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An evidenced-based, farmer-focused revival of traditional cereals

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Revival of agrobiodiversity is a lynchpin for climate resilience, improved human nutrition, local economies, and cultural diversity. Following decades of decline in traditional cereals, the highest policy levels in India are promoting their revival. The revival is potentially as transformative for agriculture and diets as the Green Revolution that promoted high-yielding rice and wheat in the early 1960s and serves as a model for other places where traditional cereals are in decline. While the Green Revolution successfully increased cereal production and self-sufficiency, in hindsight critics have identified several environmental, social, and nutritional shortcomings. Efforts to revive millets can learn from these shortcomings with ground-level, systematic data collection using an adaptive management approach. Based on our observations from over 2,000 households surveys in the central Indian Highlands, we propose three principles to guide the collection of evidence for an ecologically-, nutritionally-, and socially-secure revival: (1) maintain diversity of millet species and varieties to preserve genetic resources in a rapidly changing climate; (2) ensure equitable access to technology, inputs, information and markets for all farmers; and (3) enable farmers to balance the trade-off between income from selling and nutritional benefits from consuming millets. The case study, which indicates the need for technologies to reduce drudgery from processing and attention to the income-nutrition trade-off for the poorest segments of the population, illustrates that ground-level data is needed to link high-level policy goals with field realities.

KEYWORDS

millets, India, orphan crops, neglected crops, revival, Central India, minor millets

1 Introduction

Humanity's reliance on a shrinking number of crop species has awakened calls for revivals of crops that have fallen out of production over the last decades. Such crops--variously labeled "traditional," "orphan," "neglected and underutilized," and "opportunity" crops—potentially provide resilience in a changing climate, nutrients for human diets, and cultural value (Padulosi et al., 2021). This paper addresses the reality of achieving this revival in India, where policymakers have embraced traditional cereals at the highest levels. To link this high-level policy attention with positive outcomes on the ground, we show that evidence is needed, particularly for marginalized farmers who are critical for a successful revival. These views are based on household surveys carried out by the authors in the central Indian Highlands, the largest producer of minor millets. The learnings apply to the India context, but they transcend to other countries and regions undertaking similar revivals.

India, the most populous country in the world, ranked 160 out of 189 countries for vulnerability of its food supply to climate change in 2023 (Notre Dame Global Adaptation Initiative Country Index (ND-GAIN), 2025). Rainfed crops provide livelihoods and food security for millions of small-scale farmers (Deshpande, 2022). Moreover, the country has the highest burden of undernourishment, accounting for 42 percent of the global burden, and micro-nutrient deficiencies are a major public health concern (Young et al., 2020).

Against this backdrop of climate vulnerability and nutritional concerns, in 2018 the Government of India declared millets to be "nutri-cereals," noting that "millets hold great potential in contributing substantially to food and nutrition security of the country and thus they are not only a powerhouse of nutrients, but also are climate resilient crops and possess unique nutritional characteristics" (Ministry of Agriculture and Farmers Welfare, 2018). India proposed to the United Nations General Assembly to adopt an "International Year of Millets," which was supported by 70 countries and declared for 2023 (Permanent Mission of India to the UN, 2023).

With heightened attention on millets, various states have launched millet missions, incorporated millets in their public distribution systems and midday meal programs and promoted their production and consumption through a variety of public- and farmer-facing programs. The Odisha Millet Mission (OMM) has received international acclaim for its participatory and inclusive design (Odisha Millets Mission – Equator Initiative, n.d.). At local levels, civil society organizations are reversing the decline in millets through holistic interventions addressing processing, market linkages, and farmers' access to information and seeds (King and Nithya, 2023; Nithya et al., 2025).

1.1 What are millets?

"Millets" is a generic term encompassing many species of small-seeded grasses that grow in semi-arid regions. The literature is inconsistent in the categorization of these species, but generally "major" millets include pearl millet, sorghum and finger millet. These millets came to India through trade routes from Africa thousands of years ago and are relatively easy to process by removing the husks. "Minor" millets include foxtail, proso (also known as broomcorn), kodo, barnyard (Japanese and Indian), little millet, and more rarely grown browntop and crabgrass millet (Supplementary Table S1). Minor millets are generally grown by tribal populations in hilly, remote regions (Padulosi et al., 2021). Some of the minor millets were domesticated in India while others originated elsewhere in Asia.

