supported by the results presented in Table 12, farmers' relationships with traders were informal and typically confined to farmgate transactions, which was characterized by unstructured terms of engagement.

The finding about gender differences in engagement in partners for both farmers and trader suggests the need for enhancing inclusivity in support networks created by bean breeding programs to ensure equal access to a diverse array of support networks, especially among women. In addition, targeted financial inclusion programs, involving training in business management and bookkeeping, are needed to facilitate access to credit by female traders. The possibility of unstructured terms of engagement between farmers and traders would require strengthening of formal relationships and equitable market access.

Finally, the results indicated that partnerships had a differential impact on closing gender gaps depending on the type of bean varieties. Having partners enable men and women to equally participate in selling NUA45 but did not close gender gaps in marketing of Cherry and Gloria. Although the findings highlight the need for partnerships to support women participation contract farming and markets, there are embedded differences in how models integrate gender inclusivity. Thus, partnerships in bean production are critical for working toward the political economy narrative of inclusive innovation. Additionally, interventions tailored to the unique challenges and opportunities associated with each variety may be necessary to achieve gender equity in market participation.

6 Conclusion

This study confirms that male and female farmers are traders who often have different or similar traits which may be prioritized differently. Partnerships play a significant role in almost closing these gender gaps and can be beneficial for more intersectional groups such poor men and women and food-insecure and food-secure individuals. Some trait preferences often considered exclusively for women are often not mentioned if women consider it as their role especially traits related to threshing and winnowing which were highlighted by men not women farmers. Even though women mentioned post-harvest traits, they were prioritized last as cooking time and biofortification were prioritized higher, suggesting trade-off.

NUA45 was the most preferred variety by producers and traders due to extensive awareness creation about micronutrient trait. It was one of the varieties promoted to support the fortification policy. In addition, NUA45 was preferred by poor and rich farmers because of short cooking time, biofortification (iron and zinc), early maturing, high yield, and a good price. Thus, the fortification policy created a space for inclusive technology that considered the needs of all value chain actors with diverse social categories. Trader traits and producer traits were similar, showing that farmers are aware of what the market demands are striving to meet their needs.

Gender disparities are evident depending on the partnership engaged in bean production and marketing. While it may appear in the results that men producers have double the number of production partners as women, the actual difference is only one partner. Male traders are more likely to find financial assistance than women. This indicates an unequal access to resources and institutional support, suggesting a need for partnerships that specifically support women to achieve inclusive bean production and marketing. It is recommended that partnerships are formed to support women to participate in bean partnerships in bean production and marketing for the achievement of an inclusive bean value chain.

The primary limitation of our study is its reliance on quantitative data, which prevented a deeper understanding of the social, cultural, and economic factors influencing varietal and trait preferences in the bean value chain. Another limitation is the small sample size of traders, which restricts the generalizability of our findings and limits the statistical power for more complex analyses. Regression analysis would have provided more robust inferences in association between institutions (partnerships), gender and poverty with farmers, and traders' preferences for bean varieties. Therefore, future research could benefit from using a large sample size of traders and employing a mixed-methods approach to provide deeper insights into the complexities of bean value chain dynamics, gender roles, and the effectiveness of various partnership models.

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 humans were approved by Department of Research and Specialist Services, Zimbabwe. 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

EN contributed to the study by conceptualizing, acquiring funding, investigating, developing methodology, drafting the original manuscript, and reviewing and editing. NC, ST, and FG contributed to the study by conceptualizing, developing methodology, supervising data collection, and reviewing and editing the manuscript. JM and CL contributed to the study by developing methodology, analyzing data, writing the original draft, and reviewing and editing the final draft 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.

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Barriers and enablers of crop varietal replacement and adoption among smallholder farmers as influenced by gender: the case of sweetpotato in Katakwi district, Uganda

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Sweetpotato is climate smart crop, grown with limited external inputs (fertilisers, pesticides, less labour) making it an attractive crop for resource-constrained smallholder farmers. It is also a major cash and food crop for many countries in sub-Saharan Africa. However, adoption of the high yielding and nutritious improved varieties has been disappointingly low. This study uses qualitative methods to explore the barriers and enablers of farmer varietal replacement and adoption. Unlike the extant quantitative studies that identify the determinants of adoption, we delve deeper into understanding the reasons for or against the preference for specific varieties. We used a rich set of information collected via focus group discussions which explore *why* farmers prefer certain varieties over others and *how* they perceive the new improved varieties from the national breeding programs. Doing so enabled us to unravel specific traits or trait combinations that farmers seek and identify those that they perceive needing improvement. We find that the most preferred traits were 'yield' and 'good taste'. Implying that the neglect of sensory attributes by breeders contributes to the low adoption of improved sweetpotato varieties. Moreover, we find that altruism among the respondents plays an important role in farmer use of, and sharing of information about improved sweetpotato varieties. Women and men farmers obtained most of their information from neighbours, NGOs and radios. For women, the most important source of planting materials doubled as their most important source of information. Thus, concerted efforts to minimise information constraints are essential for unravelling the adoption puzzle.

KEYWORDS

sweetpotato, improved varieties, varietal replacement, enablers and barriers, sexdisaggregated data, Uganda

Introduction

Uganda used to be the second highest sweetpotato producer in Africa with the total production of 1.7 million tonnes (FAO Statistics, 2004) before it dropped to the current fifth position (Tavva and Nedunchezhiyan, 2012). Moreover, the total national production and yield have reduced by 23 and 7%, respectively, in the last decade (FAOSTAT, 2021). Despite the reduced production, sweetpotato remains an important crop in Uganda. It is the third leading staple in the country after banana and cassava (Mwanga et al., 2021a,b) with an estimated *per capita* consumption of 95 kg/year (Abong et al., 2016). The Eastern region is the highest producer of sweetpotato in Uganda (Uganda Bureau of Statistics, 2020) despite being drought prone. The crop is grown mainly by women who are responsible for sourcing seed and replacing varieties (McEwan, 2016). Sweetpotato is grown for multiple uses in the region namely: food, feed and fuel. The sweetpotato storage roots are mostly consumed in the boiled form, or freshly roasted popularly known as *amukaru*. The fresh roots are also chipped or flaked and dried to make more shelf-stable products namely, *amukeke* and *inginyo*. Leaves are also consumed as vegetable relish while small non-marketable roots, vines and peels are used as animal feed. Recently the practice of making briquettes from sweetpotato residues has emerged among communities as another utilization form (Odikor, 2019; Bot et al., 2022). The crop is also grown for income generation in majority of the households.

Most improved varieties are not only high yielding but also early maturing providing food three months after planting, thus playing a crucial role of bridging the hunger gap and thus addressing food insecurity (Ssemakula et al., 2013). This endears the crop to women given their role of food provision in the household. Women thus dominate sweetpotato production comprising over 60% of sweetpotato farmers in Uganda (Polar et al., 2022). They are responsible for seed sourcing, selection and conservation and, inherently, identification of new varieties with good culinary properties; usually through informal and closed networks due to their immobility (McEwan et al., 2023). These local networks play an important role in commercial seed exchange and diffusion especially in arid and semi-arid areas (Rachkara et al., 2017). Women also usually decide which varieties are best suited for food and the market (Mudege et al., 2016).

Many people are currently employed within the sweetpotato value chain as farmers, traders and processors. Sweetpotato is also climate smart and can be grown with limited external inputs (fertilisers, pesticides, less labour) making it an attractive crop for smallholder resource-constrained farmers. It is specifically suited to marginal areas yielding comparatively better than other crops (Bashaasha et al., 1995). Due to its short maturity period, sweetpotato also serves as emergency/disaster response crop (Heck et al., 2020). However, given the bulkiness of the crop's planting material, coupled with women's immobility (due to time poverty, limited access to transportation and low agency) the varietal replacement is low (Heck et al., 2020). Ultimately, this results in delayed planting and low yields. This is further exacerbated by limited access by women to agricultural resources, knowledge and technologies. Zawedde et al. (2014) cited strong preference for local land races as another reason for low varietal replacement. Access (i.e., availability and cost) to improved[1] planting material was also reported as a major production constraint (Zawedde et al., 2014). Consequently, most farmers continue to grow local low performing cultivars and recycle poor-quality planting material.

The negative trend in total production has remained despite long-term breeding efforts to develop high yielding, stress tolerant, and nutrient-rich varieties (Mwanga and Ssemakula, 2011). For instance, improved varieties such as NASPOT 8, an orange fleshed variety biofortified with provitamin A, and NAROSPOT 1 (white fleshed) have potential productivity of 33 and 35 MT/ha, respectively (Mwanga et al., 2009) but with reported actual yields of 4.4 t/ha at the national level (Loebenstein et al., 2003; Magunda, 2020). Furthermore, these varieties are not widely grown by farmers (Barker et al., 2009; McEwan et al., 2022). Past studies have sought to address farmers' low uptake of improved varieties. For example, Mwanga et al. (2021a,b) assessed men and women's trait preferences in the value chain to develop gender responsive varieties in Uganda. Mashonganyika (2018) redesigned the breeding objectives to include perspectives from multi-functional teams including end users in Kenya. Thiele et al. (2021) urged for consideration of eating quality traits during variety selection in Ethiopia. Okello et al. (2022) gathered market intelligence from sweetpotato value chain to assess the priority trait packages of different actors in Uganda. Okello et al. (2023) tested the effectiveness of behavioural interventions in stimulating demand for improved sweetpotato varieties among smallholder farmers in Uganda and found that social incentive combined with goal setting had no significant effect on knowledge and experimentation by progressive farmers, and on willingness to pay for improved seed.

Existing research have shown that behavioural interventions (nudges) can be used to stimulate adoption of agricultural technologies especially where conventional extension approaches for technology diffusion strategies have failed to work (Ben Yishay and Mobarak, 2019; Shikuku, 2019; Balew et al., 2022). The development of a behavioural intervention to incentivise farmers to regularly replace planting materials and use good agronomic practices is intended to induce adoption of improved technologies (Ben Yishay and Mobarak, 2019). While these past nudge studies have demonstrated that social incentives can increase adoption of improved varieties, Okello et al. (2023) find the converse. Rather than increasing demand for improved varieties, social incentive nudges acted to reduce it. This study interrogates the findings of Okello et al. (2023) using qualitative data collected from the same farmers. It specifically attempts to understand the barriers and enablers of variety replacement among smallholder men and women sweetpotato farmers and gives suggestions for improvement in the existing varieties. The study focuses on two objectives, namely it:

i Explores how farmers' tastes and preferences influence varietal preferences, and hence adoption and replacement.
ii Examines constraints to adoption of existing improved and local sweetpotato varieties.

Varietal replacement is the rate at which farmers replace older varieties with newer improved varieties that have been bred for better performance, and it is considered critical for farmers to achieve sustained yield gains (Spielman and Smale, 2017). Several other factors affect yield, including soil fertility and crop management practices (Adeola et al., 2019).

Improved sweetpotato varieties (ISVs) are developed to boost yields, overcome biotic and abiotic stresses that limit productivity.

1 Improved means planting material that is free from pests (sweetpotato weevils) and diseases (SPVD and Alternaria blight).

They (ISVs) are bred to address nutritional deficiencies and meet sensory acceptance (Low et al., 2017; Danso-Abbeam et al., 2022). Farmers adopt ISVs if their expected utility, through yield and other benefits, is greater than that of local varieties (Adeola et al., 2019). The adoption of improved sweetpotato varieties and varietal replacement is therefore a function of different socio-economic, institutional, and environmental factors (Adeola et al., 2019). Further, farmers replace older varieties when the genetics of the newer ones improves their utility, in function of the same factors (Spielman and Smale, 2017).

In the initial phases of agricultural intensification, there is no market for improved varieties of vegetatively propagated crops, requiring the public sector to develop them and produce the seed through parastatals (Low et al., 2017). However, once farmers start to adopt ISVs, creating a market for seed and other inputs, the private sector assumes a leading role because in principle it is more efficient in producing and disseminating the seed. As the seed sector's life cycle evolves, the private sector can take over the development of newer varieties (Mastenbroek et al., 2021).

Understanding the barriers and enablers of varietal replacement is important to plant breeders. It informs breeders about the success of their programs. It also enables researchers to better understand agricultural intensification and the development of the seed industry therein. Policy makers can, on the other hand, learn about the success of their policies. Finally, understanding the processes in the adoption of improved varieties and varietal replacement in sweetpotato is particularly important for food security in East and Southern Africa, where it is a very important food crop. The study hypothesises that varietal replacement would be increased by training (which provides information on agronomy and marketing) and the social incentive.

Materials and methods

Study purpose and scope

This study builds on an earlier research conducted in March to May 2022 by CIP and Katakwi District Production and Marketing Department (DPMD). The study tested the effectiveness of nudges on demand for improved sweetpotato varieties. The current study comprises of two parts. The first was a quantitative study to understand farmers' sources of agricultural information, the effect of knowledge of improved sweetpotato varieties, role of social networks in the diffusion of knowledge and improved varieties in the social network, and performance of the introduced varieties. The second part was a qualitative study that sought to understand the barriers and enablers of sweetpotato varietal replacement. This study focuses on the qualitative part which was implemented in November and December 2022, jointly by NARO, CIP and Katakwi DPMD.

Study location

This study was conducted in the Teso sub-region of eastern Uganda (1°55′10.0"N, 33°57′41.7″E). The region is characterised by two cropping seasons (April–June and July–November) which are followed by a long dry spell (December–March). During the dry spell, farmers lose most of the sweetpotato planting material to drought and grazing cattle. Consequently, during the first cropping season, farmers normally do not have planting material and have to wait for the residual roots to sprout to raise seed that is then planted in the second cropping season. These sprouts usually have accumulated viruses and weevils (Okello et al., 2023) and result in low yields and poor root quality.

The study covered all the three counties and 16 sub-counties of Katakwi district (Figure 1), which borders with the Karamoja region whose livelihood activity is cattle keeping. Accordingly, during the dry season herders graze their cattle in crop fields and destroy any remaining sweetpotato vines, including those planted in the lowlands to preserve planting material. This results in conflicts between herders and farmers. Additional conflicts are caused by frequent cattle raids by the Karamojong, which often result in displacement of farmers.

Data collection and analysis

This study used a series of focus group discussions (FGDs) accompanied with semi-structured interviews to collect data. A well-structured questionnaire in form of a checklist was developed interactively by the research team to guide the discussions. The main themes were, major varieties grown by farmers, trait preferences, seed sources; experience with introduced varieties; information and social networks and altruism. The FGDs were administered by a team of enumerators comprising three men and three women. The enumerators worked in pairs – one man and one woman. Prior to the actual data collection, the six enumerators were trained in qualitative methods of data collection. The guide was discussed and translated into local language. The guide was then pre-tested with sweetpotato farmers in a neighbouring district (i.e., Kapelebyong district), refined and finalised.

Farmers who participated in the first study by Okello et al. (2023) were traced and re-interviewed in mixed sex FGDs. Care was taken to ensure that both men and women were represented. In each of the FGDs, there was at least one farmer who bought the vines during the auction and therefore had grown improved sweetpotato varieties. In addition, a farmer who had been trained on sweetpotato agronomy (including importance of quality seed), marketing and seed quality maintenance [henceforth, referred to as the disseminating farmer (DF) participated in the FGD]. The DF had been linked to designated number of co-villagers and encouraged to share information obtained in the training about quality seed of ISV.

A total of 16 FGDs were conducted in 16 purposively selected villages / parishes. Eight of the selected villages had previously received nudges [i.e., the DF was promised a reward in form of public recognition (social incentive)] while the rest had not. In each of the selected villages, only the 11 farmers who participated in the first study were invited to take part in the FGD. Each FGD was moderated by two enumerators comprising a facilitator and note taker. Prior to commencement of the FGD's, each participant was verbally requested for their consent to take part in the study. FGDs were conducted in the local language and verbal and visual observations were noted by the lead researcher. The session proceedings were also audio recorded. Each session lasted approximately 2 h. After the session, data were transcribed, coded and analysed using Atlas.ti software (Muhr, 1993). Analysis of themes was used to analyse both interview and focus group data. Tables of results on numerical values were generated using

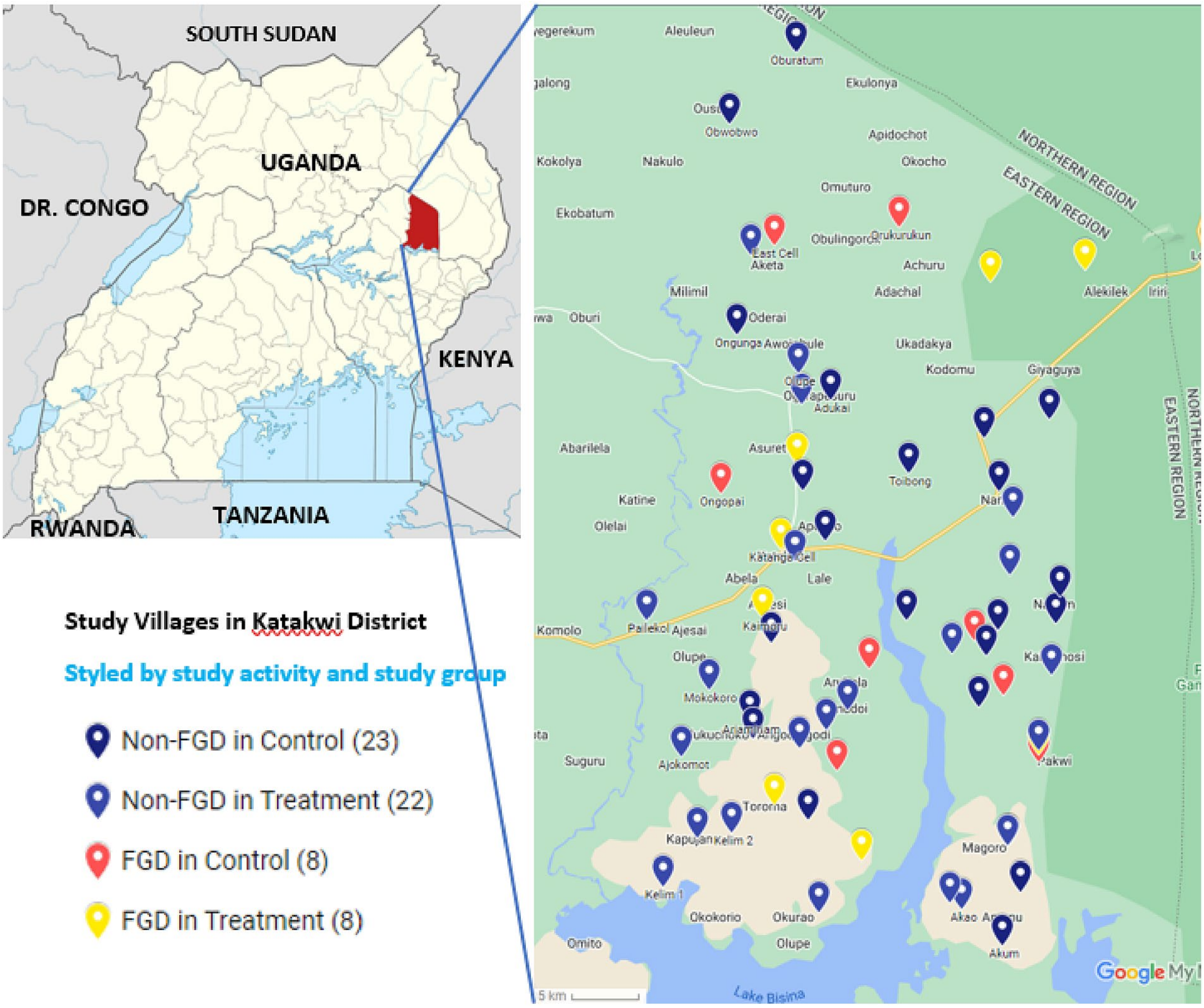

FIGURE 1
Map of Uganda showing the study area.

STATA and excel software. Representative quotes were extracted and used to back up some results.

Results and discussion

Characteristics of FGD participants

A total of 158 farmers (50.3% female and 49.7% male), participated in the FGDs (Table 1). Among the participants, 52% did not receive the nudges (control group), while 48% did (treatment group). The average age of participants was 41 years; there was no significant difference in age between the treatment and control group. Half of the participants (50%) were married and lived together with their spouses. The average education level of the participants was 5 years of schooling. Participants who received nudges had, on average, one more year of education than those who did not. The low levels of education have negative implications towards the understanding of new technology. This is in line with Oduro-Ofori et al. (2014) who found that as education level increases, output also increases. More than 80 and 90% of the participants in treatment and control groups, respectively, were engaged in farming as the main occupation.

Most planted sweetpotato varieties

Results show that the most planted varieties were local landraces (Figure 2). Among the farmers who participated in the FGDs, 28 mentioned *Iboii/Esapat*, a local landrace, as the most planted variety. This was followed by *Ekampala, Osukut* (Tanzania), then *Kakamega* and *Araka*, in that order. Among the varieties promoted under the first study, only *Ejumula* and *Osukut* (Tanzania) were mentioned, each by only two farmers. Results show that farmers consistently ranked *Iboii/Esapat*, *Osukut, Ekampala* and *Kakamega*, among the top five most commonly grown varieties, although the ranks assigned to each variety varied amongst FGD groups.

Participants also mentioned other landraces besides the top five varieties above. These included; *Ateseke, Epeet* and *Obongkwap*. These results, in general, underscore farmers' preference for the landraces to improved varieties. Clearly, *Iboii/Esapat* was the most widely grown

TABLE 1 Sociodemographic characteristics of FGD participants.

Individual and household characteristics	Total (*n* = 158)	Control (n = 82; 51.9%)	Treatment (*n* = 76; 48.1%)	*p*-value*
Gender of the respondent, (Male), *n* (%)	77 (49.7)	46 (58.5)	31 (42.1)	0.04
Farmer's age (years), mean (sd)	40.48 (17.30)	41.20 (19.25)	39.71 (15.02)	0.59
Farmer is married and live together with spouse (Yes), *n* (%)	85 (53.8)	49 (59.8)	36 (47.4)	0.12
Farming is the main occupation, (Yes), *n* (%)	145 (91.8)	78 (95.1)	67 (88.2)	0.11
Respondent's education(years), mean (sd)	5.36 (3.88)	4.96 (3.25)	5.79 (4.45)	0.18

Data source: Authors survey data (2022). **p*-values are results of Student's t-test and Pearson's Chi-Square test for continuous and categorical variables, respectively.

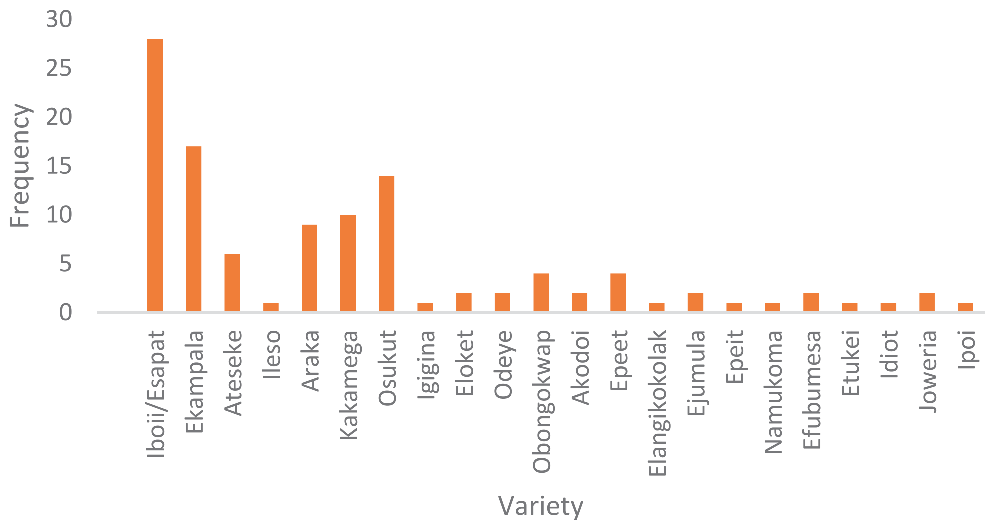

FIGURE 2
Most planted sweetpotato varieties by study participants (*n* = 155).

variety by the study participants. In most FGDs, for instance in *Adidit, Apeleun, Aterai*, and Angiriny villages, all the farmers reported growing the variety.

Altogether, participants identified more than 21 different varieties of sweetpotato that are maintained by the study communities. This finding is in line with previous studies which have indicated that a wide range of sweetpotato varieties are grown in Uganda (Zawedde et al., 2014; Yada et al., 2017; Okello et al., 2022).

Preferred traits/characteristics

Among the most preferred traits mentioned, 'yield' and 'good taste' were the leading as shown in Figure 3. It is interesting that participants emphasised the value of yield and taste because breeders have been focusing mainly on yield at the expense of eating quality traits such as good taste. Thiele et al. (2021) attributes the low adoption of improved sweetpotato varieties to the neglect of good eating qualities.

Figure 3 presents the most frequently mentioned characteristics of the top five varieties by the participants. Yield was most frequently cited for *Iboii* and *Ekampala* while good taste was mostly cited for *Iboii* and *Kakamega* as shown in the participants' sentments below. *Iboii* had a balanced combination of the traits farmers look for in a variety (i.e., high yielding, high dry matter content, pest and disease resistant, good sweet taste, good for processing, long ground storage, drought resistance, non-fibrousness, root size). Although listed among most preferred, *Kakamega* and *Araka* were not reported to have early maturity and weevil resistance characteristics, respectively.

