

International Journal of Agriculture Extension and Social Development

Volume 9; Issue 9; September 2026; Page No. 524-531

Received: 19-07-2026
Accepted: 23-08-2026

Indexed Journal
Peer Reviewed Journal

Strengthening sericulture through mulberry extension: Digital technologies, farmer adoption and sustainable development

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DOI: <https://www.doi.org/10.33545/26180723.2026.v9.i9g.4233>

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Abstract

Sericulture occupies an unusual place in agricultural development: it is simultaneously a crop system, a livestock enterprise, and a rural industry, and its extension needs cut across all three. This review examines how mulberry-based sericulture extension is being reshaped by digital technologies, and why farmer adoption of both conventional and digital innovations remains so uneven across production regions. Rather than cataloguing extension programmes or digital tools in isolation, the review traces how institutional extension structures, digital advisory platforms, and the socio-economic circumstances of smallholder rearers interact to determine whether an innovation actually reaches the rearing shed. Evidence on remote sensing of mulberry canopies, digital twin modelling of rearing houses, AI-assisted disease detection, and smartphone-based advisory services shows real technical promise, and parallel evidence from field-crop agriculture demonstrates that digital extension can measurably raise the odds that a recommended practice is adopted. Set against this, a large body of farm-level research on sericulture communities across India, Nepal, and elsewhere documents persistent constraints market information gaps, price volatility, weak technical service delivery, and uneven digital literacy that blunt the reach of both traditional and digital extension. The review argues that digital tools change the economics of information delivery but do not, on their own, resolve the institutional and behavioural barriers that have limited sericulture technology adoption for decades. Livelihood, women's employment, and climate-resilience outcomes are strongest where digital and institutional extension are combined rather than treated as substitutes. The review closes by identifying where the evidence base is thin particularly on digital extension specific to sericulture rather than field crops and by outlining research and policy priorities for building extension systems that are genuinely responsive to mulberry farmers' constraints.

Keywords: Sericulture extension, mulberry cultivation, digital agricultural advisory services, technology adoption behaviour, rural livelihoods, sustainable development goals

Introduction

Silk has never been an ordinary commodity, and the industry built around it never fit comfortably into standard agricultural categories. Sericulture asks a farmer to be an agronomist for part of the year and a livestock rearer for the rest, the two halves linked so tightly that a shortfall in mulberry leaf quality shows up, weeks later, as a shortfall in cocoon weight. That linkage is why sericulture has been positioned as a contributor to several Sustainable Development Goals at once income generation, women's employment, rural non-farm diversification rather than to any single one ^[1]. In Karnataka, the sector's economic weight is no historical footnote: recent sectoral data describe raw silk output rising from roughly 11,800 tonnes in 2022-23 to more than 13,000 tonnes in 2024-25, alongside an accelerating rollout of subsidized automatic reeling machines and an expanding network of farmer producer organizations ^[2]. Karnataka alone has, in earlier assessments, accounted for around a third of India's silk output ^[8], and mulberry's association with silk production in the Kollegal tract was already being

documented by agronomists close to a century ago ^[3] a reminder that this is an old problem that keeps acquiring new tools. A bibliometric mapping of the field shows the research base expanding steadily, with production biology and silk quality still dominating relative to extension and adoption studies ^[4].

That imbalance matters because the sector's difficulties have rarely been agronomic in the narrow sense. Reviews of sericulture across Northeast India describe a viable but institutionally thin sector, where policy pathways exist on paper more securely than they do on the ground ^[5]. Studies from Nepal report meaningful household-level socioeconomic contributions from sericulture even in districts with limited formal extension presence ^[6], and cocoon-production research in Telangana links household income gains directly to the consistency of technical support farmers receive rather than to mulberry variety alone ^[7]. Karnataka's own farmers, when surveyed on their attitude toward the state's Technical Service Centres, split roughly down the middle between medium and high favorability, with

only a small minority expressing genuine dissatisfaction a pattern that says less about the technology being extended and more about how variably it reaches different taluks^[8].