Millets are gluten-free, low glycemic, and provide high levels of micronutrients, particularly compared to rice (Dayakar et al., 2017). As a grass that follows the C4 photosynthetic pathway, millets have lower water requirements than rice and wheat (Davis et al., 2019), hence their label as "climate resilient".

As one of humanity's oldest foods, millets have deep-rooted cultural significance for beliefs, rituals, festivals, folklore, and medicinal use. Religious texts from many millennia ago mention various types of millets (Senthamil et al., 2023). Millets have been a staple for diets in semi-arid regions of the country dating back at least as far as the Harrapan Civilization (Pokharia et al., 2014).

In the second half of the twentieth century, agriculture in India underwent major transformations with the Green Revolution. With the focus on high-yield rice and wheat, both production and consumption of millets have declined. In the 1960's at the beginning of the Green Revolution, millets accounted for approximately 18 percent of all cereal production, compared with 5 percent in the 2010s (noting that overall production of cereals increased more than three-fold since the 1960s), with concomitant declines in consumption and micronutrient intake (DeFries et al., 2018). Despite the decline, India is still the world's largest producer of millets.

The millet revival is potentially as transformative for India's agriculture as the Green Revolution. It could improve drought tolerance, reduce water demand, benefit farmers' livelihoods from new markets for small and marginal farmers, and improve nutrition, with the proviso that the revival is successfully implemented by governments, private sector, and civil society to achieve these objectives. A positive outcome is far from assured.

In this perspective, we examine how learnings from the Green Revolution might guide the millet revival and the evidence required to ensure that it lives up to its potential. We illustrate how evidence from ground-level data collection can inform a farmer-focused millet revival in one millet-growing region, the central Indian Highlands, where households continue to produce and consume minor millets. The views are based on data from over 2000 household surveys in this region as well as observations from the field.

1.2 Learnings from the green revolution

India's food supply was at a crisis point with impending shortages from monsoon failures in 1965 and 1966. High-yielding dwarf varieties of wheat seeds bred in Mexico arrived in India in 1966, followed by IR-8 "miracle rice" bred in the Philippines that reached India the following year. The seeds were one part of a package of agricultural technologies aimed at increasing yields. Irrigation, fertilizers, and pesticides along with the new varieties made the increase in yields possible. In the following decades, cereal production in India increased more than 2.3-fold (DeFries, 2014). By the mid-1980s, over three quarters of land under wheat and half of land under rice were growing high yielding varieties (Parayil, 1992). India became self-sufficient in food production and currently exports food around the world.

Reams of observers have written about the outcomes, with both praise and criticism. Criticisms include environmental impacts on soil, water, and human health from heavy use of agricultural chemicals; inequitable access to inputs that exacerbated inequality; lack of focus on improving production in marginal environments; loss of genetic diversity from displacement of species and varieties other than high-yielding wheat, rice and maize; and production of abundant calories that are low in micro-nutrients such as iron and zinc (Pingali, 2012; John and Babu, 2021).

The potentially negative consequences came to the fore early in India's green revolution. M.S. Swaminathan, trained as a plant geneticist and known as India's Father of the Green Revolution for his pivotal role in introducing high-yield seeds, presciently laid out the consequences of a purely technical approach to increasing productivity (Swaminathan, 2004). He promoted a change in paradigm from exploitive agriculture, which he coined as an "evergreen revolution" based on ecological foundations.

Prior to the introduction of high yielding rice varieties, farmers across South Asia were growing more than 100,000

distinct landraces of rice that were adapted to local climate, soil, pests, and cultural preferences. This number has dwindled, though some of their germplasm is stored in seed banks (Deb, 2014; Khoury et al., 2022). In 1983, Prime Minister Indira Gandhi asked rice scientist R.H. Richharia to develop an action plan for increasing productivity in rice. Richharia had been developing high-yielding, semi-dwarf varieties from indigenous varieties, which he argued were better suited to Indian conditions. The plan, which included a recommendation to base rice development on these varieties, was shunted aside following Indira Gandhi's assassination (Dogra, 2018).

This narrative of the Green Revolution indicates that Indian scientists and policymakers were active players who were aware of the potential downsides of the rapid adoption of high-yielding rice and wheat. While it is impossible to construct a counterfactual, institutional lock-in and geopolitics that pressured India to accept advice from foreign experts and imported seeds (Kux, 1993) closed pathways for adaptive management that could have alleviated negative outcomes. With adaptive management, nimble management structures allow corrective action as new information becomes available. Key to adaptive management is monitoring, reassessing initial plans, and revising goals based on new evidence (Defries and Nagendra, 2017).

