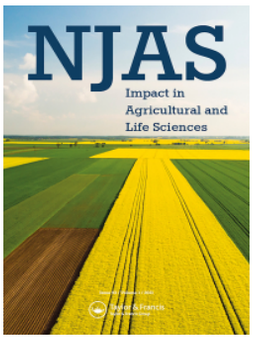

NJAS: Impact in Agricultural and Life Sciences

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/tjls21

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To cite this article: S. Coggins, S. Munshi, J. Smith, A.K. Yadav, S. P. Poonia, S. Patil, N.K. Singh, A. Sawarn, D.C. Ireland, A.J. McDonald, D.K. Singh, S.R. Sherpa & P. Craufurd (2025) How do chat apps support the use of farming videos in agricultural extension: A case study from Bihar, India, NJAS: Impact in Agricultural and Life Sciences, 97:1, 2420803, DOI: 10.1080/27685241.2024.2420803

To link to this article: https://doi.org/10.1080/27685241.2024.2420803

NJAS: IMPACT IN AGRICULTURAL AND LIFE SCIENCES
2025, VOL. 97, NO. 1, 2420803
https://doi.org/10.1080/27685241.2024.2420803

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How do chat apps support the use of farming videos in agricultural extension: A case study from Bihar, India

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ABSTRACT

Farmers and extension workers increasingly use chat apps like WhatsApp to access and share information, including farming videos. Few empirical studies have critically examined the roles of these novel extension practices in agricultural innovation systems. We asked 294 extension workers in Bihar, eastern India, to circulate three wheat agronomy videos. Extension workers relied on WhatsApp to share these videos in 70% of surveyed cases ($n = 131$). Follow-up interviews revealed that WhatsApp enabled highly efficient video sharing with farmers extension workers already knew, given that WhatsApp was embedded like "breakfast tea" in some communities in rural Bihar. However, interviewed extension workers expressed concern that WhatsApp-shared videos facilitated limited social inclusivity, limited two-way discussion, and thereby limited localisation of farming advice, feedback loops, and relationship building, at least in this context. Looking further, we anticipate these challenges with person-to-person chat apps in agricultural extension may also apply to emerging agricultural advisory chatbots powered by large language models. For researchers, our results imply that socio-technical theories, rather than transfer-of-technology theories, are required to anticipate and observe heterogeneous uses and impacts of digital extension tools. For practitioners, our results imply that chat apps can helpfully support, not replace, face-to-face extension practices. In the words of one interviewed extension worker, treat chat apps like "chutney": a helpful complement and inadequate substitute for "rice and dal" conversations and field demonstrations.

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Supplemental data for this article can be accessed online at https://doi.org/10.1080/27685241.2024.2420803

ARTICLE HISTORY Received 13 May 2024; Revised 19 August 2024; Accepted 18 October 2024

KEYWORD Digital agriculture; ICT4D; ICT4Ag; LLM; agriculture 4.0; advisory

1. Introduction

Agricultural practice changes underpin many important food system improvements, including in regard to human nutrition (Sharma et al., 2021), climate change adaptation (Bouwman et al., 2021), animal welfare (Buddle et al., 2021), and rural livelihoods (Van Campenhout, 2017). Food system actors attempt to facilitate these agricultural practice changes through "agricultural extension", with agricultural extension interpreted as "practices that are designed to help engage farmers and generate, disseminate and scale appropriate innovations in the rural sector" (Rickards et al., 2018). However, facilitating inclusive (Taylor & Bhasme, 2018), helpful (Maertens et al., 2021), and cost-efficient (Norton & Alwang, 2020) agricultural extension remains challenging. These challenges are particularly prominent in low- and middle-income countries with large and diverse farming populations (Lowder et al., 2016). For example, relatively few Indian farmers can make use of formal government extension services, partly because there are more than 1,000 farmers per government extension official in India (Nedumaran & Ravi, 2019). Moreover, conventional public extension services have commonly been particularly inaccessible for marginalised social groups, including female farmers (Alvi et al., 2021), lower caste farmers (Krishna et al., 2019), and less educated farmers (Nikam et al., 2022).

Farmers and other extension practitioners increasingly look to digital tools to make extension services more accessible "at scale" in low- and middle-income countries. We define a digital extension tool (DET) as "any digital tool through which farmers or other extension actors share, access or discuss agricultural information or knowledge" (Coggins et al., 2022). Importantly, this definition aligns with our interpretation of agricultural extension as a *practice* that farmers, input retailers, children of farmers, and any other agent can engage in, not exclusively the *role* of formalised extension workers (Manalo et al., 2019; Nettle et al., 2018; Rickards et al., 2018). DETs can generally be replicated at low-cost, making them enticingly cost-efficient and scalable for extension programs, at least in theory (Fabregas et al., 2019), albeit not always in practice (Abate, Abay, et al., 2023; Daum et al., 2022). Governments, agribusinesses, and development donors have therefore invested heavily in DETs in low- and middle-income countries (Beanstalk AgTech, 2023), leveraging fast-growing rural access to electricity, mobile networks, and mobile phones (GSMA, 2023).

Governments, agribusinesses, and development donors have typically designed DETs as one-way DETs, i.e., DETs that facilitate *one-way transfer* of agricultural information. These include DETs that prescribe agricultural advice

via text messages (Kansiime et al., 2019), pre-recorded voice messages (GSMA, 2017), and smartphone applications (Zossou et al., 2021).

Despite enthusiastic supply of one-way DETs, their impact has generally been limited (Porciello et al., 2022; Sida et al., 2023). Some one-way DETs have received noteworthy traction with farmers and extension workers. For example, the smartphone app "Plantix" diagnoses crop pests and diseases and has been downloaded more than ten million times to date (Google Play, 2024). However, one-way DETs have typically proved unpopular and uninfluential with farmers (Sida et al., 2023). Empirical studies examining this phenomenon have found one-way DETs are often insensitive to farmers' variable reading abilities (Wyche & Olson, 2018), digital literacy levels (Tata & McNamara, 2016), local languages (Kansiime et al., 2019), and agricultural terminologies (Coggins et al., 2022). Even when farmers access the information delivered by one-way DETs, this information is generally insensitive to the recipient's existing knowledge, agricultural priorities, socio-economic constraints, and local farming system (Coggins et al., 2022). Moreover, the lack of two-way discussion makes it difficult for farmers and extension workers to trust one-way DETs and the information they convey (Coggins et al., 2022). These limitations of one-way DETs would come as no surprise to rural innovation theorists, who have extensively critiqued "technology transfer" approaches to agricultural extension for neglecting the knowledge and agency of farmers, as well as the complexity of rural innovation (Glover et al., 2019; Hidalgo et al., 2024; Leeuwis, 2013).

