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Pluralistic Extension Model for Fostering the Production of Extra Long Staple (ELS) Cotton in India

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Abstract

Background

Extra Long Staple (ELS) cotton plays a vital role in producing premium quality yarns and high value textile products; however, its cultivation in India has declined due to production, climatic, institutional and market related constraints. Conventional extension approaches have been inadequate in addressing these multidimensional challenges, highlighting the need for an integrated and participatory extension framework. The present study aimed to identify the major constraints affecting ELS cotton cultivation, analyse their underlying causes and develop a participatory pluralistic extension model to strengthen stakeholder linkages, technology dissemination and the sustainability of the production system.

Results

The study was conducted among 450 ELS cotton farmers from major cotton growing districts of Tamil Nadu and Karnataka using a mixed methods approach comprising participatory rural appraisal, focus group discussions, structured interviews and Garrett ranking analysis. The findings revealed that high labour demand was the most significant constraint, followed by low market price, high susceptibility to pests, high production cost and low yield. Problem tree analysis identified four major root cause domains: production related, climate and environmental, economic and market and high cost of cultivation constraints. Based on participatory objective and strategy

analyses, a pluralistic extension model was developed by integrating research institutions, extension agencies, farmer producer organizations, financial institutions, private input suppliers and market actors. The model established functional linkages for technology transfer, input supply, financial services, collective marketing, value chain integration and feedback mechanisms, supported by institutional governance, participatory decision making, monitoring and a three-phase operational framework covering pre-production, production and post production activities.

Conclusions

The proposed pluralistic extension model provides a comprehensive and operational framework for addressing the interconnected challenges limiting ELS cotton cultivation. By strengthening stakeholder coordination, improving access to technologies, institutional support, finance and markets, the model has the potential to enhance technology adoption, productivity, profitability, market integration and farmers' livelihoods while contributing to increased domestic production and reduced dependence on imports of ELS cotton.

Keywords: Extra Long Staple (ELS) cotton; Pluralistic extension; Agricultural innovation systems; Participatory Rural Appraisal (PRA); stakeholder linkages; technology dissemination; value chain integration; cotton production.

Introduction

Agriculture continues to play a pivotal role in the economies of developing countries, contributing significantly to employment, income generation and industrial growth (Dethier et al. 2012; Nguyen et al. 2015; Hemming et al. 2018; Mizik et al. 2025). Among agricultural commodities, cotton is one of the most economically important fibre crops and serves as a critical raw material for the

global textile industry (Khan et al. 2020; Zhang et al. 2025). Cotton is cultivated in more than 80 countries across approximately 31-36 million hectares and supports the livelihoods of over 250 million people worldwide, while providing employment to nearly 7 per cent of the workforce in cotton producing developing nations (Khan et al. 2020; Vitale et al. 2025). It is the most widely utilized natural fibre globally, accounting for more than 82 per cent of total natural fibre consumption, thereby occupying a strategic position in the global textile value chain (Sener fidan et al. 2023). Although cotton is primarily valued for its fibre, it also serves as an important oilseed crop and contributes substantially to the agricultural economies of several countries (Khan et al. 2020).

Among the cultivated cotton species, *Gossypium barbadense* L., commonly known as Extra Long Staple (ELS) cotton, is highly valued for its superior fibre quality, including exceptional fibre length, strength, fineness, softness, and lustre (Avci et al. 2013; Alagarsamy 2023). These premium fibre characteristics make ELS cotton the preferred raw material for manufacturing fine and superfine yarns, high count fabrics, luxury garments and other value added textile products (Avci et al. 2013; Sankaranarayanan et al. 2021). Despite its superior quality, ELS cotton contributes only a small proportion of global cotton production and is cultivated on less than two per cent of the world cotton area due to its longer crop duration, higher production costs, specific climatic requirements and relatively lower productivity compared to upland cotton (*Gossypium hirsutum*) (Alagarsamy, 2023; Vijayaragavan et al. 2025). Nevertheless, the global demand for premium textile products manufactured from ELS cotton continues to increase, creating a substantial demand supply imbalance in international markets and highlighting the need for strategies that enhance ELS cotton production and availability (Sankaranarayanan et al. 2021).