> *'Iboii has good taste. When you cook amukeke and add peanut butter, it is really tasty'.* Female respondent, FGD Apeleun.
>
> *'It's amukeke has good taste when cooked, it is just as sweet as sugar'.* Male respondent, FGD Orukurukun village.

The early maturity trait is important for bridging the hunger gap following long drought periods, which characterise the Teso sub-region (International Organization for Migration, 2023). Preference for early maturity trait in varieties most liked by farmers is as elaborated below:

> *'Araka if you plant it this week, next week you will weed, a week later you find the heaps already have cracks. That is why it is called Araka, it saves you from hunger. It is early maturing'.* Male respondent, FGD Apeleun.

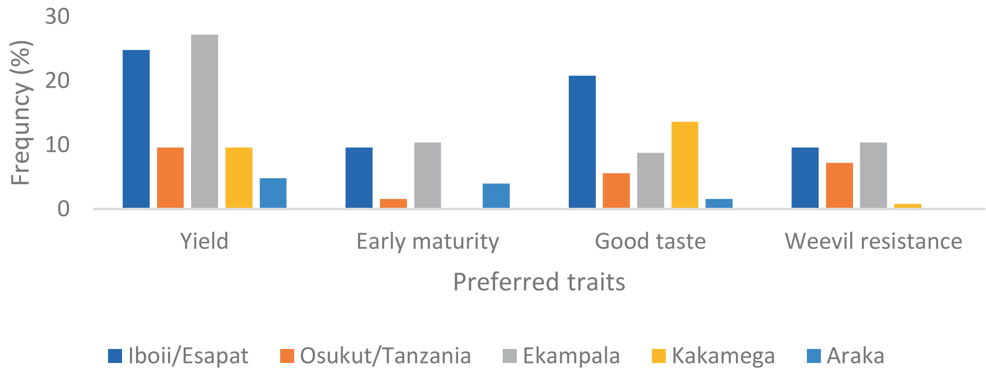

FIGURE 3
Preferred traits for the most frequently mentioned characteristics of the top five varieties of sweetpotato.

In fact the variety is named '*araka*' meaning "quick" alluding to how quickly it takes to mature.

> '*It is high yielding, you can get money from it and when you plant early people will keep coming to you to buy the roots*'. Female respondent, FGD Epaku village.

Ekampala was praised for its early maturity as elaborated below:

> '*What we like about Ekampala is that it is high yielding and early maturing and can relieve you from famine*'. Male respondent, FGD Abelan village.

Weevils are pests of major economic importance in the study area. For example, sweetpotato weevils can cause up to 100% yield loss, especially under dry conditions in susceptible varieties (Collins et al., 2019). With regards to weevil infestation, one respondent noted that:

> '*Iboii is resistant to sweetpotato weevils. Even when you slice the potatoes of Iboii variety, they are not easily attacked by weevils*'. Female respondent, FGD Abelan.

Osukut used to be the defining variety for the Teso sub-region but has since been overtaken by others because of biotic and abiotic constraints. The popularity of *Osukut* is captured below:

> '*Why we like to grow Osukut, it does not rot from the garden quickly, because for us, we do not have the manpower to dig out all the sweetpotatoes and peel it all, so, we dig little by little, that helps us, that's why we like Osukut*'. Male respondent, FGD Adidit.

Among the other landraces, *Ateseke* and *Epeet* were positively perceived for their high yield and good taste. *Obongkwap* was perceived to be high yielding and resistant to weevils. Of the varieties promoted in the first study, *Joweria* was reported to be high yielding, early maturing, marketable, and rich in vitamin A. *Ejumula* was mentioned in Congo village as a preferred variety and perceived to be high yielding, disease resistant, big and long roots, good taste, and sells easily.

Performance of varieties promoted in the first study

This section focuses on the four varieties that were promoted to study participants during the first study. These were *Ejumula*, *Joweria*, New *Dimbuka* and *Osukut*/Tanzania. Quality seed of these varieties were presented to farmers in an auction setting in each study village and one farmer purchased one of them. We therefore were keen to assess how the four varieties fared and were perceived by the participants of the current study.

Majority of the participants in the current study reported that the four varieties were high yielding, pest and disease resistant, early maturing, did not rot, and had big long roots with a good taste. For instance, a farmer said:

> '*They grow faster, had high yield*'. *It only lacked water due to little rain. I also did not observe any disease infection*'. Participant, FGD Amaratoit village.

Resistance to pests and diseases here was less related to variety performance and more related to the fact that the seed they purchased at the auction were clean. This is likely to have contributed to what farmers observed as higher yield that is described by the respondent from Amaratoit village above.

In addition to the high yield, the promoted varieties gave farmers an opportunity to re-plant some of their popular varieties which had disappeared from community. For instance one farmer said:

> '*The vines gave me the opportunity of planting a very good old variety of vine called* ***Osukut****, and indeed everyone who saw it from my garden would ask me, where did you get that variety* ***Osukut*** *from?, I also want it. I would tell them that there is an NGO that brought it and I managed to be the winner, who paid the highest bid, that's how I got it. They would also request to get some and multiply, I would then tell them, to get from the garden.*' Participant, FGD Epaku village.

The overall experience with the varieties promoted in the first study was positive. This is regardless of the fact that the study area was affected by drought during the first season. Indeed the period immediately following the introduction of the vines was characterised by a dry spell that affected vine establishment. Both male and female farmers nonetheless reported that they re-planted the introduced varieties in the second season further supporting their preference for them.

Suggested improvements in the existing varieties

Among the top five varieties, for both men and women farmers, no improvements were suggested for *Iboii* and *Osukut* (Table 2). This finding is congruent with the earlier finding that Iboii had a balanced set of farmer-preferred characteristics. For *Araka*, however, both men and women farmers suggested the need to: (i) improve root shape and, (ii) reduce incidence of rotting. Participants also recommended the need to reduce the incidence of rotting in *Kakamega* and *Ekampala*. Additional improvements suggested for *Kakamega* were: the need for increased root size, pest and disease resistance, drought resistance, reduced root fibrousness, and increased skin smoothness. Improvements recommended for *Ekampala* were: increase in yield, pest resistance, good taste, early maturity, nutrition and reduced incidence of rotting. Regarding the promoted varieties, improvements in yield and root size were recommended for *Joweria*, while pest and disease resistance were recommended for *Ejumula* in order to increase their preference. In line with previous findings, enhancing root shape and size in varieties that have good taste, nutrition and agronomic attributes has the potential to increase preference for improved varieties in general and reduce the gender technology adoption gap in particular (Mulwa et al., 2023).

Constraints to adoption of existing improved and local sweetpotato varieties

Sources of sweetpotato planting material.

FGD participants cited multiple sources of planting materials (vines). The most common source was neighbours followed by local market, own gardens/plots and vine multipliers (Figure 4). There were subtle but important differences in the most commonly used sources by men and women. While more women (71.8%) than men (67.5%) opted to source vines from neighbours, the reverse was true for markets (Figure 4). Male participants in Adidit village mentioned that they did not obtain vines from Ochorimogin, their main market, because of distance. Their sentiment is highlighted by one respondent who said:

> '*The market is located three to four km away from the village and accessing it is an obstacle to many farmers.* Man participant, FGD Adidit.

This would especially constrain women who tend to have limited mobility. The women's mobility challenge is not only a problem in sourcing sweetpotato vines but in general for women in agriculture. Nchanji et al. (2020) found significant differences in access to new varieties and yield gap of beans between men and women due to limited mobility; among others.

With regards to sourcing from neighbours, a female respondent from Adidit stressed that in order to obtain the vines; one had to "beg the neighbours." In Congo village, a female respondent mentioned that once a neighbour agrees to give vines, she had to send grandchildren to cut and bring the vines home. This alludes to the gendered division of roles in farming, and highlights the role children play in supporting family farming as well as the gendered differences in source of seed and especially of new varieties. Men in the same village mentioned that some neighbours give vines for free, while others sell them. In Agirinyi village for example, 6 farmers (3 M, 3F) indicated that they have bought vines from their neighbours in the past, which corroborates the findings by McEwan et al. (2022) and Rachkara et al. (2017) with regards to the commercial perspective of vine sourcing in arid and semi-arid regions when compared to those with bimodal rainfall patterns.

In Adidit village, Aparisa Parish, women respondents mentioned that when there is scarcity, they buy vines from Ochorimogin market, which also serves as their source of agricultural inputs. Men in the same village also indicated that it was difficult to conserve own vines because animals destroyed the vines during the dry periods. Hence, they mostly sourced vines from the market. Both women and men noted that the vines sourced from the local market were quite expensive – probably because they come from outside the community and have to be transported at high cost and tight timelines due to perishability. Men further observed that apart from the market being distant; in times of scarcity, farmers would search for vines for up to 1 week before getting them. This finding is similar to findings by Lukonge et al. (2015) who found that farmers in Meatu, Tanzania, would have to travel long distances in search of vines. The emerging picture is that of acute case of vine/seed insecurity resulting from poor access due to unavailability and costliness.

Participants further stated that vines from own gardens were mostly maintained through local conservation methods. In Apeleun, men mentioned that they multiply the vines under trees which conserves them for up to a year. Participants in other FGDs also mentioned that they conserve vines by fencing off the areas/plots with vines to prevent them from being destroyed by animals. They further mentioned that they purposely leave roots in the ground during harvesting in order for them to sprout during the next season as a way of conserving vines. These roots sprout after the onset of next season rains providing vines. These findings are in line with those of Namanda et al. (2011) and Okello et al. (2015) who found that farmers in dryer regions of Uganda and Tanzania, respectively, use volunteer plants from roots left over in the ground for planting during the new season.

There were also cases of sweetpotato farmers conserving and multiplying vines in the wetland[2] for sale to other famers. However, this was one of the least used source of planting materials. A female respondent from Kaimoru village noted that a bag of vines could cost as high as UGX 40,000 to UGX 50,000 at the onset of first season rains when vines are very scarce. This is quite expensive when compared to prices elsewhere in the country that range from UGX 15,000 to UGX 20,000 shillings moreover for improved varieties (Rachkara et al., 2013). Rachkara et al. (2017), on the other hand, indicate that local multipliers in Gulu sell a bag of local vines at only UGX 10,000. This probably explains the low utilization of this source. At the same time,

2 These are not the conventional trained multipliers – source: DAO, Katakwi.

TABLE 2 Missing attributes that need to be improved in the most preferred sweetpotato varieties.

Variety	Productivity		Biotic and abiotic stress			Ground storage	Root characteristics			Eating quality		
Top ranking varieties	High yield	Pest resistance	Disease resistance	Early maturity	Drought resistance	Rotting	Big root size	Shape	Skin smoothness	Good taste	Non fibrousness	Nutrition
Iboii	No	No	No	No	No	No	No	No	No	No	No	No
Ekampala	Yes	Yes	No	Yes	No	Yes	No	No	No	Yes	No	Yes
Osukut	No	No	No	No	No	No	No	No	No	No	No	No
Kakamega	No	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No	Yes	No
Araka	No	No	No	No	No	Yes	No	Yes	No	No	No	No
Promoted varieties												
Joweria	Yes	No	No	No	No	No	Yes	No	No	No	No	No
Ejumula	No	Yes	Yes	No	No	No	No	No	No	No	No	No

Yes = Attribute needs to be improved; No = no improvement needed.

it could prevent farmers with limited resources from using this important service. Nonetheless, such multipliers provide an important service especially in arid areas where farmers are hard pressed to conserve own vines (Rachkara et al., 2017).

Auction was mentioned as a new form of obtaining vines, but only by a few. This finding is in line with *a priori* expectations (Okello et al., 2023). By design, only one farmer was able to buy vines at the auction making it quite a limited source. Further, our results indicate that this source was mostly mentioned by men. While this is novel in the area, it nonetheless points to technology access leaning more towards men than women (Diiro et al., 2015).

Difficulties in accessing sweetpotato planting material

FGD participants reported a number of challenges relating to acquiring vines for planting (Figure 5). Poor quality vines was the universal crosscutting challenge. It was mostly associated with vines sourced from local markets, followed by own sources, neighbours, multipliers and those sourced from auction in descending order. Participants associated poor quality with adulteration of varieties, immature vines, and undesirable varieties, among others. Vines sold during the auction were deemed poor quality when leaves were wilted or yellowish (not "fresh"). Thus, farmers' perceptions of quality differed from the scientists' definition: the latter definition focusing on vines that are free from pests and diseases. Barker et al. (2009) argue that poor quality and insufficient planting materials were the most limiting factors in acquiring vines among farmers in northern Uganda. Given the effect of vine quality on sweetpotato productivity, there is therefore the need for training and sensitization on quality assessment (diagnosis) and assurance (i.e., how it is communicated) if yields are to be improved.

Pest and disease infested vines was the second most important challenge mentioned by respondents. This problem primarily, but not exclusively, occurs in vines sourced from farmers' own fields. Vines sourced from neighbours and farmer multipliers were also associated with high infestation with pests and diseases. Participants mentioned that it was difficult for them to discern infested vines from good ones, because of the "credence[3] good" nature of the quality. They indicated that they could only tell that the vines were poor quality after they have planted and obtain pencil-like tiny roots. They linked pencil-like roots to repeated use of vines especially those sourced from own fields. Studies indicate that the sweetpotato virus disease can cause devastating outcomes of up to 80% yield loss in susceptible varieties in arid and semi-arid regions (Yada et al., 2015; Okello et al., 2023).

Participants highlighted the high cost of vines as a challenge for planting material sourced from the market, multiplier and neighbours in descending order.

Lack of sufficient vines to plant when needed was a major challenge for farmers who rely on vines sourced majorly from neighbours. Participants mentioned that they would be asked to wait

3 Credence good are one whose true nature can only be deduced after consumption/use but not by visual observation.

FIGURE 4
Common sources of Sweetpotato planting material by male and female farmers.

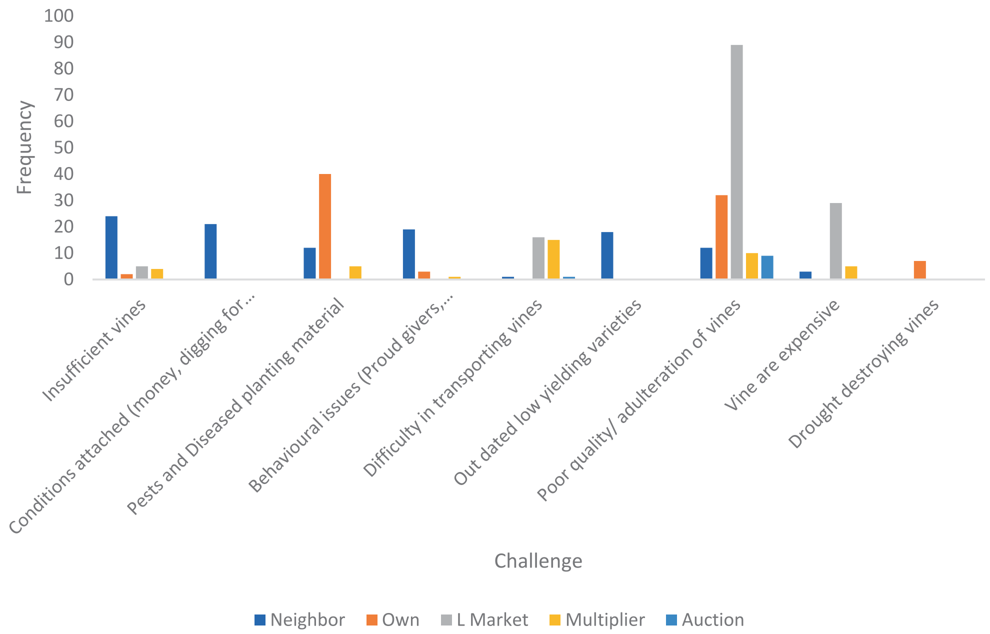

FIGURE 5
Challenges in accessing sweetpotato planting material from different sources.

when neighbours run out of planting materials, which led to late planting. One male participant shared:

> *'Sometimes you can go to the neighbour after you have made the sweetpotato heaps but the neighbour tells you: 'Wait, because I have not yet cut (vines) for myself'. This means you cannot plant in time.* Male respondent, FGD Apeleun.

Participants also indicated that neighbours attach conditions to vines as a common challenge. This includes working to get the vines. For instance, digging for vines or paying cash for vines. This appeared strange to farmers because they are used to obtaining vines from the neighbours' sweetpotato fields for free. One farmer mentioned that:

> *Sometimes you are told to first dig for the owner [of] vines before you can be given the vines. Nothing is for free.* Female respondent, FGD Amaratoit.

In some cases, farmers would not get any planting materials at all from neighbours because the vines would have been 'overcut' (i.e., overharvested) and all that remained were just the main stems. Failure to grow sweetpotatoes in some seasons for lack of vines can affect food and income security. This is evidenced by Mwangi et al. (2020) who noted that seed security influences food security and seed access.

Sources of farming advice

Generally, the most preferred source of farming advice was neighbours followed by radio, NGOs, village chairmen, agricultural officers, model farmers and newspapers; in descending order (Figure 6). For women, neighbours were the most important source followed by NGOs and radio. Neighbours as a source of information ties with their most important source of seed and corroborates the findings by Gilligan et al. (2020). Neighbours were preferred because of their close proximity and accessibility; while also being appreciated as a conduit of knowledge received from other sources such as NGOs.

> *The one way I prefer for getting agricultural information on seed and input quality is through our brothers around (peer farmer), he has been taught some good information on farming, I can also learn from him so that I can be strong in farming because I can learn from him what NGOs have taught him.* Female participant, Kaimoru FGD.

Participants, especially women, appreciated radio as a source of agricultural information because of its consistency and the diversity of knowledge shared. They indicated that from radio, they were able to learn about new crop varieties and the associated agronomic practices.

> *I prefer the radio because you get to know the new varieties that have come up and when to plant them because such information is lacking from experienced elders.* Female participant, Katanga FGD.

Some participants however felt that radio was not an optimal channel for getting agricultural information. They mentioned that while you can listen to the radio, the broadcasters would not get to you physically nor give you inputs as is the case with NGOs. In Omwatok, a female participant commented that 'without dry cells you cannot listen to radios'.

In a similar study conducted in Ethiopia and Ghana, Mayanja et al. (2020) found that women did not prioritise radio as a communication channel because of limited access to radio sets and batteries.

For men, the most preferred source of information was also radio followed by NGO and neighbours, in descending order. Participants from several villages mentioned that they preferred information from NGOs because it was accompanied by practical trainings. Some farmers mentioned making organic pesticides as an example where knowledge from NGOs was more helpful than radios. These organizations were acknowledged to be hands-on and for providing physical inputs such as seed as starter packages. Participants stated that such inputs especially seed would give them good harvests. NGOs were also noted to have a wide outreach and were commended for keeping time. Men in particular were appreciative of the information received from NGOs are elaborated as below:

> *'I prefer NGOs because they can teach you how to properly farm and how to make manure on how to grow well your crops'* Male participant, FDG Adidit village.
>
> *'I prefer NGOs because I had never been taught agricultural practices not until this organization came to our village'* Male participant, FDG Ongopai village.

The downside though was that they took long to follow up. In line with this finding, Rees et al. (2000) also found that though NGOs are important sources of information, they lack resources to do extensive follow-up in communities leading to information distortion.

Only men mentioned newspaper as a preferred source of farming advice, probably due to low literacy levels and immobility of women that deters access to this channel. Men also had better access to information from Agricultural Officers and model farmers compared to women. Further, men participants shared the multiple services Agricultural Officers provide. They were also held in high esteem because they were educated as highlighted below:

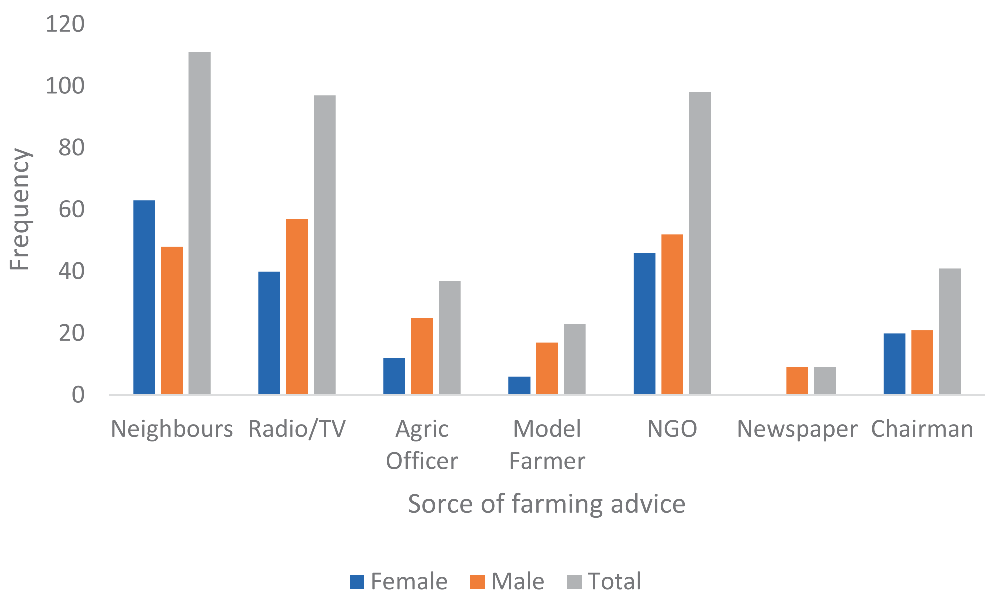

FIGURE 6
Preferred source of farming advice by men and women.

> *I prefer most agricultural officer of the sub county because he can come and check if any diseases have attacked the crops in the garden, he prescribes the pesticides to use on the various diseases.* Male participant, Adidit FGD.
>
> *I prefer agricultural extension worker because they have experience since they are educated.* Male participant, Angirinyi FGD.

Several studies have highlighted women's limited access to agricultural extension information, demonstrated by the gender yield gap in productivity (Zawedde et al., 2014; Heck et al., 2020; Nchanji et al., 2020). Efforts to disseminate new sweetpotato technologies in the area therefore need to take note and strive for strategies to improve women's access to agricultural information.

The participants stated that they get agricultural information from informal sources. For example in Orukurukun, Abelan and Omwatok villages eight participants (five men and three women) mentioned that they got information from agro-dealers as they purchased the agricultural inputs. Similar to findings by Katungi et al. (2008), eight participants from Abelan village mentioned church as a source of information. Other informal sources of agricultural information mentioned were friends, parents, drinking joints and social media. The social networks in communities like churches and drinking joints trigger discussions that end up generating useful agricultural related information that can be used to improve their farming enterprises. A study by Skaalsveen et al. (2020) found that interpersonal networks are important for farmers and influence farmer learning and decision making since they depend on each other for information. Additionally, Dapilah et al. (2020) reported that social networks form an essential source of information for agricultural technologies.

Community information networks thus play an important role in diffusion of new seed technologies especially to women because they are the ones who mostly participate in these gatherings. As noted by McNiven and Gilligan (2012), such networks played a substantial role in providing initial access to OFSP vines and later in the sustained adoption of the technology.

Altruism

The findings of this study suggest that during times of scarcity, farmers face challenges getting vines from neighbours even though the tradition has been to share vines for free. We therefore assessed the extent of altruism among the study participants to determine its role in farmer use of, and sharing of information about improved sweetpotato varieties. All the study farmers participated in an experiment designed to assess their altruistic behaviour. They were specifically asked to donate to a charity organisation out of an endowment of 5,000 UGX provided as part of the experiment.

According to Shikuku (2018) altruistic behaviour is denoted by a donation exceeding the median value of the donations. In the current study the median value of the donations was 2000 UGX. Twenty four percent of the participants gave donations that were above the median value suggesting that majority of the FGD participants were not altruistic. There are several reasons why this could be the case. For instance, at the time of the study, farmers were emerging from a long dry period characterised by food scarcity. The COVID-19 pandemic had also imposed mobility restrictions on the farmers thus disrupting the food systems. Part of the study area especially neighbouring the Karamoja region also experienced insecurity caused by cattle-raid by the Karamojong herders. These were associated with the following statements:

> *I felt like this, that what will my children eat but I was happy, I also gave the NGO little money.* Female participant, FDG Adidit village.
>
> *I felt bad. This is the first time I am giving to charity. There was a call for donating for village initiatives but people were not willing to give. I also gave but painfully.* Female participant, FDG Aterai village.
>
> *I never felt happy at all because how can they give me their money and then ask me to give back again yet you came in the name of helping me.* Male participant, FDG East cell village.
>
> *I felt happy when I was told that the money was mine but then when I was told to also donate, my heart folded a bit because in my mind I knew that some of my bills were going to be sorted. It is my first time to donate.* Female participant, FDG East cell village.

Men (28%) seemed more inclined to altruism compared to women (21%). This could be related to their giving nature that could render them more altruistic with the aim of spreading the feeling of giving and wellbeing within the community.

Conclusion

In this study, we used qualitative methods to understand the barriers and enablers of varietal replacement and constraints to adoption among smallholder men and women sweetpotato farmers. The main causes of low varietal replacement can be summarised as the persistent dominance of local varieties and the strong preference of older varieties due to possession of preferred traits compared to newer varieties. Among the wide diversity of varieties grown in the study area were *Iboii, Ekampala, Osukut*/Tanzania, *Kakamega* and *Araka*, in the order of importance. These varieties were mostly preferred because of high yield and good taste. While *Iboii* and *Osukut* stood out for having a balanced set of preferred traits, *Ekampala, Araka* and *Kakamega* lacked some key characteristics such as early maturity, weevil and disease resistance, and drought tolerance.

