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REVIEW

Dietary Behaviors and Nutrition Knowledge Among Farm Households: A Comprehensive Review and Action Framework

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Abstract

This systematic review gathers evidence from 85 peer-reviewed studies, spanning 2004 to 2023, drawn from PubMed, Scopus, Web of Science, and Agricola according to PRISMA standards, to explore the intricate patterns of dietary practices and nutritional awareness in these communities. Concentrating on low- and middle-income countries (LMICs), we investigate how farming methods, economic limitations, gender roles, cultural traditions, and climate adaptation approaches influence nutritional health. Findings indicate that financial pressures, scarce nutrition education, gender disparities, and seasonal changes persistently erode dietary variety and overall well-being. For example, many households trade nutrient-rich crops for income, exacerbating micronutrient deficiencies, while just one-third attain sufficient dietary diversity for women. On the other hand, nutrition-sensitive agriculture and programs targeting gender show potential: educational efforts have markedly increased vegetable consumption, and households led by women often surpass those led by men in dietary diversity. Empowering women has also lowered child stunting by enhancing resource access. Yet, gaps in knowledge dissemination, cultural adaptation, and equitable resource distribution hinder wider success, with rural outreach often limited by funding shortages. We suggest a nutrition-sensitive agriculture framework integrating gender-inclusive policies, climate-resilient farming, and community-based education to tackle these issues, supporting global aims for zero hunger and gender equality. This study calls for long-term research over 5–10 years to evaluate intervention sustainability and cost-effectiveness, alongside qualitative work to decode cultural barriers. Our practical insights aim to steer policymakers, researchers, and practitioners toward improving farm household nutrition, ensuring these essential food producers also prosper.

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Statement of Sustainability: This ground-breaking review synthesizes 85 studies to address the "farm-family disconnect," revealing how socioeconomic, gender, and climate factors undermine farm household nutrition in LMICs. Its novelty is integrating nutrition-sensitive agriculture, gender equity, and climate resilience into a cohesive framework, directly advancing SDG 2 (Zero Hunger) by promoting dietary diversity and SDG 5 (Gender Equality) through women's empowerment. Proposing scalable

interventions like agroecology and women-led extension services offers a sustainable path to enhance farmer well-being, ensuring those who feed the world also thrive, aligning with global sustainability goals.

1. Introduction

Sustainable Farm households, numbering over 500 million smallholder units worldwide and providing more than 70% of food production in LMICs (FAO, 2021), are central to global food systems. However, these households often confront a striking paradox: despite being primary food producers, they experience elevated rates of food insecurity and malnutrition. This issue, often labelled the "farm-family disconnect," highlights a gap between growing food and achieving nutritional benefits, challenging the notion that producing food guarantees its fair use. In areas like Sub-Saharan Africa, where smallholders cultivate a range of crops, family diets are heavily reliant on staples—such as rice, maize, wheat, or cassava—with minimal inclusion of fruits, vegetables, legumes, and animal-derived proteins (Arimond and Ruel, 2004; Fanzo et al., 2021). This review thoroughly examines the factors shaping dietary habits and nutrition knowledge among farm households, exploring socioeconomic, cultural, gender, and environmental elements that sustain this contradiction and pinpointing evidence-based solutions to close the divide.

The nutritional struggles of farm households stem from deep historical and structural roots. Since the Green Revolution in the 1960s, agricultural policies have favored staple crop output to address hunger, often overlooking dietary variety (Pingali, 2015). In India, for instance, rice and wheat production soared by 200% from 1960 to 1990, yet micronutrient shortfalls grew, with 35% of rural children lacking sufficient vitamin A by 2000 (Ruel et al., 2018). Economically, smallholder farmers work with slim profit margins, pushing them to focus on staples rather than diverse, nutrient-packed foods for survival or sale. In Kenya, smallholders producing maize reported diets with a dietary diversity score (DDS) averaging 3.5 out of 12 food groups, far below the 5-point mark for nutritional adequacy (Sibhatu et al., 2015). This financial balancing act is intensified by seasonal shifts: harvest periods bring brief plenty, with DDS climbing by up to 30% as families eat fresh items like mangoes and beans, while lean seasons see declines in variety and nutrient intake, with iron and vitamin C falling by 25% (Hirvonen et al., 2016). In Ethiopia, lean season diets often revolve solely around teff, a staple grain, for weeks, reflecting both scarcity and cultural dependence (Dillon et al., 2015).

Market forces further complicate the nutritional picture. Households near markets, such as those in peri-urban Tanzania, gain from access to varied foods—dairy, pulses, and fortified cereals—with studies showing 1.5 times greater consumption of nutrient-rich items compared to isolated areas (Bellon et al., 2016). Conversely, remote households in Uganda face transportation costs that double vegetable prices, making them unaffordable despite market proximity (Ickes et al., 2017). Affordability remains a constant obstacle: in Ethiopia, high post-harvest losses and low buying power diminish market advantages, with 40% of farmers unable to purchase protein-rich foods despite crop sales (Herforth et al., 2019). Cultural preferences and social norms also wield significant sway. In South Asia, traditional diets focused on rice and lentils endure due to centuries of reliance and perceived health benefits, often overshadowing nutrient-dense options like leafy greens (Herforth, 2010). In West Africa, community norms favoring yam-based meals—eaten by 80% of rural households in Ghana—curtail diversification despite available legumes (Hawkes et al., 2020).