Digital technology enters this picture at a moment when the traditional weaknesses of face-to-face extension its cost, its reach, its dependence on the skill of the individual extension officer are being reframed as solvable problems. Analyses of digital tools in agricultural extension more broadly describe mobile applications and web-based platforms as instruments capable of narrowing the information gap between research stations and farm gates, provided language and regional adaptation are built in rather than assumed^[9]. Evidence from smartphone-based extension in China's Zhejiang province is unusually precise on this point, reporting adoption increases of roughly 75 percent in treated area and 73 percent in treated volume once a government-designed WeChat advisory application was in use^[10]. Whether that scale of effect is achievable in a biologically constrained, disease-sensitive enterprise like silkworm rearing is one of the central questions this review returns to.

The remainder of the review builds toward that question. It traces how mulberry extension has evolved from centralized technical service delivery toward more networked, increasingly digital models; it examines what remote sensing, digital twins, AI-based rearing support, and mobile advisory platforms actually contribute once stripped of promotional framing; it treats farmer adoption as the section needing most scrutiny, since decades of constraint research and a handful of years of digital-adoption research sit side by side with little cross-reference; and it closes on what this means for livelihoods, policy design, and the research agenda sericulture extension science still needs.

Evolution of Mulberry Extension

Sericulture extension in India grew up around a demand-driven institutional model rather than a single national curriculum. Karnataka's Technical Service Centres, positioned at hobli and taluka level, were designed to combine input supply mulberry saplings, bed disinfectants, growth promoters with technology dissemination and monitoring of both cultivation and rearing, and their footprint is dense enough that a study covering only two districts could still draw on twenty-four separate centres^[8]. That density is unusual for Indian agricultural extension generally, and it reflects sericulture's specific vulnerability: a rearing shed that misses a disinfection cycle or receives poor-quality saplings does not get a second season to recover in the way a field crop might.

Parallel to this input-and-monitoring model, cluster-based participatory approaches have been used deliberately to push bivoltine sericulture the higher-value, higher-risk silkworm strain into areas where farmers had reason to be cautious about switching from established multivoltine practice. Cluster Promotion Programmes built around bivoltine sericulture in areas such as Madakasira have been documented as improving the socio-economic position of participating farmers, which suggests that concentrated, geographically bounded extension effort can shift adoption in ways that thinly spread, universal programming cannot^[11]. The lesson generalizes awkwardly, however: a cluster approach that works because it concentrates scarce extension staff in one place is not obviously scalable to an entire silk-

producing state without diluting the very concentration that made it effective.

What has changed more recently is less the extension model itself than the channel through which it operates. Reviews of digital technology in agricultural extension describe a shift from blanket, undifferentiated advisory content toward information that can, at least in principle, be tailored to a farmer's location, crop stage, and language^[9]. The Zhejiang smartphone case is again instructive here, not because it concerns sericulture directly but because it isolates the mechanism cleanly: personalized digital information reduced the labour and search cost of obtaining fertilization advice enough to shift adoption substantially, with the effect noticeably stronger for farmers who had previously been the hardest to reach through conventional channels^[10]. Sericulture extension has not yet produced a comparably rigorous impact estimate of its own digital tools, and that gap a rich literature on what digital extension does for field crops, and a thin one on what it does for mulberry-silkworm systems specifically runs through much of what follows.

Digital Technologies in Sericulture

The most methodologically careful digital-technology study available in the sericulture literature concerns something unglamorous: whether satellite vegetation indices can be used to estimate how much mulberry leaf a field has actually produced. Using PlanetScope imagery over two rearing seasons in Veneto, Italy, researchers found that the decline in NDVI and SAVI values during the fifth larval instar the stage at which silkworms consume roughly nine-tenths of their total feed correlated with cocoon production per box, average cocoon weight, and silk shell weight, with coefficients of determination reaching about 0.56 for the strongest relationships^[12]. That is a modest but genuine result, and it matters for extension because it points toward a low-cost way of monitoring leaf availability without requiring farmers to report anything themselves precisely the kind of passive, low-burden data source that struggling extension systems can rarely afford to build from scratch.