Instead, farmers and extension workers have typically engaged more with two-way DETs, i.e., DETs that facilitate *two-way exchange* of agricultural information (Coggins et al., 2022; Faxon, 2023; Munthali et al., 2018; Patel et al., 2010; Thar et al., 2021). Two-way DETs include Facebook groups (Facebook, 2024; Faxon, 2023; Lee & Suzuki, 2020), person-to-person phone calls (Boas, 2022; Butt, 2015), and chat-based mobile applications hereon named "chat apps" (Jomantas et al., 2024). Interestingly, these two-way DETs have typically been created by users, adapting technologies that were not originally designed for agricultural extension, a process termed "appropriated agritech" by Faxon (2023). The user-driven nature of two-way DETs enables farmers to make DETs relevant to users' languages, knowledge, priorities, socio-economic constraints, and local farming systems, thus addressing the common pitfalls of one-way DETs described above (Coggins et al., 2022). The risk of mis/disinformation from two-way DETs should not be neglected, just as the risk of mis/disinformation from one-way DETs should not be neglected (Chowdhury et al., 2023). Even so, the apparent utility of two-way DETs has been unsurprising to rural innovation experts (Kelly et al., 2017; Klerkx et al., 2019), especially given that social networks and two-way knowledge sharing are central to rural innovation (Klerkx et al., 2012; Leeuwis, 2013).

Chat apps, like WhatsApp and Telegram, have emerged as particularly popular platforms for two-way DETs (Coggins et al., 2022; Dahlan et al., 2024; Jomantas et al., 2024; Munthali et al., 2018; Seminar & Sarwoprasodjo, 2019; Voutier, 2020). For example, Munthali et al. (2018) observed that agricultural extension workers typically rejected a one-way agricultural extension app designed specifically for their use. Instead, extension workers turned to informal WhatsApp and Telegram groups, largely because they enabled discussion of agricultural challenges with their peers (Munthali et al., 2018). On top of facilitating discussion, the hyperlink- and video-sharing functionality of chat apps has created novel opportunities for farmers and extension workers to share and discuss one-way DETs like YouTube videos (Dahlan et al., 2024; Voutier, 2020). In other words, chat apps have enabled farmers to turn one-way information transfer into two-way information exchange, thus making one-way DETs more usable, useful, and scalable (Sousa et al., 2019).

Chat apps are becoming even more prominent in agricultural extension given the recent and rapid emergence of chatbots, i.e., chat apps powered by "large language models" or other forms of artificial intelligence (AI). These chatbots include "ChatGPT", "Claude", and chatbot plugins for WhatsApp, Facebook Messenger, and Telegram. Such chatbots are also being tailored specifically for use in agricultural extension, such as "Farmer.Chat" and "KissanAI". These chatbots present novel extension opportunities, but also threats for farmers and food systems (De Clercq et al., 2024; Tzachor et al., 2022).

Despite the growing use, opportunities, and risks of chat apps in agriculture, chat apps have been largely neglected in literature evidencing use and impacts of DETs in low- and middle-income countries. A systematic scoping review by Porciello et al. (2022) captured 240 empirical studies researching use and impacts of digital extension tools in low- and middle-income studies. However, just 12 of these studies focused on chat apps (Porciello et al., 2022). Moreover, notwithstanding some exceptions (Boas, 2022; Munthali et al., 2021), these chat app-focused studies generally analyse the use of DETs in isolation, rather than in interaction with other extension platforms. This limited analysis leaves practitioners with substantial uncertainty regarding the potential synergies and risks created by chat apps (Ding et al., 2022; Jomantas et al., 2024; Rijswijk et al., 2019), and thereby their most effective roles in agricultural innovation systems (Klerkx, 2021).

Bihar is an eastern state of India where additional research into the use and impacts of chat apps in agricultural extension would be particularly valuable. The practice of agricultural extension plays important roles in Bihar, given high rates of poverty and food insecurity in the largely agrarian state. 84% of the population live in rural areas (Government of Bihar, 2023, p. 366), including more than 16 million farmers (Government of India, 2019, p. 61). These farmers face significant challenges to improve their relatively low levels of agricultural productivity, given increasingly harsh summers and variable rainfall (McDonald et al.,

2022). Overcoming these challenges might be made easier with a growing, albeit gender inequitable, proportion of farmers in the state have access to mobile networks and smartphones (Alam, 2021). This has facilitated uptake and adaptation of DETs, with farming videos and farming WhatsApp groups appearing particularly popular (Coggins et al., 2022; Singh, 2020; YouTube, 2024). However, uncertainty regarding the interactions of WhatsApp with videos and agricultural innovation systems makes it difficult for farmers, the Government of Bihar (personal communication, 2022), the digital extension NGO "Digital Green" (personal communication, 2022), and other extension practitioners to engage, or not, with this emerging agricultural extension platform effectively. We therefore asked two interlinked research questions:

(1) To what extent do extension workers use WhatsApp to engage with farmers, particularly in relation to farming videos?

(2) How do extension workers perceive the role of WhatsApp and farming videos in their extension work?

