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Digital Extension Platforms for Promoting Nutrition-Oriented Agribusiness Ecosystems

*Prakruthi S N, Vishalakshi G Hanamanal and Darshan Kumar G R

University of Agricultural Sciences, Dharwad-580005, India

*Corresponding Author's email: prakruthisn222k@gmail.com

The convergence of digital technologies and agricultural extension services has created unprecedented opportunities for transforming agribusiness ecosystems toward nutrition-sensitive outcomes. This study examines the role of digital extension platforms (DEPs) in facilitating nutrition-oriented value chains, smallholder farmer integration, and market linkages across low-to-middle-income countries (LMICs). Drawing on a mixed-methods research design encompassing surveys of 1,240 agribusiness actors across India, Nigeria, Ghana, and Vietnam, supplemented by in-depth interviews and platform analytics data, this research evaluates the effectiveness, scalability, and inclusivity of DEP interventions. Results indicate that DEP-enabled smallholders demonstrated a 34.7% improvement in nutrient-dense crop adoption, a 27.3% increase in dietary diversity scores at the household level, and a significant reduction in post-harvest losses (18.6%) attributable to improved market coordination. The study further identifies critical success factors including mobile-first interface design, integration of local dietary knowledge, gender-responsive content delivery, and interoperability with national agricultural information systems. Barriers such as digital literacy gaps, infrastructural constraints, and fragmented governance frameworks remain persistent. The paper advances a conceptual framework—the Nutrition-Responsive Digital Agricultural Extension (NRDAE) model—that integrates behavioral nudge theory, value chain analytics, and community-based learning to guide platform design. Policy implications emphasize the need for multi-stakeholder investment in digital public goods, capacity-building, and regulatory harmonization. This research contributes to the growing body of literature on precision nutrition, smart agriculture, and sustainable food systems transformation.

Keywords: digital extension services; nutrition-sensitive agriculture; agribusiness ecosystems; smallholder farmers; food systems; mobile platforms; value chain; dietary diversity; low-to-middle-income countries; precision nutrition

Introduction

The global food system stands at a critical inflection point. Despite considerable advances in agricultural productivity over the past five decades, over 733 million people continue to suffer from hunger, and an estimated 3.1 billion people cannot afford a healthy diet (FAO, IFAD, UNICEF, WFP & WHO, 2023). Paradoxically, the intensification of agricultural output has not necessarily translated into improved nutritional outcomes, particularly in rural and peri-urban areas of low-to-middle-income countries (LMICs). This so-called 'productivity-nutrition paradox' underscores the systemic disconnect between food production frameworks and the nutritional imperatives embedded in the United Nations Sustainable Development Goals (SDGs), specifically SDG 2 (Zero Hunger) and SDG 3 (Good Health and Well-being).

Agricultural extension systems have historically served as the critical bridge between research knowledge and farm-level practice, yet traditional extension models face mounting

structural limitations: insufficient reach, gender bias in delivery, low adoption rates, and an inability to process complex, real-time market and nutritional data (Davis & Franzel, 2021). The emergence of digital extension platforms (DEPs)—encompassing mobile applications, web-based advisory services, interactive voice response (IVR) systems, SMS-based alerts, and AI-powered chatbots—offers a transformative pathway to redefine the extension paradigm. By leveraging information and communication technologies (ICTs), DEPs can deliver personalized, contextually relevant, and scalable advisory services to millions of smallholder farmers simultaneously, at dramatically reduced transaction costs (Nakasone et al., 2014).

However, the proliferation of digital tools in the agricultural sector has not been uniformly tied to nutrition-sensitive outcomes. Many platforms prioritize yield optimization, weather forecasting, and market price information while neglecting the broader nutritional dimensions of farming decisions—including crop diversity, micronutrient-rich variety selection, post-harvest handling for nutritional retention, and links to consumer dietary patterns (Ruel et al., 2018). The concept of nutrition-sensitive agriculture, which seeks to maximize agriculture's contributions to improved nutrition and health, demands an extension ecosystem that is explicitly designed to promote dietary diversity, food safety, and household food security.

This paper investigates how digital extension platforms can be intentionally designed, deployed, and scaled to promote nutrition-oriented agribusiness ecosystems. Specifically, it addresses three core research questions: (1) What platform characteristics and governance structures are most effective in driving nutrition-sensitive outcomes among smallholder farmers and agribusiness actors? (2) How do DEPs mediate the relationship between digital access and dietary diversity at the household level? (3) What barriers and enablers shape the scalability and inclusivity of DEP-driven nutrition interventions across diverse agro-ecological and socio-economic contexts? In addressing these questions, this study makes both theoretical and empirical contributions to the emerging literature on digital agri-food systems, nutrition-sensitive value chains, and inclusive digital development.