Digital twin approaches aim at a different part of the same problem: not the mulberry field but the rearing house itself. Chinese researchers have outlined a digital twin framework intended to model the environmental conditions of the silkworm rearing house continuously, arguing that such systems could improve rearing efficiency and support the sector's shift from empirical, experience-based practice toward something closer to factory farming discipline^[13]. The framework is presented at the level of concept and technology inventory rather than field validation, and the paper is candid that key technical and adoption challenges remain unresolved. Much the same caveat applies to AI-driven automation proposals combining IoT sensing, automated temperature control, precision feeding, and deep-learning-based disease detection: the stated aim is to reduce human intervention and losses while keeping practices scalable and environmentally sound, but the description reads as a system architecture rather than a reported field deployment^[14]. A mechatronic multilayer silkworm feeder aimed at raising productivity through mechanised leaf delivery sits in the same promising-but-narrowly-demonstrated category^[15], as does closed-environment cutting propagation for establishing intensive mulberry

maternity groves, which extends the same logic of control back to the nursery^[16].

None of this technical promise closes the gap that field-crop digital agriculture research has already identified as decisive: technology adoption depends less on whether a tool works in principle than on whether farmers can access, trust, and afford it. Evidence from Sichuan on digital agricultural technology services finds that farmers' willingness to choose digital production technology tracks closely with service quality and perceived usefulness rather than with the sophistication of the technology on offer^[17]. Systematic reviews of digital literacy and technology adoption in agriculture converge on a similar list of enabling conditions: infrastructure access, skills, perceived relative advantage, and social network effects that apply as much to a sericulture rearing house as to a grain field^[18, 19]. A study measuring digital literacy directly among Chinese farmers found that its effect on green-technology adoption worked through three distinct pathways: it raised farmers' tolerance for the risk of trying something new, it expanded their digital social networks, and it made government technology promotion more effective when it did reach them with the effect concentrated among larger-scale and middle-generation farmers rather than the youngest or oldest cohorts^[20]. That last finding is worth holding onto, because sericulture households, particularly in regions with high out-migration of younger family members, may not resemble the "middle-generation, larger-scale" profile in which digital literacy pays off most clearly.

Farmer Adoption

If the digital technologies described above are to matter, they have to clear a bar that non-digital sericulture technologies have struggled to clear for decades. The constraint literature on this point is large, geographically dispersed, and strikingly consistent in its findings. Farmers in Solapur district named inadequate market information, cocoon price fluctuation, and transport difficulty as their principal constraints, with calls for better-timed leaf supply and more regular equipment training^[21]. Studies from Jorhat district in Assam identify a comparable cluster around production technology adoption^[22], while adoption-gap research on Tasar rearing technologies documents a persistent shortfall between recommended and practiced technique^[23]. Constraint studies from Tamil Nadu describe similar barriers during rearing itself^[24], and technological-gap research from Karnataka's cultivation practices and Northern Karnataka's adoption constraints point to the same pattern: practices exist, extension has communicated them, and farmers still are not applying them at the intensity researchers expected^[25, 26]. Garret ranking analysis of constraints among silkworm rearers offers a way of ordering these barriers by relative severity rather than simply listing them, which is analytically useful precisely because it forces a distinction between constraints that are merely present and constraints that are decisive^[27].

Adoption-level studies complicate any reading of the constraint literature as blanket failure. Research on recommended technology adoption in Krishnagiri district found meaningful uptake rather than uniform non-adoption^[28], and adoption-behaviour research in Assam found farmers engaging with improved technologies to a degree, even where

full adoption fell short^[29]. Where Tasar rearing technologies were actually adopted, cocoon production improved measurably^[30] the clearest evidence that the constraint literature documents a gap in intensity and consistency of adoption, not an absence of adoption altogether. Adoption-level research from Udalguri district and from bivoltine rearing in Chitradurga both describe partial, unevenly distributed adoption^[31, 32], and profiling work on Chitradurga's bivoltine rearers situates that unevenness against farmers' socio-economic characteristics rather than treating adoption as one undifferentiated outcome^[33]. Perception research on Tasar rearers' experience of climate change adds a further layer: farmers are not simply failing to adopt, they are also adapting or failing to adapt to a shifting climatic baseline the original recommendations may not have anticipated^[34].