67 India is one of the world's leading cotton producing countries and is unique in cultivating all four
68 domesticated cotton species, namely *Gossypium hirsutum*, *G. arboreum*, *G. herbaceum* and *G.*
69 *barbadense* (Kumar, 2023). However, despite being a major cotton producer, the area under ELS
70 cotton cultivation remains extremely limited compared to other cotton species. More than 95 per
71 cent of the cotton area in India is occupied by *G. hirsutum*, while the area under *G. barbadense*
72 has steadily declined over the years, resulting in reduced domestic production of ELS cotton and
73 a widening gap between demand and supply (Prasad et al. 2025). The domestic requirement of
74 ELS cotton is estimated at approximately nine lakh bales, whereas the current availability is only
75 about four lakh bales, and the demand is projected to increase to nearly 20 lakh bales by 2030
76 (Sankaranarayanan et al. 2021). Consequently, India remains heavily dependent on imports of ELS
77 cotton from countries such as the United States, Egypt and Sudan to meet the requirements of the
78 domestic textile industry (Sankaranarayanan et al. 2021; Prasad et al. 2025).

79 The limited adoption and expansion of ELS cotton cultivation in India can be attributed to several
80 production, economic and marketing constraints. Compared with upland cotton, ELS cotton is
81 characterized by lower yield potential, longer crop duration, susceptibility to sucking pests and
82 diseases, higher labour requirements for harvesting, greater production costs and lower
83 adaptability to diverse agro climatic conditions (Avcı et al. 2013; Vijayaragavan et al. 2025). In
84 addition, farmers cultivating ELS cotton encounter significant challenges related to labour
85 shortages, difficulty in boll picking, market price fluctuations, involvement of intermediaries,
86 delayed payments and transportation constraints which collectively discourage large scale
87 adoption of the crop (Deepika and Asokhan, 2019). These challenges have contributed to yield
88 instability, reduced profitability and poor adoption of ELS cotton production technologies. Given
89 the rapidly growing demand for premium textile products and the strategic importance of ELS

cotton to the Indian textile sector, enhancing domestic ELS cotton production has become a national priority for reducing import dependence, strengthening the competitiveness of the textile industry and improving farmers' income and livelihood security (Sankaranarayanan et al. 2021; Prasad et al. 2025).

Despite the substantial body of research on cotton production, existing studies have predominantly focused on production aspects such as varietal improvement, crop management practices, pest and disease management and yield enhancement. Research on ELS cotton has similarly concentrated on production constraints, technology adoption and marketing issues at the farm level, with limited attention given to the institutional and extension dimensions that influence technology dissemination and farmer decision making. Previous studies have reported several challenges related to agricultural extension systems, including weak research-extension-farmer linkages, inadequate stakeholder coordination, limited farmer participation in extension planning and poor integration among public, private and farmer led organizations. However, the most of these studies have examined individual components of the extension system in isolation rather than adopting a comprehensive Agricultural Innovation Systems (AIS) perspective. Furthermore, while the importance of pluralistic extension approaches and stakeholder collaboration has been widely acknowledged, empirical studies that systematically identify stakeholders, analyse their functional linkages and develop operational extension models tailored to specific commodity systems remain limited. In the context of ELS cotton, there is a notable lack of integrated extension frameworks that address production, institutional, financial, marketing and value chain constraints through coordinated stakeholder participation. Therefore, the present study aims to address these knowledge gaps by identifying the major constraints and underlying factors affecting ELS cotton cultivation, analysing the roles, interactions and institutional linkages among key stakeholders and

developing a pluralistic extension model that provides a practical framework for enhancing technology dissemination, stakeholder coordination, market integration and livelihood outcomes for ELS cotton farmers.

The increasing complexity of agricultural production systems has necessitated a shift from conventional linear extension approaches towards more integrated and collaborative frameworks that promote innovation, stakeholder participation and knowledge co-creation. The AIS perspective recognizes innovation as the outcome of interactions among multiple actors, including research organizations, extension agencies, farmer organizations, financial institutions, private enterprises and market actors, rather than the product of a single institution (World bank, 2006; Klerkx et al. 2012). Within this framework, effective agricultural development depends on the strength of linkages, learning processes, and institutional arrangements that facilitate the generation, dissemination, adaptation and utilization of knowledge (Meena et al. 2013; Bhattacharjee & Saravanan, 2015).

In recent years, pluralistic extension systems have emerged as an important strategy for enhancing the effectiveness and inclusiveness of agricultural extension services. Pluralistic extension recognizes the complementary roles of public agencies, private organizations, non-governmental organizations, farmer organizations, research institutions and market actors in addressing the diverse needs of farming communities (Swanson and Rajalahti, 2010; Davis and Heemskerk, 2012). Such systems are particularly relevant in complex commodity sectors where production, input supply, financial services, processing and marketing are interconnected and require coordinated stakeholder engagement. Furthermore, participatory approaches to technology dissemination have gained prominence because they actively involve farmers in problem identification, technology evaluation, adaptation and feedback processes, thereby improving the

relevance and adoption of agricultural innovations (Chambers, 1994; Pretty, 1995). Participatory mechanisms facilitate the incorporation of local knowledge into extension interventions and contribute to the development of demand driven agricultural services.