The three most common sources of planting material for both men and women were neighbours, local market and own field. There was little infusion of planting material from outside the community. Hence, poor quality of the vines was highlighted as the most important challenge across the different sources. Pests and disease infested planting material, high costs and unavailability of vines were also highlighted as major challenges. Farmers also had different understanding of quality from how scientists define it and had difficulty knowing/assessing quality of vines *a priori*. This implies the need for a credible signal of quality such as certification label that is commonly used in cereals. Women and men farmers obtained most of their information from neighbours, NGOs and radios. For women, the most important source of planting materials doubled as their most important source of information. The public agricultural extension system was not among the dominant information sources as would have been expected.

The study found some evidence of altruism among the farmers even though the level did not reach the threshold recommended by existing in literature. The finding that neighbours stood out as the main source of information and planting materials also exemplifies the existence of altruism among study farmers. However, scarcity seems to be eroding this virtue as farmers increasingly seek compensation for their vines from neighbours. The use of social information sources such as churches and drinking joints additionally illustrates the presence of altruism in the community. Nonetheless, there is no clear link between altruism and technology diffusion among farmers.

Vines that circulate in the community have high loads of pests and diseases which contributes to poor quality hence low sweetpotato productivity. This implies that there is a need to introduce sources of quality vines in the community or link the community to external sources of quality vines. Key traits that are preferable across varieties, like early maturity, pest and disease resistance and yield, are must-have traits in breeding objectives. Similarly, good sweet taste is a critical trait for enhanced demand for improved varieties, especially among women. Entrenching these traits in breeding objectives has the potential of increasing demand for improved varieties in general, and reducing the gender technology adoption gap in particular, through higher adoption among women.

The finding that there was limited use of public extension system as sources of agricultural information suggests the need to revamp the system. Additionally, there is need to invest more in extension work by training and sensitizing the agricultural officers. Thus, improved coordination between actors around the value chain will be critical to maximizing benefits for the wider seed sector and society. Given the importance of informal information sources as demonstrated in this study, the consideration for their inclusion in technology adoption strategies is justified. Thus, concerted efforts to minimise information constraints are essential for unravelling this adoption puzzle. The lack of a clear link between altruism and technology diffusion suggests the need for further research to examine its role in agricultural technology diffusion and adoption.

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 humans were approved by International Livestock Research Institute (ILRI), Internal review board (IRB), (ILRI-IREC2022-13). 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

IB: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing, Validation, Visualization. JO: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing, Visualization. SM: Conceptualization, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. MN: Conceptualization, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. SN: Conceptualization, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. FO: Conceptualization, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. SO: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – review & editing. KS: Conceptualization, Investigation, Methodology, Validation, Visualization, Writing – review & editing. C-JL: Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Validation, Visualization, 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, social, household, and ecological factors influencing wheat trait preferences among the women and men farmers in India

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The goal of public breeding programs is to develop and disseminate improved varieties to farmers. This strategy aims at providing farming communities with superior crop varieties than they are growing. However, the strategy rarely considers the needs and preferences of farmers, especially gendered preferences, failing to solve real field problems by addressing the differences and inequalities prevalent in the farming communities. Our research examines how personal, household, agronomic and ecological characteristics of wheat growers in Bihar, India's eastern Indo-Gangetic Plains, affect women and men's wheat trait choices. Data were obtained from 1,003 households where both male and female respondents from the same household were interviewed. We accounted for 23 traits of wheat from a careful assessment of production, environment, cooking quality, market demand, and esthetic criteria. Binomial logistic regression was used to determine women's and men's trait preferences. The results imply that gender influences the preferences of wheat traits. Some traits are favored by both women and men, however, in other instances, there are striking disparities. For example, men choose wheat varieties that are well adapted to extreme climate conditions, have a higher grain yield, and produce chapati with a superior taste, while women prefer wheat types with superior chapati making quality, higher grain yield, and high market prices. Other socioeconomic, agronomic, cultural, and geolocational factors have a considerable impact on trait preferences. These human dimensions of traits preferred by women and men farmers are important for trait combinations to develop breeding product profiles for certain market segments.

KEYWORDS

wheat traits, gender, trait preferences, logistic regression, Bihar

1 Introduction

Public breeding programs traditionally follow a supply-driven approach, which attempts to develop and disseminate improved varieties that meet or outperform the predefined trait criteria set by the governmental agencies and are expected to enhance grain yield, disease resistance, climate resilience and market acceptability. Although this approach has a good intention of providing the best crop varieties to farmers, it often fails to consider their needs and preferences. There is almost non-existence of a mechanism that connects the farmers' needs and preferences with the breeders' product profiles (Suri and Gartaula, 2023). Product profiles are the set of targeted attributes that a new crop variety or animal breed is expected to meet to successfully be released onto a market segment (Ashby and Polar, 2021), which is a geographic area or a group of people having a relatively homogeneous demand for a crop variety or a commodity in general (Ragot et al., 2018). Consequently, hundreds of improved crop varieties never reach the farmers' fields or have limited adoption, making the traditional public breeding program a place for academic exercise, rather than providing solutions to the real field problems, especially in the Global South, including India. This has resulted in a slow turnover of improved varieties, especially among the resource-poor and marginalized farmers who continue cultivating old varieties that are susceptible to pests and climatic stresses (Krishna et al., 2016).

In recent years, borrowing the approach from the private sector that have been applying it for a longer time, public sector breeding has started collecting farmers' demands and requirements to feed into their breeding pipelines and developing target product profiles (Teeken et al., 2021). This brings down to the understanding of the needs and preferences of diverse end-users, including women, men, the poor and other marginal farmers, and feeding them into the breeding pipeline, an approach called demand-led breeding (DLB, 2022). Moreover, in addition to considering biophysical and climatic parameters, mobilizing market intelligence to understand the end-user perspective is equally important to develop better market segmentation and breeding product profiles (CGIAR-EiB Platform, 2019). This will help improve crop varieties to address problems associated with biophysical, social, economic, and climatic challenges farmers are facing, which eventually lead to better adoption, faster turnover, and deliver improved genetic gains to the farmers' field. In this paper, we examine how the personal, household, agronomic and ecological characteristics of the wheat growers in Bihar influence wheat trait preferences among women and men farmers.

Wheat makes a good case for studying trait preferences in India, not only because it is the major cereal crop cultivated in about 30 million hectares of agricultural land and a critical commodity for the farmers' livelihood system, but also because India is the second-largest wheat-producing country in the world after China, contributing to the food security and economy of the country and at the global scale (Joshi et al., 2007; Tiwari et al., 2014). The history of wheat improvement in India dates to 1960s, the Green Revolution era, when the high-yielding semi-dwarf varieties were introduced and since then several improved varieties have been released in the country (Gupta et al., 2018). Wheat improvement is mainly done through the government funded program under the All India Coordinated Research Project on Wheat and Barley, nationally coordinated by the Indian Institute of Wheat and Barley Research (IIWBR), a subsidiary of the Indian Council of Agricultural Research (ICAR).

Wheat yield in Indian states varies according to the technology used and agroclimatic conditions (Soni et al., 2017), with a productivity gap of more than 40% in the eastern Indo-Gangetic Plains compared to the west (Badstue et al., 2022). The growing popularity of high-yielding varieties and mechanization have increased the demand and wages for male labor but decreased the same for female labor due to limited scope for performing women's traditional tasks of transplanting and weeding in mechanized wheat production system (D'Agostino, 2017). This further marginalized women in the wheat sector in terms of their wages and agency in decision making, despite their significant presence in the provision of labor (Farnworth et al., 2023).

New varieties could be developed to address various concerns and these technologies (new varieties) could be transferred to farmers' fields (Joshi et al., 2007; Soni et al., 2017). Due to smaller landholding and staple diet of people, wheat is cultivated almost exclusively for subsistence and fulfilling the dietary requirement of the household members, indicating an important (reproductive and economic) role of women farmers, and justifying the importance of gender consideration for wheat varietal selection and trait preferences in Bihar (Badstue et al., 2017). However, to what extent do the existing (public) breeding programs consider the inputs from diverse groups of farmers, including women, the poor and marginalized, in a participatory manner? Suri and Gartaula (2023), in a recent study conducted in the same region, report a lack of a feedback mechanism to collect farmers' needs and experiences. They observed that some meetings and workshops organized at regional levels are represented by the so-called progressive farmers, who are mainly men or rich, limiting the opportunities for women and marginalized farmers to provide input.

The way women and men farmers are considered in the process of target product profile development also depend on how gender and other intersectional factors are organized in a society. Generally, in India, and particularly in Bihar, caste system has a strong influence on how household decisions are made and how women are involved. Caste in Hindu society is a hierarchical system marked by superiority and purity beliefs. At the top are the General Caste (GC), so called upper caste, followed by mid-level Other Backward Castes (OBC) and marginalized groups like the Scheduled Castes (SC, Dalits) or the lower caste and Indigenous people or the tribal communities (Adivasi, Scheduled Tribes or ST) with different levels of men and women's involvement in access to resources and household decision making (Bidner and Eswaran, 2015). Moreover, the intersectional identities of gender, caste, and class are attuned to create opportunity structures that may make certain groups privileged, while others deprived of accessing resources, services, and livelihood options (Patnaik and Jha, 2020; Farnworth et al., 2023). For example, women in upper caste and women in lower caste households, or in poor or rich households are not the same, and they have different access to information and decision-making over varietal selection.

As such, to promote farmers' meaningful participation in varietal development, agronomists, plant breeders, and policymakers must understand the preferences and needs of the farming community. This would not only aid in the promotion (or introduction) of new varieties but also in their wider scaling (Krishna and Veettil, 2022). Perhaps due to not having a robust feedback mechanism on how farmers could feed their needs and preferences into breeding pipelines with their diverse and context-specific needs, breeders continue to work on the predefined traits, such as yield and tolerance to biotic and abiotic stresses, with relatively less tailored to the needs of the farmers' specific contexts. To address these context-specific needs and preferences and develop more targeted product profiles, modern breeding programs are trying to step up from the conventional approach and striving to go beyond productivity and economic gains and the biotic and abiotic traits to feed into the breeding pipelines. As such, non-biophysical traits such as milling, baking, and cooking quality have long been considered for wheat breeding programs (Nehe et al., 2019).

The preference to choose certain traits may differ depending on the ecological, social, economic, and cultural contexts of farmers, the ultimate adopter of improved varieties. However, the existing literature lacks these dynamic realities of the farming contexts. Earlier studies have focused on grain yield, compared to a negligible focus on other traits such as straw yield, height, grain size, tillering, seed rate, climate stress, disease resistance, crop duration, and market demand. There are also negligible enquiries into traits such as biofortified wheat, chapati making quality, threshability, and processing quality of wheat grain. Gender and social differentiation were also inadequately considered in many of these studies. Therefore, in our study, we have considered 23 traits related to the climatic, agronomic, genetic, economic, and esthetic characteristics of wheat. We have not found any previous study that has considered these many traits in a single analysis.

It is often assumed that women and men have different trait preferences, but very few studies have performed a systematic analysis on how gender of a farmer plays a role in trait preferences. The comparison between male vs. female household heads is the classic gender comparison; however, gender analysis goes beyond the household headship and affected by several intersectional factors of age, caste, class, and geographies. For example, Krishna and Veettil (2022) indicate that women and marginalized farmers in India preferred better grain quality (for the chapati making) of wheat, compared to yield-enhancing and risk-ameliorating traits. Tesfaye et al. (2020) observed that yellow rust resistance, frost resistance, grain yield, and white grain color are among the traits that Ethiopian wheat farmers (no gender and social segregation) preferred the most. By doing a sex-disaggregated analysis, Gartaula et al. (2024) observed that women prefer traits that give good taste and have better cooking quality, while men preferred high biomass and resistance to diseases, among Ethiopian wheat growers. In contrast to these straightforward trait preferences, Teeken et al. (2021) made a different observation in their cassava study in Nigeria and reported that trait preferences are complex and go beyond men's traits versus women's traits. They observed significant differences in prioritization between women and men of different cassava trait preferences. They further illustrated regional differences as an important factor where the cultural use of cassava is different, and poverty and food security of farm households are among other crucial factors. Using the case of rice, Bacud et al. (2024) demonstrate how diversity of marginalization and intersectionality matters more than men vs. women's traits. They observed that the intersection between gender and other socioeconomic categories like sex of the household head, lower-and upper-income groups provides varied response to women's and men's trait preferences.

As such, the contemporary literature on wheat trait preferences and crop improvement does not pay enough attention to the heterogeneity of farmers caused by gender, social, economic, and other household characteristics, as most of these studies consider farmers a homogeneous category. This paper will shed light on how trait preferences interact with the female and male farmers' personal, household, agronomic, and ecological characteristics. This characterization of the influencing factors in the wheat trait preferences among women and men farmers will help analyze our results (partially) using the socio-ecological systems model. This model helps us to understand the social prescriptions and expectations of the roles of women and men farmers, and gender-based values, beliefs, and practices in agriculture-based livelihood systems (Oteros-Rozas et al., 2019; UNFPA, 2019). Using this model, we illustrate how gendered wheat preferences are influenced by individual/personal, household, agronomic (technical), and ecological contexts, and we will further discuss the relevance of policy and the wider contribution to the literature. To perform this highly interdisciplinary socio-ecological analysis, we will seek answers to the research questions: How do male and female farmers differentiate the wheat varietal trait preferences? How do trait preferences interact with gender, socioeconomic, household, agronomic, and ecological characteristics of farmers and farm households? And, what lessons could be learnt for crop improvement through gender-responsive trait prioritization and associated breeding product profiles?

2 Methodology

2.1 Research design, data collection and analysis

This study is designed to analyze socially disaggregated information based on gender and other social identities such as age, education, caste, and ethnicity. We understand that the decision-making in agricultural innovations happens inside the household, and thus considering head of the household as the gender parameter could be misleading by not capturing the intra-household gender dynamics (Shibata et al., 2020). Therefore, we collected data from female and male respondents from the sample households. This yielded a total of 1,003 households, including men (1,003) and women (1,001) primary decision makers (ideally the spouses, and in this paper referred to as primary man and primary woman) from the same households for allowing their own perspectives rather than the household as a single unit. In one household, respondents who declined to be interviewed separately (independent of each other or without influencing each other's interviews) were discarded from the analysis. The sampling frame was prepared based on the village census carried out earlier by CIMMYT for another study, covering the four agroecological zones in the Bihar State of India. To have more distributed sampling across the state, we followed a stepwise stratified random sampling: first, randomly selected 10 (out of 38) districts, and four villages in each district, and finally about 48–54 women and men respondents were selected for interviews from each village.

In this paper, we included 23 traits and characteristics of wheat, identified through a rigorous review of the literature, and based on the experiences of wheat breeders working in CIMMYT. These traits were related to production, climate, cooking attributes, market demand, and other esthetic values such as color, flavor, etc. (Table 1). As trait preference was measured on a binary scale ("yes" =1 and "no" =0), we used binomial logistic regression to identify factors associated with men's and women's trait preferences. The 15 independent variables used in the regression analysis and their expected relationship with the preference for wheat traits are provided in Table 1.

The age of the respondent (AGE) is a proxy for the duration of experience of the respondent working in the agricultural sector, which may affect their decision to have preference over certain traits. We hypothesize that older people may be more inclined to yield-enhancing traits than younger people. Education, which means the

TABLE 1 Independent variables and their expected hypothesis.

Covariate	Notation	Explanation
Age	AGE	Age of the principal man and woman. Older respondents prefer certain traits that are more of economic value, whereas younger one go for climate resilient.
Education	EDU	Education of the principal men and women, in years of formal schooling. Well educated respondent prefers yield enhancing and climate resilient traits.
Marriage status	MARRY	Marital status of the respondents. Respondents who are living with spouses prefer certain traits.
Household head	HEAD	Respondent is the household head. When the respondent is household head, he/she take part in household decision-making and prefer certain type of traits. Involvement in decision-making on wheat farming increases preference for the traits.
Caste group	CASTE	Caste also determines the preference of wheat traits. Disadvantages and backward caste prefer yield enhancing traits.
Religion	RELIGION	Religion and diets are related thus may influence wheat trait preference.
Wheat cultivated area (acre)	AREA	Wheat cultivated area, measured in acre. Higher the area, more preference on the yield and market demand traits.
Cultivated at least one new wheat variety over the last 5-year period	NEWVAR	New wheat variety introduction in recent years demand yield enhancing wheat traits.
Summative index for the 26 wheat production constraints	WPCONS	Sum of 26 self-reported wheat production constraints, measured as presence (1) and absence (0). Higher number of wheat farming constraints positively relate to trait preference. Higher the constraints, higher will be the preference.
Summative index for the 12 household amenities	ASSET	Sum of the 12 household amenities, measured by presence (1) and absence (0). Higher number indicates well-off family and may demand certain traits.
Ate less food than thought over 12 months	LESSFOOD	Insufficient food at household means more demand of wheat traits.
Water logging problem in any area of the land	WRLOG	Self-reported water logging problem in the agricultural plot, measured as 1 when yes, and 0 otherwise. Water logging problem may determine certain wheat traits, for example short height, logging resistance and so on.
Soil salinity problem in any area of the land	SOILSAL	Self-reported soil salinity problem of the agricultural plot, measured as 1 when yes, and 0 otherwise. Soil salinity may affect preference of wheat traits.
Flood hazard category	HAZARD	Flood hazard categories of the district. Intensity of flood hazard may determine the preference of certain traits, for example logging resistance in the case of high hazard areas.
Agro-climatic zone	AGROZONE	Agroecological zonation of the district.

number of years of schooling (EDU), may enhance preferences on wheat traits, so we assume a positive relationship of EDU with all traits. Other independent variables included in the regression are the marital status of the respondent (MARRY), household headship, whether the respondent is the head of the household (HEAD), caste group, whether the respondent self-identifies as scheduled caste, other backward castes, or a general caste group member (CASTE), whether the respondent identifies as a Hindu or Muslim (RELIGION), wheat acreage (AREA), whether the respondent has cultivated at least one new wheat variety in the past 5 years (NEWVAR), number of production constraints selected by the respondents (WPCONS), household assets (ASSET), whether the respondent ate less food over the period of last 12 months (LESSFOOD), whether the respondent reports waterlogging (WRLOG) or soil salinity (SOILSAL) problems in any of their cultivated plots. To give an ecological perspective in the analysis, we included two variables: flood hazard category (HAZARD) and agroclimatic zone (AGROZONE) of the districts. Flood hazard categories (high to very high, moderate, and low to very low) were derived from a government report (NRSC-ISRO, 2016) and four agroclimatic zones (zones I, II, IIIa, and IIIb) from a website (Thakur, 2020).

The 15 independent variables were then classified into four groups: personal, household, agronomic, and ecological characteristics. Variables in personal characteristics include age, education, marital status, and household headship, while household characteristics include caste group, religion, introduction of new wheat varieties, household assets and perceived food security. Likewise, the agronomic characteristics include the area under wheat cultivation, the number of wheat production constraints reported, and the waterlogging and soil salinity conditions reported, and the ecological characteristics are the hazard categories and agroclimatic zones.

2.2 Characteristics of research location

The study draws on data collected from 10 districts of Bihar, India, covering all four agroecological zones of the state: Zone I – North-west alluvial plain, Zone II—North-east alluvial plain, Zone IIIa—South-East alluvial plain and Zone IIIb—South-West alluvial plain (Figure 1). Zones I and II are located north of the river Ganges, while the other two zones are located south, placing the whole state on the river

FIGURE 1
Map of Bihar showing the study districts and sample villages (shown as triangles) by agro-climatic zones. Source: Village coordinates extracted from Google Maps by authors.

floodplain. Located in the eastern Indo-Gangetic Plains, Bihar is the second most populated (over 104 million) state in India after Uttar Pradesh. It is one of the poorest states, with about 52% of the population living below the poverty line. Caste wise, the Extremely Backward Classes (EBC) dominate with 36% population, followed by OBC (27%), SC (20%), ST (2%), and others. Religion wise, it is predominantly occupied by Hindu (83%) and Muslim (17%) followers with negligible presence of others (NITI Aayog, 2021); approximately 90% of the population lives in rural areas and more than 80% practice agriculture as a source of income in an average landholding size of about 0.4 ha, much less than the national average of 1.15 ha (Keil et al., 2019). Bihar's agriculture is characterized by smallholding, rice-wheat dominated cropping system, with many non-and off-farm economic activities built into the livelihood system where women and men household members put their efforts to strive for a living. About 74% of the state workforce is employed in agriculture and related sectors, which contributes about 20% to the state economy (Thakur, 2020). Another important consideration in Bihar is the widespread inequalities caused by age, gender, class, caste, and ethnicity (Badstue et al., 2022), which implies the agency of women and men farmers in selecting suitable crop varieties according to their livelihood requirements.

3 Results

The women and men farmers mentioned that they cultivate different wheat varieties on their farmlands. They have used both private (Shriram 303, Kedar Ankur, etc.) and public sector (UP 262, HD 2967, etc.) varieties, with the dominance of Shriram 303, UP 262, and HD 2967 as the top three most preferred varieties. They have been cultivating very old varieties (released in 1978) to recently released varieties like HD 3226 (released in 2019). These varieties have different attributes and characteristics, abiotic, biotic, and esthetic (Figure 2). Shriram 303 has been the most popular variety, covering more than 40% of the total area where farmers grow wheat. Farmers could not identify some varieties they have cultivated on their farmlands.

3.1 Does gender matter in wheat trait preferences?

The results indicate that gender does matter in trait preferences. Some traits are preferred by both men and women, while in some cases there are marked differences. As presented in Figure 3, men prefer the wheat varieties that are well adapted to extreme climatic conditions, and had superior chapati taste, while women prefer wheat varieties with better quality for chapati making (dough extensibility) and high market values; higher grain yield is preferred by both women and men. Few traits are preferred by more than 50% of the respondents and, except for the 'red color' trait, all other preferences are statistically significant at the 5% level on the Chi-square test.

We have aligned these differences in trait preferences between women and men farmers (Figure 4), showing that traits related to climate resilience, grain yield, chapati taste, grain size, tillering, market demand, straw yield, grain processing quality, threshability, and disease resistance are among the top 10 traits preferred by men, while chapati taste, grain yield, market demand, grain size, tillering, grain processing quality, chapati making quality, disease resistance, lodging tolerance, and climate-smart are among the top 10 traits

FIGURE 2
Wheat varieties used by the respondent farmers with released year and main attributes.

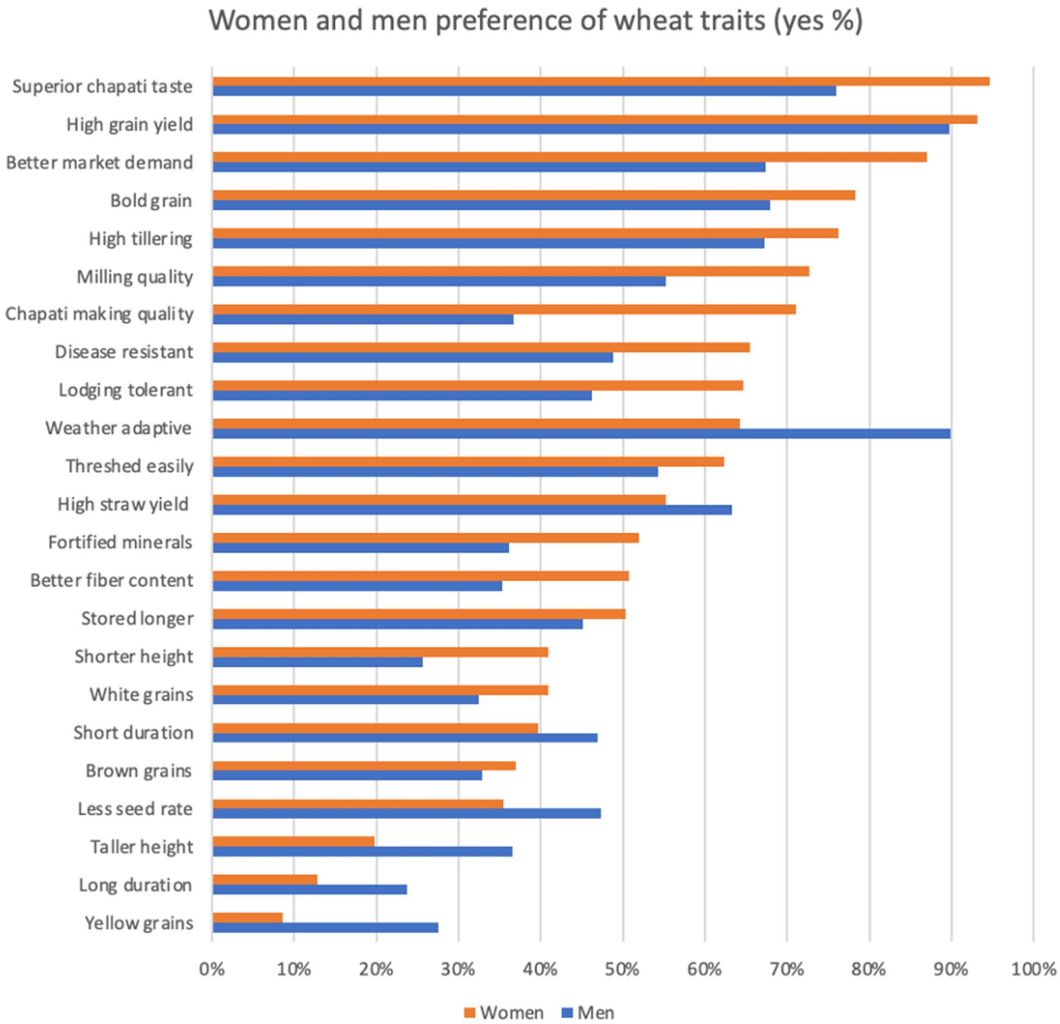

FIGURE 3
Wheat trait preferences for women and men (Yes %).

preferred by women, both in the order of high to low preference in ranking. Looking closely, threshability and straw yield are among the top 10 men traits that are not part of the women's list, whereas chapati making quality in grain and lodging tolerance do not make it to the men's top 10 list. The other eight traits are the same for both women and men, with some differences in priority sequence. These observations indicate that the traits of economic importance and productivity are among the most preferred wheat traits for both women and men, but women go a step further to include the taste and esthetic value of the grain in the list.