Read together, this body of work suggests that sericulture's adoption problem has never been primarily a knowledge-transfer problem in the narrow sense assumed by classical diffusion-of-innovations thinking. Farmers in these studies are generally aware of recommended practices; what they lack, repeatedly, is reliable market information, price stability, transport infrastructure, consistent technical service delivery, and in the newer digital-adoption literature the digital social capital and risk tolerance that determine whether a smartphone advisory tool gets used rather than merely installed^[20]. This is precisely why the smartphone-based digital extension results from field-crop agriculture cannot be read as directly transferable to sericulture: the Zhejiang application worked by reducing the cost of obtaining personalised technical information for farmers who already had reasonably functioning input and output markets^[10]. Superimposing a similar digital tool onto a sericulture value chain still constrained by cocoon price volatility and weak market information^[21] is unlikely to reproduce the same magnitude of effect unless those underlying market failures are addressed at the same time.

Impact on Sustainable Development

Where sericulture extension functions reasonably well, the livelihood evidence is fairly convincing. Sericulture's contribution toward Sustainable Development Goals rests on its capacity to generate income in semi-arid and marginal land regions where conventional cropping options are limited^[1], and household-level research across Indian states supports the underlying claim even without testing SDG alignment directly. Livelihood-improvement research from Kokrajhar district in Assam links sericulture participation explicitly to women's economic empowerment^[35], and a study of tribal women's empowerment through sericulture in Chhattisgarh's Lailunga block reaches a comparable conclusion in a different agro-social setting^[36]. A related study from Gharghoda tribal block frames sericulture as a livelihood-opportunity model for populations with limited access to other rural non-farm income^[37]. Profitability research from Kamrup district in Assam, across two related studies, finds sericulture generating meaningful household income even where formal extension support is inconsistent^[38, 39], and comparative income analysis of silkworm farming in Indonesia situates cocoon-rearing profitability against alternative rural enterprises^[40].

The sustainability case extends beyond household income. A

review of silk production in Romania frames *Bombyx mori* rearing as an underused opportunity for rural diversification in a European context where sericulture has largely disappeared, arguing for its reintroduction on economic and environmental grounds ^[41]. Economic analysis from Himachal Pradesh's Bilaspur district quantifies cocoon returns in a temperate setting distinct from the tropical mulberry belts that dominate the literature ^[42], and research on sustainable Eri silkworm rearing in Manipur's Bishnupur district extends the sustainability argument to a non-mulberry silk system a reminder that "sericulture extension" is not synonymous with mulberry-*Bombyx mori* extension alone ^[43]. On the agronomic side, research into climate-resilient nutritional strategies for mulberry cultivation reports on approaches intended to maintain cocoon quality under increasingly variable growing conditions, directly linking agronomic innovation to climate adaptation rather than treating the two as separate research tracks ^[44].

What is harder to find in this literature is rigorous evidence connecting digital extension specifically as opposed to sericulture participation generally to these sustainability outcomes. The livelihood and empowerment studies cited above were largely conducted without reference to digital advisory tools, and the digital-technology studies reviewed in the previous section were not designed to measure livelihood or gender outcomes. Where the two literatures meet, it is in the field-crop digital extension research showing precision fertilisation and other resource-efficient technologies scaling up faster once digital advisory support is available ^[10] a mechanism plausible enough to expect in sericulture, but not yet demonstrated there with comparable rigour.

Policy, Governance and Extension Systems

Institutional density appears to matter as much as institutional design. Karnataka's sericulture ecosystem combines Technical Service Centres, more than thirty farmer producer organisations, research collaboration with the Central Silk Board, and a subsidy structure for automatic reeling machines covering up to ninety percent of costs for marginalised groups a layering that recent sectoral analysis credits with turning a traditionally labour-displacing mechanisation process into one that has instead restructured rural employment toward more skilled reeling work ^[2]. That is encouraging, but it is drawn from a single high-performing state with unusually dense governance architecture, and the same analysis is candid that its transferability to thinner institutional settings cannot be assumed ^[2].