The application of systems thinking in agricultural extension further emphasizes the need to view agricultural challenges as interconnected rather than isolated problems. Systems thinking promotes a holistic understanding of production, institutional, financial, technological and market related constraints and highlights the importance of coordinated interventions across the entire value chain (Rolling and Wagemakers, 1998; Leeuwis and Van den Ban, 2004). Given the multidimensional constraints associated with ELS cotton cultivation, the adoption of a system based pluralistic extension approach is essential to strengthen stakeholder collaboration, enhance innovation networks, improve technology dissemination and adoption, facilitate market integration and promote the overall sustainability and competitiveness of the ELS cotton production system. Therefore, the development of a participatory pluralistic extension model is expected to provide a comprehensive framework for addressing the complex constraints faced by ELS cotton farmers and for promoting sustainable production and livelihood outcomes. Based on the above considerations, the present study was undertaken with the following objectives: To identify the major constraints affecting ELS cotton cultivation and analyse their underlying causes and to develop an extension model that addresses identified constraints while strengthening stakeholder linkages, technology dissemination and the overall resilience and sustainability of the ELS cotton production system.

Methodology

Study area

The present study was conducted in Chamarajanagar district of Karnataka, Coimbatore and Tirupathur districts of Tamil Nadu, which represent major ELS cotton growing regions in South India. These districts were purposively selected owing to their extensive area under ELS cotton cultivation their significant contribution to the production of premium quality cotton for the textile and spinning industries. The regions represent diverse agro climatic conditions and a large population of experienced ELS cotton farmers, making them suitable for investigating cultivation practices and production constraints. Furthermore, ELS cotton plays a vital role in the local economy by contributing to rural livelihoods and strengthening the textile value chain.

Sampling design

A multistage purposive random sampling technique was adopted to obtain a representative sample of ELS cotton farmers from the selected study regions. In the first stage, Tamil Nadu and Karnataka were purposively selected owing to the prominence and economic importance of ELS cotton cultivation in these states. Subsequently, Coimbatore and Tirupathur districts of Tamil Nadu and Chamarajanagar district of Karnataka were chosen based on the extent of area under ELS cotton and the concentration of ELS cotton growers. In the second stage, major ELS cotton growing blocks and villages were identified in consultation with agricultural department officials, extension personnel and farmer organizations to ensure representation of diverse production environments. In the final stage, ELS cotton farmers were selected from the identified villages using simple random sampling. A total of 450 farmers constituted the study sample.

Data collection methods

Data were collected using a mixed methods approach that integrated both qualitative and quantitative techniques to enhance the comprehensiveness, reliability and validity of the study

180 findings. Participatory Rural Appraisal (PRA), Focus Group Discussions (FGDs) and structured
181 face to face interviews were employed to capture farmers' attitude, knowledge, adoption behaviour
182 and perspectives on the challenges associated with ELS cotton cultivation.

183 PRA was employed to identify and analyse the major constraints affecting ELS cotton production.
184 Among the PRA tools, the problem tree analysis technique served as the primary participatory
185 framework for diagnosing production related issues. Initially, the core problem in ELS cotton
186 cultivation was identified through consensus among stakeholders, after which its underlying
187 causes were represented as roots and the resulting consequences as branches of the problem tree.
188 Subsequently, the identified constraints were transformed into desirable outcomes through
189 objective analysis, leading to the development of an objective tree. Finally, strategy analysis was
190 undertaken to identify feasible interventions and operational measures for addressing the identified
191 constraints and strengthening the ELS cotton production system.

192 To further explore these issues, FGDs were conducted with ELS cotton growers across the selected
193 districts. A total of 238 farmers participated in 5 FGDs, which provided in depth qualitative
194 insights into production constraints, market related challenges, labour availability and pest and
195 disease incidence in ELS cotton cultivation. The FGDs also served to validate and refine the issues
196 identified through the PRA exercises.

197 Quantitative data were collected through personal interviews using a structured interview schedule
198 developed in accordance with the study objectives. Prior to the main survey, the questionnaire was
199 pre tested in a non-sample area to evaluate the clarity, relevance and reliability of the questions
200 and necessary modifications were incorporated based on the feedback received. The schedule
201 elicited information on several constraints faced by the farmers. The face-to-face interview method

facilitated effective interaction with respondents, improved data quality and minimized non response errors.