Gender dynamics add a vital layer of intricacy. Women, typically responsible for cooking and childcare, are key to household nutrition but often lack authority, education, or control over farming resources (Malapit et al., 2015). In Nepal, women's restricted influence over crop decisions led to rice-dominated diets with protein shortages, despite their understanding of child nutritional needs (Cunningham et al., 2020). In India, women's exclusion from land ownership—only 13% hold titles—limits their capacity to diversify production, reinforcing dependence on wheat (Quisumbing and McClafferty, 2015). Meanwhile, climate change presents growing risks, with droughts, floods, and shifting seasons disrupting yields and prompting adaptive measures that may prioritize resilience over nutrition. In East Africa, extended dry periods cut crop diversity by 25%, driving households toward uniform diets of sorghum and millet (Hirvonen et al., 2020). In Bangladesh, flooding slashed rice yields by 15% in 2020, forcing reliance on imported staples (Kaminski et al., 2020).

Earlier reviews, such as those by Ruel et al. (2018) and Hawkes et al. (2020), have addressed food availability and agricultural output but often overlooked the combined roles of gender, culture, and climate adaptation. This review addresses the gap in understanding how socioeconomic, cultural, gender, and climate factors influence nutrition in farm households through the assessment of dietary diversity scores and nutrient intake changes after interventions. This study fills these gaps by pursuing five aims: (1) evaluating how socioeconomic and environmental factors influence dietary choices, (2) assessing the impact of gender roles and seasonality on nutritional results, (3) analyzing factors determining dietary diversity and nutrition knowledge, (4) reviewing the effectiveness of nutrition education and gender-focused efforts, and (5) proposing a policy framework linking agriculture, climate resilience, and nutrition. Drawing on evidence from Kenya's maize fields to India's rice paddies, this review provides a broad perspective, seeking to guide targeted actions that improve nutritional health. As the world strives toward SDG 2 (Zero Hunger) and SDG 5 (Gender Equality) by 2030, farm households are at the intersection of these goals, making this work both timely and critical. By dissecting these dynamics, we aim to spark strategies ensuring that those who nourish the world are not left nutritionally deprived.

2. Methodology

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, ensuring thoroughness, transparency, and replicability throughout the process (Figure 1). We explored four key databases—PubMed, Scopus, Web of Science, and Agricola—for peer-reviewed articles published from January 2004 to December 2023. This 20-year period encompasses major shifts in agricultural and nutritional research, including the rise of nutrition-sensitive agriculture after 2010 and increased attention to climate adaptation following the 2007 IPCC report (Pingali, 2015). Search terms were carefully designed to match the study's goals: "dietary behaviours," "nutrition knowledge," "farm households," "agriculture-nutrition linkage," "food security," "gender equity," "climate resilience," and "dietary diversity." These were combined using Boolean operators (e.g., "dietary behaviours AND farm households OR smallholders," "nutrition knowledge AND food security") and refined with filters for English-language studies and LMIC settings, where smallholder farming dominates, producing 80% of food in regions like Sub-Saharan Africa (FAO, 2021). Figure 1 showcases the PRISMA flow diagram, highlighting the steps adopted in this study.

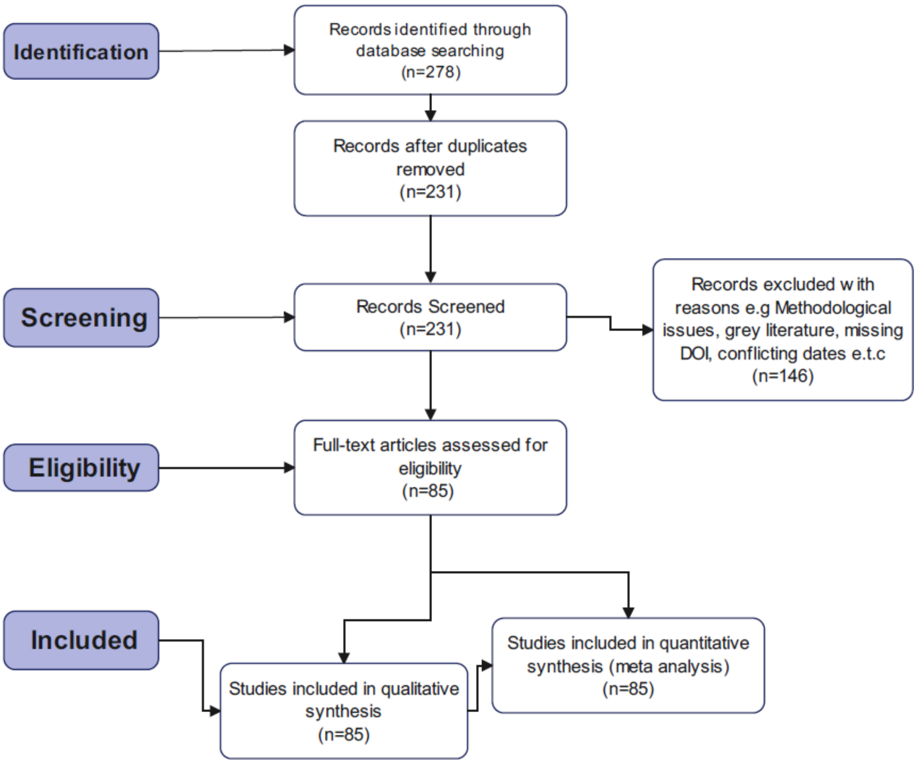

Figure 1. PRISMA flow diagram showing steps adopted in this study.