Regional policy reviews elsewhere describe a much less settled picture. Northeast India's sericulture sector is characterised as viable and rich in indigenous silk traditions Eri and Muga alongside mulberry but constrained by policy pathways that remain underdeveloped relative to Karnataka's model, with the review calling explicitly for stronger institutional coordination rather than further technical research alone ^[5]. International comparisons reinforce the point that institutional context, not technology, is usually the binding constraint: silkworm development strategy research from Pasuruan, Indonesia frames extension and market-linkage weaknesses as more limiting than any deficit in husbandry knowledge ^[45], while rural-development-oriented studies of silkworm breeding in Bursa, Turkey and Diyarbakır's Silvan district tie sericulture revival explicitly

to regional development policy rather than treating it as a purely technical programme ^[46, 47]. Research on mulberry cultivation's effect on beneficiary farmers in Amravati district, and older survey work on mulberry tree production in Korea, point to the same requirement: agronomic support has to be sustained institutionally across seasons, since one good season of extension contact does not compensate for weak follow-up in the next ^[48, 49].

The cluster-promotion and Technical Service Centre evidence discussed earlier suggests one governance principal worth stating plainly: concentrated institutional support in defined geographic clusters appears to outperform thin, universal coverage, at least in the cases documented so far ^[8, 11]. Digital tools are sometimes framed as a way of substituting for that institutional density reaching farmers a physical technical service centre cannot reach but the evidence reviewed here supports a more modest claim: digital channels appear to work best as a complement to institutional extension, reducing the marginal cost of repeat contact with farmers who are already inside some form of institutional network, rather than as a freestanding substitute for that network where it does not exist.

Challenges

The technical challenges facing digital sericulture extension are real but probably the most tractable of the four categories considered here. Rural connectivity gaps, the cost of sensor and satellite-derived data relative to smallholder margins, and the early-stage nature of digital twin and AI rearing-support systems which remain largely conceptual rather than field-validated in the sericulture literature specifically ^[13, 14] all constrain what can be deployed today, but these are the kinds of constraints that tend to ease with time and falling technology costs.

Social and institutional challenges are more stubborn. The constraint literature surveyed above returns again and again to the same list: inadequate market information, unreliable technical service contact, and weak transportation and market infrastructure ^[21, 22, 23, 24, 25, 26, 27]. Traditional versus scientific rearing comparisons documented, for instance, in Eri silkworm systems in the Bhubaneswar zone illustrate how far practice can lag behind recommendation even where scientific rearing methods have been established and communicated for years ^[50]. Digital literacy research adds a further layer of social constraint specific to the newer generation of tools: the same studies that find digital literacy driving green-technology adoption also find that effect concentrated among particular age cohorts and farm sizes ^[20], which means a digital extension strategy applied uniformly risks widening rather than narrowing the adoption gap between better-resourced and more marginal sericulture households.

Economically, the persistent finding across constraint studies is that farmers are weighing technology adoption against cocoon price volatility and market uncertainty that no amount of extension messaging, digital or otherwise, can resolve on its own ^[21]. A rearing technology that improves yield is a poor proposition for a farmer who cannot predict what that additional cocoon output will actually sell for. This is arguably the single clearest point at which agricultural extension science and agricultural marketing policy need to be treated as one connected problem rather than two separate portfolios.

Future Perspectives

The most defensible near-term direction is not a leap to speculative technologies but a consolidation of what has already shown partial promise. Remote sensing of mulberry canopy condition, validated so far only in a small European trial, is a plausible candidate for scaling into tropical and subtropical mulberry belts where leaf-yield estimation is

currently done almost entirely by farmer judgement [12]. Digital twin and AI-based rearing-house monitoring remain, on the evidence available, further from field deployment than their conceptual framing suggests [13, 14], and treating them as five-to-ten-year research investments rather than near-term extension tools would be the more honest framing for policy purposes.