Data analysis

Qualitative data collected through the problem tree technique under the PRA approach were analysed using three complementary components: problem analysis, objective analysis and strategy analysis. Through structured brainstorming sessions, participants identified and discussed the key constraints associated with ELS cotton cultivation. A focal problem was selected by consensus and represented as the trunk of the problem tree, with its underlying causes depicted as roots and resulting effects as branches. The problem tree was subsequently converted into an objective tree by reformulating identified problems into positive and achievable outcomes. Participants responses, recorded through discussions and flip chart documentation were systematically categorized into problems, causes, effects, objectives, means and expected outcomes. Finally, strategy analysis was undertaken to define the overall objective, purpose and intervention strategies, leading to the development of integrated problem, objective and strategy analysis frameworks for identifying constraints and potential solutions in ELS cotton cultivation. The quantitative data collected from the farmers were analysed with the Garrett ranking analysis.

Results

Problem analysis of constraints faced in ELS cotton cultivation

The problem tree analysis revealed that the central issue perceived by stakeholder was the low adoption of ELS cotton cultivation by farmers in the potential areas, which emerged as the focal constraints affecting its production (fig. 1). The participatory assessment further demonstrated that this focal problem was shaped by multiple interconnected economic, climatic, technological and

224 institutional constraints operating across the production and marketing systems. The major causes
225 contributing to the low adoption of ELS cotton cultivation were identified as climate change, high
226 cultivation costs, low productivity and low market price of ELS cotton. Collectively, these
227 constraints reduced farmers' willingness and capacity to adopt the recommended production
228 technologies, despite the superior fibre quality and market demand associated with the crop.

229 Climate related constraints emerged as one of the major root causes influencing the cultivation of
230 ELS cotton. Farmers perceived irregular rainfall patterns, increasing temperature fluctuations due
231 to global warming and greenhouse gas emissions, changes in humidity and prolonged drought
232 conditions leading to water scarcity as major climatic constraints adversely affecting crop
233 establishment, growth and productivity. Since ELS cotton is highly sensitive to abiotic stress,
234 climatic variability was perceived to increase production risk and yield uncertainty, thereby
235 discouraging its larger scale cultivation. High cultivation costs also emerged as a major underlying
236 constraint limiting the adoption of ELS cotton production technologies. Farmers reported that ELS
237 cotton cultivation is highly labour intensive and involves substantial expenditure on inputs and
238 crop management operations. The long crop duration, high labour charges, increased expenditure
239 on manual cotton picking due to labour shortages, inadequate subsidy and the limited access to
240 timely credit and crop insurance facilities further intensified the financial burden on growers.
241 These constraints reduced the profitability of ELS cotton cultivation and increase economic risk,
242 particularly for small and marginal farmers.