Adaptive management for a successful millet revival is more possible today than in the early days of the Green Revolution with developments in multiple methods for data collection and communication, e.g., crowd sourcing, remote sensing, analytical tools, information sharing, and appreciation for traditional knowledge and diversity. Based on the learnings from the Green Revolution and our observations from the case study in the Central Indian Highlands, we propose three principles to guide collection of evidence for an ecologically-, nutritionally-, and socially-secure millet revival: (1) maintain diversity of millet species and varieties to preserve genetic resources for breeding climate resilient and other desirable traits in the future; (2) ensure equitable access to technology, inputs, information and markets for all farmers; and (3) enable farmers to balance the trade-off between income from selling and nutritional benefits from consuming millets. Recognizing that each geography has its own ecological and cultural heritage, the case study illustrates that evidence can contribute to a successful millet revival based on these three principles.

2 Case study of minor millets in the central Indian highlands

Adaptive management to achieve high-level goals for a millet revival depends on evidence and understanding ground realities of farmers' constraints. As an example of an effort to collect such data, we focus on the district of Mandla and surroundings in the central Indian highlands (DeFries et al., 2016). Mandla district, which lies in the southwestern portion of the state of Madhya Pradesh, is the largest producer of minor millets in the country with a high proportion of tribal populations (Supplementary Figure S1). Many households suffer from food insecurity (Neelakantan et al., 2020). In this perspective article, we use this illustrative case study to highlight pathways for evidence-based adaptive management rather than to present a full set of empirical results.

We carried out 2082 baseline surveys in households across 117 villages in March and August 2023 (with subsequent annual survey rounds to track changes which are not reported here). The purpose of the surveys is to help several non-governmental organizations who are working at ground-level to adaptively manage their interventions.

The data collection was designed to assess trends in millet production and consumption in relation to NGO interventions in agronomy and awareness programs over five years. We selected villages based on locations where the NGOs are carrying out interventions and an equal number of villages with similar soil, climate, topography and demographic characteristics (Supplementary Figure S2 for village locations). For the analysis in this paper, we aggregated all the surveys across 117 villages for the baseline surveys carried out in March and August 2023. We surveyed approximately 25 randomly-identified households per village. Survey questions included household demographics, cereals that the household grows, whether and how much the household sells its cereal crops, and cereal consumption patterns.

Based on our observations in the baseline surveys, we propose key variables that need to be tracked for adaptive management to achieve positive outcomes for farmers: diversity of species and varieties, access to markets and technologies, and trade-offs between income and nutrition. Disaggregating these variables by asset class (as a proxy for income) enables insight into equitable distribution of benefits from interventions (see Supplementary materials for details on methodology for analyzing survey results).

2.1 Diversity of millet species and varieties

Approximately 90 percent of surveyed households grow rice, incentivized by government procurement and guaranteed price. Some farmers also grow minor millets, predominantly kodo millet (38%) and little millet (34%). The percentage of farmers growing these native millets is on par with maize (38%) and more than wheat (28%). The region maintains a dwindling diversity of other species of minor millets (Figure 1A; Supplementary Figure S2). Many of these millets have fallen out of production.

Disaggregated by asset class (proxy for income, 1 to 4 lowest to highest, see Supplementary materials), asset-poor farmers are more likely to grow millets than higher asset classes. Reasons that farmers respond about why they do not grow millets include lack of seeds, no land for growing millets (sloping land to grow millets might have been leveled for paddy cultivation), low production, and lack of resources.

2.2 Access to markets and technologies

Private buyers come to the villages to purchase kodo and little millet as a raw, unhusked product. A greater proportion of households in higher level asset classes sell their millets (Figure 1B), suggesting that these farmers have greater access to the market and are more likely to gain income from their millet production.

The traditional practice to de-husk and process millets at home is very labor intensive and is carried out by women. Anecdotally, this drudgery is a major reason why the younger generation does not aspire to include millets in their diets. More than 90 percent of households that consume millets de-husk at home across all asset