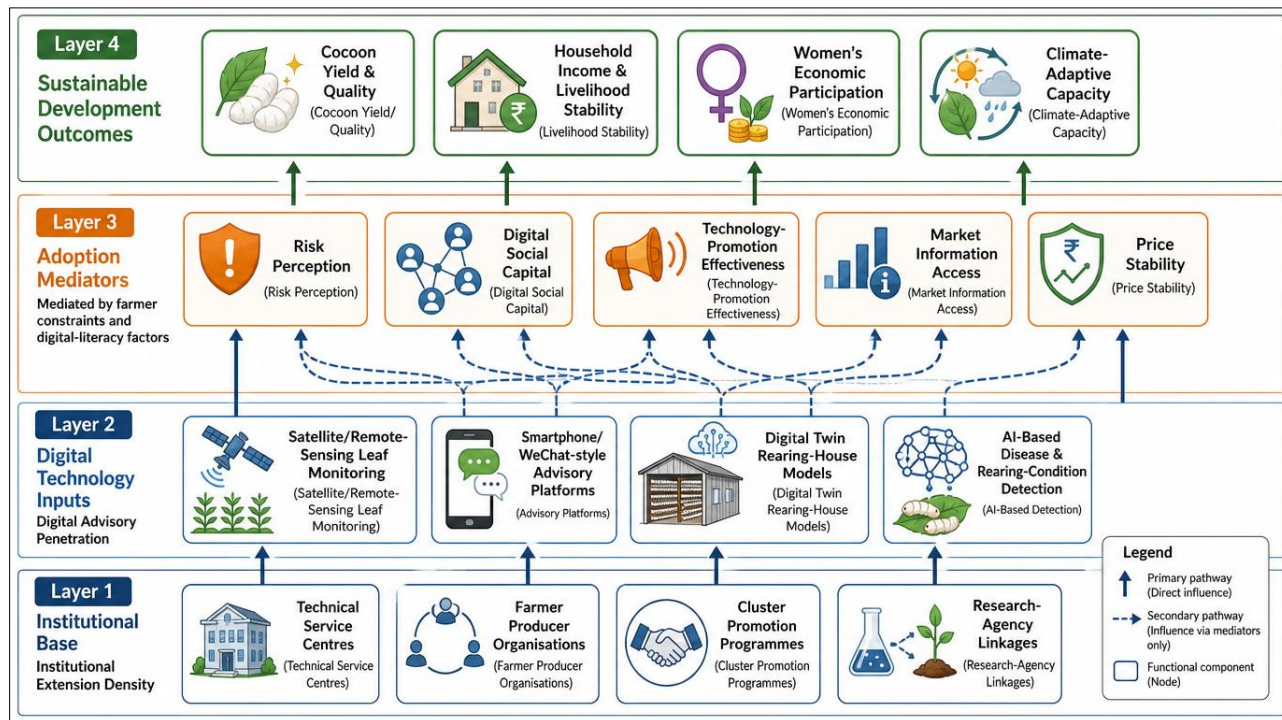


Fig 1: Framework linking mulberry sericulture extension, digital technology layers, farmer adoption mediators, and sustainable development outcomes