3.2 What factors influence wheat trait preferences?

The summary statistics of the independent variables used in the logistic regression are presented in Table 2. Regression analysis includes 1,987 observations (female 1,000 and male 987 respondents). The average age of male respondents is higher (47 years) than that of females' (44 years). Slightly more than one-third of women can read and write. The male literacy rate (61%) is almost double that of women (33%), with average years of

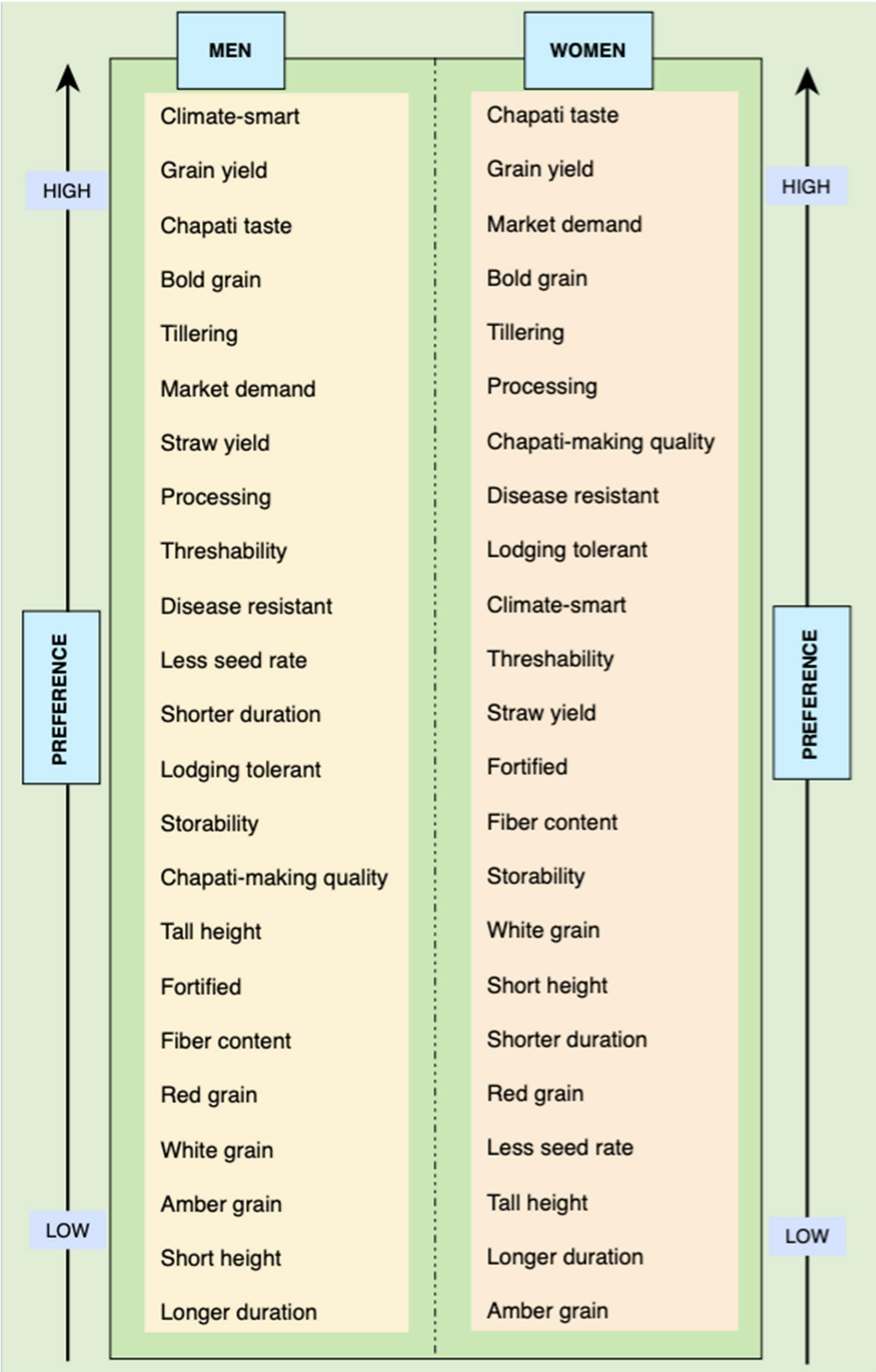

FIGURE 4
Order of wheat trait preferences, difference between women and men.

schooling for women (2.8) half that of men (5.6). Almost 88% of men reported themselves as the head of household, while that proportion was 9.4% for women. About 63% of the survey households belong to other backward castes (OBC), while about 22% are scheduled castes (SC), and 15% general caste (GC). Similarly, the overwhelming majority (92%) follow Hinduism and the remaining 8% follows Islam among the survey households. The average area reported under wheat cultivation is just above one acre.

More than half of the male respondents reported that they introduced at least one new wheat variety in the last 5 years, while that is outnumbered above two-thirds in the case of the female respondents. Of the 26 challenges listed related to wheat farming, the average number of challenges women reported is slightly higher (13.4)

TABLE 2 Summary of the independent variables used in the logistic regressions.

Variables	Notation	Option	Value	Principal men		Principal women	
				Mean	%	Mean	%
Age	AGE			47.4		43.6	
Education	EDU			5.6		2.8	
Marriage status	MARRY	Otherwise	0		8.7%		8.7%
		Married	1		91.3%		91.3%
Household head	HEAD	No	0		12.4%		90.6%
		Yes	1		87.6%		9.4%
Caste group	CASTE	Scheduled caste	1		21.8%		21.8%
		Other backward caste	2		62.9%		62.9%
		General caste	3		15.3%		15.3%
Religion	RELIGION	Muslim	0		7.7%		7.7%
		Hindu	1		92.3%		92.3%
Wheat cultivated area (acre)	AREA			1.29		1.14	
Cultivated at least one new wheat variety over the last 5-year period	NEWVAR	No	0		45.6%		32.5%
		Yes	1		54.4%		67.5%
Summative index for the 26 wheat production constraints	WPCONS			11.5		13.4	
Summative index for the 12 household amenities	ASSET			6.6		6.6	
Ate less food than thought over 12 months	LESSFOOD	No	0		66.9%		48.2%
		Yes	1		33.1%		51.8%
Waterlogging problem in any area of the land	WRLOG	No	0		83.1%		83.0%
		Yes	1		16.9%		17.0%
Soil salinity problem in any area of the land	SOILSAL	No	0		88.3%		88.2%
		Yes	1		11.7%		11.8%
Flood hazard category	HAZARD	High to very High	1		20.1%		19.8%
		Moderate	2		40.4%		40.5%
		Low to very Low	3		39.5%		39.7%
Agro-climatic zone	AGROZONE	Zone I	1		40.2%		39.9%
		Zone II	2		20.4%		20.3%
		Zone III(a)	3		19.8%		19.9%
		Zone III(b)	4		19.7%		19.9%

than that of men (11.5), indicating that women are exposed to more challenges than men. The average ownership of household assets is slightly higher than 50% of the 12 items asked during the survey. Due to many circumstances, especially due to less food production at the household level, one-third of men and slightly more than half of women stated lower food consumption over the past 12 months. In summary, male respondents were found to be relatively older, more educated, less exposed to wheat production constraints, and would consume more food. On the other hand, women respondents are better informed on the constraints of wheat farming and are more involved in the labor market in the village, even if they are a little behind in other demographic indicators, especially age and education, which could be considered having better knowledge, indicating that their experience matters. At the ecological level, the respondents are distributed in different categories of hazard and agroclimatic zones.

3.3 How do these factors influence the gendered trait preferences in wheat?

As mentioned earlier, the regression results are organized into four categories of independent variables based on their personal characteristics (age, education, marital status and household headship), household characteristics (caste, religion, introduction of new wheat varieties, household assets and access to food), agronomic (wheat cultivation area, wheat production constraints, waterlogging condition and soil salinity), and ecological (hazard categories and agro-climatic zones) characteristics. Details of the regression results are presented in Appendix Table 1; in this section, we illustrate the coefficients of binomial logistics regression in each of the categories, with a focus on statistically significant *p*-values for some key traits.

3.3.1 Effects of personal characteristics

The results show that personal attributes influence trait preference in different ways, some have a positive association, while others have negative (Figure 5). It is evident that as women's age increase, their preference for disease resistance and red[1] grain color traits decrease. In the case of men, the preference for threshability and white-colored grain decreases with age. Men's education negatively influences the preference for the storage trait and positively for the red grain trait, while women's education enhances the preferences for wheat varieties that are fortified with minerals for better nutrition. On many wheat traits, the marital status of women and men had no significant influence; however, married men tend to prefer less on those varieties that have high demands in the market, and married women tend to prefer less lodging-resistant varieties. For household management role, women who are also household managers are less likely to prefer resistance to lodging, shorter duration, and zinc-fortified wheat varieties. For men, the household management would increase their preference for the zinc-fortified trait (by 1.8 times).

3.3.2 Effects of household characteristics

Whether the respondent had recently introduced new wheat varieties (in the last 5 years) has an implication in understanding their traits' preferences. For example, men who had introduced at least one new wheat variety in the last 5 years are less likely to prefer wheat traits such as high grain yield (0.5 times), longer duration (0.6 times), amber[2] grain color (0.7 times); however, they are more likely to prefer high straw yield (1.8 times), good tillering varieties (1.9 times), superior chapati taste (1.9 times), and better market demand (1.7 times). In the case of women, those who had introduced at least one new wheat variety over the last 5 years are likely to prefer the grain yield trait (4.1 times), straw yield trait (1.4 times), lodging tolerance trait (1.7 times), disease resistance trait (1.6 times), the zinc-fortified wheat varieties (1.4 times), chapati making quality (1.8 times), and better fiber content (1.7 times); however, their preferences were less in bold grains (0.6 times), longer duration (0.6 times), lower seed rate (0.7 times), and storability traits (0.5 times) traits.

With respect to the ownership of household assets, the effects on trait preferences for both men and women are limited. The number of household assets does not have a significant influence on women's trait preferences; however, men tend to prefer more traits of threshability and prefer less resistant to lodging, and traits of amber and red grain color when the number of household assets increase. Likewise, religion seems to have implications for gendered trait preferences; being a woman following the Hindu religion, the preference for (i) high grain yield increases by 2.4 times, (ii) bold grain increases by 1.8 times, but the preference for (iii) high straw yield trait decreases by 0.5 times. Likewise, being a Hindu man, the preference for the good tiller attribute decreases by 0.5 times (Figure 6).

The respondent who ate less food than they thought over the last 12 months, a proxy for household food insufficiency, seems to influence the preference over several traits significantly, but the relationship is not straightforward, which varies by trait. The household food insufficiency tends to improve the preference of women for traits such as high grain yield (4.4 times), taller height (1.5 times), longer duration (2.1 times), threshability (5 times), storability (2.4 times), high quality of grinding (5.7 times), and better market demand (3.7 times). In a similar situation, men tend to prefer high straw production (1.5 times), good tillering (1.6 times), and superior chapati (1.8 times).

Household food insufficiency significantly decreases the preferences of men and women for many traits of wheat. For example, in food-insufficient households, a reduction in men's preference for lodging resistance (0.4 times), disease resistance (0.3 times), lower seed rate (0.7 times), threshability (0.5 times), amber grain color (0.3 times), red grain color (0.4 times), zinc fortified (0.5 times), chapati making quality (0.4 times), and better market demand (0.5 times) is seen. Likewise, women in food-insufficient households prefer less in traits such as tillering (0.4 times), better climate adaptation (0.1 times), less seed rate (0.7 times), red grain color (0.8 times), zinc fortified (0.6 times), chapati making quality (0.5 times), and better fiber content (0.7 times).

The caste group also influences the gender preference for some of the traits. For example, women from SC and OBC had a higher preference for grain yield potential (3.8 and 4.4 times, respectively, compared to those from GC), and climate adaptive traits (2.0 and 1.7 times, respectively, compared to GC); however, their preference for the grinding trait was reduced by 0.5 times, compared to GC. This could be because GC people are relatively better off, meaning they have alternative livelihood options, which may entail that yield potential specifically from wheat may not be of their interest compared to that of people from the OBC and SC groups.

3.3.3 Effects of agronomic characteristics

Figure 7 presents the agronomic characteristics that influence wheat traits by gender. The wheat crop area at the household level had no significant influence (at the 5% confidence interval) on the trait preferences of men and women. The summative value of wheat production constraints seems to positively influence the preference of both men and women for many wheat traits, indicating that greater exposure to production constraints led to the preference of all traits, probably believing that the perceived production challenges they face are solved.

The preferences of women and men for many traits of wheat differ when their farmland had problems such as waterlogging and soil salinity. The influence of such conditions on their preferences is not straightforward and varies by traits as highlighted in Figure 7 and Appendix Table 1. In such conditions, women seem to prefer more nutritional traits than agronomic traits.

3.3.4 Effects of ecological characteristics

Finally, the association between gendered trait preferences with flood hazards and agroecological zonation is provided in Figure 8. In the case of flood hazards, we are interested in the adaptive weather trait. We noted that increasing flood hazard intensity tends men to prefer weather adaptive traits (5 to 6 times), but not necessarily the situation prompts women to do so. The preferences for gender traits vary by agroecology. Compared to Zone I (for the four agroecological zones in Bihar), the preference of men for the adaptive weather trait is 5.6 times more in Zone II and 4.8 times more in Zone IIIb, while for Zone IIIa, this relationship is negative, meaning that men are less likely to prefer the adaptive weather in Zone IIIa, compared to those

1 Some farmers identify this grain color as red.

2 Some farmers identify this grain color as yellow.

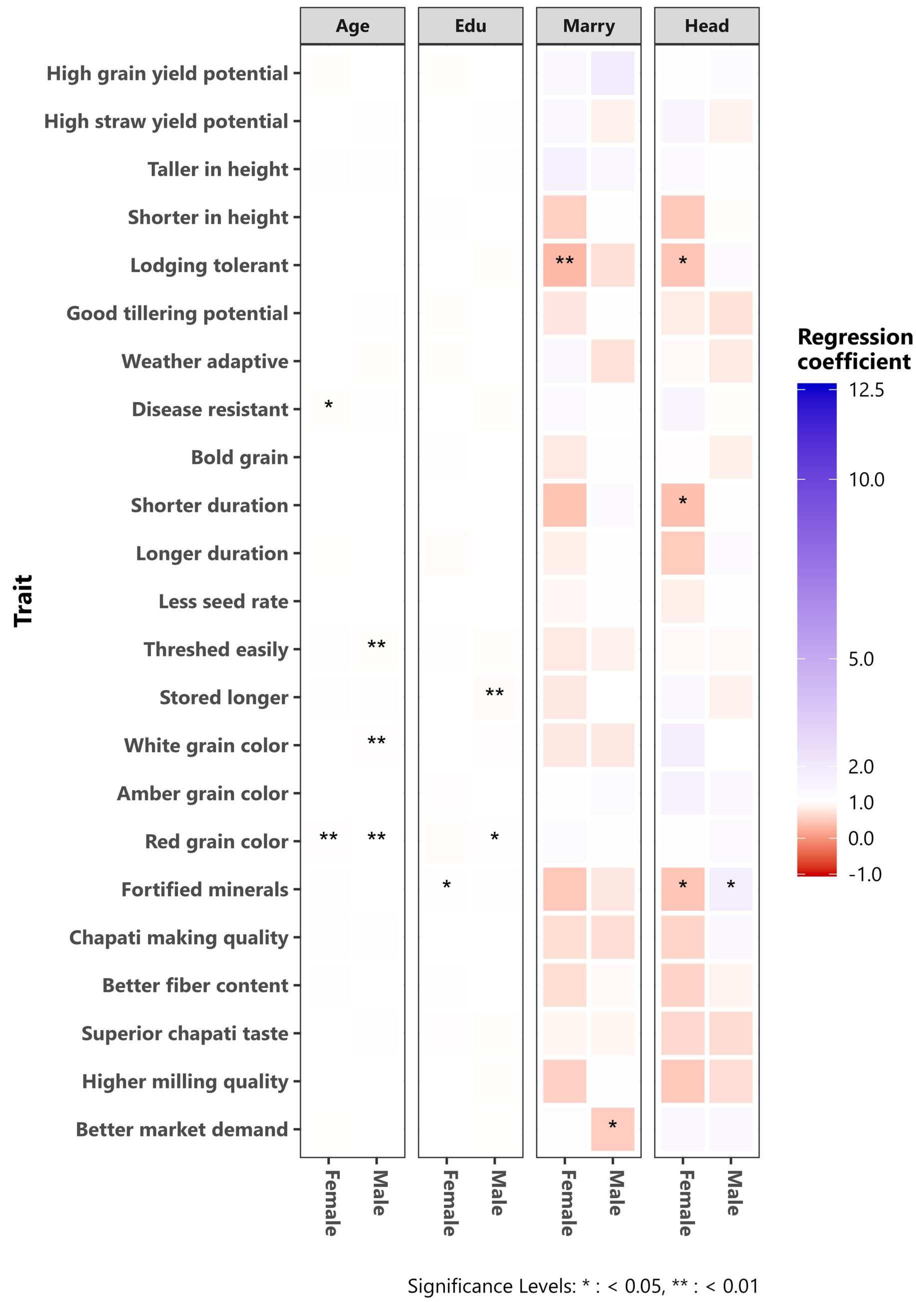

FIGURE 5
Personal attributes influencing wheat trait preferences.

who live in Zone I. The demands of bold grain trait in those zones are also greater, compared to Zone I. Women living in all agroecological zones have a similar preference for weather adaptive traits, as none of them showed statistically significant results.

4 Discussion

Our study seeks to broaden the notion of women traits versus men traits and dived deep into the matter by looking at what other social, household, agronomic and ecological factors influence if the women and men farmers had a chance to choose traits. We observed that gender continues to matter in trait preferences, but it goes beyond the gender of farmers and is subject to the factors that help build farmers' livelihood in broader social, economic, cultural, and ecological settings, which is in confirmation with other recently conducted studies (Teeken et al., 2021). The paper reports that several factors influence trait preferences, and the influence of these factors varies for women and men farmers. The factors are interrelated and organized in a nested fashion of individual, household, agronomic, and ecological (landscape) aspects of the socio-ecological model. Preferences for specific traits (we examined) increase when a person is exposed to more challenges in wheat production. Flood hazard intensity in the research area may have led both women and men to choose a weather-adaptive trait.

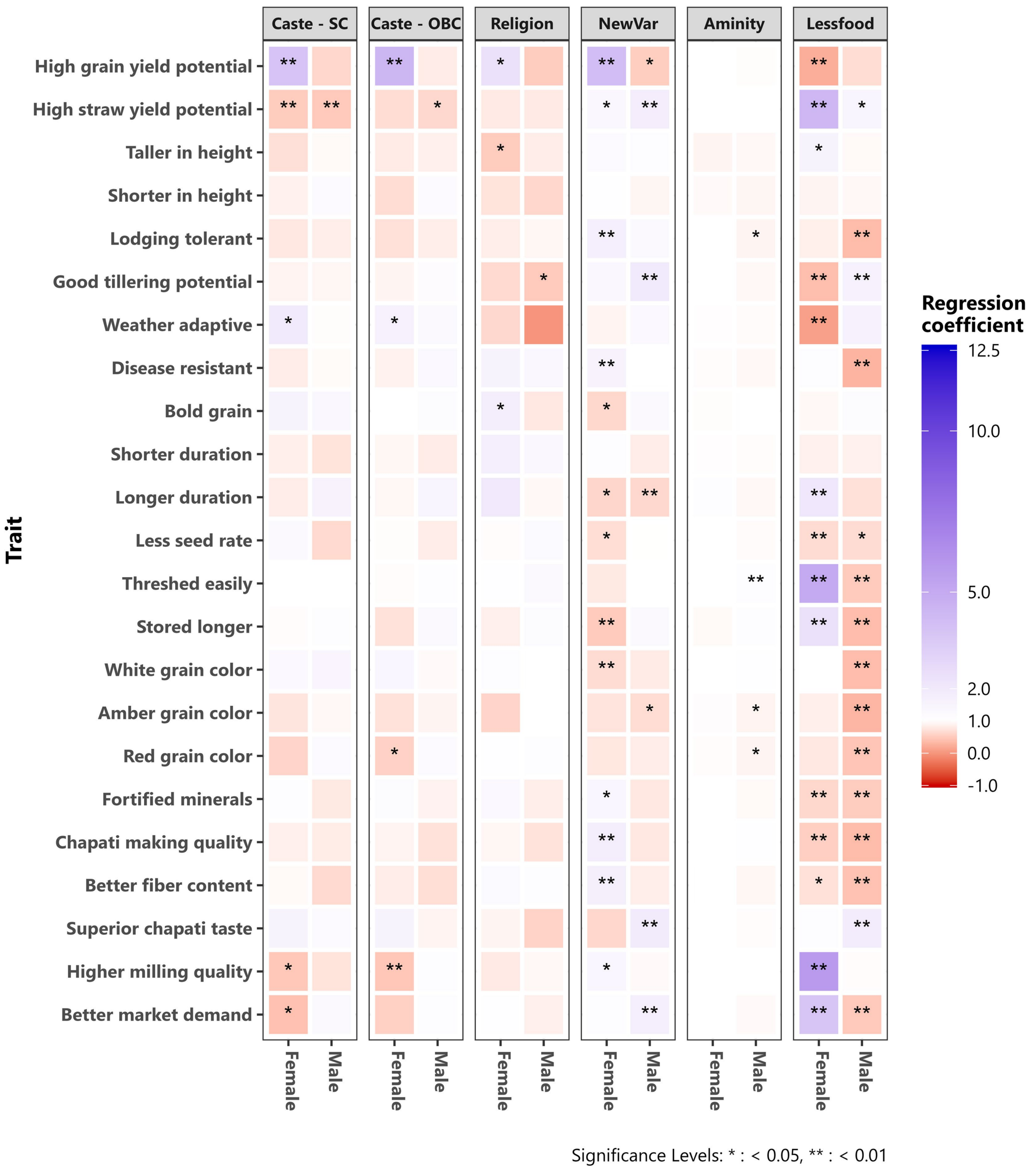

FIGURE 6
Household characteristics influencing wheat trait preferences.

The findings are consistent with previous studies conducted on this matter. The literature shows that trait preferences differ by labor division, contrasting the roles and responsibilities women and men farmers perform for various crop production or post-harvest activities (Weltzien et al., 2019). The differences in trait preferences between women and men farmers may also be because of their involvement in alternate (or complementary) livelihood activities. It is evident in our study that men prefer higher straw yield and good tillering traits, which would be because men tend to keep more larger livestock such as cattle and buffalo than women, requiring more straw for feeding (Quisumbing et al., 2015; Galiè et al., 2019; Bonis-Profumo et al., 2022).

The individual attributes of age, education, and marital status, which largely contribute to someone's agency and capability to influence on decision-making (Sen, 1985; Gangas, 2016); it is important how these factors play a role to prefer specific traits than others. In our study, it was observed that aged women are less likely to prefer red trait. Red trait contributes to high protein content, which gives chapati with greater chewiness and higher tearing resistance (Panghal et al., 2019). Thus, women who are aware of these grain qualities may not like red wheat trait. As evident in Figure 2, Shri Ram 303, UP262, and HD2967 are the three mostly grown varieties in the study area. All these varieties have desirable protein content (Siddiqi et al., 2021), which might be the source of this knowledge for trait preference. Likewise, educated women are more likely to prefer mineral-fortified varieties, while that is not the case for men and are more likely to prefer red grain trait. Data further shows that marital status has no significance on specific wheat trait preferences.