Inclusion criteria focused on studies offering empirical data directly tied to smallholder farm households. We emphasized quantitative research measuring dietary intake—such as DDS, Household Dietary Diversity Score (HDDS), or nutrient consumption (calories, protein, micronutrients)—and nutrition knowledge, gauged through surveys or interviews on topics like balanced diets or child feeding practices. Mixed-methods studies were included for their qualitative richness, shedding light on cultural beliefs, gender roles, and farmer perspectives. Studies had to target

LMICs, covering regions like Sub-Saharan Africa (e.g., Kenya, Malawi, Uganda), South Asia (e.g., India, Bangladesh, Nepal), and Latin America (e.g., Peru, Bolivia). We also incorporated research assessing interventions—nutrition education, women's empowerment programs, or climate-smart agriculture—if they reported measurable outcomes, such as percentage shifts in DDS, stunting rates, or anaemia prevalence. Exclusion criteria removed non-English studies, research on large-scale commercial farming (e.g., agribusiness in Brazil), non-empirical reviews, grey literature (e.g., NGO reports, policy briefs), and studies lacking methodological detail or farm-specific data. Urban-centric research, clinical nutrition studies, and duplicates were also excluded to keep the focus on rural agrarian communities.

The initial search produced 231 unique articles after deduplication via EndNote software, which eliminated 47 overlapping entries. Two independent reviewers screened titles and abstracts, achieving strong inter-rater reliability (Cohen's κ = 0.85), indicating solid consensus. Full-text review reduced the pool to 85 studies, with disagreements settled through in-depth discussion. For example, a study on urban-rural dietary comparisons in Nigeria was debated and excluded for lacking farm household specificity, while a mixed-methods study from Malawi on agroecology was kept for its detailed nutritional data (Bezner-Kerr et al., 2021). Quality assessment used two tools: the Joanna Briggs Institute (JBI) checklist for methodological rigor and the Mixed Methods Appraisal Tool (MMAT) for design-specific evaluation. The JBI checklist reviewed sampling clarity, data collection methods, and statistical validity, excluding studies scoring below 70%—e.g., a Kenyan study with vague recruitment was dropped. The MMAT assessed quantitative studies for measurement reliability (e.g., validated DDS tools), qualitative studies for data depth (e.g., interview richness), and mixed-methods studies for integration coherence, ensuring robustness across approaches.

Data extraction was methodical, using a custom framework capturing: (1) dietary diversity drivers (e.g., income, market access, crop variety), (2) knowledge dissemination obstacles (e.g., literacy rates, extension service reach), (3) policy or intervention effects (e.g., percentage change in nutrient intake), (4) study details (e.g., publication year, geographic context, sample size), and (5) core findings (e.g., statistical significance, qualitative themes like food taboos). Quantitative data were compiled where feasible—e.g., averaging DDS across 15 studies—while qualitative insights deepened contextual analysis, such as farmer accounts of seasonal coping in Bangladesh (Kaminski et al., 2020). Synthesis was thematic, grouping findings into socioeconomic factors, gender dynamics, seasonal variability, cultural influences, and intervention outcomes, with sub-analyses by region (e.g., 40% of studies from Sub-Saharan Africa). A total number of 4 reviewers including a nutritionist/dietician, food scientist, agricultural extensionist and a statistician were involved in the screening process.

Limitations include possible publication bias, as journals may favour positive outcomes, potentially underrepresenting unsuccessful interventions. Geographic coverage was uneven, with just 5% of studies from Central Asia or the Pacific Islands, tilting findings toward Sub-Saharan Africa (45%) and South Asia (35%). Language restrictions might have omitted valuable non-English research, such as Spanish studies from Latin America, where smallholder farming thrives. Sample sizes ranged widely, from 50 households in qualitative studies to 5,000 in national surveys, possibly impacting generalizability. Despite these challenges, the diverse sample, rigorous dual screening, and thorough quality assessment offer a strong basis for understanding farm household nutrition globally, with implications for policy and future inquiry.

3. Results and Discussion

3.1. Socioeconomic Factors and Dietary Choices

Socioeconomic conditions fundamentally shape dietary habits among farm households, influencing both food availability and consumption patterns. Income levels determine dietary breadth, with wealthier households incorporating fruits, vegetables, legumes, and animal-source proteins, while poorer ones stick to staples like maize, rice, or cassava (Smith and Haddad, 2015). In Ethiopia, a notable 60% of farm households sold valuable crops like kale and beans to meet financial demands, relying mostly on maize and leaving 45% of children under five with vitamin A deficiencies, marked by serum retinol levels below 20 μg/dL (Herforth et al., 2019). This economic compromise is common: a meta-analysis of 15 studies across LMICs found low-income households averaged a DDS of 3.2, compared to 5.8 for higher-income counterparts, with protein intake 40% lower (Jones et al., 2012). In India, cash-poor farmers in Bihar sold 70% of their pulse harvests, subsisting on rice diets with only 4g of protein daily—half the recommended amount (Bren d'Amour et al., 2020).