To address these research questions, we implemented a video circulation experiment in collaboration with agricultural extension workforces of the "Bihar Rural Livelihoods Promotion Society" (JEEViKA) and "Cereal Systems Initiative for South Asia" (CSISA). JEEViKA is a poverty alleviation and rural livelihood mission of the Government of Bihar, while CSISA is a research and extension program led by the International Maize and Wheat Improvement Center (CIMMYT) and co-implemented by the International Rice Research Institute (IRRI) and the International Food Policy Research Institute (IFPRI). CSISA has been funded by international development donors, particularly USAID and the Bill and Melinda Gates Foundation. It is important to note that these extension workforces represent formal extension actors, and thus the research findings may not be representative of behaviours and perceptions of less formalised extension actors, like farmers and large language models. Even so, from a practical perspective, this empirical research can help formal extension actors interpret the roles of chat apps in extension services in Bihar and other contexts like it. Further, from a scientific perspective, this empirical research on "appropriated agritech", which existing literature neglects, can help researchers advance conceptual frameworks for detecting and anticipating the uses and impacts of digital extension tools in agricultural innovation systems (Faxon, 2023).

Data from this empirical study was also analysed, separate from this paper, to research circulation of farming videos with a gender lens (separate journal paper forthcoming), as well as critique the idea of "adoption" in understanding how extension workers share farming videos and other agricultural technologies (another separate journal paper forthcoming). We report these three analyses in different journal papers because they each report distinct results and conclusions, and with distinct uses and

audiences in mind. The three analyses only overlap in their data collection methods. For consistency, each paper reports methods using the same text, figure, table and appendices.

2. Materials and methods

2.1. Summary

We performed and monitored a video sharing experiment in Bihar in collaboration with JEEViKA and CSISA between November 2022 and January 2023. Specifically, we asked 294 extension workers from JEEViKA and CSISA to circulate three wheat agronomy videos with farmers in their respective communities (see section 2.3 and 2.4). We researched extension workers' video sharing experiences and behaviours using a Mixed Methods methodology with a sequential explanatory design (Creswell et al., 2003). We first used link tracking and telephonic surveys to quantitatively monitor how many times – and how – each extension worker shared these videos (see section 2.5). We then led 20 qualitative interviews with participating extension workers to explain the quantitative results (see section 2.6).

2.2. Ethical considerations

The ethical aspects of this research were approved on 11 October 2022 by the Australian National University Human Research Ethics Committee (Protocol 2022/511). Efforts to mitigate potential harms included only engaging in telephonic surveys and interviews with extension workers giving genuinely informed consent, minimising the number and duration of telephonic surveys and interviews, ensuring participant confidentiality in data collection, analysis and publication, and ensuring copies of the wheat agronomy videos were still accessible to extension workers after data collection was completed.

2.3. Research participants

Two hundred and ninety-four extension workers that owned smartphones participated in the experiment. Two hundred and fifty-one these extension workers were JEEViKA-supported agri-entrepreneurs. At the time of the study, JEEViKA, a poverty alleviation and rural livelihoods program of the Government of Bihar, provided training and subsidies for approximately 400 agri-entrepreneurs. These agri-entrepreneurs were not only supported to sell agricultural inputs to farmers, but also help farmers access agricultural extension services, banking services, markets for agricultural produce, and rice seedling nurseries. JEEViKA officials were aiming to use farming videos, in combination with agri-entrepreneurs and other extension workers, to

inclusively reach six million farmers by 2025, from a base of approximately two million farmers in 2022 (personal communication, 2022). The 251 agri-entrepreneurs included in the study were those recommended by JEEViKA officials and were perhaps more engaged in their work than the average JEEViKA agri-entrepreneur. In addition, 43 CSISA field technicians participated in the trial. CSISA aimed to benefit eight million farmers through its agricultural research and extension program. At the time of the study, CSISA employed a total of 43 field technicians in Bihar (and neighbouring districts of eastern Uttar Pradesh) to facilitate on-farm field trials to develop and circulate knowledge about improved farming practices. A small majority of the 294 field technicians that participated in the study worked in the North Bihar districts of East Champaran or Muzaffarpur (Figure 1). To our knowledge, most of the 294 extension workers were familiar with managers using WhatsApp to send them farming videos to share, even though this was not a routine practice.

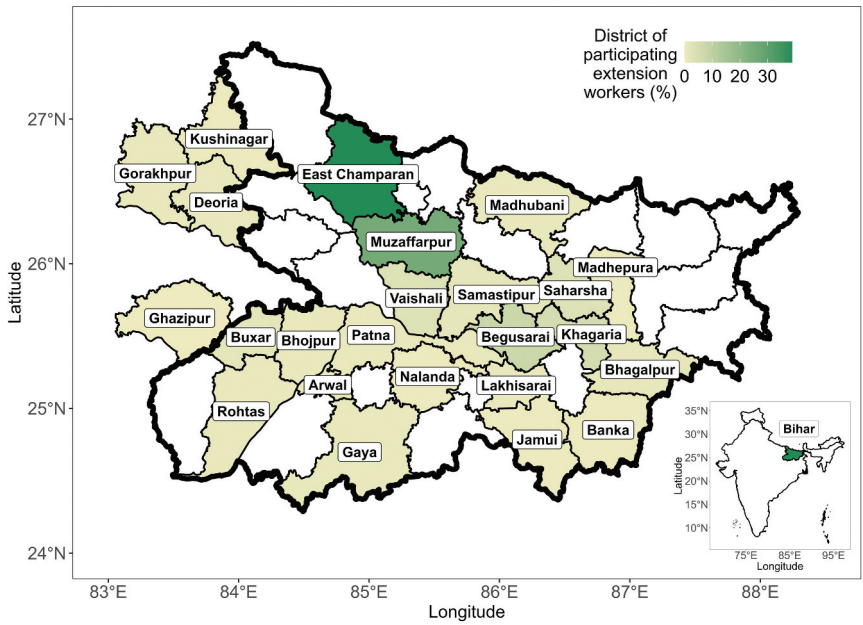

Figure 1. District of work for extension workers that participated in the study, see Table 1 for the precise percentage values. The location of Bihar within India is also depicted in the bottom-right corner of the figure. A small minority of participating CSISA field technicians worked in districts of Uttar Pradesh that neighbour Bihar, namely Deoria, Kushinagar, Ghazipur, or Gorakhpur. CSISA field technicians worked in these districts because farming systems in Bihar and eastern Uttar Pradesh are commonly aggregated as the "Middle Indo-Gangetic Plains", given similar cultural practices, as well as similarly variable rainfall, low average incomes, small landholdings, and fertile soils (ICAR, 2016).