These diverse influences of men and women's personal attributes (associated with their agency capability) imply to what

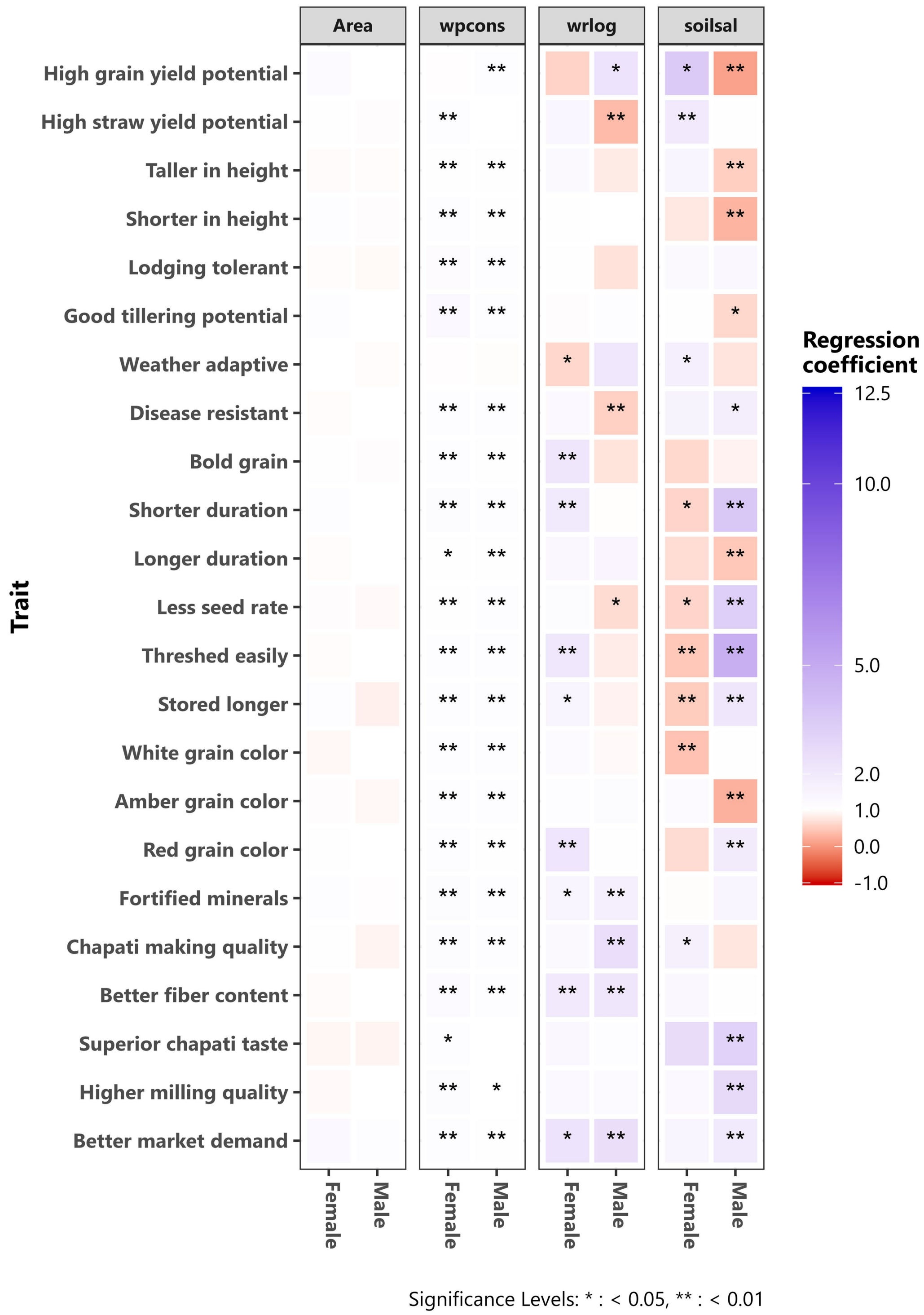

FIGURE 7
Agronomic characteristics influencing wheat trait preferences.

they would provide information if consulted during demand collection. As such, the agency and capability are inherent qualities of individuals to have different trait preferences. However, equally important is how they are taken into consideration as feedback to feed into target product profile development, the process that is governed by the wider social, cultural, and institutional environment the individuals live in. It further implies that they are larger issues of how gender and social differences are included in the agricultural innovation process.

The results show some implications of religion for gendered trait preferences. Even though religious beliefs may not directly impact the trait preferences, they can certainly shape food and dietary choices through cultural norms and individual convictions (Minton et al., 2019; Mekoth and Thomson, 2020). These inclinations may vary depending on

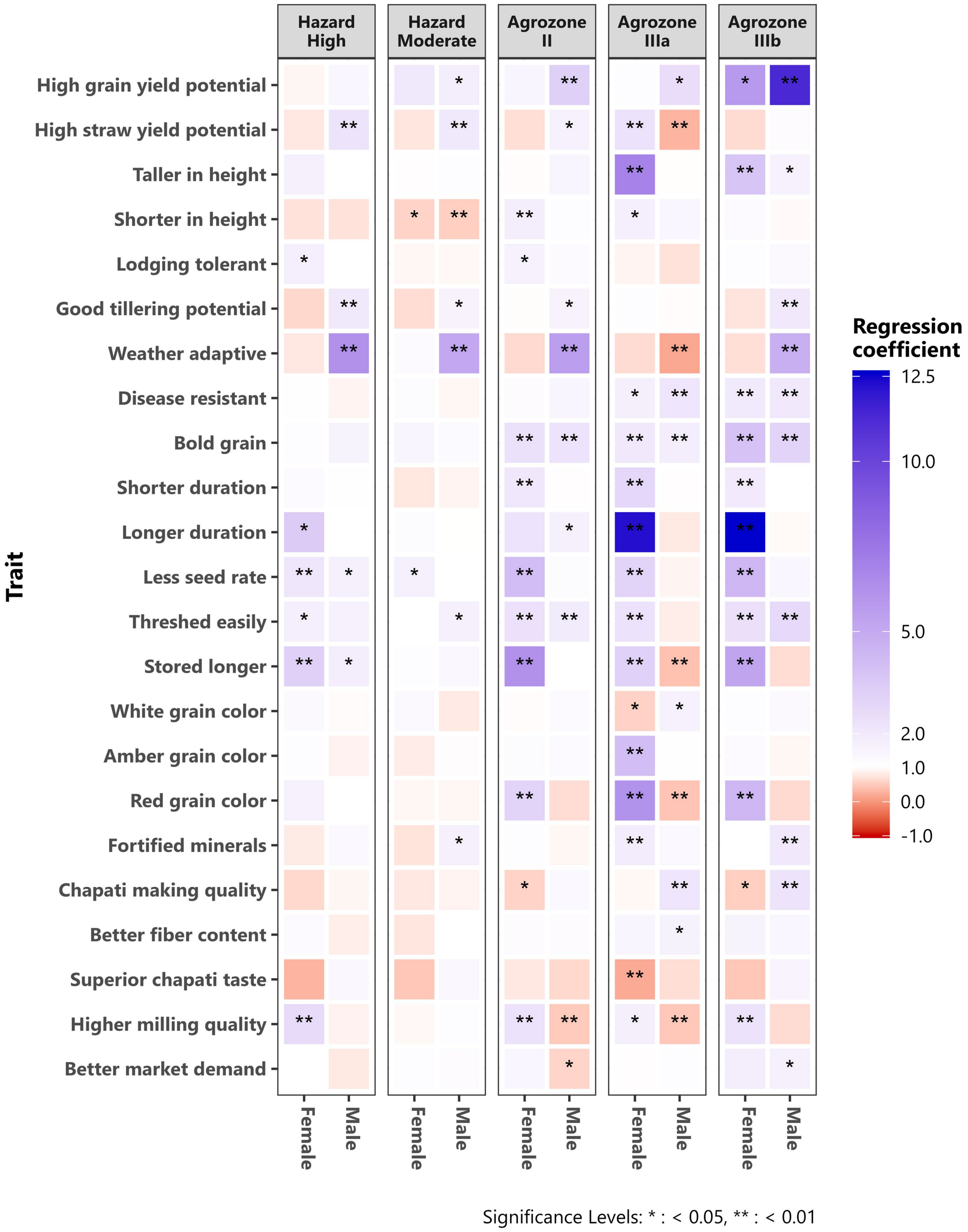

FIGURE 8
Ecological characteristics influencing wheat trait preferences.

the extent of religious involvement. In our investigation, we found that Hindu women exhibited a stronger inclination toward traits such as high grain and straw yield, as well as bold grain. This tendency could be linked to their engagement in religious practices, including fasting, and the common use of wheat flour in the preparation of *'Prasad'* (food offered to deities). For instance, Hindu women might opt for wheat chapati over rice during *'Ekadashi'* fasting rituals. Similarly, they might be tasked with preparing *'Prasad'* made from wheat flour during festivals. Nevertheless, further research is recommended to comprehensively understand and validate these findings.

This study also shows that the gendered trait difference also depends on their behavior of allowing new varieties on their farm. Those who introduced new varieties in the last 5 years preferred high yielding (both women and men), better cooking quality (for women), and better taste (for men) traits. Looking at the mostly grown varieties in the areas, HD 3226 (released in 2019) is known to have high yielding, high protein, superior grain quality, disease resistant, cooking quality, and taste traits (Yadav et al., 2019). Krishna and Veettil (2022) report that women opt for grain quality attributes (better cooking quality, supporting our results). The same study suggests that women tend to explore newer varieties with different traits due to their close association with their concerns about food insecurity. This also relates to another finding of this study how farmers experiencing production constraints tend to opt for newer varieties, as a way of trying new things as a coping strategy.

Morris and Bellon (2004) observed that farmers' varietal preferences vary according to seasons, locations, and individuals. This variation in the perception of varietal traits among individual farmers determines the rate of adoption of improved varieties (Kalinda et al., 2014). Tikadar and Kamble (2021) report that farmers prefer high-yielding improved varieties under low input conditions. They also point out farmers' adaptations toward practicing conservation tillage and drought-resistant varieties to address climate risks. Singh et al. (2013) and Singh et al. (2014) observe that farmers prefer improved high-yielding varieties, but due to the higher cost of production caused by expensive improved seeds, farmers are discouraged to opt for such varieties, which is also in line with Kumar et al. (2018), who report the use of substandard seeds due to the high cost of improved varieties in eastern India.

One of the main policy implications and a significant contribution (to science) of this analysis is the dynamic interface between women's traits preferences, involvement in agriculture in general, but in wheat production in particular, and their limited access to agricultural extension and training services. It is evident that women tend to face a higher number of constraints and challenges in wheat production and thus have preferences over the traits required to cope with these challenges. This is coupled with the higher number of women involved in wheat production, compared to men who are involved in cash crop production or other non-agricultural jobs like wage labor within or outside of their village. For instance, women's labor force participation in agriculture is 65% in India, which is much more than the participation of men in the same sector (50%; Pattnaik et al., 2018). Due to the limited opportunities for women to leave agriculture, their participation in agriculture will not change, compared to that of for men. Therefore, increased participation of women in training and extension services is important to continually improve their management capacity and perform agricultural job better. However, in the situation of already limited human resources employed in India's agricultural extension system, extension workers are very few (Nandi and Nedumaran, 2019). It is difficult for male extension workers to reach out to female farmers due to the cultural taboo for women not to contact an 'external' man. Moreover, it is usually men who receive training and extension services, especially those from the government, while it is women who are involved in agriculture more than men, which further marginalizes women and have more labor burden. A solution policymakers can consider is hiring more female extension workers or targeting more women farmers (in any way) in relevant training and extension activities, getting them in the (agricultural) community meetings where strategic decisions such as seed demand Research Topic and discussion on trait prioritization occur (Suri and Gartaula, 2023).

Another robust indication this analysis suggests is the influence of agroecological zones for wheat trait preferences differing for women and men farmers. In a study carried out in Nigeria in the case of Cassava, Teeken et al. (2018) have similar findings, significant regional differences in trait preferences. This seems obvious but has a great implication for crop improvement and breeding programs in considering regional parameters for the development of the target product profiles and market segmentation.

Putting together, the diversity of trait preferences that are influenced by the personal, household, agronomic and ecological characteristics of the men's and women's livelihood system. These findings are very critical for developing target product profiles, which are subject to specific market segments that would also include other parameters like climate, farming system, market development, agronomic practices, technologies in use, and so on. These human dimensions of traits preferred by women and men farmers could be considered to select packages of traits to develop target breeding product profiles for specific market segments. A recent report produced by the CGIAR System Organization highlights that the existing breeding program assessment tool does not have a strong mechanism that embraces the systematic use of product profiles, continuously updated market intelligence, and agile stakeholder consultations, to ensure that new varieties would meet the requirements and preferences of women and men farmers, consumers, traders, processors, and others along the value chain (CGIAR System Board, 2018). Therefore, the results from this analysis will contribute to narrow down the gap identified in the above-mentioned report. As wider implication, this study provides an important lesson for the research organizations like CGIAR and other national system who have crop breeding mandates.

5 Conclusion

Our study has shown how personal, household, agronomic, and ecological factors influence the preferences of women and men farmers differently for wheat traits. It is revealed that gender plays an important role in determining the preferences of wheat traits. Men prefer wheat varieties that are well suited for extreme climate conditions, followed by higher grain yields and superior chapati taste, while women prefer wheat varieties with excellent chapati making quality followed by higher grain yield and higher market prices. Other socioeconomic, agronomic, cultural and geolocation factors also have a significant effect on traits preferences.

The variations in preference for traits between men and women within the same household can inform the selection of traits for developing target product profiles tailored to specific market segments. For instance, the individual agency and capabilities to make decisions for the male and female farmers significantly influence their preferred traits, underscoring the importance of considering their perspectives in target product profile development and market segmentation. This broader perspective extends to how gender and social disparities are integrated into the agricultural innovation process.

Moreover, these findings address a gap in the current assessment tool CGIAR uses for breeding programs, which lacks a robust mechanism for systematically incorporating product profiles and market segmentation. This gap highlights the need to ensure that new varieties align with the requirements and preferences of both male and female farmers.

While this study solely relies on structured surveys, it could have been enhanced by complementing quantitative data with qualitative insights gathered through a mixed research design. Integrating both types of data would provide a more comprehensive understanding of trait preferences and decision-making processes among farmers.

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 humans were approved by Institutional Research Ethics Committee (IREC), CIMMYT. 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

HG: Conceptualization, Project administration, Supervision, Writing – original draft, Writing – review & editing. KA: Data curation, Formal analysis, Methodology, Writing – review & editing. NK: Data curation, Visualization, Writing – review & editing. SM: Validation, Writing – review & editing. RS: Funding acquisition, Validation, 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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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2024.1284817/full#supplementary-material

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A gendered assessment of crop traits to improve breeding product design and uptake: the case of potato in Kenya

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The study assesses the gender implications of a target product profile for table potato in Kenya. Breeding programs mostly emphasize farmers' trait requirements and rarely pay attention to other value chain actors' preferences. This partially contributes to the low uptake of improved varieties. Therefore, efforts are required to assess the gender implications of crop product profile proposals during development, testing, and dissemination. In this paper, we assess the gender implications of traits targeted by a potato breeding program in Kenya using the G+ tools. The study applies the G+ product profile tool to examine the instances the selected traits may exacerbate gender disparity along four domains: unpaid labor, access to employment opportunities, requiring extra inputs and control over benefits. We use mixed methods including a review by social scientists, key informant interviews and a multistakeholder workshop to gather insights from female and male farmers, breeders, and other stakeholders. Findings show that pest, disease resistance, and shelf-life traits benefit women and men in the target customer segments. On the other hand, earliness, dry matter, and yield could increase drudgery for women. The traits increase demand for women's unpaid labor during harvesting, sorting and food preparation time while also displacing women from profitable nodes. We recommend that gender-responsive strategies accompany the release of the target variety to mitigate inequities and enhance adoption.

KEYWORDS

gender-responsive, breeding, potato, target product profile, G+ tools, traits preferences, Kenya

1 Introduction

A senior breeder recently said at a multistakeholder meeting convened to map trait preferences of different breeding customers: "We breed for all people, not women." Many breeders share this sentiment. That is, there is little recognition that breeding customers extend beyond the farm and are a heterogeneous group of actors along the value chain actors with different interests. The disconnect between breeders' and customers' preferences arises from a lack of interest in each other's perspectives (Haverkort et al., 2022). Participatory Plant

Breeding (PPB) and Participatory Variety Selection (PVS) were introduced to address the divide and dominance of breeders' priorities in designing new varietal traits and accelerate the adoption of customer preferred traits. Nonetheless, despite considerable gains in breeding programs, the input of men and women across crop value chains in the traits they would like to see in improved varieties is uneven. There has been slow progress in the incorporation of gender preferences in breeding processes, even with the recognition that this could help increase adoption. The failure to consider the varietal and trait preferences of heterogeneous customers is linked to the low adoption of improved varieties developed by the Consultative Group for International Agricultural Research and National Research Institutions (McEwan et al., 2021; Thiele et al., 2021). Consumption traits that are hardly considered have a significant role in impeding adoption (Walker and Alwang, 2015). While improved disease resistance motivates adoption, "entrenched consumption preferences are major constraints to adoption."

The PPB and PVS processes were to get information from all customers (consumers, traders and the industry) besides the farmers for poorly understood varietal traits (Walker, 2006). Conversely, plant breeders have used these approaches mainly to get feedback from farmers albeit late in the breeding process. The feedback has also tended to focus on the elite clones developed on-station (Almekinders et al., 2006). Failure to consider the trait preferences of the broader group of breeding customers along the entire value chain leads to the promotion of unsuitable varieties, resulting in low adoption rates among important actors (Muhinyuza et al., 2016). For example, Kisakye et al. (2020) found that in Uganda, the desired characteristics of raw potatoes differ among stakeholders in the potato industry. Producers, traders, and consumers prefer potatoes with red skin color, yellow flesh color, smooth skin, and big size tubers. On the other hand, processors favor potatoes with white/cream flesh color, medium to large size, shallow eye depth, smooth skin, and high dry matter content.

Gendered trait preference of value chain actors predisposes women to lower adoption of certain improved varieties (Mudege et al., 2021). New crop varieties might possess traits that inadvertently disadvantage women, leading to an increase in their workload or necessitating additional inputs that women have limited access to compared to men (Kramer and Galiè, 2020). Women usually prioritize culinary traits in relation to their caregiving roles, while men opt for market-preferred traits (Mudege et al., 2021). Differences in trait preference are related to the varying actors' roles in the crop value chains (Okonya et al., 2019). Banana, cassava, and potato studies show that the preference for traits varies with the sociocultural context, gendered labor, and access to markets. Rather than conforming to rigid, binary models where women and men have distinctly different preferences, there exists an overlap (McDougall et al., 2022). Female cassava processors prioritize culinary traits that are given low priority in breeding profiles (Teeken et al., 2018). Male processors tend to focus on agronomic traits with preferences depending on geography and religion. Male and female banana growers' trait preferences differ and align with gender-specific roles. Female farmers are involved in cooking and male farmers in the manufacture of beer (Marimo et al., 2020). While men and women have common preferences in traits such as drought tolerance and pest resistance, there are gender variations for attributes such as seed coat color (Jinbaani et al., 2023).

Breeding programs have to understand their clientele and take into account their varying roles, choices, and the implications of varietal traits on the different gender categories. There is a consensus on the significance of breeding programs being more gender-responsive but treading unfamiliar territory. A primary obstacle is the absence of data on gendered preferences and the incomplete knowledge/expertise of how to incorporate this information into the different phases of breeding profile building. In this paper, therefore, we apply the G+ tools (Ashby and Polar, 2021a) to interrogate, with a gender lens, a target product profile (TPP) for table potato in Kenya with the *Shangi* variety as the benchmark. The paper specifically examines the use of the G+ tools under three settings, namely: (1) review by social scientists based on their expertise with support from existing literature; (2) subjecting the G+ tools to opinions of key informants drawn from across potato value chain; and (3) administering the G+ tools to participants in a multistakeholder workshop involving breeders, agronomists, social scientists and customers representing key roles or functions in the potato value chain. The specific objectives of this paper are:

i Assess the gender implications of each trait in the table potato target product profile using the G+ tools.
ii Compare the outcome of G+ tools in assessing varieties of traits under different methods.

2 Study context

Potato is a major crop in tropical highlands of sub-Sahara Africa (SSA). With approximately 800,000 farmers in potato cultivation, potatoes have emerged as Kenya's second most important food crop, gaining popularity in 15 counties, particularly in the Rift Valley and Western regions (CIP, 2019). Due to its productivity per unit area and time, potato cultivation holds significant promise in ensuring food security (Muthoni et al., 2013). It reduces poverty by serving as a livelihood source for farmers and individuals involved in the value chain (Gikundi et al., 2023). According to the National Potato Council of Kenya, consumption projection by 2022 was 2.3 million Metric Tons, with an average consumption per person of 5 kilograms per year. A 40% increase in the number of farmers growing potatoes could lead to a 0.3% boost in Kenya's GDP (National Potato Council of Kenya, 2023). The varieties grown include Unica, Dutch Robijn, Asante, Tigoni, Desiree, Kenya Karibu, Kenya Sifa, Sherehekea and Shangi. Shangi is incredibly popular and currently commands an estimated 80% market share (National Potato Council of Kenya, 2023). Shangi's popularity can be attributed to its appropriateness for boiling, shorter cooking time, early maturation, large tubers, and high yields (Sinelle, 2018).

For decades, breeders have strived to introduce new potato varieties in SSA to improve production and productivity. While these efforts have led to the release of new varieties, only a few are utilized by farmers (Mumia et al., 2018). The study emphasizes the limited attention breeding programs paid to quality traits, which consumers, especially women, prioritize when selecting table potatoes. Further, it notes that potato breeding has focused on disease and climate change resilience, ignoring marketability and cooking quality traits which are central to end users' preferences. Insufficient attention paid to consumer-preferred traits has led to low adoption of roots, tuber and banana modern varieties but there is a paucity of ample evidence to determine whether the neglect of gender differences among users contributed to low adoption (Thiele et al., 2021). The gender dimension of low adoption of improved varieties has been explored recently, and findings indicate a paucity of research on gender-specific potato trait preferences (Mudege et al., 2021).

Gender roles determine access to knowledge, resources (including plant genetic resources), decision-making, labor allocation and control over benefits and employment, all of which have a role in varietal adoption decisions (Tufan et al., 2018). The actor's role in the value chain, individual and household characteristics, and cultural factors influenced end-users' prioritization of traits (Weltzien et al., 2019; Marimo et al., 2020). Gender-specific preferences and intrinsic cooking quality characteristics such as color, flavor, and text were critical to adopting new hybrid banana varieties (Nasirumbi Sanya et al., 2017). Understanding gendered trait preferences as an expression of underlying structural gender inequalities in assets, resources and opportunities for growing and processing a crop can help breeders assess demand for new varieties that address gender-specific objectives for food, nutrition or economic security (Polar et al., 2022). Weltzien et al. (2019) portray the adoption of new crop varieties as a coping strategy in the face of changes in agroecological and social conditions that are major transformative factors of farm and food systems. Production goals (subsistence versus commercial), understood as coping strategies, can often differ by gender and may play a significant role in the varietal preferences of women and men. Women often prioritize production for home consumption and usage traits, and men favor market traits, reflecting their unequal access to markets and commercial opportunities (Elango and Kawarazuka, 2019).

In Uganda, Mudege et al. (2021), while developing a gendered product profile for boiled potatoes, concluded that in addition to agronomic traits, breeders need to consider how gender roles and social norms condition market relationships and feed into trait preferences which influence the selection of new varieties by farmers. Household members are employed, among others, as producers, hired farm labor providers, and pesticide applicators, and they provide significant unpaid family labor. Women mostly engage in seed conservation, establishment, weeding, roguing, harvesting and packaging. These activities are not mechanized, are backbreaking, and are offered as unpaid family labor. Men are involved in initial land preparation, pesticide application, transportation and selling to urban markets (Okello et al., 2020).

In contrast to activities done by women, men-led activities are mechanized and geared towards commercialization. For example, land preparation is done using oxen ploughs. With the commercialization of potatoes, men can hire labor in joint activities like pest and disease control; women fetch the water for mixing chemicals while men operate the spray pumps (Okello et al., 2020). Further, even when it comes to participation in profitable activities such as seed production, it is estimated that 78% are men (Sebatta et al., 2014). Potato contributes 22% of the income for male farmers transitioning from subsistence farming to commercial compared to 17% for women (Mugisha et al., 2017). Men are the main price negotiators in commercial potato production (Kyomugisha et al., 2017). Commercial potato seed production is a male niche because women lack productive resources. At the household level, gender disparities exist concerning access to products and services offered by upstream (such as seed traders and extension workers) and downstream actors (such as traders/marketers, transporters, processors and consumers). For instance, women have limited access to agricultural extension services, improved seeds, fertilizer and pesticides mainly due to low mobility and purchasing power (Kisakye et al., 2020; Mudege et al., 2020; Puskur et al., 2021). This is compounded by their limited access to and control over benefits from the potato enterprise. The above findings call for gender mainstreaming across the breeding pipeline, i.e., from setting breeding objectives to varietal release and dissemination. Specifically, there is a need to assess the effects breeding for specific traits can have on men and women.

3 Materials and methods

3.1 The G+ tools

The G+ tools are a suite of three tools which assess the gender-responsiveness of target or actual breeding product profiles at the variety design stage and other stages of varietal development. The tools include (i) the G+ Customer Profile tool (Orr et al., 2021), (ii) the G+ Product Profile Query tool (Ashby and Polar, 2021a) and (iii) the G+ Standard Operating Procedure tool (Ashby and Polar, 2021b). The G+ Customer Profile organizes the evidence from gender analysis, including information on how men and women value important plant traits, to decide which customer segments to prioritize using a socially inclusive and gender perspective (Orr et al., 2021). For a specific customer, the G+ Product Profile Query (G + PP) appraises each trait proposed for inclusion in the design of a variety, i.e., Product Profile (Ashby and Polar, 2021a). Together, they provide a framework for multidisciplinary research teams to incorporate the results of gender analysis into two decisions that public-sector plant breeders routinely make for variety development. These are (i) the intended customers of the plant breeding products, that is, varieties and (ii) the important features of the breeding product intended for this customer. The tools have been piloted in sweetpotato (Uganda), beans (Kenya), cassava (Nigeria), bananas (Uganda) and lentils (Morocco) value chains (Polar et al., 2022).