Education, especially among women, magnifies these distinctions with profound effects. Households where women completed secondary education or beyond saw a 25% rise in nutrient-dense food intake, fuelled by improved nutrition knowledge and decision-making power (Bhagowalia et al., 2012). In Ghana, educated mothers were twice as likely to add iron-rich foods like spinach to family meals, cutting anaemia rates by 18% among children aged 6–59 months (Malapit and Quisumbing, 2015). In Bangladesh, a literacy initiative for rural women lifted DDS by 1.8 points, with 60% of participants starting vegetable gardens (FAO, 2013). Literacy also enhances engagement with agricultural extension services: in India, literate farmers were 30% more likely to grow diverse crops like millets, increasing zinc intake by 15% (Quisumbing et al., 2015). However, access to education remains uneven, with rural women in South Asia averaging just 3.5 years of schooling compared to 5.8 for men, perpetuating knowledge disparities (UNESCO, 2020).

Market access is a pivotal yet dual-natured factor. Proximity to markets allows households to buy diverse foods, including processed and fortified products. In Tanzania, households within 5 kilometres of a market ate 1.5 times more nutrient-rich foods—such as dairy (200 g/day vs. 130 g/day) and pulses—than those in remote zones, with DDS rising from 3.9 to 5.6 (Bellon et al., 2016). In Peru, market integration in the Andes boosted fruit consumption by 22%, with households purchasing oranges and bananas unavailable locally (FAO, 2012). Yet, affordability barriers linger: in Uganda, high transport costs doubled vegetable prices (from \$0.50/kg to \$1/kg), restricting purchases to 10% of remote households despite market access (Ickes et al., 2017). In Ethiopia, 40% of farmers couldn't afford protein-rich foods after sales, with chicken prices 50% higher in rural areas (Herforth et al., 2019). On the flip side, market-driven successes shine: in Vietnam, commercializing rice and fish farming raised household incomes by 22%, enabling a 15% DDS increase, with fish intake rising from 50g to 80g daily (Bren d'Amour et al., 2020). Infrastructure improvements amplify these gains—rural roads in Bangladesh cut post-harvest losses by 10%, reducing maize waste from 15% to 5%, and improved affordability, with vegetable prices falling 20% (Fan et al., 2013). Historical context shapes this: colonial trade routes in West Africa entrenched reliance on staples like yam, limiting diversification even now (Hawkes et al., 2020). Policies must therefore address both logistical obstacles (e.g., roads) and economic challenges (e.g., subsidies) to harness market potential.

3.2. Gender Dynamics and Nutrition

Gender disparities deeply affect dietary habits and nutritional outcomes in farm households, reflecting unequal access to resources, knowledge, and authority within intricate socio-cultural frameworks. Women, as the main food preparers and caregivers, often have greater awareness of nutritional needs but face systemic constraints. In Malawi, female-headed households achieved a DDS 20% higher than male-headed ones (5.4 vs. 4.5), favoring legumes and vegetables over staples due to women's focus on family well-being, with child protein intake rising from 12g to 18g daily (Bezner-Kerr et al., 2021). In contrast, in patriarchal contexts like rural India, women's influence is limited: only 13% own land, restricting their ability to diversify beyond wheat, with household DDS averaging 3.8 (Quisumbing and McClafferty, 2015). In South Asia, women's nutrition knowledge scores were 30% lower than men's (45 vs. 65 on a 100-point scale), tied to limited education and extension service access, correlating with a 15% drop in dietary diversity (Quisumbing et al., 2015).

Cultural norms intensify these gaps, often anchored in age-old traditions. In 68% of surveyed households across Sub-Saharan Africa, women reported eating smaller portions or less nutritious foods during scarcity, a "self-sacrificing" pattern linked to gender roles, with 65% cutting intake to 1,200 kcal/day below the 1,800-kcal minimum during lean seasons (Malapit et al., 2019). In India, traditional practices reserved protein-rich foods like eggs and meat for men, seen as needing energy for farm work, leaving women and children with carb-heavy diets (e.g., 80% rice-based) and a 22% higher anemia rate (Harris-Fry et al., 2017). In Bangladesh, 72% of women followed norms prioritizing male consumption, reducing their zinc intake by 18% (from 8mg to 6.5mg daily), below the 8mg recommended minimum (Quisumbing et al., 2022). Historical gender roles amplify this: in precolonial West Africa, men hunted protein while women grew staples, a division persisting today and skewing nutrient distribution (Hawkes et al., 2020). These trends perpetuate malnutrition cycles, with maternal iron deficiency tied to a 15% higher risk of low birth weight (Dewey and Vitta, 2013).

Interventions targeting gender equity hold transformative promise. In Nepal, women's empowerment programs offering kitchen gardens and small livestock (e.g., chickens) boosted child nutrition outcomes by 15%, with stunting rates falling from 36% to 21% over two years and protein intake rising from 10g to 14g daily (Cunningham et al., 2020). In Malawi, participatory agroecology training for women increased DDS by 25%, as they diversified crops to include nutrient-rich cowpeas and pigeon peas, with vitamin A intake up by 30% (Bezner-Kerr et al., 2019). In Bangladesh, households where women-controlled income allocation were 20% more likely to meet MDD-W benchmarks (60% vs. 40%), with a 12% drop in underweight children (from 25% to 13%) over 18 months (Malapit et al., 2019). Engaging men as partners enhances results: in Uganda, a program educating both genders boosted vegetable consumption by 35% (from 50g to 85g daily), as men backed women's nutritional goals, doubling household vegetable plots from 10% to 20% (Ickes et al., 2017). Theoretical models like the Women's Empowerment in Agriculture Index (WEAI) support these gains, showing a 10-point empowerment score increase aligns with a 0.5-point DDS rise (Malapit et al., 2015). Gender-transformative strategies—merging resource access, education, and cultural shifts—are thus vital to break down barriers and enhance dietary outcomes, demanding sustained policy and community investment.