2.4. Experiment details

2.4.1. Videos

The 294 extension workers each received three videos regarding wheat farming practices. Each video was circulated preceding crop calendar dates relevant to the video topic. The first video focused on early wheat sowing, the second on irrigation scheduling, and the third on chemical weed management. All videos were between 3:30 and 3:48 minutes in duration and in Hindi language. Each video featured a wheat agronomist and wheat farmer from Bihar that had successfully implemented the recommended wheat farming practice. The videos' wheat focus, agronomy topics, duration, language, and structure (i.e., featuring an expert farmer and expert scientist) were prioritised based on nine pre-conducted key informant interviews with farmers and extension workers in Bihar. Each of the three videos had two subtly different versions – one featuring a successful male farmer and one featuring a successful female farmer. Supplementary information 1 for copies of the videos used in the experiment, including versions with English subtitles.

2.4.2. Video dissemination

The video sharing task was flagged with extension workers via a standardised Hindi message sent by their respective managers via WhatsApp groups. Supplementary information 2 for a copy of this standardised message. The same personal WhatsApp account responded to any questions from message recipients.

Each extension worker then received each video via standardised WhatsApp messages. These messages contained the video link along with a description of the video and a request to share it with farmers in their community by means of their choice. All the videos were messaged from the same personal WhatsApp account and signed off with the same name and affiliation with JEEViKA and CSISA. Supplementary information 3 for copies of these standardised messages. Extension workers received the wheat sowing date video on 26/10/22–27/10/22, the irrigation scheduling video on 9/12/22–11/12/22 and the chemical weed management video on 23/12/22 (Figure 2). All messages were sent between 8:38 am and 5:27 pm India Standard Time. Not all messages could be sent simultaneously so the order in which each extension worker received their video link was randomised. Each extension worker also received a standardised WhatsApp group reminder message four days after each of the videos were disseminated (supplementary information 4 for a copy of this standardised reminder message).

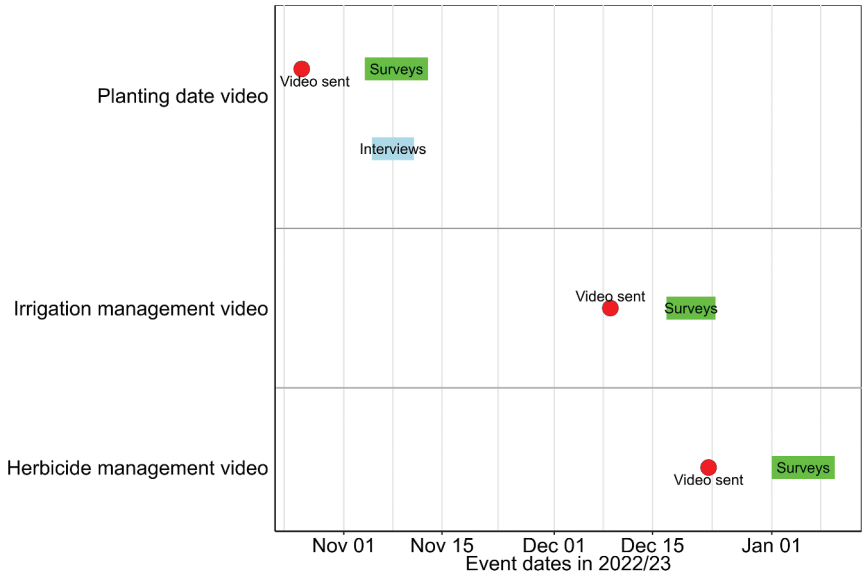

Figure 2. Timeline for dissemination of videos to extension workers, and subsequent observation of their video sharing behaviours through link tracking, telephonic surveys, and in-depth interviews.

2.5. Quantitative measurement of video circulation

"Wistia", a commercial video tracking software, was used to measure the number of video views and shares generated by each extension worker. Every recipient received a unique link to each of the three videos. "Wistia" monitored the number and duration of video views for each link, as well as the number of unique IP addresses that accessed each link. Extension workers were not informed that they received a unique video link and that their video sharing behaviour would be monitored. Ethical aspects of this covert observation were addressed with JEEViKA and CSISA collaborators, and approved on 11 October 2022 by the Australian National University Human Research Ethics Committee (Protocol 2022/511).

In addition, all participating extension workers were invited to participate in telephonic surveys following the circulation of each of the three videos. Telephonic surveys for each video were conducted 8–17 days after each video was first sent. The telephonic survey response rates for the wheat sowing video, irrigation scheduling video, and chemical weed management video were 68%, 65%, and 81% respectively. The telephonic surveys included questions on how extension workers shared the video. Supplementary information 5 for the survey questions.

2.6. Follow-up qualitative interviews

Between 5 and 11 November 2022, we conducted 20 semi-structured interviews of extension workers that participated in the video sharing trial. The purpose of these interviews was to better understand how and why participating extension workers did or did not share the first video and other farming videos like it. We selected respondents using purposive sampling to maximize diversity regarding work location, gender, age, religion, and engagement in video sharing according to the "Wistia" link tracking data (Table 1; Robinson, 2014). We used these criteria to stratify sampling because such social factors have influenced engagement with DETs in other low- and middle-income contexts (Porciello et al., 2022). Only selected extension workers who gave informed consent were interviewed. All interviews were conducted in Hindi, in-person (aside from one telephonic interview) and audio-recorded (aside from one). Supplementary information 6 for the protocol of the semi-structured interview, including what topics were covered and in what sequence. Interview notes and audio transcripts were analysed in English using inductive coding and thematic analysis (Braun & Clarke, 2006), implemented with the software program "NVivo version 14".