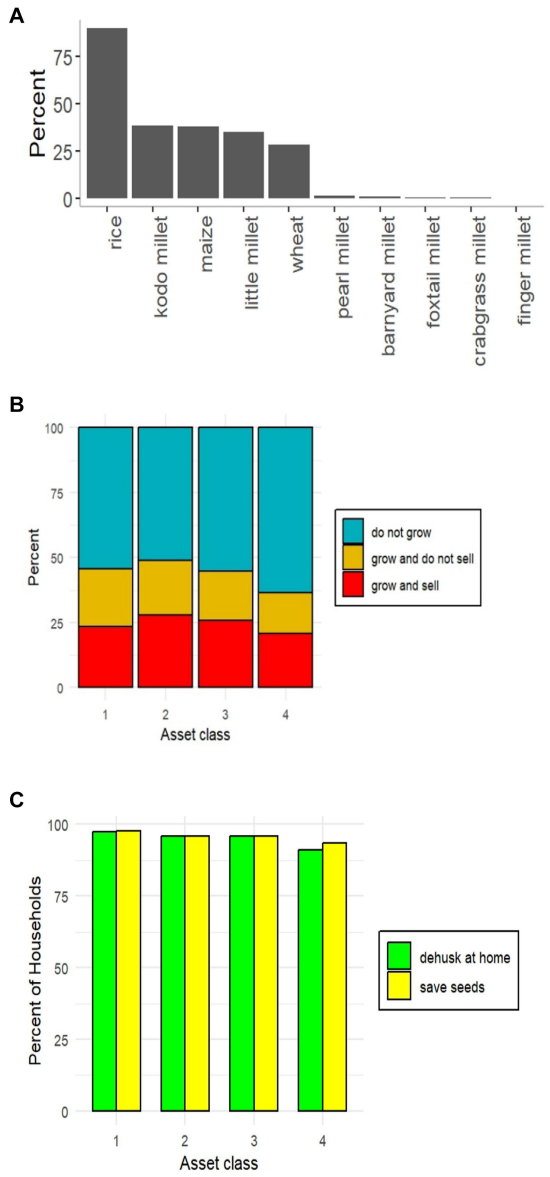

FIGURE 1
Frequency of growing millets and mainstream (rice, wheat, and maize) in 2082 surveyed households **(A)**. Percent of households growing and selling millets by asset class **(B)**. Use of technologies for de-husking and seeds across asset classes **(C)**.

classes. Slightly more households in higher asset classes de-husk in mills or purchase or barter to obtain millets (Figure 1C).

More than 95 percent of all households who grow millets use seeds saved at home from previous harvests (Figure 1C). Access to improved varieties through the government and universities is very limited across all asset classes (Hariprasanna, 2023).

2.3 Trade-off between income and nutrition

Rice is a staple in the diets of all households, with 97 percent of households reporting that they consume rice as their main cereal. Homegrown rice is the main source with the public distribution system (PDS) providing some portion of rice.

Sixty-six percent of households report that they currently include millets in their diets, with 48 percent of surveyed households reporting that they eat millets more than once a month, 27 percent more than once a week, and 3 percent every day (Figure 2A). Twenty-two percent of households report that they previously ate millets but no longer consume them, with 12 % reporting that in their memory the household never consumed millets. In response to questions about why they stopped eating millets, responses included that millets are not available, that they do not grow it anymore, that children in the house do not like it, and that they eat rice now.

Disaggregated by asset class, survey responses illustrate the potential tradeoff between benefits from small millets as sources of income and nutrition. Frequency of eating millets is highest in lower asset classes, suggesting the importance of millet consumption for nutrition in the poorest segments of the population (Figure 2B). Frequency of consumption declines if households sell millets. Survey results also point towards increasing dependence on low nutrient-quality rice from the PDS for households who sell their millets. Forty-two percent of households who sell millets depend on PDS rice, while only 27 percent of households eat rice from the PDS if they grow but do not sell their millets.

The survey results collectively paint a picture of the remaining presence of minor millets in this region, although production and consumption have markedly declined. This evidence suggests that improved access to a variety of seeds for different kinds of millets; improved market access and government support particularly for poor farmers; assurance that millets are available and affordable for local populations; and reduced drudgery through processing technologies could promote a successful millet revival in this region. Surveys repeated over time can track the effectiveness of interventions.

3 Discussion

The millet revival is part of a growing global movement to elevate "orphan" and "neglected and underutilized species" as "opportunity crops" (Fowler, 2023). After decades of investments focused heavily on the three main cereal commodities – rice, wheat, and corn – climate change, persistent food insecurity amidst abundance, and the need for food sovereignty to buffer against international price spikes have raised consciousness about alternative paradigms.

The millet revival has the benefit of advanced data collection and communications that were not possible during the Green Revolution. These capabilities enable civil society, governments, and the many parties involved in India's millet revival to build on the learnings from the Green Revolution. Ground-level evidence can inform adaptive management based on the principles above, particularly for marginalized and women farmers who might otherwise remain less visible in the millet ecosystem.