In this study, we applied the G+ PP tool. This tool organizes and synthesizes the evidence from gender analysis so that the breeding team makes evidence-based judgments to evaluate each trait's positive and negative features from a gender perspective. Specifically, the G+ PP tool assigns two "gender impact" scores to each trait in a product profile: (i) a negative or neutral score based on a "do no harm" analysis and (ii) a positive or neutral score based on a gendered analysis of the benefits of each trait. Scoring is similar to the nominal index breeders use to assign a value for disease tolerance of a variety. The tool requires the breeding team to make the final choice or trade-off, between the positive and negative gender aspects of each trait analyzed by providing a traffic light warning system: (i) Stop- there's a risk of overlooking an important gender inequality (ii) Take care- there are ambiguous gender inequality outcomes or (iii) Go- a gender-neutral or beneficial outcome is possible.

Lastly, the G + PP tool evaluates individual traits included or proposed in a breeder's target product profile[1] (TPP). As illustrated in Figure 1, for each trait, the tool generates a gender impact score for 'Do No Harm" ranging from −2 (reject) to 0 (gender neutral) and another gender impact score for "Positive Benefit" ranging from 0 to +3 (required). Two scores are generated because breeders

1 A target product profile simply refers to a description of traits that are embodied in a variety.

often weigh trade-offs between the downside and upside of a given trait to decide whether to include the trait in the final TPP. In the "Do no harm" scale, −2 implies an increase in the gender inequality dimensions with serious harm to women and men or households' wealth and welfare for more than 50% of the target customer segment. A score of −1 shows moderate harm for the majority, and variety release should be accompanied by interventions to remove identified gender inequalities. A score of zero implies that the trait is gender neutral for the "Do no harm" and "Positive benefit" assessments. For the "Positive benefits" scale, a score of +3 is rated as a 'must have' trait with benefits with anticipated major improvements for all women and men or household wealth and welfare in a target customer segment. A score of +2 implies significant improvement for the more than 50% of the women. Such a trait is rated to be 'important'. A score of +1 implies a moderate benefit for most women in the target customer segment and is rated as 'nice to have' (Figure 1).

3.2 The PASTTA project

We applied the G+ PP tool to assess the table potato TPP developed under the Partnership for Seed Technology Transfer in Africa (PASTTA) project. The PASTTA project is a Global Development Alliance (GDA) between the United States Agency for International Development (USAID) Feed the Future initiative and the Syngenta Foundation for Sustainable Agriculture (SFSA). Its main objective was to assist African smallholder farmers in Mali, Senegal, Kenya, Malawi, and Uganda in accessing quality seeds of improved crop varieties to increase their productivity and profit/income. The project targeted seven staple food and cash crops: sorghum, maize, pearl millet, beans, groundnut, soybean, and Irish potato (herein referred to as potato).

CIP provided gender expertise, which, among others, entailed a gendered analysis of the table potato TPP focus traits using the G+ PP. The profile targeted six traits (Table 1): disease and pest resistance, tuber yield, Earliness, dry matter content and shelf-life. The TPP aligns with the findings of Okello et al. (2019), which indicate that the primary factors driving potato farmers' decision to invest in quality seed potatoes are "high yield," "good taste," "early maturity," "disease resistance," and "long shelf-life." The first version of the TPP was created in 2019, coinciding with the launch of Seeds to Business Project's new strategy. The version was based on a demand-led breeding TPP template and tailored to fit the context of the Syngenta Foundation's activities. Ideally, conducting a market study would be necessary before writing the TPP. However, the extensive list of segments made conducting a market study impractical. To overcome this challenge, the team developing the TPP relied on various sources of information, leveraging internal expertise through local utilizing internal and external protocol examples sources and conducting extensive bibliographic research.

The TPP is benchmarked on Shangi, which has existed in Kenya for less than one decade. Shangi "escaped" from the breeding station/program during trials/evaluation and went into spontaneous production, multiplication and dissemination by farmers before its official release in 2015. Shangi is one of the dominant potato varieties in Kenya. Among the things that have made it very popular with farmers is its short dormancy. It also has good taste and high demand. This is usually a testimony to a variety of highly desirable end-user traits. The TPP creates preference groups from Syngenta's client/customer base. These preference groups are determined by identifying distinct needs and preferences of different segments. Among these groups are women (W), whose preferences are highly sought after and catered to in Syngenta's variety's design.

Similarly, men (M) have specific preferences addressed through intentional design considerations. Additionally, the younger demographic, encompassing both men and women under 30 (Y), is recognized by targeting to incorporate traits that align with their preferences. Lastly, a category denoted as W + M + Y (All) indicates that the traits associated with this group suit users across different genders and age groups.

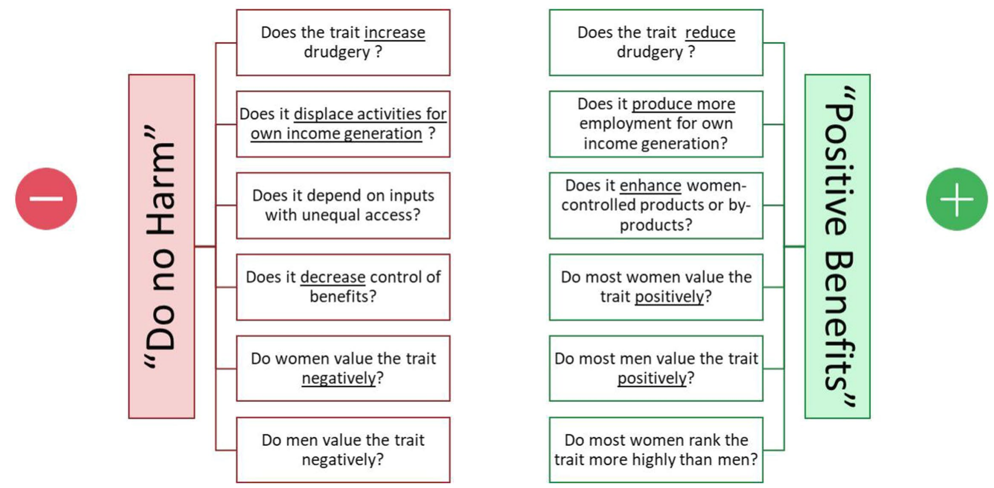

FIGURE 1
G+ Product Profile Query tool for "Do no harm" and "Positive benefits".

TABLE 1 Target product profile developed by PASTTA project for table potato in Kenya.

Client/ customer	Driver	Trait category	Preference group: Women (W); Men (M); Youth (Y); All (W + M + Y)	Trait demand classification: 1 = Essential/"must-have"; 2 = Niche opportunity; 3 = Added value; 4 = Winning trait	Target traits	Trait description (Quantitatively measures)	Name of benchmark variety	Performance required compared to benchmark variety, etc.
Consumer	Satisfaction		All		Dry matter content (%)		Shangi	≤
Farmer	Crop management and harvesting	Plant architecture	All	3	Earliness (days), normalized by Planting date	Maturity date – planting date	Shangi	≤
	Productivity	Yield components	All	3	Tuber Yield (t/ha), normalized by Plot area (m2)		Shangi	≥
		Biotic stress resistances	All	3	Pest resistance	Percentage of plot infected	Shangi	≥
		Biotic stress resistances	All	3	Disease resistance	Percentage of plot infected	Shangi	≥
Retailer	Sales and profit	retailer shelf-life	All		Shelf life	Number of days after sprouting	Asante, Shangi	≥

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3.3 Data collection

One objective of this paper is to compare three methods to evaluate individual plant traits listed in Table 2: desk based social scientists review (SSR), interviews with key informants (KIIs) drawn from key roles and functions in the value chain, a multistakeholder workshop (MSP) in which the tool was applied to generate consensual judgments using evidence form gender analysis. The three methods were undertaken in a stepwise fashion. The need to trial different methods arose from the paucity of available evidence in applying the G + PP tool, which involves scoring each plant trait in the Product Profile using the G + PP gender gap questionnaire (Ashby and Polar, 2021a). This questionnaire is designed to help the breeding team select and organize the results of available gender analyses of the target customer population relevant to each plant trait under consideration. The social scientists' review identified gaps in the evidence needed to complete the G+ PP gender gap questionnaire.

Therefore, we collected primary qualitative data from key informant interviews (KIIs) and a multistakeholder workshop to address the lack of suitable evidence.

3.3.1 Step 1: social scientists' review

In April 2021, 4 CIP social scientists (3 agricultural economists and 1 gender scientist) reviewed the TPP to engender it. To support their analyses of gender impact scores, they relied on a scoping literature review of published and unpublished sources. The scoping review sought to gather information related to drudgery, as well as the roles and responsibilities of men and women farmers in the potato value chain in Kenya. Due to the limited availability of gender-specific studies and the lack of explicit coverage of the issues in most relevant research, a systematic review was not feasible. The primary objective of the search was to address the 12 questions outlined in the gender gap questionnaire (Ashby and Polar, 2021a). Google Scholar and CG Space databases were utilized to search, using keywords such as gender, Kenya, potato, men, women, female, male, unpaid labor, control, employment, benefits, equity, traits, farmer, and preferences.

3.3.2 Step 2: key informants' interviews

Key informants' interviews were conducted with 13 (7 male and 6 female) selected from the different nodes of the potato value chain to represent the major actors. The participants included breeders (1 male and 2 female), seed producers/trader (1 female and 1 male), agricultural extension worker (1 female), commodity marketer (1 male), farmers (2 female and 1 male), food scientist (1 male), social scientist (working with the breeding program) (1 male) and social scientist (national potato council) (1 male). They were interviewed by phone using a checklist of questions adapted from the G+ PP tool to probe their assessment of the effects each trait was likely to have on women and men using the parameters shown in Figure 1. The traits assessed during the interviews were limited to traits prioritized by the PASTTA project for the target potato TPP. A trained research assistant conducted the interviews between August and September 2021.

3.3.3 Step 3: multistakeholder workshop

In the third stage we conducted a workshop with participants from different nodes of the potato value chain selected using the EiB guide (Mashonganyika, 2018). The participants included breeders (2 male and 1 female), seed producers/trader (1 female), agricultural extension worker (1 female), commodity marketer/trader (1 male), farmers (2 females and 1 male), food scientist (1 male), social scientists (2 male and 1 female) and gender specialist (1 female). All the actors were also potato consumers; hence, we did not include separate representatives for the consumer node due to limitations on the size of face-to-face meetings imposed by the COVID−19 restrictions.

The one-day workshop was designed so that participants would discuss the gender implications of the table potato TPP (Table 1), and generate consensus scores on the gender impacts. The workshop was organized into four sessions: the first session introduced the participants to the purpose of the meeting. It exposed them to gender principles and how culture and social norms entrench gender inequalities in agriculture. To summarize the session, participants watched a video illustrating how culture and social norms influence gender in sweetpotato production. The second session explained the gender assessment process and discussed the questions used in generating the scores to ensure that all participants understood the questions and scoring process.

In the third session, participants were paired and asked to score the traits in the CSPro program using the tablets to ease data entry, collation, and analysis. This exercise allowed familiarization with the gender assessment explained in the second session. Finally, in session four, the results of the scores were presented to the whole group. The groups whose scores differed from those of others were asked to explain their scores and the whole group discussed the responses in the plenary. Explanations were offered, and key points from the discussion were recorded. Based on the results and ensuing discussion, the participants were asked to agree on a consensual gender impact score for each trait.

4 Results

This section presents, first, the assessment of five traits with the G + PP tool using the findings from the three methods used to generate the judgments required for scoring. Next, the comparison of the methods is presented.

4.1 Gender analysis of the table potato TPP traits

The findings of the assessment of five traits using three methods: desk-based social scientists review (SSR), individual interviews (KIIs) and assessment by the multistakeholder workshop participants (MSP), are presented in Figure 2 and Table 2.

4.1.1 Dry matter

The results indicate SSR associates high dry matter reduced drudgery for female farmers and consumers a positive benefit (Figure 2A). According to the reviewers, the trait improves the acceptability of boiled potatoes for all household members, regardless of age. An increase in mealiness enhances the taste and reduces cooking time, reducing women's unpaid domestic labor. The KIIs discussed trade-offs associated with dry matter, other traits and the implications. A food scientist pointed out the link between high dry matter content and small tubers, which could increase peeling time

TABLE 2 **Engendered product profile – with the overall gender impact scores[1] for each trait.**

Client/customer	Driver	Trait category	Preference group: Women (W); Men (M); Youth (Y); All (W + M + Y)	Target traits	Trait description (Quantitative measures)	Name of benchmark variety	Performance required compared to benchmark variety	Social Scientists (SS)		Individual Interviews (KIIs)		Multistakeholder workshop participants (MSP) Consensus scores[2]	
								"Do No Harm"	*Positive Benefit*	*"Do No Harm"*	*Positive Benefit*	*"Do No Harm"*	*Positive Benefit*
Consumer	Satisfaction	Consumer	All	Dry matter content (%)		Shangi	$\leq$	0	3	0	3	−1	3
Farmer	Crop management and harvesting	Plant architecture	All	Earliness (days), normalized by Planting date	Maturity date less planting date	Shangi	$\leq$	−1	2	0	3	0	3
	Productivity	Yield components	All	Tuber yield (t/ha), normalized by Plot area (square meters)		Shangi	$\geq$	−1	2	0	3	-1	3
		Biotic stress resistances	All	Pest resistance	Percentage of plot infected.	Shangi	$\geq$	0	3	0	3	0	3
			All	Disease resistance	Percentage of plot infected	Shangi	$\geq$	0	3	0	3	0	3
Retailer	Sales and profit	retailer	All	Shelf life	Number of days after sprouting	Asante, Shangi	$\geq$	0	3	0	3	0	3

[1] -1 = Amend; 0 = neutral; 1 = nice to have 2 = important; 3 required. [2]The consensual score was agreed upon based on the plenary session discussions.

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and thus increase women's unpaid labor. Further, high dry matter content does not necessarily equate to reducing cooking time, which depends on the preparation method. Per the KIIs agribusiness officer, dry matter alone will not guarantee a reduction in cooking time. The officer gave the example of Dutch Robijn, a potato variety with high dry matter which takes long to cook and has an unpleasant taste rendering it unsuitable as a table potato.

MSP highlighted the trade-off between high dry matter and early maturity. Participants reflected on a low-dormancy and early maturity variety, Sherehekea to evaluate the trade-off. Sherehekea has lower dry matter content and a longer maturity period than Dutch Robijn. This trade-off holds implications that farmers prioritizing early maturity may need to make concessions in achieving the desired dry matter content. This compromise could influence the quality characteristics of the harvested potatoes.

Further, contrary to SSR and KIIs, MSP associated dry matter with the likelihood of displacing women from income-generating activities. They argued if the trait implied a heavier tuber, it would generate more income, hence the likelihood of potato farming becoming a male-dominated enterprise. Secondly, though high dry matter was perceived as attractive to chips processors and consumers, the MSP concluded that women processors using such varieties risked losing control over their income to their spouses as the business became more profitable. Thus, while the trait benefits consumers, female farmers and processors will likely face negative income benefits.

4.1.2 Earliness

SSR results in Figure 2A shows that early maturing potatoes could increase drudgery, displace women from their income generation activities and lose control over income. If the trait attracts male farmers to engage more in commercial potato production, women may have less control over the income generated from the crop.

The SSR noted that early maturing potato varieties may lead to increased drudgery for farmers due to intensified labor requirements. Farmers may need to invest more time and effort into planting, tending, and harvesting early varieties than traditional ones if the planting cycle is doubled. This shift in labor requirements may favor male farmers if specialized knowledge, physical strength or mechanization are prerequisites for this engagement. The KIIs and MSP assessments, considered earliness to be positively valued and beneficial to women farmers. Most farmer KII respondents associated earliness with alleviating labor constraints in production, such as minimizing planting, weeding and spraying needs and reducing the labor required for monitoring thefts. Male farmers observed that earliness increases farmers' returns to land and capital. It enables a farmer to grow the crop thrice a year and increases profits because early potatoes are sold at a higher price when there is no glut.

However, a breeder in the KIIs had a different perspective, noting that the effect of earliness farmers' labor requirements would remain the same, hence no influence on unpaid time. Even if farmers adopt early planting practices, it would not affect unpaid time because essential farming activities, such as land preparation, planting, weeding, and harvesting, depend on the crop's maturity time. The breeder stressed that early maturity would allow farmers to harvest and sell their crops earlier in the season leading to higher profits or better market prices. The benefit would outweigh any perceived increase in labor requirements, as it provides improved opportunities for farmers to generate income.

According to the MSP, earliness decreases drudgery and enhances women-controlled products, and most women rank the trait higher than men (Figure 2C). They were also aligned with the SSR regarding the narrative that once men got attracted by the high prices associated with earliness, they would take control of the sales, edging out the women. After evaluating the trade-offs between positive and negative gender equity implications of earliness, the MSP decided that earliness is associated with multiple benefits for women, such as reduced cost of production, food security, reduced costs of crop protection products, and minimized tuber rotting incidences. Other positive effects mentioned were adaptation to climate change, reduced disease pressure, reduced labor costs, higher prices in the market, and enabling farmers to plant more than twice a year. Women also benefit from food being available earlier in the season, thus bridging the hunger gap and boosting household food security. Male farmers value increased income opportunities, while women value food security (Okello et al., 2020). The MSP results (Figure 2C) indicate that women rank 'earliness' higher than men, which is divergent from the views of the KIIs and SSR.

4.1.3 Tuber yield

SSR results indicate tuber yield could increase drudgery, displace women from income-generation activities, require inputs with unequal access, and reduce benefits control (Figure 2A). Farmers in the KIIs did not associate increased yield with negative effects for the four dimensions. However, other actors, the agriculture extension officer, seed multipliers and agronomists, observed that increased yields could increase women's workload during harvesting, transporting (from the field to sales or storage points), grading/sorting, packaging and storage. For example, the female seed agronomist noted, "*If you have high tuber yields, it means you will need more labor for harvesting, grading, transporting, sorting, packaging and storage….. women mostly do these activities.*"

Regarding the anticipated effect of tuber yield on income control, the KIIs also had different opinions from the SSR. One breeder mentioned that women's control over income from increased yields could increase, arguing that: "*I do not see this trait impacting this [*i.e., *control of income] since it is more of social arrangement; maybe the women will make more money and might cause some change on the social arrangement. It is about meeting a particular criterion required by the processor.*" Women farmer participants in MSP mentioned the danger of being displaced by men with the advent of a high-yielding variety in alignment with SSR, which is something that breeders should note.

4.1.4 Pests and diseases resistance

Pests and disease-resistant varieties reduce unpaid family labor use based on the SSR. Biotic stress resistance traits benefit married women participating in labor-intensive pest and disease management practices such as rouging and fetching water for spraying against crop protection products. Further, they associate the traits with increased production, food security, and incomes, which benefit both women and men farmers. From the KIIs, reducing drudgery for women was mainly associated with lower labor costs for female farmers who have to pay the male sprayers. Men benefit because they provide financial resources for purchasing agrochemicals. Pest and disease-tolerant varieties will also minimize pesticide exposure, implying improved health for farmers and consumers. The KIIs associate the trait with

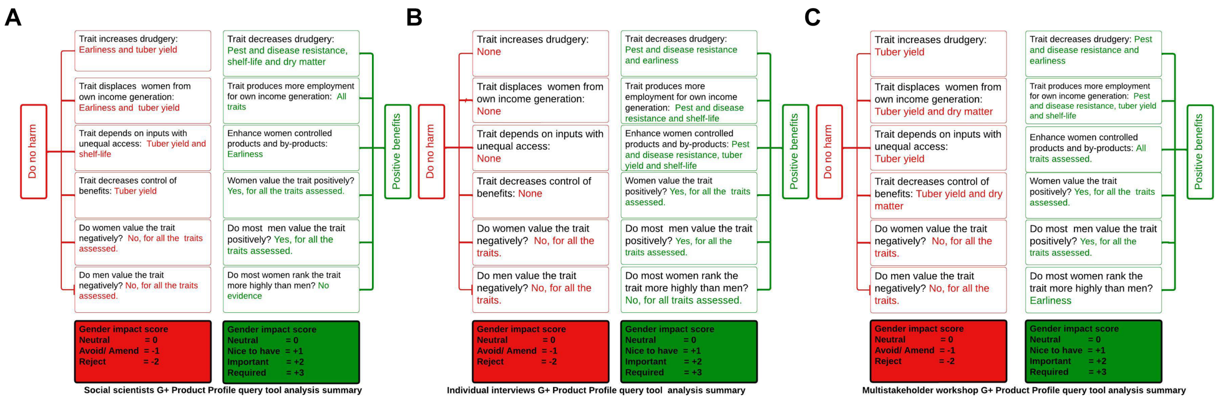

FIGURE 2
Summary of the "Do no harm" and "Positive benefits" analyses from the G+ Product Profile Query tool.

increased employment opportunities and enhanced control of benefits because of higher yields for all the farmers. Workshop discussions highlighted that reducing the usage of crop protection products would reduce drudgery for women because they would not have to fetch water for mixing the pesticides nor purchase water for spraying, thus saving money and reducing time poverty.

4.1.5 Shelf life

The SSR observed that this long shelf life is beneficial; while the TPP targets this trait to retailers, it is important to female farmers. Most female potato farmers who use quality seed rank long-shelf life highly because it enables early entry into the markets, and they are not forced to sell at low prices during the glut (Okello et al., 2019). The SSR assessment shows that shelf-life positively benefits women and inputs and information access are dimensions of inequality that require mitigation. Women retailers could be disadvantaged if they lack access to storage facilities like their male counterparts. Shelf life was associated with increased employment opportunities and enhanced control of inputs, which respondents in the KIIs and MSP considered beneficial. During the workshop, plenary discussions revealed that longer shelf life was associated with reduced post-harvest losses and better prices. The KIIs respondents mentioned reduced fumigation treatments to prevent rotting and cold storage-related costs, while farmers could benefit from price hedging.

4.1.6 Gendered product profile

Table 2 presents an engendered product profile with scores from the three methods. The SSR results revealed that dry matter content was a positively valued trait with potential benefits to women consumers. Its "Do no harm" gender impact was rated 0, and "Positive benefits" scored 3, qualifying this trait as required. The KIIs' gender impact scores for dry matter were positive, aligning with the SSR assessment. The MSP scored dry matter a −1 for the "Do no harm," a result divergent from the SS and KIIs. The MSP elected to retain high dry matter as a priority trait but recommended a mitigation strategy to counter the negative effects of reduced employment opportunities and women's control over potato income.

The SSR analysis shows that earliness can have both negative and positive effects on gender equality during potato production (Table 2), depicted by a "Do no harm" gender impact score of −1 and a "Positive benefits" score of 2. "Positive benefits" were associated with better control of products and by-products by women. Potatoes with a maturity period of less than 4 months benefit women because they ensure a stable food supply and income (Mudege et al., 2021). In this study, women mentioned that early sales enabled them to cover basic household expenses like school fees, clothing and hospital bills.

SSR suggested an 'amend' for the "Do no harm" assessment of tuber yield. This necessitates developing strategies that foster joint household planning and equitable allocation of benefits to go hand-in-hand with disseminating high-yielding varieties. The strategies will ensure that 'high yield' does not further amplify the gender inequalities associated with the allocation of household labor and access to and control over resources and benefits from potatoes. The overall gender impact score generated from the KIIs showed that 'increased yield' is *required* by most women farmers. The informants argued that even if they (women) were disadvantaged in some instances, e.g., the loss of control of the resources, high yield increases food security, which is very important to them. Female farmer interviewees also argued that increased yields could offset the additional labor requirements by selling higher harvest volumes and using part of the proceeds to pay for hired labor.

The MSP final 'Do no harm' gender impact score for tuber yield is −1, which aligns with the results of the SSR (Table 2). After the plenary discussions on the likely impacts of the trait, the MSP changed their "Do no harm" score from 0 (Neutral) to amend (−1). This score implies that the trait could induce increased gender disparities related to unpaid labor and control over benefits (Figure 1). Notably, the switch from *neutral* in the individual and group scoring to *amend* in the multistakeholder workshop was mostly influenced by contributions from the farmers and extension agents. They argued that, while the potato was mainly a women's crop in Limuru (located in the highlands of the central region of Kenya), the higher the yield, the more likely men would also start growing it, displacing women from remunerable nodes of the potato chain. This result suggests the need for a gender-responsive strategy to accompany the promotion of high-yielding varieties to mitigate the potential gender disparities.

Results from all three methods indicate that disease and pest resistance are positively beneficial and associated with a major decrease in drudgery for male and female farmers. Thus, they are key traits given that they were associated with no 'Do no harm' across scoring in all three methods. Following consensus in the workshop plenary session, the "Positive benefits" gender score for pest and disease traits was a 3, implying the trait is required, and participants agreed that "Do no harm" was neutral (Table 2).

Shelf life was the other key trait with a neutral score for 'Do no harm' across the analysis. The SS analysis shows that the trait would benefit most women retailers positively, with the "Do no harm" and "Positive benefits" scores of 0 and 3, respectively. For retailers, reducing value-addition practices to improve shelf-life, such as repackaging to minimize spoilage, could reduce unpaid labor. In addition, a longer shelf-life would reduce losses and costs associated with preservation.