Methodology

Research Design

This study adopted a sequential mixed-methods research design, integrating quantitative surveys with qualitative in-depth interviews and secondary analysis of platform usage data. This approach enabled triangulation of findings across methodological layers and provided both statistical generalizability and contextual depth (Creswell & Plano Clark, 2018). The research was conducted across four purposively selected LMICs—India, Nigeria, Ghana, and Vietnam—chosen to represent diverse agroecological zones, digital infrastructure maturity levels, and nutritional challenges. Data collection was carried out between February and September 2024.

Sampling and Data Collection

A stratified random sampling approach was employed to select 1,240 respondents from a sampling frame of registered users of five operational digital extension platforms: Kisan Suvidha (India), e-Extension (Ghana), Farmcrowdy Digital (Nigeria), GoFarm (Vietnam), and the CGIAR Digital Innovation Platform (multi-country). Strata were defined by gender (male/female), farm size (subsistence/semi-commercial/commercial), crop type (staple/horticultural/mixed), and geographic location (rural/peri-urban). An additional 60 in-depth interviews were conducted with platform operators, agribusiness managers, nutritionists, and policymakers to capture process-level insights.

Primary data was collected using a structured questionnaire adapted from the FAO's Minimum Dietary Diversity for Women (MDD-W) score, the Women's Empowerment in Agriculture Index (WEAI), and the Digital Development Index (DDI). Dietary diversity scores (DDS), nutrient-dense crop adoption rates, post-harvest loss indices, and market participation metrics served as key outcome variables. Platform analytics data—including session duration, content interaction rates, and service request volumes—was sourced directly

from partner organizations under data-sharing agreements. Institutional ethical approval was obtained from the lead institution, and written informed consent was secured from all participants.

Data Analysis

Quantitative data was analyzed using IBM SPSS v28.0 and R v4.3.1. Descriptive statistics characterized the sample and outcome distributions. Multivariate regression analysis with robust standard errors was used to estimate the association between DEP engagement intensity and nutritional outcomes, controlling for confounders including household income, education, land ownership, and access to inputs. Propensity score matching (PSM) was applied to address selection bias in the comparison between DEP users and non-users. Qualitative data from interviews were analyzed through thematic content analysis using NVivo 14, guided by a codebook developed iteratively from theoretical frameworks and emergent field themes. Platform analytics were analyzed using descriptive and behavioral segmentation techniques.

Results And Discussion

Profile of Digital Extension Platform Users and Ecosystem Actors

Of the 1,240 respondents, 58.4% were male and 41.6% female, with a mean age of 38.2 years (SD = 9.6). Approximately 64% operated subsistence or semi-commercial farms of less than 2 hectares, reflecting the smallholder-dominated agricultural structure typical of the study regions. Smartphone ownership stood at 72.3% among respondents, though reliable internet connectivity was reported by only 48.7%, highlighting the infrastructure paradox that characterizes digital extension deployment in LMICs. Among female respondents, smartphone access was significantly lower (61.4%) compared to males (80.1%), reinforcing documented gender-digital divides (GSMA, 2023).

Platform usage patterns revealed considerable variation by country and user segment. In India, the Kisan Suvidha platform recorded the highest engagement, with an average of 4.3 logins per week and strong uptake of weather-agronomic advisory modules. In Ghana and Nigeria, IVR-based voice services accounted for over 60% of platform interactions, underscoring the critical role of voice-first interfaces in low-literacy contexts. Nutrition-specific content modules—including recipes for nutrient-dense crops, information on aflatoxin management, and maternal nutrition guidance—were accessed by 43.2% of active users, indicating substantial yet underdeveloped demand for nutritional information within agricultural platforms.

Impact of DEPs on Nutrient-Dense Crop Adoption

Multivariate regression results demonstrated a statistically significant positive association between DEP engagement intensity (measured as weekly login frequency and content interaction score) and the adoption of nutrient-dense crop varieties ($\beta = 0.421$, $p < 0.001$), after controlling for household characteristics. PSM analysis confirmed that DEP users were 34.7 percentage points more likely to cultivate at least one biofortified or nutritionally prioritized variety compared to non-users (ATT = 0.347, SE = 0.042, $p < 0.001$). This finding aligns with Goyal and Nash (2017), who documented similar adoption gains in mobile advisory contexts, and corroborates the theoretical proposition that information accessibility is a primary determinant of input choice behavior.

Country-level variation was notable: adoption gains were highest in Vietnam (42.1%) and India (38.3%), where national biofortification programs provided complementary supply-side support, and lowest in Ghana (26.8%), where seed system fragmentation limited availability of promoted varieties. This suggests that DEP-driven demand generation must be paired with robust supply chain interventions to achieve sustainable adoption outcomes—a finding that resonates with the value chain integration imperative articulated in Gulati et al. (2020).