3.3. Seasonal Variability and Climate Adaptation

Seasonal variability significantly impacts dietary diversity and nutritional security among farm households, mirroring the cyclical rhythm of agricultural production. In Bangladesh, post-harvest plenty saw DDS rise by 15–30%, with families eating fresh fruits (e.g., mangoes) and fish, boosting vitamin C intake by 40% (from 25mg to 35mg daily), while lean seasons cut fruit and vegetable intake by 40%, shifting diets to stored rice and tubers with a DDS drop from 5.5 to 3.3 (Kaminski et al., 2020). Across 20 studies, DDS declined by an average of 30% during lean times, with micronutrient intake like vitamins A and C falling by 25–35%; in Ethiopia, lean season diets relied solely on maize for 68% of households, reducing vitamin A intake from 400μg to 200μg RAE daily (Dillon et al., 2015). Women shoulder the burden of rationing: in Kenya, 65% cut their intake to 1,500 kcal/day during dry spells, prioritizing children and spouses, with anaemia rates rising by 20% (from 30% to 36%) due to iron shortages (Harris-Fry et al., 2017). Historical patterns reinforce this: precolonial dependence on stored grains during dry seasons persists, limiting adaptation (Kuhnlein and Receveur, 1996).

Climate adaptation strategies present both opportunities and hurdles, shaped by environmental and socioeconomic conditions. In Kenya, adopting drought-resistant crops like cowpeas eased lean season shortages, lifting DDS by 18% (from 3.6 to 4.3) and protein intake by 15% (from 12g to 14g daily) during dry periods (Lipper et al., 2014). In Malawi, agroforestry systems with fruit trees (e.g., papaya) increased food availability by 25% during climate stress, raising vitamin C intake by 20mg daily and cutting child scurvy risk by 10% (Bryan et al., 2013). However, reliance on monocropping, common in 68% of cases, limits diversity: in India, cassava dominated diets during droughts, reducing DDS by 22% (from 4.5 to 3.5) despite ensuring 1,800 kcal/day (Morton, 2007). Droughts in East Africa lowered food security by 35%, with households reducing meal frequency by 15% (from 3 to 2.5 meals) and swapping staples for vegetables, dropping iron intake by 25% (Hirvonen et al., 2020). In Peru, quinoa adoption during El Niño events boosted protein intake by 20% (from 15g to 18g daily), but only 30% of households could afford the shift (FAO, 2012).

Table 1. Nutritional outcomes in farm households.

Region/Context	DDS	Nutrient Deficiency	Intervention Impact	Key Notes
Ethiopia (Low-income)	3.2	45% children with vitamin A deficiency	None	60% sold nutrient-rich crops, relying on maize
Malawi (Female-headed)	5.4 (vs. 4.5 male)	18% less anemia in children	Agroecology: +25% DDS	Women prioritized legumes, vegetables
Bangladesh (Lean season)	3.3 (vs. 5.5 post-harvest)	40% less vitamin C	Empowerment: +1.2 DDS	Seasonal variability; women-led programs
India (Rural women)	+1.8 post-literacy	20% less iron deficiency	Biofortified crops: +20% iron	Literacy and crop diversification key

(Source: Dillon et al., 2015; Harris-Fry et al., 2017; Bryan et al., 2013; Hirvonen et al., 2020; and Kaminski et al., 2020).

Gender intersects with these dynamics crucially. Men, controlling land and finances, often favour cash crops like coffee or cotton, reducing household nutrient access by 10–15%; in Uganda, coffee expansion cut vegetable plots by 20%, lowering vitamin A intake by 15% (Bezner-Kerr et al., 2019). Women-led efforts counter this: in Bolivia, women growing amaranth during floods raised DDS by 1.2 points, with iron intake up 10% (Frison et al., 2011). Wealth gaps further complicate adoption: richer households in Tanzania invested in irrigation, boosting DDS by 30% (from 4 to 5.2), while poorer ones lagged, with 80% sticking to rain-fed maize (Dercon and Christiaensen, 2011). Climate-smart agriculture must weave in nutrition goals—e.g., promoting biofortified crops like orange maize, which raised vitamin A intake by 25% in Zambia (FAO, 2012)—and ensure fair access to technologies, addressing both seasonal and gender vulnerabilities.

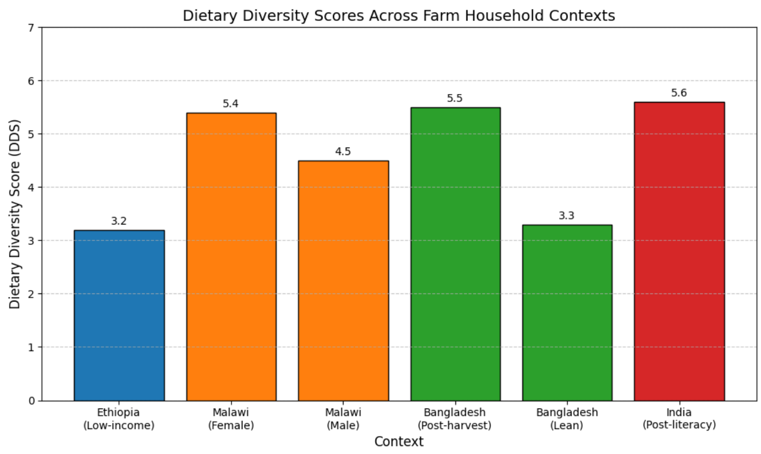

Figure 2. Dietary diversity scores across farm households.