4.2 Comparison of methods for generating evidence and engendering the product profile

The methods we used to engender the TPP have different strengths and weaknesses (Table 3). The SSR engaged with the tool more intensively, which helped guide the other methods and identify difficulties early in the G+ tools application. As the reviewers interacted with the literature to support their analysis, they obtained and provided base evidence on the four gender aspects analyzed using the G+ PP query tool. Then, the SSR process is quick and has in-house expertise, which can help identify research gaps to be addressed in future surveys and tool applications. Nonetheless, the approach can be constrained by individual assumptions and beliefs in the assessment process, including evidence gaps concerning gender-disaggregated data and reliance on context-specific studies, lack of a multidisciplinary team and biases of the individual team members.

KIIs provided an opportunity to include up-to-date information unavailable from published literature into the analysis. Additionally, it offered the opportunity to probe and gain an in-depth understanding of the local context and identify gender-specific issues necessary to apply the G+ tools. In this study, the interviews facilitated an understanding of the challenges faced by women. KIIs enabled an understanding of the socio-economic perspective of potato production in Limuru that was contrary and divergent from views held by subject matter specialists and existing literature. Furthermore, KIIs provided an opportunity to gather tacit knowledge from female farmers, who shared valuable insights from their lived experiences, particularly regarding income and benefits control issues. Meanwhile, the breeders expressed their opinions on topics they may not typically be vocal about.

However, the subjectivity of participants is a weakness of the approach and requires keenness to identify respondents that can capture the views of target customers. Onwuegbuzie and Leech (2007) highlighted the potential for bias in interview responses and the difficulty of generalizing findings due to the small sample size. Additionally, as Bergen and Labonté (2020) argued, power dynamics and social desirability bias may affect the accuracy of the information obtained. Also, some interviewees hesitated to discuss issues, especially those related to monetary benefits, perhaps due to societal expectations and power imbalances.

Multistakeholder workshops involving a plenary for consensus building have several strengths that can contribute to their effectiveness in engendering crop product profiles. The collaborative process enabled stakeholders with diverse values and objectives to develop a shared opinion, understanding and a well-balanced perspective in engendering the TPP. In the workshop, participants could identify trade-offs and deliberate on blindspots not adequately addressed in the other methods. As a result, the method led to robust and gender impact scores that were acceptable to a wide audience. By building consensus on the gender impact scores, multistakeholder workshops strengthen the reliability of the engendered TPP. On the other hand, dynamics within plenary can result in unequal participation and dominance of certain individuals or groups. This can lead to quiet members taking a passive position and affirming consensus that does not adequately represent their perspectives.

5 Discussion

5.1 Gender-responsive product profiling

While breeders have traditionally considered 'yield' beneficial for all end-users, the analyses showed that the trait could have a potential 'harm' associated with increased drudgery and displacement of women from income-generating activities. Increased income from crop commercialization can displace women from remunerative nodes in the value chain (Mudege and Heck, 2019). Thus, while the recommendation would not be to 'reject' the trait, breeders need to be aware of the potential negative consequences of high-yielding varieties for gender equity. An innovation resulting in income loss could perpetuate dependency and loss of agency (Wigboldus et al., 2016). The fact that women potato farmer participants in MSP mentioned the danger of being displaced by men with the advent of a high-yielding variety raises a red flag that breeders should acknowledge. The findings corroborate those of Beuchelt and Badstue (2013), who found that high-yielding technologies often lead to increased drudgery, especially for women, creating a livelihood trade-off and low uptake of new technologies. Higher yields are associated with higher labor demand, which women may not attain due to the limited mechanization of most activities in smallholder settings in Kenya (Doss, 2018; Kahan et al., 2018). Household labor allocation follows social hierarchies' where men's plots take precedence (Pierotti et al., 2022). Increased yield is associated with complementary inputs such as fertilizer, for which women have unequal access and control (Doss et al., 2011). Even when women have the financial means and cultural support to hire labor, they may encounter difficulties in effectively managing male laborers (Zambrano et al., 2012).

Then, the SSR indicates that a high yield reduces control of the benefits. Mudege et al. (2021) observed that male farmers collaborated with this sentiment. However, while female farmers undertook most of the production activities, men had the upper hand in controlling potato income, aligning with the social-cultural context and gendered division of roles and responsibilities. While tuber yield is an important trait for women, they rarely score it first (Mudege et al., 2021). Thus, the implication is that the new table potato variety distribution should consider social disparities that could emerge in the target areas and how these could affect men and women.

Accompanying tuber yield with complementary technology to reduce drudgery (e.g., simple planters and harvesters) and improve

TABLE 3 Comparison of the strengths and weaknesses of the three approaches to implementing G + PP analysis.

Methods	Strengths	Weaknesses
Social scientists review	• Provides a research evidence base and support for evaluations on the four aspects under consideration in the G+ PP • Allows easy access to a narrative about gender roles, responsibilities, and power relationships in crops • Allows sufficient time for interaction with the G+ tools suite for reference and guiding other methods that may be used to generate evidence or scoring • Quick methods, when limited with time and resources	• They are constrained by a lack of gender-disaggregated data on breeding to inform processes of implementing the G+ tools • The main references are context-specific studies; hence, generalizing findings and scores from one context need caution • Requires a multi-disciplinary team of specialists to be on the same level of understanding of the application of the tool and deciphering the scale • The positionalities of the team and reliance on individual perspectives and experiences can introduce subjectivity and bias into the application of the G+ tools
Key informant interviews	• Sets a framework for participants to interact with the tool before the multistakeholder workshop is held • It provides an opportunity to probe the complex issues in the G+ PP. Offer a holistic space for stakeholders to share their experiences, perspectives, and knowledge. Gender scientists can gather information not only on technical aspects of crop production but also on broader issues such as traditional knowledge, local practices, and market dynamics • Informants possess tacit knowledge gained through experience. This knowledge may not be available through published sources or grey literature • Up-to-date and current information about the crop, the latest trends, innovations, or challenges in crop production, ensuring that the crop profile is accurate and reflects the current state of the industry	• It is time-consuming, especially where interviews are virtual. Identifying and engaging with suitable informants, arranging interviews, and analysis may require significant effort. Limited time and resources limit the depth and breadth of the interviews or the number of interviews conducted • The tool may feel repetitive during the assessment as each trait is assessed independently • The positions of the informants may influence the responses. For instance, some model farmers may feel pressured to provide socially desirable answers or may hesitate to express dissenting opinions, particularly when discussing sensitive topics related to gender dynamics or traditional norms • Informants may not have exhaustive knowledge of all aspects of the crop or its market. They may have specific expertise in certain areas while lacking insights into others
Multi stakeholder workshop	• Up to date, the representative opinion of the participants carefully selected to represent different nodes in the value chain. An ideal mechanism for establishing familiarity among key decision-makers about the product profile • Discussion aids in highlighting trade-offs that would otherwise be left in the dark • Creates a 'buy-in', especially amongst natural scientists, on the importance of gender in breeding • Simplify the cognitive tasks for participants, especially those without prior exposure to the repeated independent gendered assessment of each trait • It reveals grey areas and articulates new perspectives to the existing interpretation and adaption of the G+ PP questionnaire • Supports the process of validating gender impact scores and improves the reliability of the engendered product profile through negotiation and consensus building	• Some participants may be passive depending on the power relations and language used • With the multistakeholder team, less confident participants' contributions may be influenced/adversely affected by those of dominant speakers

access to complimentary inputs could result in a win-win situation. Such technology packages should be easily accessible to women, given their premier role in production and limited ability to purchase improved seeds and fertilizer. For example, packaging fertilizer in smaller packs and promoting decentralized agro-input dealers could increase women's access and use. Consequently, this changes the status quo where women farmers generate lower yields than men because they operate smaller farms with less use of these complementary purchased inputs (Puskur et al., 2021). With regards to the earliness trait, early crop maturity allows farmers to shorten the production cycle, harvest and sell their crops sooner, and perhaps plant twice a year. This results in increased income from crop commercialization as they can generate revenue more frequently within a given period. Okello et al. (2019) found that only male farmers prioritized 'early maturity' because it fosters early market entry and, thus, better prices.

The final gender score for pest and disease resistance was positive, indicating that these are key traits. The focus on this trait by Syngenta Foundation, which has a more commercial outlook, is timely. According to Gildemacher and ter Steeg (2023), addressing late blight and virus resistance concerns have not received high priority from commercial breeders. The authors note this objective is not aligned with the interests of commercial breeding companies and there has been a lack of development in varieties with stable resistance to bacterial wilt. Yet, most potato cultivation in the East African region is rainfed, and the control measures implemented by farmers to combat late blight are typically mediocre. Dissemination of pest and disease-resistant varieties should still be accompanied by information on proper use and management. Past evidence indicates farmers use ineffective practices due to limited awareness of recommended pest and disease management practices (Okello et al., 2020). Additionally, women have limited access to new technologies, such as new varieties, given their limited access to extension services, training and limited mobility (Mudege et al., 2020). This calls for gendered integrated pest and disease management training and field advice to accompany the release of biotic-resistant varieties. Just scheduling farmer training (and extension services) does not necessarily help women; rather, the training must intentionally target women (Mudege et al., 2017). For example, training schedules (e.g., time and season), location, methods, and length should be designed with women's needs and abilities in mind. Institutional biases within extensibility reproduce gender inequality. At dissemination, the seed system design should foster equity in availability and access to seed, for example, packaging in smaller units, demonstrations at accessible points, dissemination leaflets with easy-to-decipher graphics and integration of farmer-managed seed systems.

About 27% of potato farmers lose their stocks because of sprouting and greening (Musita et al., 2019). According to Kaguongo (2014), most post-harvest losses occur at the open market level, estimated at 24.4%. Therefore, SSR deemed the trait key and was supported by results from the other methods. These losses result from wastage due to greening, rotting, and sprouting, amounting to 815,000 tons annually, with an approximate value of KES 12.9 billion. However, From the scoping review, SSR found female farmers may be disadvantaged if they lose control over benefits from stored potatoes (Mudege et al., 2016). Men retailers, on the other hand, are disadvantaged due to their limited knowledge of food handling and storage (Musita et al., 2019).

Additionally, breeding for longer shelf life will negatively correlate with short dormancy, a trait women farmers prefer because they can plant their own saved seed from last-season harvest and obtain good yields (Thiele et al., 2021). A short dormancy in bi-modal production regions of Sub-Saharan Africa is advantageous as it allows farmers to replant their farm-saved seeds quickly. Still, its negative effect on seeds' storability causes breeders to hesitate to prioritize it (Gildemacher and ter Steeg, 2023).

The finding relating to short shelf life implies that farmers and male retailers must be given comprehensive post-harvest training to reduce losses and waste. This trait should be closely monitored because of its contrasting implications on gender equality. Longer shelf life may thus harm women who lack equity capital (i.e., savings) to buy externally sourced seeds during planting. Additionally, unlike men, women may not have access to storage facilities and can be marginalized by a variety with a longer shelf life. Poor storage leads to greening and sprouting, and the production of glycoalkaloids associated with a bitter taste in potato tubers harms consumers (Wamuyu, 2019). Thus, producing a variety with short dormancy should be accompanied by a training program targeting these challenges, with special emphasis on male retailers in the case of greening. Since shelf life was the other key trait, breeders should consider these important trade-offs between various value chain actors, i.e., to remain attractive to women farmers and not negative to traders.

Dry matter was found to decrease drudgery. The results align with Jansky et al. (2010) and Kisakye et al. (2020), who link dry matter to mealiness, a texture most boiled potato consumers prefer. Tubers with high dry matter (≥20%) absorb less oil during cooking, making them an excellent choice for health-conscious consumers who seek low-fat food options (Ooko, 2008). The evidence from applying the G+ PP query analysis on dry matter through the different methods should draw the breeder's attention to the highlighted trade-offs, particularly concerning cooking time, tuber size, ease of peeling, and taste. Recent studies, such as Okello et al. (2019) and Mudege et al. (2021), provide support for the preference and benefits associated with the combination of these traits, especially among women when making decisions regarding the use of quality potato seed and in the preparation of boiled potatoes. All these are consumption traits that women prefer but are not in the current TPP. Striking a balance among these traits when adjusting dry matter level is essential to ensure that the resulting varieties meet the desired standards and fulfil the expectations of all farmers and consumers.

Overall, potato breeding programs should expand the focus and development of their product profiles to encompass gender dynamics and preferences. Further, the implication of target traits concerning the use of unpaid labor, access to internal and external inputs, and control over benefits should be considered. Incorporating gender dynamics in decision-making processes and acknowledging women's specific needs and preferences can empower them in agriculture, leading to increased participation.

5.2 Strengths and limitations of the three approaches to implementing G+ PP analysis

Tarjem (2022) assesses but does not apply the G+ tools for three uses: (i) communication and marketing, (ii) management and (iii) diagnostic and screening tools. Our assessment complements the diagnostic and screening component. Using the G+ tools at the three levels led to a rich and deeper analysis of the gender implications of the bundle of traits identified. For social scientists, using an evidence base was crucial as it enabled an impartial analysis. Through their expertise, social scientists help inform evaluations of the four aspects of the G+ PP that can be applied to other research areas in an organization. Additionally, they allow for quick analysis while having sufficient time for interaction with the G+ tools suite, enabling a deeper understanding of the subject matter. However, this was challenged by the lack of data and information, especially where existing studies did not provide a gender lens.

Individual interviews were equally rich, with respondents carefully selected to represent a wealth of knowledge in the potato sub-sector. Key informant interviews were an important method to introduce participants to the G+ PP tool and its complexities before engaging in a multistakeholder workshop. Their perceptions augmented the findings of the first stage of the multistakeholder workshop, where participants analyzed pairs. The consensus building in the multistakeholder workshop added a rich layer of confirmatory analysis; hence, it is a significant component of the G+ PP process.

Carefully selected participants representing diverse perspectives and nodes in the value chain are brought together to discuss and evaluate the product profile. The workshop serves multiple purposes, including familiarizing key decision-makers with engendering the product profile, facilitating discussions to address trade-offs that may not have been apparent previously, and uncovering new perspectives. It also aims to create "buy-in," especially among natural scientists, regarding the importance of considering gender in breeding decisions.

Furthermore, the workshop simplifies cognitive tasks for participants who may not have prior exposure to the G+ PP tool, ensuring their engagement and understanding of its application. Through participatory negotiation, the workshop supports validating gender impact scores and enhances the reliability of the engendered product profile. From the workshop, breeders perceived the resultant analysis positively, some of whom had previously stood on the fence with a minimal appreciation of the gender analysis. As noted by one of the lead breeders: 'This has changed my perception a lot: "*I always perceived that we breed for human beings, but now I see the importance of the social perspective to breeding*." For complementarity and rich gender analysis, the three approaches are recommended for future users. However, should there be a constraint of resources, the breeding program can conduct a cost–benefit analysis to select between the key informant interviews and multistakeholder workshops approaches as the social scientist analysis is given.

6 Conclusion

Results from the three approaches identified pest, disease resistance, and shelf life as key traits in the target TPP. The multistakeholder approach findings show yield and dry matter will need accompanying strategies to address the anticipated gender disparities that could arise. Consequently, it shows the importance of gender integration at the various breeding stage gates if we attain varieties that meet end users' needs.

An important finding from the key informant interviews and multistakeholder workshop is the need to go beyond individual trait assessment, as the interaction between traits has trade-offs. Trade-offs amongst stakeholder requirements for some traits could be better analyzed and inferred if factored during study design. This could be done using the G+ Customer Profile tool to enable better framing and assessing traits to include in breeding profile plans. Additionally, a cross-functional team constituted as recommended by Mashonganyika (2018) engagement in design and product testing to ensure the delivery of a more socially acceptable innovation that benefits all gender categories is recommended.

We also recommend trait dissection (especially for quality traits like dry matter taste and cooking time, which are important for women) to understand the biochemical and biophysical characteristics underpinning these traits. Drawing from Dufour et al. (2021), this would help breeders develop improved selection tools to measure and include or account for quality traits in the product profile, thus enhancing the adoption of modern varieties. To achieve this, the breeding program should constitute an interdisciplinary team comprising breeders, food scientists, gender researchers and agricultural economists. These would allow for a holistic approach to determining and including end-user-preferred traits in TPPs.

Data availability statement

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

Author contributions

JM: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Visualization, Writing – original draft, Writing – review & editing. SM: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing. JN: Conceptualization, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. SS: Conceptualization, Funding acquisition, Project administration, Resources, Writing – original draft, Writing – review & editing. CR: Conceptualization, Funding acquisition, Project administration, Resources, Writing – review & editing. CO: Conceptualization, Funding acquisition, Project administration, Resources, Writing – review & editing. GH: Funding acquisition, Project administration, Resources, Supervision, Writing – review & editing. VP: Conceptualization, Funding acquisition, Methodology, Resources, Writing – review & editing. JA: Conceptualization, Formal analysis, Methodology, Writing – review & editing. JO: Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Supervision, 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.

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Gender analysis is not only about gender: reshaping the potato breeding priorities to increase varietal adoption in Kenya

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Public breeding programs are pushing to implement demand-led breeding to increase variety adoption, while tackling multiple challenges for increased production under climate change. This has included the improvement of variety target product profiles involving multiple stakeholders. A special case involves the unexpected and rapid spread of the Shangi potato variety in Kenya. This variety was not an especially outstanding variety and the levels of its traits did not exceed the expected thresholds defined in the target product profile for table potato in East Africa. By examining the customer segments looking at gender but also social contexts of smallholder and disadvantaged farmers such as access to markets, inputs, and labor, it became apparent that ready availability of potatoes for consumption, processing, or planting was of prime importance. Given the storage and market constraints, Shangi's very short dormancy, which had been assumed to be a negative trait for farmers, women cottage processors and consumers, was actually meeting the needs for available product and planting material. Consequently, this provided these groups increased control over their productive activities. The case study presented here analyzes different components of potato variety change in Kenya. It explores the challenges and tradeoffs faced by public sector breeding programs and how gender analysis from a broader inclusion perspective can uncover the underlying causes of varietal adoption. Focusing on the Shangi potato variety, the case study reveals a series of lessons learned that have re-shaped the definition of breeding priorities.

KEYWORDS

potato breeding, gender-responsive breeding, social inclusion, market segments, target product profiles

1 Introduction

Potato is the second most important staple crop in Kenya after maize. There are about 800,000 producers covering 214,600 ha of production (Kaguongo et al., 2014) with an average yield of 9.8 t/ha and total production of 2.1 million tons (FAOSTAT, 2021). However, production and consumption suffer from a number of challenges including biotic and abiotic stresses and post-harvest losses due to poor storage facilities. To address the diversity of challenges, the plant breeding programs from the International Potato Center (CIP) and Kenyan partners are developing new high-yielding varieties with improved disease and virus resistance and drought and heat tolerance. In addition, the breeders strive to maintain tuber quality. Although these traits address the main production constraints, there are other factors that play into the adoption of such varieties. The rates of adoption have been much lower than hoped for (Thiele et al., 2021; Kwambai et al., 2024). Moreover, the age of varieties still in production since release in Kenya is quite high, reaching an average of over 19 years. There are mainly two factors explaining low adoption. There is a need to consider quality traits that respond to the needs and demands of stakeholders along the potato value chains (Kisakye et al., 2020; Mudege et al., 2021). In addition, there is a lack of access to clean quality seed of new improved varieties (Okello et al., 2016; Thiele et al., 2021; Kwambai et al., 2024). A study in Ethiopia showed adoption of potato varieties was dependent on the income status of the farmers, which affected their access to improved varieties and associated technologies (Yenenesh et al., 2017).

This case study analyzes different components of potato variety change in Kenya. It explores the challenges and tradeoffs faced by public sector breeding programs and how gender analysis from a broader inclusion perspective can uncover the underlying causes of varietal adoption. Focusing on the Shangi potato variety, the case study reveals a series of lessons learned that have re-shaped the definition of breeding priorities.

2 The context of potato breeding and variety change in Kenya

2.1 Variety changes in Kenya

Shangi is a farmer selection that was taken up by farmers from on-farm trials. Preliminary molecular analysis of Shangi seems to place it in the CIP genebank germplasm (Thiele et al., 2021). It has expanded rapidly across production areas since 2005. Shangi was officially released in 2015 and now occupies around 80% of the production area[1] in Kenya. It is a high yielding, quick maturing, short dormancy, cream skinned potato, with good tuber size, good taste and quick cooking time and moderate Late Blight resistance.[2] However, the outstanding differences between Shangi and the rest of the varieties available in the market are its very short dormancy and early maturity that make Shangi suited to year-round production. Therefore, traders in markets and processors as well can rely on a continuous supply, and farmers are able to find planting material when needed giving them greater control over their productive activities. Indeed, improved availability of produce and planting material are major causes for adoption as reviewed in Thiele et al. (2021).

A number of surveys of the potato value chain and markets have been carried out to examine varietal preferences and elucidate the related traits. A farmer survey conducted in five main potato growing counties in Kenya found issues with supply of potato tubers for processing into chips or crisps is in part due to lack of potato storage facilities (Kaguongo et al., 2014). A market survey by Manyasa (2015) of the main destination markets for fresh ware potatoes found Shangi was the most preferred variety and most of the traders surveyed (55% male, 45% female) cited availability as the most important factor for preferring Shangi. Additionally, customers desired to have affordable potatoes available throughout the year, hence availability was a major aspect of user demand.

Good storability was identified as a major trait needed by both farmers and processors, due to a lack of good storage infrastructure across the country (Okello et al., 2017) and the high cost of cold storage which is only available for large commercial farmers or large processors (Kaguongo et al., 2010; Manyasa, 2015). Indeed, a study found that farmers generally do not have good storage facilities and typically store potato seed and food in their homes/farms (Kaguongo et al., 2010; Manyasa, 2015). For potatoes to store well for a few months in between growing seasons, as well as to wait for better market prices or to provide a steady input to large processing facilities, a variety must also have a long dormancy so that it does not sprout.

In 2017 a study looked at the potential of investing in storage facilities along the value chain in Kenya (Soethoudt and Gitau, 2017). Shangi was found to be the most popular variety, as the market is mainly for direct consumption shortly after harvesting, so long post-harvest storage was barely mentioned. Traders preferred Shangi because availability was the most important factor for them. Processors had a number of quality attributes required including a thin peel to reduce waste, so Shangi with its thicker peel was less preferred. Customers were found to choose varieties based on price, size, and quality attributes, such as taste and oil consumption when frying. In terms of storage of potatoes, the study found that farmers store tubers for planting in the next season, or to aggregate for collection by traders, but not for aiming for better prices in the future. Most farmers sell immediately after harvest. In Bomet where the variety Dutch Robijn is preferred for processing into chips or crisps, storage was considered a pressing challenge. The study concluded that the main driver for investment in storage was to ensure continuity of product supply for processing, perhaps by rural brokers and was not warranted for smallholder farmers.

There are various preference rankings that farmers, processors, and consumers take into consideration when adopting or choosing a variety. A study by Sinelle (2018) interviewed 289 farmers in six of the major potato production regions in Kenya. The results showed that market demand and income are the most important criteria for choosing a variety, more than pest and disease and adverse weather impacts. Therefore, even if a variety does not have the best resistance to a disease such as Late Blight, if it has a high yield potential and there is demand for it in market, farmers generally preferred to grow it instead of more resistant varieties. This was the same for both women and men farmers.

A recent study using focus group discussions with male and female potato farmers and a household survey in three important potato growing regions in Northwest Kenya revealed that availability and access of healthy seed was a critical factor for varietal choice (Kwambai et al., 2024). The seed sources were mostly from farmer-kept seed. In addition, market demand played a dominant role in variety selection by farmers. Shangi was the predominant variety in the market.

2.2 Variety design

Breeding programs are tasked with addressing challenges from various angles, including a crop's production, the successful adoption of the breeding products by end-users, as well as significant market penetration. This entails a process of prioritization of objectives and desired trait combinations to be selected for. Therefore, variety design is the first step in the

1 National Potato Council of Kenya 2023- https://npck.org/.

2 NPCK Kenya Variety catalog-2021- https://npck.org/catalogue/.

development of a new variety while incorporating knowledge and learnings from the development of previous varieties in the breeding cycle (e.g., what needs to be improved or changed). Consequently, as promoted and implemented by the CGIAR RTB program and Excellence in Breeding Platform (EiB),[3] breeders and ideally multi-functional teams first determine the market segments that will be the targets of the breeding program. The market segments are comprised of the basic agronomic, demographic and economic characteristics of the geographic region being targeted. This is complemented with production and consumer components. Thereafter, product profiles are developed that correspond to each market segment. A product profile is comprised of a specific list of key traits with defined levels being targeted in a new product (variety) that will achieve the goals of the breeding program. The concepts of market segments and product profiles are described in Donovan et al. (2022).

2.3 Potato breeding scheme at CIP

Breeding of vegetatively propagated crops such as potato comes with unique challenges and these have been described extensively (Jansky and Spooner, 2018; Bradshaw, 2022; Lindqvist-Kreuze et al., 2024). This process usually takes 8–10 years from crossing to variety release. CIP was established in 1971 with an initial mandate on potato improvement for production in developing countries (Lindqvist-Kreuze et al., 2024). It was located in Peru, which is part of the potato's center of origin and diversity. The main traits targeted for selection in the CIP breeding program had to do with agroecological conditions and the main diseases under those conditions. Resilience for low-input production and poor soils, and quality traits were not prioritized. Having good dormancy for around 3 months was taken for granted to allow storage of potato tubers until the next planting season. A study in 2015 in Kenya stated that 3 months storage are needed by farmers to reach periods of higher prices, and 4 months needed by processors to avoid periods of limited supply (Manyasa, 2015).