3. Results

3.1. How much did extension workers depend on WhatsApp?

Extension workers relied on WhatsApp to share the videos in 70% of "verified cases" (Figure 3). We defined a "case" as the self-reported

Table 1. Demographic characteristics (according to telephonic surveys) and video sharing performance (according to link tracking data) of extension workers that participated in the research. For simplicity, the numbers for the link tracking data and telephonic survey data in this table were averaged across all three videos. Please see supplementary information 7 for these values disaggregated for each of the three videos. The average sample size for the link tracking data is less than 294 because each video link failed for an average of 24 extension workers, according to telephonic surveys conducted after each video.

	Link tracking data	Telephonic surveys	Semi-structured interviews
Average sample size per video	270	179	20 (only following the first video)
Organisation	85% JEEVIKA, 15% CSISA	83% JEEVIKA, 17% CSISA	80% JEEViKA, 20% CSISA
Gender	23% women, 77% men	24% women, 76% men	20% women, 80% men
Age (median)	32 years	32 years	35.5 years
Age (range)	20-55 years	20-55 years	23-50 years
District	40% East Champaran, 24% Muzaffarpur, 36% other	39% East Champaran, 25% Muzaffarpur, 36% other	60% East Champaran, 28% Muzaffarpur, 12% other
Video views	75% zero, 11% one, 14% multiple	69% zero, 13% one, 18% multiple	19% zero, 25% one, 56% multiple

video sharing behaviour of one extension worker regarding one of the three videos. We "verified" these cases by ensuring the given extension worker generated at least one view of the given video, according to the link tracking data. Extension workers who shared the video outside WhatsApp typically did so by displaying the video on their smartphone, or simply discussing the content of the video with farmers (Figure 3).

3.2. How scalable, efficient, and two-way was the WhatsApp-based video circulation? (quantitative results)

Sharing videos via WhatsApp had capacity for reaching large numbers of farmers, at least relative to extension workers showing videos on their phones. Extension workers facilitated a *median* of three video views from their unique video link by sharing it via WhatsApp. Similarly, extension workers facilitated a *median* of two video views from their video link by showing it on their phone. However, the *average* video view per extension worker was 9.0 for those that relied on WhatsApp, almost double the average video views of 4.8 for extension workers that mainly showed videos on their phone. The difference between these average values appear driven by the small minority

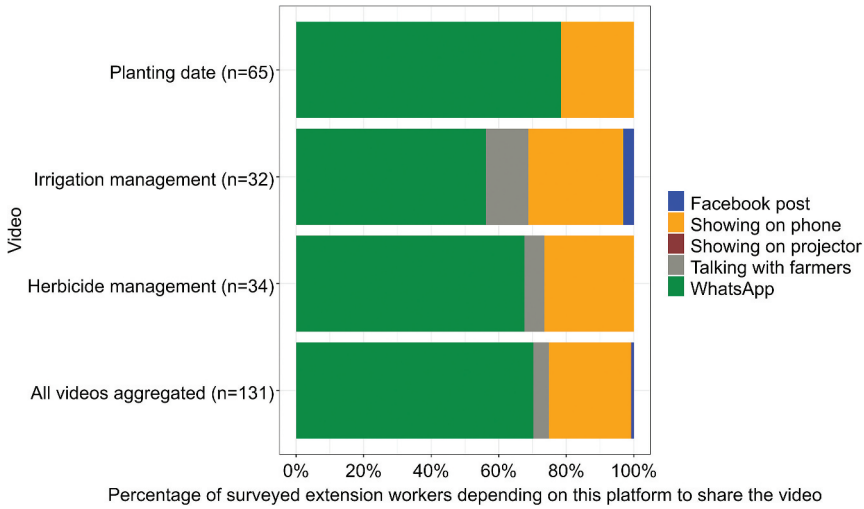

Figure 3. Platforms used most by extension workers to circulate the three farming videos. The most used platform for each video and each extension worker was self-reported by extension workers in telephonic surveys. The sample size is relatively small and variable across each video because we only include data from extension workers that participated in the telephonic survey for a given video, reported their most used platform for sharing this video, and generated at least one view of this video according to the link tracking data.

of extension workers that facilitated most of the total video views (Figure 4). Indeed, extension workers reported relying on WhatsApp for 19 of the 22 verified cases where an extension workers facilitated more than ten video views from their given video link (Figure 4). In the most "successful" verified case, the responsible extension worker facilitated 133 views from their unique video link and reported relying on WhatsApp to do so. In view of this, WhatsApp seemed to have a relatively high ceiling for engaging large numbers of farmers with a farming video. Having suggested that, this observational analysis is based on correlations, not causation, and such implications should be interpreted with caution.

Sharing videos via WhatsApp also appeared to be reasonably time-efficient for extension workers. In verified cases, extension workers reported that video sharing via WhatsApp took them an average of 63 minute to circulate each video independently ($n = 90$). This means an average of 7 minute of extension workers' time per video view they facilitated via WhatsApp. We calculate this average based on the average of 9.0 video views generated by each extension worker that predominantly shared videos via WhatsApp ($n = 92$).

However, the scalability and efficiency of circulating videos via WhatsApp may have been at the cost of two-way discussion. On average, extension workers that relied on WhatsApp to share videos reported that only 31% of farmers they shared the video with responded with a comment or question ($n = 90$). We suspect this low figure was still an overestimate, given that

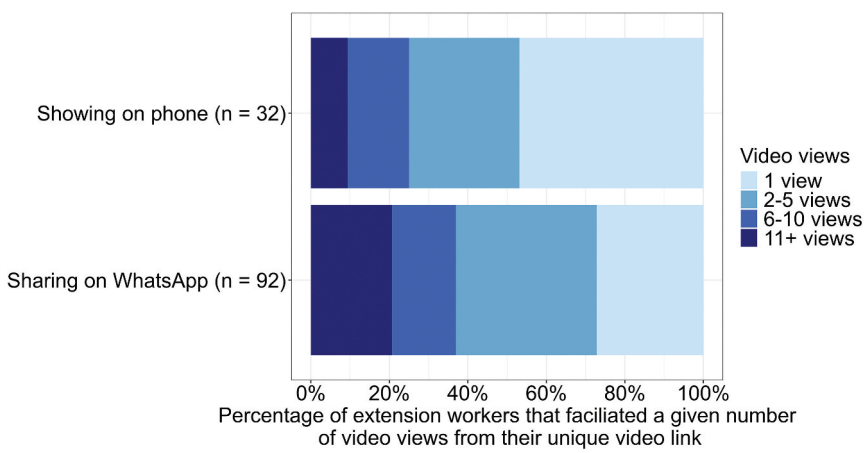

Figure 4. Video views facilitated by each extension worker, disaggregated by platform they mainly used to circulate a given farming video. The figure aggregates telephonic survey and link tracking data from all three videos in the experiment. We only include data from extension workers that participated in the telephonic survey for a given video, reported their most used platform for sharing this video, and generated at least one view of this video according to the link tracking data.