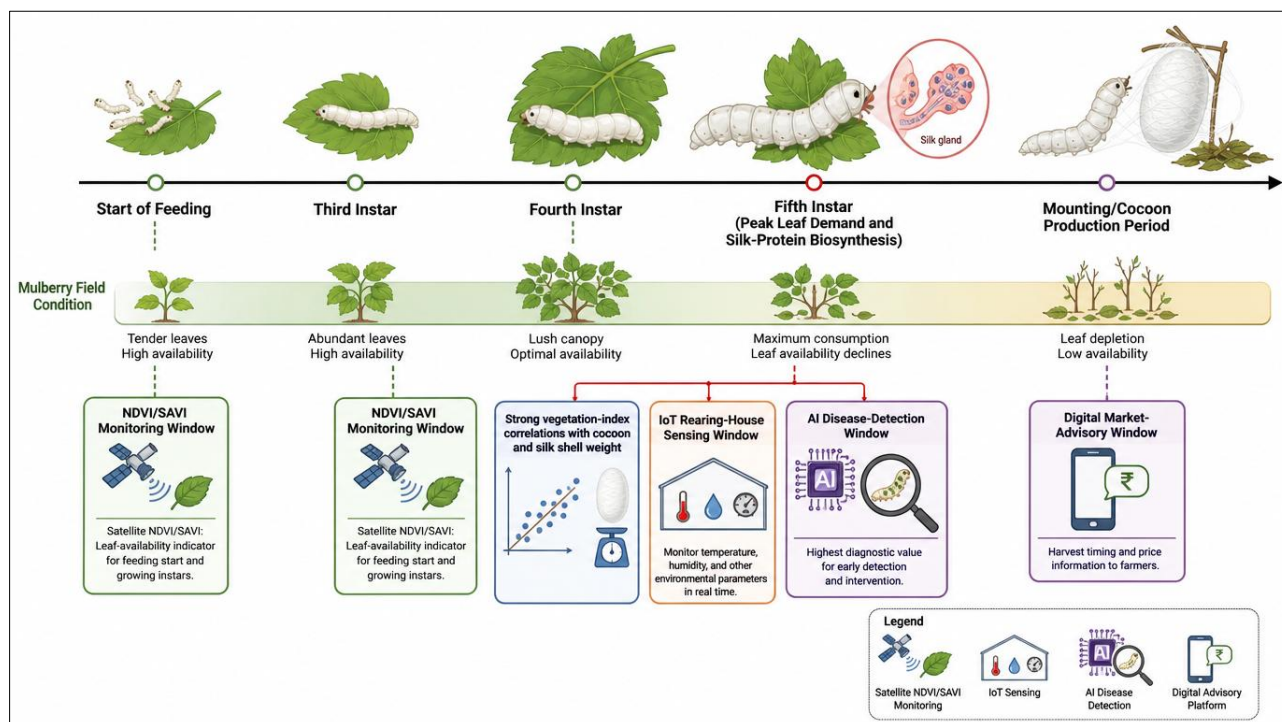


Fig 2: Digital intervention points across the mulberry silkworm production cycle

Personalised digital advisory delivery, modelled on the mechanism demonstrated in Chinese field-crop extension^[10], is the digital intervention with the clearest existing evidence base and the most plausible transfer to sericulture, provided it addresses the specific constraints documented here market and price information above all, not agronomic advice alone. Systematic reviews of digital literacy and technology adoption converge on infrastructure, skills, and social network effects as preconditions for any of this working^[18, 19], which argues for sequencing: infrastructure and literacy investment first, sophisticated advisory content second. Multilingual, regionally adapted advisory platforms are a recurring recommendation in the digital extension literature^[9], and sericulture's diversity from Karnataka to Assam to Northeast India's tribal belts makes this more than a generic best practice.

Claims about blockchain-based silk value-chain traceability and large-scale big-data analytics for sericulture appear intermittently in adjacent digital agriculture literature, but the evidence base supplied for sericulture specifically does not yet support detailed technical claims about either; both remain reasonable hypotheses for future research rather than demonstrated interventions. The bibliometric evidence that sericulture research still sits concentrated in production biology relative to extension and socio-economic adoption research^[4] is itself a research-priority finding: closing that imbalance, by funding rigorous impact evaluations of digital extension tools specific to mulberry-silkworm systems, would do more for the field than any single new technology currently under discussion.

Conclusion

Mulberry sericulture extension sits at an unusually demanding intersection of agronomy, animal husbandry, rural sociology, and now digital technology, and the evidence reviewed here does not support a simple story in either direction. Digital tools remote sensing of mulberry condition, digital twin rearing-house models, AI-assisted disease detection, and smartphone-based advisory delivery show genuine technical promise, and the smartphone evidence from field-crop agriculture demonstrates that digital channels can substantially change adoption outcomes when they reduce the real cost of obtaining personalized information. Set against that promise, decades of constraint research across Indian sericulture regions describe a consistent set of barriers market information gaps, price volatility, uneven technical service reach, and now uneven digital literacy that digital tools alone do not resolve, and in some cases, risk reproducing along new lines. The livelihood evidence is more encouraging where institutional extension is dense and sustained, as in Karnataka, than where it is thin, as several regional reviews describe elsewhere. The honest research priority is not to choose between institutional and digital extension but to test, with the same rigour applied to field-crop digital agriculture, whether digital tools can be built specifically around the constraints market information above all that sericulture farmers themselves have identified as decisive.

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