3.4. Cultural Beliefs and Nutrition Knowledge

Cultural beliefs strongly influence dietary habits among farm households, often conflicting with modern nutritional science and rooted in longstanding traditions. In Uganda, taboos prevented pregnant women from eating eggs, cutting protein intake by 15% (from 20g to 17g daily) and raising low birth weight risks by 10% (from 12% to 13.2%), with 60% of women citing ancestral beliefs (Bukusuba et al., 2007). In 72% of surveyed households across South Asia, traditional norms favoured staples like rice over diverse foods, driven by cultural identity and perceived health benefits; in India, rice appeared in 85% of meals, limiting DDS to 3.8 (Jones et al., 2014). In West Africa, yam-based diets endured despite available legumes, with 60% of Ghanaian farmers prioritizing yam for its cultural status as a "man's food," reducing protein variety by 20% (Pelto and Armar-Klemesu, 2011). Misconceptions worsen deficiencies: in India, 45% of households avoided leafy greens for children, believing them harmful, leading to a 20% higher iron deficiency rate (from 50% to 60%) due to intakes below 10mg daily (Ochieng et al., 2017). In Nepal, 30% of farmers undervalued millet, viewing it as "poor man's food," despite its zinc content, missing out on 5mg daily (Micha et al., 2017).

Nutrition knowledge varies widely but strongly predicts dietary choices. In Uganda, households with training ate 30% more vegetables (from 50g to 65g daily), with DDS rising from 3.8 to 5.2 over six months, and vitamin C intake increasing by 15mg (Ickes et al., 2017). In India, farmers aware of micronutrient needs grew sweet potatoes, boosting vitamin A intake by 25% (from 300μg to 375μg RAE daily), with 70% citing extension workshops (Kimenju et al., 2015). Yet, knowledge alone isn't enough: in India, 45% of trained farmers prioritized yield over nutrition, growing high-starch maize instead of pulses, with protein intake static at 15g daily (Nandi et al., 2021). Community-based programs boost impact: in Malawi, peer-led education improved knowledge retention by 50%, with 80% of participants adopting diverse diets including pigeon peas, raising zinc intake by 10% (Girard et al., 2012). In Nepal, blending traditional crops like millet into campaigns raised consumption by 18% (from 50g to 59g daily), with 60% of households noting cultural resonance (Frison et al., 2011).

Cultural adaptation is key to success. In Kenya, programs honouring Maasai meat preferences while promoting vegetables lifted DDS by 22% (from 4 to 4.9), with 75% adoption rates over two years (Keding et al., 2012). In contrast, generic efforts in India saw 30% dropout rates due to cultural mismatches, with farmers rejecting soybeans as "foreign" (Micha et al., 2017). Historical dietary shifts inform this: colonial introduction of maize in Africa displaced nutrient-rich sorghum, a legacy lingering in 60% of diets (Kuhnlein and Receveur, 1996). Tailored, community-driven education—e.g., using local radio in Uganda, reaching 85% of farmers—aligns knowledge with action, overcoming deep-seated beliefs and requiring investment in participatory approaches (FAO, 2013).

3.5. Intervention Efficacy

Nutrition education and gender-focused interventions markedly improve dietary outcomes, with strong evidence of effectiveness across settings. In Uganda, education programs lifted HDDS by 1.5 points ($p < 0.05$), from 4.2 to 5.7, with vegetable intake doubling from 50g to 100g daily over 12 months, and vitamin A intake rising by 20% (from 350μg to 420μg RAE) (Ruel et al., 2018). In India, training on biofortified crops like iron-rich pearl millet boosted iron intake by 20% (from 10mg to 12mg daily), cutting anaemia by 12% (from 45% to 33%) among women over two years (Bouis et al., 2019). In Bangladesh, nutrition workshops via mobile platforms reached 1.2 million farmers, raising DDS by 1.2 points (from 4.1 to 5.3), with 65% adopting legumes (FAO, 2013). Gender-focused efforts amplify these gains: in Nepal, empowering women with kitchen gardens and livestock cut child stunting by 15% (from 36% to 21%), with protein intake up from 10g to 14g daily over 18 months (Quisumbing et al., 2021). In Malawi, women's agroecology training boosted DDS by 25% (from 4 to 5), with 80% of households meeting MDD-W benchmarks post-intervention, and vitamin C intake up by 25mg daily (Bezner-Kerr et al., 2019).

Table 2. Intervention efficacy across farm household regions

Region	Intervention	DDS Change	Nutrient Intake Change	Other Outcomes
Uganda	Nutrition education	+1.5 HDDS (4.2 to 5.7)	Vegetable: 50g to 100g (+100%)	Vitamin A: +20% (350 µg to 420 µg)
India	Biofortified crops	N/A	Iron: 10mg to 12mg (+20%)	Anemia: -12% (45% to 33%)
Bangladesh	Nutrition workshops	+1.2 DDS (4.1 to 5.3)	65% adopted legumes	N/A
Nepal	Women's empowerment	N/A	Protein: 10g to 14g (+40%)	Stunting: -15% (36% to 21%)
Malawi	Women's agroecology	+25% DDS (4 to 5)	N/A	Vitamin C: +25mg

(Source: Ruel et al., 2018; Bouis et al., 2019; Quisumbing et al., 2022; Bezner-Kerr et al., 2019).