The first principle highlights the need to maintain diversity of species and varieties of millets to allow for greater adaptation to changing climatic and environmental conditions. Minor millets hold stores of diversity but get less policy attention than other cereals. Seed

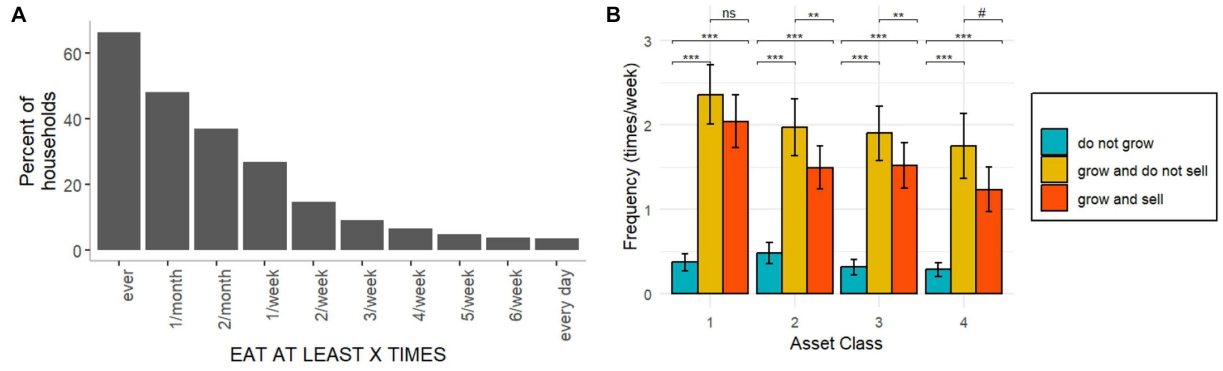

FIGURE 2
Frequency of eating millets **(A)**. Average frequency of eating millets by asset class and whether households sell millets (n = 2,820). p-values for differences between groups are *** < 0.001, ** < 0.01, * < 0.05, # < 0.10 **(B)**.

banks are critical, but not sufficient as substitutes for *ex situ* conservation which help varieties adapt and evolve to new conditions. Custodial farmers and other investments can help maintain rapidly dwindling diversity (Nithya et al., 2025).

To address the second principle, access to markets and processing technology needs to reach the poorest farmers. Without equitable access to improved technologies that reduce drudgery and boost yields, the next generation of farmers is likely to lose interest in growing and consuming millets. This requires government support, and cannot be left purely to the market.

With respect to the third principle, insights from the case study and elsewhere suggest that players in the millet revival need to pay particular attention to potential negative outcomes from the cash crop-nutrition tradeoff, for instance by ensuring that millets are affordable and locally available. A transition from subsistence to commercial (more likely a combination of both) holds promise of increasing income but is potentially damaging if farmers substitute less nutritious, easily available rice for more nutritious millets.

Evidence from similar transitions in other parts of the world point to the range of possible outcomes from a cash crop-nutrition tradeoff, with positive outcome for diets from teff in Ethiopia (Assefa et al., 2024; Gebrehiwot and Ndinda, 2024) and negative outcomes for oil palm in Ghana (Anderman et al., 2014).

In the case study of minor millets in the central Indian Highlands, the cash crop-nutrition tradeoff requires monitoring and attention. Household nutrition could improve with the income generated from selling millets. However, national-level consumption data indicates that micronutrients that drop out of diets with declining millet consumption were historically not replaced by additional high-nutrient items in diets (DeFries et al., 2018).

Positive outcomes from a millet revival are possible but are not assured, particularly for the poorest farmers. With ground-level evidence collected at repeated intervals and ability to intervene to redirect negative outcomes, a farmer-focused millet revival can build on the learnings from the Green Revolution and contribute to nutritional sovereignty, equity, and climate-resilience amidst rapid change.

Data availability statement

The aggregated raw data will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Columbia University IRB protocol number AAAU3879. The studies were conducted in accordance with the local legislation and institutional requirements. The ethics committee/institutional review board waived the requirement of written informed consent for participation from the participants or the participants' legal guardians/next of kin because respondents were not literate in all cases.

Author contributions

RD: Investigation, Conceptualization, Writing – original draft, Methodology. EK: Writing – review & editing, Conceptualization. MM: Writing – review & editing, Investigation. HN: Writing – review & editing, Conceptualization. AN: Investigation, 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.2025.1592723/full#supplementary-material

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