surveyed extension workers may have sought to exaggerate their extension performance, even though they were assured their telephonic survey responses were anonymised. Indeed, extension workers' video sharing effectiveness according to telephonic surveys often significantly exceeded their performance according to the link tracking data. Extension workers provided more in-depth and seemingly candid responses in the qualitative interviews, which we report in the remainder of the results section.

3.3. Why did extension workers depend on WhatsApp? (qualitative results)

Interviewed extension workers reported the efficiency of WhatsApp drove their dependence on the platform for circulating farming videos. Extension workers observed that in-person sharing of farming videos via phone and projectors can be time-consuming and impractical, particularly for engaging large numbers of farmers. In comparison, WhatsApp was perceived as a uniquely fast and easy mechanism to communicate with large numbers of farmers, including farmers that "do not belong to my locality or [are] not from my area". Extension workers observed that the scalability of WhatsApp communication was enabled by its widespread usage in rural Bihar. One extension worker in Motihari district likened WhatsApp to "breakfast tea" given its pervasiveness in his community. He observed that "if you want to spread a news in 10 minute, WhatsApp is the only way".

Some interviewed extension workers also reported relying on WhatsApp to share farming videos as it enabled farmers to access information when convenient for them. One extension worker noted that for videos shared on WhatsApp, "I can watch it, rewatch it and keep it saved for my future understanding".

3.4. Why were extension workers concerned about their WhatsApp dependence? (qualitative results)

Despite the efficiency and convenience of WhatsApp, extension workers observed that WhatsApp-shared farming videos were not accessible for marginalised social groups. Extension workers observed that less educated farmers were less able to read and type messages, less wealthy households were less likely to own a smartphone, and female farmers were less likely to access smartphones, even if their members of their household owned a smartphone.

Relatedly, extension workers commonly observed that WhatsApp-based video sharing was only accessible and useful to farmers they knew personally. This issue was particularly salient for newly employed extension workers, who reported limited farmer contacts and hence

limited opportunity to share farming videos via WhatsApp. Beyond the practical challenges of WhatsApp-messaging farmers they did not already know, extension workers explained that farmers were generally sceptical of farming videos shared on digital platforms by unknown or untrusted people and organisations. One extension worker elaborated that "villagers know these days there are fake videos on YouTube". Similarly, another extension worker observed a common perception that people uploaded videos on YouTube to "make money", and not necessarily offer useful agricultural information. In view of this, extension workers commonly observed the usefulness of WhatsApp-based video sharing depended on extension workers already having trusting relationships with farmers.

In addition to their concerns about inequitable access to WhatsApp-shared videos, interviewed extension workers observed that WhatsApp-based video circulation involved limited two-way communication. Despite exceptions, interviewed extension workers reported that farmers rarely replied to WhatsApp-shared videos, particularly those shared via group messages. Extension workers identified limited literacy, ease of ignoring WhatsApp messages, and social norms as reasons for why farmers rarely engaged in discussion over WhatsApp. Nevertheless, some interviewed extension workers identified situations where one-way communication over WhatsApp indirectly facilitated two-way communication in-person. For example, a particularly successful video sharer, according to the link tracking data, explained:

> Farmers here are not involved in such kind of activities that they will like the video and comment on it that the video is good or anything else. If they find [the video] useful, they will come [to my input shop], take the thing and implement it and tell what things they need but they will not share a response on WhatsApp.

Even so, interviewed extension workers elaborated that limited discussion of WhatsApp-circulated farming videos still meant they facilitated limited feedback loops, influence, and relationship building with farmers. Without discussion, extension workers expressed frustration that they did not know what farmers thought of the videos' advice, let alone whether they watched the video. Moreover, extension workers observed that videos without discussion provided little opportunity for farmers to engage with, localise and trust the information presented. A male video sharer, that was successful according to the link tracking data, explained:

> Videos shared on WhatsApp don't create room for discussion. For example, farmers might see a video [about early wheat sowing] and reject it, saying it's too warm to plant. But if an [extension worker] is there to discuss, he can pushback and convince them.

In comparison, extension workers observed that face-to-face discussion enabled more engagement with their agricultural advice, as well as building trusting relationships. One extension worker explained:

> Among all the modes of dissemination, the best until now, has been sharing the video with the farmers who have been visiting my shop. I found people-to-people connection when I showed videos to the farmers. The people-to-people connection also helped to spread the word … While people in the WhatsApp group simply liked the video and left, the one-to-one connection at my shop encouraged people to ask questions and made the discussion on the video more interactive and engaging.

3.5. How did extension workers address WhatsApp's opportunities and limitations? (qualitative results)

In view of WhatsApp's opportunities and limitations, interviewed extension workers commonly advocated for using chat apps to supplement, not replace, face-to-face communication with farmers. For example, one extension worker explained that "I share [videos] on WhatsApp as the phones are with men so they are able to watch it on phone when I share it there. And whenever I hold physical meetings, I show [videos] to women". Another extension worker neatly summarised this approach to chat apps by likening WhatsApp to a "chutney" that can complement without replacing face-to-face extension (Figure 5):

> Suppose when we eat rice and dal and sabji, we take chutney along with it to enhance the taste. The chutney improves the taste of the food, it's taken on the side. The [WhatsApp-shared] video's role is similar to what the chutney does.

4. Discussion

The present study was designed to better understand extension workers' use of chat apps in relation to farming videos and face-to-face extension in Bihar. In collaboration with CSISA and JEEViKA, we implemented and monitored an experiment that invited – via WhatsApp – 294 extension workers to circulate three wheat agronomy videos with farmers in their respective communities. We observed three key results and discuss their implications below.