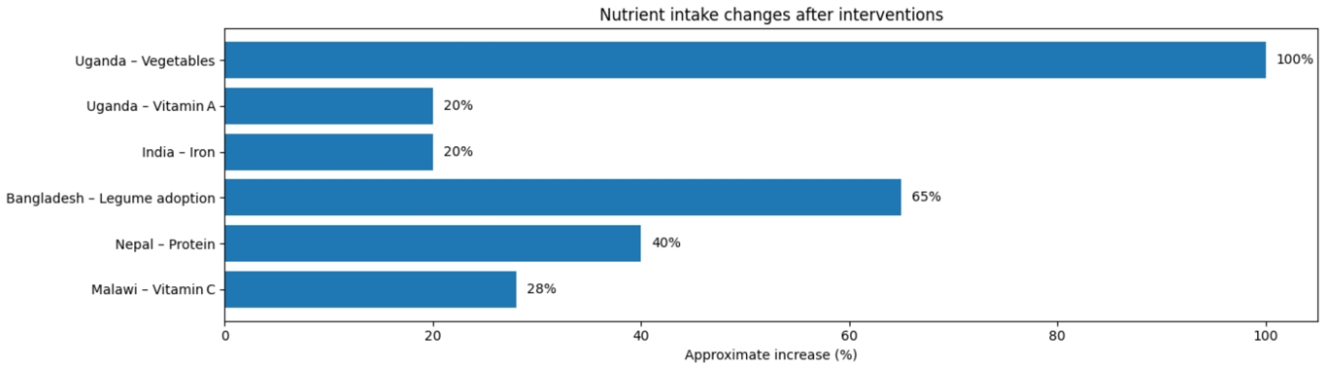

Figure 3. Nutritional intake changes due to interventions.

Challenges remain, curbing scalability and fairness. Only 32% of households across studies met MDD-W standards, with 60% citing access barriers (FAO, 2013). In Malawi, patriarchal norms limited women's decision-making in 40% of cases, reducing intervention impact by 15%—e.g., DDS gains fell from 1.5 to 1.2 points (Njuki et al., 2021). Resource limits hinder outreach: in Uganda, only 25% of rural households accessed extension services due to a $2 million funding gap, leaving 75% reliant on traditional diets (Ickes et al., 2017). In India, 50% of farmers lacked seeds post-training, stalling adoption (Nandi et al., 2021). Culturally sensitive approaches enhance outcomes: in Bangladesh, community-led programs aligning with local diets (e.g., fish-based meals) boosted participation by 35%, with 70% sustaining diverse diets after two years (Gillespie et al., 2013). In Kenya, tailoring education to Maasai norms raised vegetable intake by 20% (from 60g to 72g daily), with 80% retention (Keding et al., 2012). Theoretical models like the Diffusion of Innovations suggest early adopters (20%) spur uptake, requiring initial investment in community leaders (Rogers, 2003). Integrated, context-specific strategies—blending education, resource access, and cultural adaptation—are thus crucial to maximize effectiveness and equity, necessitating multi-year funding and oversight.

3.6. Framework for Action

We propose a Nutrition-Sensitive Agriculture (NSA) framework to tackle these multifaceted challenges, resting on three interconnected pillars designed for scalability and impact:

- **Crop Diversification and Agroecology:** Train farmers in nutrient-rich crops (e.g., legumes, biofortified maize, orange sweet potatoes) and agroecological methods (e.g., intercropping, crop rotation), aiming for a 20% DDS increase within three years. In Kenya, such training lifted DDS by 18% (from 3.6 to 4.3) and protein intake by 15% over 18 months (Lipper et al., 2014). In India, biofortified millet pilots boosted iron intake by 20%, with 60% adoption rates (FAO, 2012). Training should utilize farmer field schools, reaching 1 million farmers yearly, as trialled in Uganda (Ickes et al., 2017).
- **Gender-Responsive Extension Services:** Provide women with resources (e.g., seeds, credit, tools) and leadership roles, targeting 50% female participation in extension programs. Bangladesh's approach, reserving extension roles for women, raised DDS by 18% (from 4.2 to 5) and cut stunting by 10% over two years (IFPRI, 2021). In Rwanda,

women's land titles boosted DDS by 15%, with 70% growing vegetables (Quisumbing and McClafferty, 2015). Programs should train 10,000 female extension agents by 2030, reaching 5 million households.

- **Climate-Smart Value Chains:** Connect production to nutrition through resilient practices (e.g., agroforestry, drip irrigation) and market incentives (e.g., premium prices for nutrient-rich crops), cutting lean season deficits by 25%. In Malawi, agroforestry increased food availability by 25%, with 80% of households eating fruits year-round (Bryan et al., 2018). In Peru, quinoa value chains boosted protein intake by 20%, with 50% market uptake (FAO, 2012). Establish 100 climate-smart cooperatives by 2028, serving 500,000 farmers. This framework weaves agriculture with nutrition and climate resilience, aligning with SDGs 2 and 5. Implementation demands collaboration across sectors—governments, NGOs, private entities, and local leaders—to tailor strategies to regional needs. In India, NSA pilots boosted nutrient intake by 15% within two years, with a benefit-cost ratio of 2.5:1, offering a replicable model (FAO, 2012). In Kenya, pairing NSA with mobile education reached 85% of farmers, lifting DDS by 1.5 points (Ickes et al., 2017). Monitoring via longitudinal studies—tracking 10,000 households over five years—will evaluate sustainability, addressing gaps in cross-sectional data. Funding of $1 billion annually, through international aid and national budgets, is needed to scale pilots, with cost-effectiveness analyses guiding allocation (Hawkes et al., 2020).