2.4 The need to address gender for social inclusion and equity

By taking into consideration the social dynamics of gender relations at various levels, and gender roles along the value chain, gender research can help identify constraints and challenges faced by women that can affect variety adoption. This is especially relevant in cases where production systems and subsequent post-harvest activities are carried out differently by men and women (Christinck et al., 2017). Variety adoption studies have shown that women producers may be less likely to adopt improved varieties (Polar et al., 2021) for a number of reasons. These can include the social context as well as trait preferences, especially quality traits.

Studies in various crops and livestock have shown certain desirable traits to actually affect the livelihoods of women producers, processors and consumers which resulted in lower adoption of improved varieties and breeds as reviewed in Polar et al. (2021). For instance, in groundnut in Malawi, a variety was developed with resistance to a major disease, but it also had hard shells. Women opted to grow another variety, less resistant but with soft shells, as the hard shells made shelling much more difficult and also increased the risk of contamination with mycotoxins (Tufan et al., 2018). This led to a refocusing of the breeding program, to develop resistant varieties with soft shells. Ease of peeling of cassava was especially highlighted by women in a study in Nigeria and Cameroon as peeling is mostly done by women and children (Ndjouenkeu et al., 2021).

In the potato crop, women play important roles in production, home consumption and marketing. In Uganda, a study of gender-preferred potato traits showed that although there were similar preferences between men and women for sensorial quality traits, women ranked attributes that are easier for processing higher than men, since women are normally more engaged in processing (Mudege et al., 2021). Market preferences, which were gender neutral included appearance of the tuber, namely red skin and yellow flesh. Women preferred large size of tubers and mealiness. From this approach that also included gender specialists, it became apparent that breeders must consider gender roles, social norms, and market preferences in addition to the usual agronomic traits prioritized in breeding programs. Resistance to Late Blight was highlighted by both men and women, as well as cooking qualities. Interestingly, varieties with long dormancy such as KACHPOT 1 were not popular, whereas the variety Victoria was popular due to its short dormancy, early maturity, and large tubers, even though it was not market-preferred and was not considered to have a good taste.

For women, the primary purpose for growing potato in Uganda is one of food security-so their production plots are subsistence farming, with less inputs, and cooking by boiling (Kisakye et al., 2020). Priority traits for boiled potato were appearance, color, size, texture and dry matter content. As the crop becomes more commercialized, the report showed the crop to become more male-dominated. Moreover, women farmers having limited mobility and many domestic responsibilities, are more restricted in participating in marketing of the potatoes. Market demand by traders and consumers was found to be crucial for variety selection by farmers. Traders grading potatoes looked at the variety, appearance and size, maturity level, water content and damage. The report showed NAROPOT4, Victoria and Kinigi as the most popular varieties grown due to their disease resistance and high yields. Interestingly, the report also noted that Shangi is becoming popular in eastern Uganda, though they did not mention its short dormancy trait as a reason. Organized storage is also a problem in Uganda and most likely across potato growing areas in East Africa, leading to high post-harvest losses. It will be interesting to see how this affects the expansion of Shangi and the development of new product profiles for Uganda.

2.5 GBI approach to define customer segments and gender-sensitive traits

Breeding objectives historically have mainly sought to improve yields and biotic and abiotic resistance. Due to issues related to low adoption of improved varieties stemming from lack

3 https://excellenceinbreeding.org/

of attention or strategies to address needs and preferences of stakeholders along value chains, the CGIAR established the Gender in Breeding Initiative (GBI)[4] in 2016, led by the CGIAR Research Program on Roots, Tubers & Bananas (RTB). The aim was to mainstream gender into breeding programs, especially to enhance the design of new varieties. The objective was to develop a common ground and facilitate communication and collaboration between breeders and gender specialists (Polar et al., 2022). The initiative established procedures to create multidisciplinary teams. These were comprised of breeders, social scientists, gender specialists, food scientists and others to jointly design varieties for breeding programs by defining and perfecting product profiles. Moreover, the initiative developed tools (the so-called G+ Tools) to describe and define gendered customer segments and a gender-responsive product profile which are now available as manuals (Ashby and Polar, 2021a,b). This has led to various CGIAR and partner organization breeding programs to adopt the G+ tools and include gender specialists in their breeding teams (Polar, 2019).

3 Analysis

The evolution of the Target Product Profiles (TPPs) went through an iterative process, through the involvement of the GBI and active participation of the breeders. What started with breeders only, evolved into product design teams that involved experts from multiple disciplines. This resulted in the definition of TPPs that responded to the needs and preferences of specific and relevant market segments.

3.1 Early product profiles

Early attempts by CGIAR breeding teams to define product profiles, ranked traits as either "must have" or "good to have". This was followed by a quantified description of the desired level of the trait (such as maximize, reach specified level, maintain a certain minimum level, etc.), and a unique rank or priority was assigned. A target trait level was determined, defined in terms of the levels of the predominant variety for that region to be replaced. The traits were then ranked taking into consideration factors such as the genetic variability available for that trait, the heritability of the trait, the ease of measuring the trait, in addition to the expected impacts of the trait.

Following these criteria, a draft potato product profile was developed for the tropical highlands of Africa and Latin America in 2017 by the CIP potato breeding program (see Table 1, T. Mendes, personal communication). At this time, the market segment was quite broad and did not differentiate between fresh market and processing types. Moreover, most potato processing is through cottage industries that do not utilize processing type potatoes. Instead, they use dual-purpose types to deal with under-developed markets for processed potatoes such as chips and crisps. In this product profile, table quality traits were rather vague, and dealt more with the issue of rises in glycoalkaloid content under hot conditions (Gastelo et al., 2014). Dormancy was mentioned but given at least 60 days for two cropping seasons a year, or 90 days for one season per year, with the greatest emphasis in the product profile being on resistance to various major diseases and nematodes. Nevertheless, this initiated a process of quantifying and ranking traits to be included in a breeding program, and gathering feedback from breeders and other stakeholders to design the product profile.

The product profiles were further refined in a workshop bringing together breeders, gender specialists, food scientists and economists in 2020 (Friedmann et al., 2020). First, the market segments were determined according to a framework provided by the Excellence in Breeding Platform. Then specific traits for each category were listed in the associated product profile following quantity traits and quality traits, each with defined scales and minimum scores required. The workshop further helped define the market segment, that was too broad for the draft potato product profile. Discussions also centered on how to access the needed data to properly establish the market segment and the need for social scientists and economists to work with breeders to develop it. It also became apparent that a crop usage category needed to be added to the market segment template. This would help to better elucidate the quality traits to be considered in the product profile. It also brought to light the value of the G+ tools mentioned above, and the need to find better strategies to incorporate the tools into the variety design process. This was a good exercise to bridge to what later became more rigorous establishment of market segments and target product profiles (TPPs) with further inputs from the EiB and the establishment of the CGIAR Market Intelligence Initiative (MIPPS).[5]

In late 2018, the CIP potato breeder based in Kenya participated in a GBI workshop to fine tune the G+ tools, test them with real-world examples of breeding programs, and provide feedback and how to best incorporate and implement them in breeding programs (Hershey, 2018). The workshop looked at the potato breeding program in Kenya as one of the case studies to apply the G+ tools. For the customer profile tool, the case study segmented the customers based on geography- concentrating on tropical highlands, and then disaggregating based on population size, gender and age in the major potato producing counties. However, as Shangi was already estimated to be grown in 80% of the production area, it was not possible to do such a segmentation according to these criteria. More research on gender roles was suggested, on the use of the potato product, and what the end markets are, using gender disaggregated data, as well as information on age, income, and separating consumers as rural or urban in order to re-assess to develop a customer segmentation that might support gender equality and inform the development of the product profiles. There were many points raised in the feedback sessions. Among them, workshop participants suggested that analyzing what traits are important in varieties that are currently grown can inform the development of effective product profiles for new varieties. This led to looking more closely at the traits of Shangi. The agronomic and quality characteristics of the variety are good, but not outstanding. The main trait that stood out was its short dormancy. This was counter-intuitive, given the importance of

4 https://gender-portal.rtb.cgiar.org/breeding/

5 https://www.cgiar.org/initiative/market-intelligence/

TABLE 1 Draft potato product profile for tropical highlands.

Region/market segment	Trait (economic, sustainability, livelihood) and value	Target trait level	Market priority	Selection objective
African and Andean highland tropics				
Fresh market and processing	Yield	10% greater than X variety across a range of soil and management conditions	*1*	Maximize
	Table quality	tuber appearance and cooking type (check X), glycoalkaloid concentration <15 ppm.	1	Reach threshold
	Earliness	<110 days maturity	1	Reach threshold
	Resistance to late blight	Late blight susceptibility scores <3	1	Reach threshold
	Resistance to PVY	Extreme resistance to PVY	1	Reach threshold
	High Fe or Zn concentration	At least 35 ppm Fe or 30 ppm Zn	3	Opportunistic
	Drought tolerances (water productivity)	TBD (ratio of fresh tuber yields to applied water expressed as kg ha1 mm)	3	Reach threshold
	Good storability/dormancy	Unimodal >90 days and Bimodal to >60 days—sprouting with low water loss in storage	1	Reach threshold
	PLRV resistance	Resistance to PLRV as high or higher than variety X.	3	Opportunistic
	PVX resistance	Extreme resistance to PVX	3	Opportunistic
	Chipping ability	Chip score < 3	1	Reach threshold
	PCN resistance	No symptoms of PCN in inoculated plants and tubers	3	Opportunistic
	Bacterial wilt resistance	No symptoms in inoculated plants and tubers	3	Opportunistic

a mid-to long dormancy for effective storage of potato seed tubers, and that breeding programs usually selected for storability (longer dormancies) historically. This led to the breeding team to reconsider its assumptions regarding short dormancy and triggered their interest and curiosity about why and how this trait affected potato variety preferences.

A follow up workshop in Nairobi in 2019 aimed to share various experiences using a number of tools and strategies to integrate social differentiation and gender into product profile development (Polar, 2019). The group on potato evaluated survey data taken from 120 farmers (50% women), 22 processors and restaurant owners, 12 traders (mostly men), and 40 retailers (mostly women) from Uganda. Sensorial and organoleptic data were found to be still missing. It was determined that the breeding program still needed to properly define quality traits, translate farmer preferences to standardized scales for use by breeders, establish cross-functional teams, increase interaction with processing industry and improve communication with NARS and government stakeholders.

3.2 Market intelligence for East Africa market segment

Although much work has been done to elucidate varietal preferences of farmers through participatory variety selection (PVS), more systematic, accurate, forward-looking and scalable approaches are needed to capture the size and nature of current and future demand for varieties. Therefore, the CGIAR Initiative on Market Intelligence (MIPPS) is striving to standardize and develop tools for breeding teams to define market segments that will inform the design of TPPs for each segment. In this manner, information and data are collected to prioritize and align investments in breeding pipelines and seed systems (Donovan et al., 2022).

For potato, consumer requirements have a strong weight in determining the market segments. The data collected has been compiled in a Seed Product Market Segment Database[6] including potato, with currently nine market segments. For example, the market segment for table potato in the highlands of East Africa covers a target area of 412,000 hectares.[7] A dashboard provides the main criteria defining the market segment. Data characterizing the population in the region such as the population living in poverty and being malnourished can inform on the potential impact of a breeding pipeline investment. This segmentation provides the basis for developing the TPP for this segment. It is noteworthy that early maturity, and short dormancy are highlighted for this market segment.

6 https://ebs.excellenceinbreeding.org/wp-content/uploads/2023/03/MS-public.html

7 https://glomip.cgiar.org/target-product-profiles

3.3 G+ tools to inform potato market segments and target product profiles for East Africa

The development of the information on potato for the dashboard mentioned above was extensively described by Ojwang et al. (2023). In it, the authors analyzed the International Potato Center (CIP) and partners' potato breeding programs' potential impacts according to indicators of poverty, malnutrition, and gender. Using the seed product market segmentation blueprint developed by the EiB described above, the study identified and estimated the sizes of the market segments at subregional levels. A qualitative analysis described the sub-regions considering target populations of environments (TPEs) which are comprised of sets of farmers and seasons where a variety will be grown. The production systems were then described (e.g., rainfed vs. irrigated), as well as input systems and maturity. The criteria for consumer preferences then captured parameters such as cooking time, nutritional enhancement, flesh color, mealiness and hardness and the use of the product such as fresh market, consumption at home, or processing. This resulted in nine market segments being described. The market segments were then characterized quantitatively based on estimated size and opportunities for poverty alleviation, nutrition and gender equity outcomes using data from open-access databases.

The East Africa region had two market segments defined by use, household consumption (termed "table potato") and dual purpose (suitable for both commercial processing and household consumption). Fast cooking, early maturity and short dormancy were determined as the defining traits for this sub-region. The study then went further to estimate the potential poverty and nutrition impacts of investments in the respective market segments. The analysis showed more stunted children are found in the table potato market segments than the dual-purpose segment. The East Africa potato pipeline was shown to have 10.7 million stunted children in the table segment and 2 million in the dual-purpose segment. There was a 22% prevalence of undernourishment (Ojwang et al., 2023).

Using multidisciplinary teams, the G+ tools were then used to evaluate the gender-responsiveness of the breeding programs. The G+ Customer Profile Tool was used to map the customers for various products in the different market segments using gender-disaggregated data (Ojwang et al., 2023). The G+ Product Profile Tool was used to examine potential harmful as well as beneficial effects of specific traits in the product profiles. The teams looked at drudgery and time poverty, control over critical on-farm resources, access to inputs and control over benefits such as income from sales of the potato crop. The results identified traits associated with the "do no harm" concept, receiving a score to "amend". Therefore, the study showed that future gender-responsive breeding programs should take account of gendered quality traits such as taste, that are currently missing in the product profiles. The "do no harm" analysis highlighted the need to address gender relations to mitigate unequal benefit sharing. This kind of market segment analysis allows the breeding program to evaluate its breeding pipeline, looking at investments and potential impacts in the various segments across and within countries.

A recent study looked at end user preferences to inform product profiles in potato breeding in the Rakai and Kabale districts in Western Uganda (Nantongo et al., 2023). The G+ tools were used to evaluate priority quality traits for acceptance and adoption. Physico-chemical methods including instrument-based texture measurements such as penetration force and near-infrared spectroscopy (NIRS) were used to evaluate quality traits, so that breeders could use these in selecting material. The study followed a five-stage stepwise process to evaluate the quality characteristics for boiled potato as described in Forsythe et al. (2021). From a gender perspective, large tuber size, fast cooking time, moderately firm and good taste were identified as essential traits, as women are mainly involved in cooking the potatoes. For example, large tubers resulted in less waste due to peeling. Shangi was classified as soft and less mealy.

Another study applied the G+ tools using a multi-functional team of value chain actors to evaluate and modify a TPP developed under the Partnership for Seed Technology Transfer in Africa (PASTTA) project for table potato in Kenya, using Shangi as the benchmark (Mwende Mutiso et al., 2024). The profile targeted six traits: disease and pest resistance, tuber yield, earliness, dry matter content and shelf-life. However, dormancy was not highlighted among the key traits as most varieties have dormancy periods of a few months. Nevertheless, in analyzing the key traits through the gender lens, issues were identified that could bring forth the importance of short dormancy. Male farmers preferred earliness that allowed them to grow the crop thrice a year thus increasing profits because early potatoes are sold at a higher price when there is no glut. This is possible with varieties with short dormancy such as Shangi. Shelf-life was more controversial, as long shelf-life allows for storing potatoes with reduced post-harvest losses and getting higher prices after the harvest glut season. However, women retailers could be disadvantaged as they usually have less access to storage facilities than male counterparts. In addition, in respect to tuber seed availability, longer shelf-life that is negatively correlated with short dormancy, would prevent women from planting their own saved seed, especially when planting two seasons a year (Mwende Mutiso et al., 2024).

3.4 Shangi variety traits and development of the new potato product profile for Kenya

Dormancy is a physiological state in potato tubers, that affects production and storage. If the tuber is still dormant when planted, it will not start sprouting properly, thus affecting yields. If stored when not dormant, it will sprout prematurely and lead to spoilage and losses, whereas a dormant tuber will store stably until it sprouts (Kwambai et al., 2023). For production in tropical highlands, when more than one crop cycle is grown per year, a short dormancy of 1 or 2 months is required. In temperate regions with long winters, long dormancies for storage of both seed and ware potatoes are required.[8]

A study was carried out to examine the dormancy of 47 different varieties in Kenya grown at three altitudes over two seasons (Kwambai et al., 2023). As in Kenya potatoes are grown in the long rainy season as well as the short rainy season at mid-

8 https://blog.potatoworld.eu/dormancy-and-sprouting

to high altitudes, dormancy was evaluated and compared between the seasons. Ideally, breeders should select adapted varieties with a dormancy profile that can balance the ware storage with the optimal seed physiological age for planting, tailored for specific growing conditions (season and altitude). Shangi, Dutch Robijn, and Tigoni were the local checks in the study. There were large differences between the genotypes on days to dormancy release, with Shangi being the shortest with an average of 53.8 days to sprout. Other popular varieties had much longer dormancies such as 75.7 for Dutch Robjin and 72.3 for Asante.

As Shangi became a prevalent variety in most potato growing regions, preferred both by farmers, traders, and processors, it became necessary to re-evaluate commonly held assumptions in regard to storability and dormancy traits. This became apparent when the potato breeders, together with other stakeholders, economists, food technologists, gender specialists, went through the process of looking at variety design following the principles and strategies of demand-led breeding and the GBI. Consequently, market segments were designed looking at the whole potato value chain, both for fresh table produce, and processing into chips or crisps. Moreover, by examining the customer segments looking at gender but also social contexts of smallholder and disadvantaged farmers such as access to markets, inputs, labor, etc. it became apparent that availability at the right time of potatoes for consumption, processing or planting was of prime importance. Especially in the context of lack of storability infrastructure and poor access to distant markets due to poor infrastructure and undeveloped market structures (Manyasa, 2015). Shangi's very short dormancy, which had been assumed to be negative trait both for farmers, women processors and consumers, and cottage processors, was actually meeting the needs for available product and planting material given the storage and market constraints (Manyasa, 2015; Mwende Mutiso et al., 2024). In this manner, a need for potatoes could be met year-round. Moreover, some farmers, due to the short dormancy, were able to shift production to three seasons a year.

The iterative process described in this section led to the formulation of two updated TPPs for table potato and for dual-purpose (table and processed) potato for East Africa as well as another seven TPPs for other CIP potato breeding team target market segments (see text footnote 7). The TPP for table potato for East Africa is shown in Table 2. The TPPs follow the EiB structure for defined market segments followed by the traits, their description, desired levels, and a ranking of importance. By evaluating the market demand for Shangi and examining what traits contribute to its popularity, the dormancy trait is now part of the TPP. The profile now requires the new variety to be bred to have a short dormancy of under 60 days for production areas where two seasons are produced in 1 year (Bimodal). For the processing potato TPP, this is not a requirement, as part of the crop will need to be stored to ensure continuous supply to the processors. In addition, the TPPs have defined essential and nice to have tuber quality traits related to flavor, texture, cooking quality and cooking time, in response to the various studies that showed tuber taste and cooking attributes to be important for women (Mudege et al., 2021; Nantongo et al., 2023).

4 Conclusions

The ongoing efforts by CGIAR and partner breeding teams to shift to more demand-led breeding while establishing processes for more standardized variety design and genetic material advancement decisions using multidisciplinary teams is leading to well-characterized breeding pipelines based on priority market segments.[9] For the potato breeding program, this has resulted in nine TPPs linked to nine market segments, each with ranked sets of traits with desired ranges. Not only does this make more efficient use of limited resources, but it allows the monitoring and evaluation of breeding programs as well as capturing valuable learnings of processes and what works and what needs improvement. The expansion of this strategy to gender-responsive breeding using the tools and approaches of the GBI is enhancing the relevance and future adoption of new improved varieties coming thru the breeding program pipelines.

In the case of potato in East Africa, gender considerations have elevated the priority of quality traits such as taste (Mudege et al., 2021; Ojwang et al., 2023) and the need to develop effective assays for screening such traits (Nantongo et al., 2023). Even though short dormancy was found to be gender-neutral, the process of analyzing the product profiles through a gender lens, using the G+ tools made the breeders and multi-functional teams aware of the importance of re-evaluating long held conceptions about prioritizing long dormancy in all breeding contexts. The gender analysis of long shelf-life with conflicting views of benefit and harm to women raised the issue of how to handle the interaction with dormancy (Mwende Mutiso et al., 2024). In East Africa, where two and sometimes three potato crops are grown in the year, together with the lack of storage facilities (needed for long dormancy varieties), the dominant popularity of the Shangi variety is apparent. Shangi provides much needed ware and seed availability at all times. Therefore, the above process resulted in a dramatic change in the corresponding TPP, prioritizing short dormancy instead of having long dormancy as a given in all the breeding material. Therefore, attention to gender triggers closer attention to different segments of the population and can help breeding programs be more inclusive and responsive to a diversity of needs.

As mentioned in Mwende Mutiso et al. (2024), evaluating traits in a TPP using the "do no harm analysis" provides insights into possible impacts on gender equality. This is especially important in relation to commercialization of the crop, where men dominate and women may not share in the benefits, even if they must provide more labor for the commercial crop. For positive traits such as higher yields, these kinds of considerations must be taken into account, and the programs with improved higher-yielding varieties may need to accompany their release with strategies that mitigate such negative impacts on women. For example, early maturing varieties can be accompanied by extension activities to promote staggered planting and piecemeal harvesting to mitigate the burden of labor for women that have many other chores during planting and harvesting (Mwende Mutiso et al., 2024). In addition, in considering traits with a positive impact, this can bring added

9 https://ebs.excellenceinbreeding.org/wp-content/uploads/2023/03/MS-public.html

TABLE 2 Updated target product profile for table potato[a] for East Africa.

Trait type	Trait name*	Scale option	Trait requirement	Desired score
Agronomic	Tuber yield	Tons/ha	Nice to have	10% above check
	Marketable tuber yield	Tons/ha	Essential: improve	10% above check
Biotic—disease	Late Blight susceptibility	1 to 9	Essential: improve	<3
	Potato Virus Y resistance	1 to 7	Essential: threshold	1
	Potato Virus X resistance	1 to 7	Nice to have	1
	Bacterial Wilt resistance	1 to 6	Nice to have	<3
Biotic—pests	Potato Cyst Nematodes resistance	1 to 9	Nice to have	<3
Quality—analytical	Tuber dry matter content	%	Nice to have	18–20
	Chips oil absorption rate	%	Nice to have	<2
	Tuber flavor	1 to 5	Essential: threshold	>4
	Tuber cooking quality	1 to 7	Nice to have	<5
	Tuber cooking time	min	Essential: threshold	<10
	Tuber glycoalkaloids concentration	ppm	Essential: threshold	<15
	Tuber dormancy period	days	Essential: threshold	<60
Quality—visual	Predominant tuber skin color	1–9	Essential: threshold	6, 5 or 1
	Predominant tuber flesh color	1–8	Essential: threshold	4, 2 or 1
	Chips color	1–5	Nice to have	<2
	French fries color	1–5	Nice to have	<2
	Tuber depth eye	1–9	Essential: threshold	<3
	Tuber texture	1–5	Essential: threshold	>4
	Tuber appearance	1–9	Essential: threshold	>5
	Tuber shape	1–8	Essential: threshold	2–7
	Tuber uniformity	1–9	Essential: threshold	>5

*Based on the potato ontology available at https://cropontology.org/term/CO_330:ROOT.
[a]https://glomip.cgiar.org/target-product-profiles.

benefits to a new released variety, enhancing productivity, food security, and community resilience.

The changes to breeding program priorities to address the need for short dormancy reveals the farmers', processors' and traders' intention to have better control over their access to seed and product. Thus, they take advantage of this trait to address their limitations stemming from lack of storage facilities and underdeveloped market structures limiting access to distant markets.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: https://glomip.cgiar.org.

Author contributions

MF: Conceptualization, Writing – original draft, Writing – review & editing. VP: Conceptualization, Writing – review & editing. TM: 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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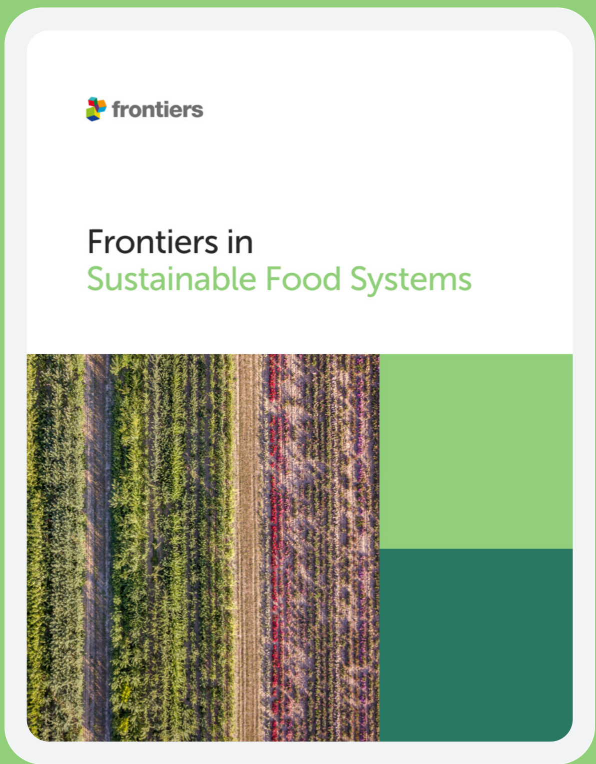

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