4.1. Key result #1) the efficiency of WhatsApp led most extension workers to rely on the platform to share farming videos

The first key result was that WhatsApp's efficiency led extension workers to depend on the platform for circulating farming videos.

Figure 5. Illustration of interviewed extension workers' analogy and recommendation for using WhatsApp-based video sharing as a "chutney" (right) for "rice and dal and sabji" face-to-face extension practices (left). Rice, dal, and sabji (i.e., vegetables cooked with spices) is a staple meal in Bihar. In contrast, chutneys are rarely consumed on their own, and are instead added to staple dishes. The image of rice and dal (left) was sourced from Mrsagar105 (2020), licensed under CC-BY-SA-4.0. The image of coriander mint chutney (right) was sourced from Pduaroxxx (2015), also licensed under CC-BY-SA-4.0. Both images have been modified through the addition of white text, highlighted black.

Interviewed extension workers perceived that WhatsApp has potential to reach large numbers of farmers remotely, quickly, and easily, and the link tracking data supported this perception (Figure 4). In addition, the video links shared on WhatsApp could function as reference material, creating opportunities for recipients to make use videos when relevant and convenient to them. Sharing videos on WhatsApp had its own limitations (discussed below) and still costed extension workers 7 minute of time per video view they facilitated (on average). Even so, the relative efficiency of WhatsApp-based video circulation suggests chat apps might complement face-to-face extension activities, especially since similar synergies have been observed for other digital platforms (Ding et al., 2022; Eastwood et al., 2019; Materia et al., 2015). For example, chat apps might help complement face-to-face screenings and discussion of farming videos, an extension practice that has been extensively evaluated and implemented in Bihar (Baul et al., 2024; Vasilaky et al., 2015) and other low- and middle-income contexts (Abate, Bernard, et al., 2023; Cai et al., 2019; Hörner et al., 2019; Lecoutere et al., 2023; Van Campenhout, 2021; Zossou et al., 2010). Using WhatsApp to provide reminders and refence material for these face-to-face screenings might help extension workers expand accessibility and usefulness of these screenings for farmers with access to WhatsApp and extension worker social networks.

4.2. Key result #2) WhatsApp-based video circulation was socially exclusive

The second key result was that farmers' access to WhatsApp-based video circulation was socially inequitable. Interviewed extension workers reported to two main sources for this exclusivity. First, extension workers observed that, women, less educated, and less educated farmers generally had less access to WhatsApp. Second, extension workers reported that they generally only shared and discussed videos with farmers already knew personally (see section 3.4 for details). Both barriers demonstrate that existing social structures framed the usage of WhatsApp-based video sharing. One interviewed extension worker illustrated this neatly by likening WhatsApp to "breakfast tea" - a beverage similarly embedded in local cultures in rural Bihar. This integration of WhatsApp-based video sharing with existing social systems has both theoretical and practical implications.

From a theoretical perspective, the integration of WhatsApp-based video sharing with social systems illustrates the falseness of separating "digital extension" from "non-digital extension". This study joins at least 59 others in finding that person-to-person social networks influenced use of digital farming services in low- and middle-income countries (Porciello et al., 2022). In other words, digital extension tools are not used in isolation but interact with socio-cyber-physical systems (Boas, 2022; Daum et al., 2022; Faxon, 2023; Fielke et al., 2020; Klerkx, 2021). This means that technology-transfer frameworks, like "Diffusion of Innovations", are ill-equipped for detecting heterogeneous uses and impacts of digital extension tools like WhatsApp. Instead, socio-technical theories, like domestication theory (Ogunyiola & Gardezi, 2022) and affordance theory (Davis & Chouinard, 2016; Glover, 2022), are needed to observe and anticipate uses and impacts of digital extension tools across users and contexts. Such frameworks enable researchers to "clap with two hands" by focusing on the interaction of technologies and social systems, not just the technologies on their own.

From a practical perspective, the embeddedness of WhatsApp in existing social networks illustrates the ongoing need to invest in inclusive extension networks, not just digital extension tools. Existing extension networks often exclude marginalised social groups, particularly women, less wealthy, less educated, and/or lower caste farmers (Alvi et al., 2021; Krishna et al., 2019; Nikam et al., 2022). This limited access to information-rich social networks makes WhatsApp less *useful* to marginalised social groups, in addition to WhatsApp generally being less *usable* for these social groups (see section 3.4). Sustained investment in social inclusive extension networks, such as JEEViKA's self-help groups, is therefore needed for digital extension tools to be more socially inclusive in rural Bihar and other contexts like it. Practical

pathways to do so are analysed in forthcoming gender-focused paper mentioned in the introduction.

4.3. Key result #3) WhatsApp facilitated little two-way discussion in this context

The third key result was that WhatsApp facilitated little two-way discussion, and thereby little opportunity for extension workers farmers to localise recommended farming practices, provide feedback to each other, and build relationships with each other. WhatsApp can be used for two-way communication but was generally used for one-way communication, at least for the videos circulated in this study. Munthali et al. (2021) observed similar trends within formal extension systems in Ghana. Conversely, studies in other contexts have observed considerable dialogue in farming chat apps (Boas, 2022; Jomantas et al., 2024). Interviewed extension workers explained the lack of online discussion in the present research context by highlighting social norms regarding the use of WhatsApp in rural Bihar, in combination with ease of ignoring WhatsApp messages and variable literacy levels of farmers in rural Bihar (see section 3.4 for details). The level of two-way discussion would have presumably also been influenced by the selection of extension actors asked to share farming videos (Munthali et al., 2021), and how these extension workers were asked (Glover et al., 2019).