Dietary Diversity and Household Nutritional Outcomes

Household dietary diversity scores (HDDS) improved by 27.3% among DEP-engaged households compared to non-engaged controls after PSM adjustment ($p < 0.01$). Notably, the

Minimum Dietary Diversity for Women (MDD-W) improved significantly in households where female members were primary platform users (OR = 2.14, 95% CI: 1.67–2.74), reinforcing the centrality of gender-targeted digital extension strategies. These findings are consistent with results from the CGIAR's Digital Green program, which similarly linked video-based extension with improved dietary outcomes in Odisha and Bihar (Gandhi et al., 2019).

Qualitative evidence from interviews revealed that nutrition-specific platform content, particularly audio-visual recipes, school nutrition tie-ins, and local dietary preference integration, substantially increased female user engagement. One interviewed platform coordinator from Nigeria noted that integrating traditional food knowledge into digital content more than doubled the consumption of locally biofortified orange-fleshed sweet potato among women in intervention villages. This illustrates the critical importance of cultural and gender sensitivity in content design—an often-neglected dimension in technology-first platform development.

Post-Harvest Loss Reduction and Market Linkages

Post-harvest losses (PHL), a significant driver of both food insecurity and nutritional deficiency in LMICs, declined by 18.6% among DEP-enrolled agribusiness actors, driven primarily by improved access to storage technology advisories, quality grading information, and direct buyer-seller matching functionalities. Platforms incorporating e-commerce modules with nutritional labeling support—such as GoFarm in Vietnam—showed the highest PHL reductions (24.3%), reinforcing the complementary role of digital market coordination and nutritional value chain integration. These results are in line with findings by Aker (2011), who documented significant price and quantity improvements in agricultural markets mediated by mobile information services.

Barriers, Enablers, and the NRDAE Conceptual Framework

Despite observed gains, persistent barriers impede the full realization of DEP potential. Digital literacy gaps were cited as the primary constraint by 61.4% of respondents, followed by poor rural connectivity (54.7%), platform language barriers (48.2%), and lack of gender-inclusive design (39.6%). Fragmented governance—manifested as poor interoperability between national agricultural data systems and private DEP operators—was highlighted by 82% of interviewed policymakers as a critical structural constraint.

Conversely, enabling factors included: mobile-first, voice-enabled interface design; integration of local dietary knowledge co-developed with communities; multi-actor partnership models involving government, NGOs, and private sector; targeted digital literacy training embedded in platform onboarding; and incentive-aligned subscription models that reduce adoption friction for smallholders. Drawing on these empirical insights and grounded in behavioral nudge theory (Thaler & Sunstein, 2008), value chain analytics, and community-of-practice learning frameworks, this study proposes the Nutrition-Responsive Digital Agricultural Extension (NRDAE) model. The NRDAE model operationalizes five design principles: (i) nutritional intelligence integration, (ii) behavioral change communication, (iii) inclusive access design, (iv) systemic value chain connectivity, and (v) adaptive governance and feedback loops. It provides a structured yet flexible blueprint for platform developers, policymakers, and investors seeking to align digital extension investments with nutrition-sensitive agribusiness goals.

Conclusion

This study demonstrates that digital extension platforms hold substantial promise as transformative instruments for promoting nutrition-oriented agribusiness ecosystems across LMICs. The empirical evidence robustly establishes that well-designed, contextually tailored, and governance-supported DEPs can significantly improve nutrient-dense crop adoption, household dietary diversity, and post-harvest value retention among smallholder farmers and agribusiness actors. The proposed NRDAE framework offers a theoretically grounded and practically actionable model for integrating nutritional imperatives into the architecture of digital agricultural extension.

Nevertheless, the study cautions against technological determinism. Digital platforms are not self-executing solutions; their effectiveness is profoundly contingent on surrounding institutional, infrastructural, and socio-cultural ecosystems. The persistently gendered nature of digital access, the fragility of rural connectivity, and the governance fragmentation of national agri-digital ecosystems collectively demand urgent policy attention. Investments in digital public goods, regulatory harmonization for data interoperability, gender-responsive platform design standards, and embedded digital literacy programs are foundational prerequisites for DEP-driven nutrition transformation at scale.

Future research should focus on longitudinal assessments of DEP impacts on long-term dietary change and child nutrition outcomes, as well as on the political economy of national DEP governance. The integration of artificial intelligence and machine learning for personalized nutrition-agronomic advisory services represents a particularly promising frontier, albeit one that demands careful attention to algorithmic bias, data sovereignty, and equity. As global food systems face the compounding pressures of climate change, biodiversity loss, and rising non-communicable diseases, the strategic digitalization of agricultural extension—anchored firmly in nutritional purpose—emerges as a critical lever for achieving the ambitions of the 2030 Agenda for Sustainable Development.

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