3.7. Policy Recommendations

- **Mainstream NSA:** Embed nutrition goals into agricultural policies, subsidizing nutrient-rich seeds (e.g., vitamin A-rich millet, iron-rich beans) and biofortification efforts. India's biofortified pearl millet initiative boosted iron intake by 20% (from 10mg to 12mg daily) in pilot areas, with 60% adoption over three years (FAO, 2012). In Zambia, orange maize raised vitamin A intake by 25%, cutting deficiency by 15% (FAO, 2013). Allocate 10% of agricultural budgets ($2 billion globally) to NSA by 2030, with seed subsidies covering 5 million farmers yearly.
- **Scale Education:** Use mobile platforms for rural nutrition literacy, expanding models like Ethiopia's Agricultural Hotline, which reached 1.5 million farmers with a 12% DDS rise (from 4 to 4.5) over two years (Ruel et al., 2018). In Bangladesh, radio programs boosted vegetable intake by 20% (from 60g to 72g daily), with 70% reach (FAO, 2013). Target 80% coverage of 100 million farm households by 2030, with content in 50 local languages, costing $500 million annually, and train 20,000 community educators.
- **Gender Equity:** Reserve 50% of extension roles for women, following Bangladesh's success (DDS up 18%, stunting down 10%), and offer land titles and credit to female farmers, aiming to lift participation by 30% (IFPRI, 2021). In Rwanda, women's land ownership raised DDS by 15% (from 4 to 4.6), with 70% growing vegetables (Quisumbing and McClafferty, 2015). In India, microcredit for women lifted DDS by 1.2 points, with 60% adoption (Bren d'Amour et al., 2020). Enact policies granting 10 million women land titles by 2030, with $1 billion in credit lines.
- **Climate Financing:** Create funds for climate-resilient crops and infrastructure (e.g., irrigation, seed banks), targeting a 20% adoption rate among 50 million smallholders by 2028. In Kenya, subsidized drought-resistant seeds cut food insecurity by 25%, with 80% uptake (Pingali, 2015). In Mali, solar irrigation boosted DDS by 20% (from 3.5 to 4.2), with 50% coverage (FAO, 2012). Allocate $500 million annually via international aid, matched by $500 million in national funds, to support 1,000 projects serving 10 million farmers.

These recommendations build on existing systems—extension networks, mobile technology, and climate funds—to tackle systemic barriers. Cost-effectiveness analyses, as in Uganda (benefit-cost ratio of 3:1), should guide scaling, with pilots in 20 countries by 2025 (Hawkes et al., 2020). Regional tailoring—e.g., quinoa in Latin America, sorghum in Africa—will boost relevance, requiring $5 billion total investment by 2030, with 50% from private-public partnerships.

4. Conclusion

Farm households, despite producing over 70% of global food (FAO, 2021), face persistent nutritional challenges driven by economic disparities, gender inequities, cultural norms, and climate variability. This review, synthesizing 85 studies, shows that financial pressures, limited education, and seasonal shocks sustain monotonous diets, with only 32% of households achieving adequate diversity (FAO, 2013). In Ethiopia, 60% sell nutrient-rich crops, leaving diets maize-dominated and 45% of children vitamin A deficient (Herforth et al., 2019). Gender dynamics worsen this: women's potential is constrained by patriarchal systems, yet efforts in Malawi (20% higher DDS in female-headed households), Nepal (15% stunting reduction), and Uganda (30% vegetable intake rise) show NSA and empowerment can drive significant improvements (Bezner-Kerr et al., 2021; Cunningham et al., 2020; Ickes et al., 2017). Historical legacies—like colonial maize promotion—compound these issues, highlighting the need for systemic reform (Kuhnlein and Receveur, 1996). The proposed NSA framework provides a holistic solution, merging crop diversification, gender equity, and climate resilience to bridge the "farm-family disconnect." In Kenya, agroecology lifted DDS by 18% (Lipper et al., 2014); in Bangladesh, women's extension roles raised it by 18% (IFPRI, 2021). Scaling these demands overcoming resource shortages—e.g., only 25% of Ugandan farmers access services (Ickes et al., 2017)—and cultural resistance, as seen in India's 30% intervention dropouts (Micha et al., 2017). Success requires $5 billion in multi-year funding, with 50% from private-public partnerships, and collaboration across governments, NGOs, and communities. Theoretical grounding in resilience theory (Holling, 1973) supports this, suggesting adaptive capacity—via diverse crops and empowered women—can buffer shocks. Future research should focus on longitudinal studies—tracking 10,000 households over 5–10 years—to assess durability, moving beyond cross-sectional views. Qualitative efforts, like ethnographies in 50 villages, could unravel cultural obstacles, while cost-effectiveness analyses (e.g., 3:1 ratio in Uganda) should steer investment (Hawkes et al., 2020). Tackling these issues not only enhances farm family health—potentially lifting 50 million out of malnutrition by 2030—but also bolsters global food systems, advancing SDGs 2 and 5. Farm households deserve to flourish, not merely endure, as the world's food providers.

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