In any case, interviewed extension workers expressed three main concerns with the lack of two-way discussion sparked by WhatsApp-based video circulation in this research context. First, extension workers observed that discussion is typically needed for farmers to actively engage with novel farming practices and work out how to adapt them to their unique farming systems. This observation resonates strongly with existing literature on use and impacts of farming videos and other DETs (Porciello et al., 2022). For instance, a study in Uganda found "[farmer participants] believed learning mainly occurred outside the video hall as they discussed and implemented what was shown in the video" (Karubanga et al., 2019). A second concern is that lack of two-way discussion constrained farmers from providing their perspectives on farming practices recommended in the videos. In this study, WhatsApp was rarely a vehicle for such farmer participation in agricultural innovation systems; extension workers often did not even know if farmers watched the videos shared with them over WhatsApp. The third key concern raised by extension workers was that lack of discussion over WhatsApp did not create opportunities for trust and relationship building between farmers and extension workers, at least relative to face-to-face discussion. In summary, WhatsApp-based video circulation enabled extension workers to reach more farmers, but with questionable benefits to "reached" farmers, at least in this research context.

Existing empirical literature has routinely found that two-way discussion facilitated usefulness of DETs to famers and extension workers in low- and middle-income countries (Asaka & Smucker, 2016; Butt, 2015; Coggins et al., 2022; Porciello et al., 2022). We therefore suggest that extension service managers broaden the assessment of their digitisation initiatives beyond "farmers reached". Expanding extension "reach" can have positive impacts (Jensen, 2007), negative impacts (Chowdhury et al., 2023), or insignificant impacts (Abate, Bernard, et al., 2023). Facilitating two-way communication, not just one-way "reach", could facilitate more of the positive impacts by supporting localisation of farming advice, foster person-to-person relationships, and integrate farmers' insights and priorities into agricultural innovation systems (Ayre et al., 2019). In other words, we might engage with DETs more effectively by aiming to *intermediate* with more farming communities, not just *reach* more farmers (Klerkx & Leeuwis, 2008; Klerkx et al., 2019; Munthali et al., 2018). For instance, we could test opportunities for DETs to help farmers to advise agricultural scientists and extension service managers, not just the other way around.

4.4. Implications for extension chatbots powered by large language models

We anticipate that the observed benefits and limitations of WhatsApp may also apply to emerging chatbots for agricultural extension, such as "Farmer.Chat" and "KissanAI". From an inclusion perspective, women, less wealthy and less educated farmers may be excluded from chatbots, if such chatbots are not designed with these social groups in mind (Tzachor et al., 2022). From a two-way discussion perspective, chatbots may enable farmers to request and interact with information. However, such interactions can influence users without necessarily influencing the underpinning large language model (Bender et al., 2021). This lack of two-way influence would limit opportunities for farmers and extension workers to integrate their local priorities and knowledge in agricultural innovation systems (Rose & Chilvers, 2018; Tzachor et al., 2022, 2023). And finally, from a relationships perspective, chatbots may not facilitate social networks and interactions required for functional agricultural innovation systems (Klerkx et al., 2012; Leeuwis, 2013). In view of all this, removing human intermediaries from chat apps risks amplifying, not addressing, the challenges that interviewed extension workers highlighted with chat apps in agricultural extension.

Having suggested all of that, it must be noted that chatbots were not directly addressed in our empirical research. Further research is much needed to facilitate effective identification, prioritisation, and mitigation of opportunities and risks posed by chatbots in agricultural extension.

4.5. Conclusions

We summarise the three key findings and implications below:

(1) The efficiency of WhatsApp led most extension workers to rely on the digital platform, rather than in-person interactions, to share farming videos. This implies WhatsApp-based video sharing can help extension workers time- and cost-efficiently communicate more frequently, and with more reference material, with farmers they already engage with.
(2) Extension workers expressed concern that WhatsApp-based sharing of farming videos excluded farmers they were not already in contact with, as well as farmers lacking access to WhatsApp (typically women, less wealthy and less educated farmers in this context). WhatsApp's embeddedness in existing social systems illustrates the need for socio-technical theories to detect and anticipate heterogeneous use and impacts of digital extension tools. This result also implies that investing in more socially inclusive extension networks can enable more socially inclusive digital extension tools.
(3) Extension workers were also concerned that WhatsApp facilitated limited two-way discussion with farmers, and thus limited localisation, feedback loops, and relationship building, at least in this research context. We therefore suggest extension practitioners evaluate digitisation efforts based on their effectiveness for *intermediating* with more farmers, not just *reaching* more farmers.

Overall, we conclude by agreeing with one interviewed extension worker that chat apps can be best used as a "chutney": a helpful complement and inadequate substitute for face-to-face extension activities in Bihar and other contexts like it.

Acknowledgments

First, we acknowledge the 294 extension workers that participated in this research, particularly the 20 extension workers that generously shared their time and insights in the semi-structured interviews. Second, we acknowledge the many other collaborators that facilitated this research. These collaborators include extension service managers from the Bihar Rural Livelihoods Promotion Society (JEEViKA), as well as extension service managers from the Cereal Systems Initiative for South Asia. These collaborators also include the six expert farmers who co-developed videos used in this trial, namely B. Devi, P. Devi, K. Kumar, K. Pandey, S. Rai, and G. Rani. These collaborators also include those from Bihar Agricultural University that not only provided advice on the videos but also hosted them on their YouTube channel named 'Bihar Agricultural University Sabour'. These collaborators also include research associates who facilitated telephonic surveys, interview translations, and interview transcriptions, all with precision and care for participant privacy. Third, we would like to acknowledge

funders that enabled this research. This work was supported by an Australian Government Research Training Program (RTP) Scholarship; a Westpac Future leaders Scholarship; and the Cereal Systems Initiative for South Asia (CSISA; http://csisa.org/), itself funded by USAID under Grant BFS-G-11-00002 and the Bill and Melinda Gates Foundation under Grant OPP1052535 and Grant OPP1133205. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of any individual or organisation acknowledged above.

Disclosure statement

Some co-authors were employed by the same organisations (CSISA and JEEViKA) that employed the extension workers that were researched in the study. All employment of authors by CSISA and JEEViKA is made transparent in the author affiliation list. No other potential conflict of interest was reported by the author(s).

Funding

The work was supported by the Bill and Melinda Gates Foundation [OPP1052535]; Australian Government Research Training Program; United States Agency for International Development [BFS-G-11-00002]; Westpac Scholars Trust.

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