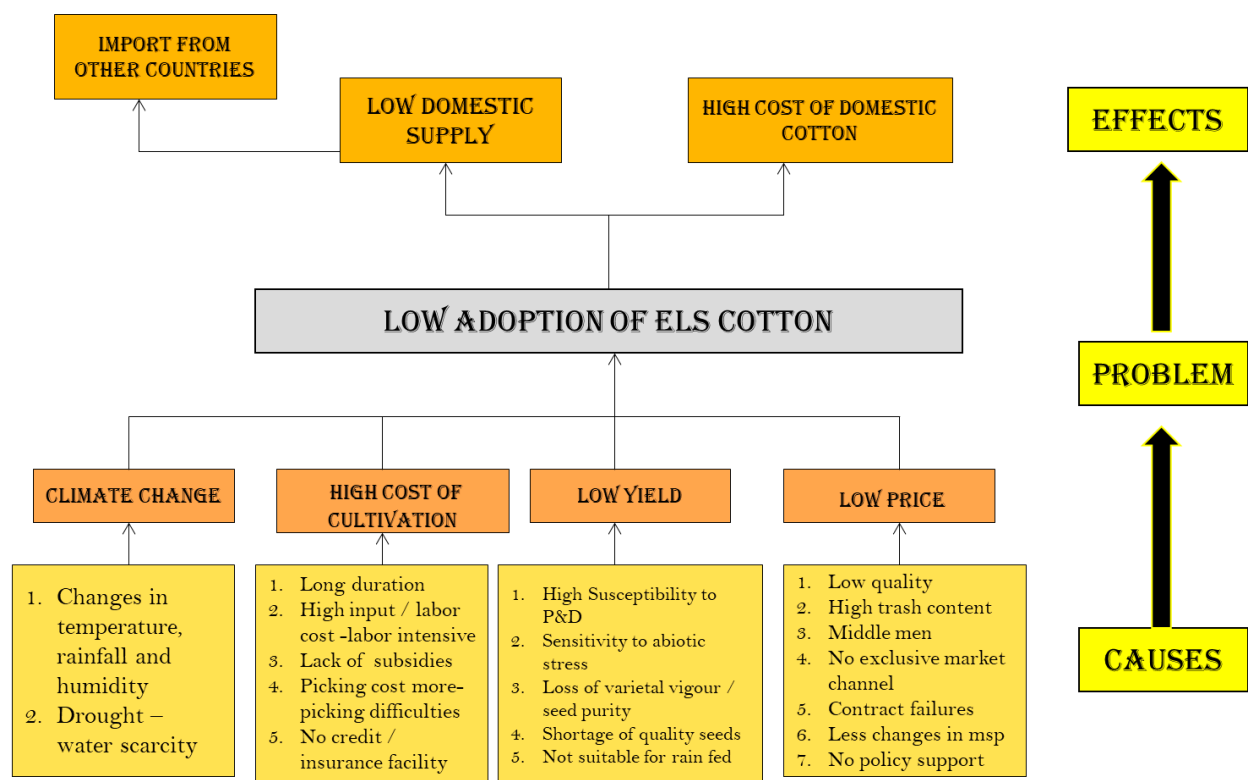


Fig. 1 Problem analysis of constraints faced in ELS cotton cultivation

Low yield was also identified as a major production related constraint limiting the expansion of ELS cotton cultivation. Farmers attributed low productivity due to the high susceptibility of ELS cotton varieties to pests and diseases, sensitivity to abiotic stress conditions, deterioration in varietal vigour and seed purity, inadequate availability of quality seeds and the poor suitability of ELS cotton under rainfed conditions. This production related challenges not only affected yield stability but also weakened farmers' confidence in adopting recommended cultivation practices. Marketing related issues constituted another important category of constraints. Farmers reported that low market price of ELS cotton was primarily attributable to poor fibre quality, high trash content resulting from improper picking practices and the dominant role of intermediaries in the marketing system which collectively reduced price realization.

Delayed sales in Agricultural Produce Market Committee (APMC) yards, absence of exclusive marketing channels for ELS cotton, weak or non-existent contractual arrangements between buyers and farmers, inadequate revisions in minimum support price (MSP) and limited policy support were identified as major institutional bottlenecks affecting farmers' profitability. These issues significantly reduced market confidence and discouraged growers from expanding ELS cotton cultivation.

The cumulative effect of these root causes ultimately contributed to the broader systemic outcomes of inadequate domestic production, insufficient supply of quality ELS cotton and increased dependence on imports from other countries. The findings indicate that the constraints associated with ELS cotton cultivation are multidimensional and interrelated, necessitating integrated technological, institutional and policy interventions rather than isolated production oriented approaches.

Objective analysis on fostering the adoption of ELS cotton cultivation

The objective analysis was carried out by systematically transforming the identified constraints from the problem tree into positive and achievable outcomes through participatory stakeholder discussions. In this process, each problem identified during the problem analysis was reformulated into a desirable future condition, thereby converting the problem tree into an objective tree (Fig. 2). The exercise enabled stakeholders to identify strategic intervention pathways and prioritize feasible solutions for enhancing the adoption and sustainability of ELS cotton cultivation in India.

The focal objective that emerged from the analysis was to foster the adoption of ELS cotton cultivation among potential and traditional cotton growers. To achieve this broader objective, several interrelated sub objectives were identified by the participants. This included strengthening

278 farmers' capacity to cope with climate change through appropriate climate change mitigation and
279 adaptation strategies, reducing the cost of cultivation through the adoption of modern technologies,
280 enhancing crop productivity through yield improving technologies and ensuring premium price
281 realization for ELS cotton produce.

282 The objective analysis also identified broader developmental outcomes expected from the
283 successful adoption of these interventions. These included reduction in the import dependence on
284 ELS cotton, enhancement of domestic production and supply and reduction in the cost of
285 domestically produced ELS cotton. The findings indicate that enhancing the adoption of ELS
286 cotton cultivation requires a comprehensive and integrated approach that simultaneously addresses
287 technological, climatic, economic and institutional constraints. Furthermore, the objective analysis
288 served as a foundation for developing field level strategies and extension interventions aimed at
289 strengthening the adoption of recommended ELS cotton cultivation practices. The participatory
290 nature of the exercise facilitated collective understanding among stakeholders regarding the
291 interdependence of production, market and policy factors, thereby enabling the development of a
292 more inclusive and context specific extension framework. The analysis underscores the importance
293 of a coordinated, pluralistic extension approach involving research institutions, extension
294 agencies, market actors and farmer organizations to promote the sustainable adoption of ELS
295 cotton cultivation in India.

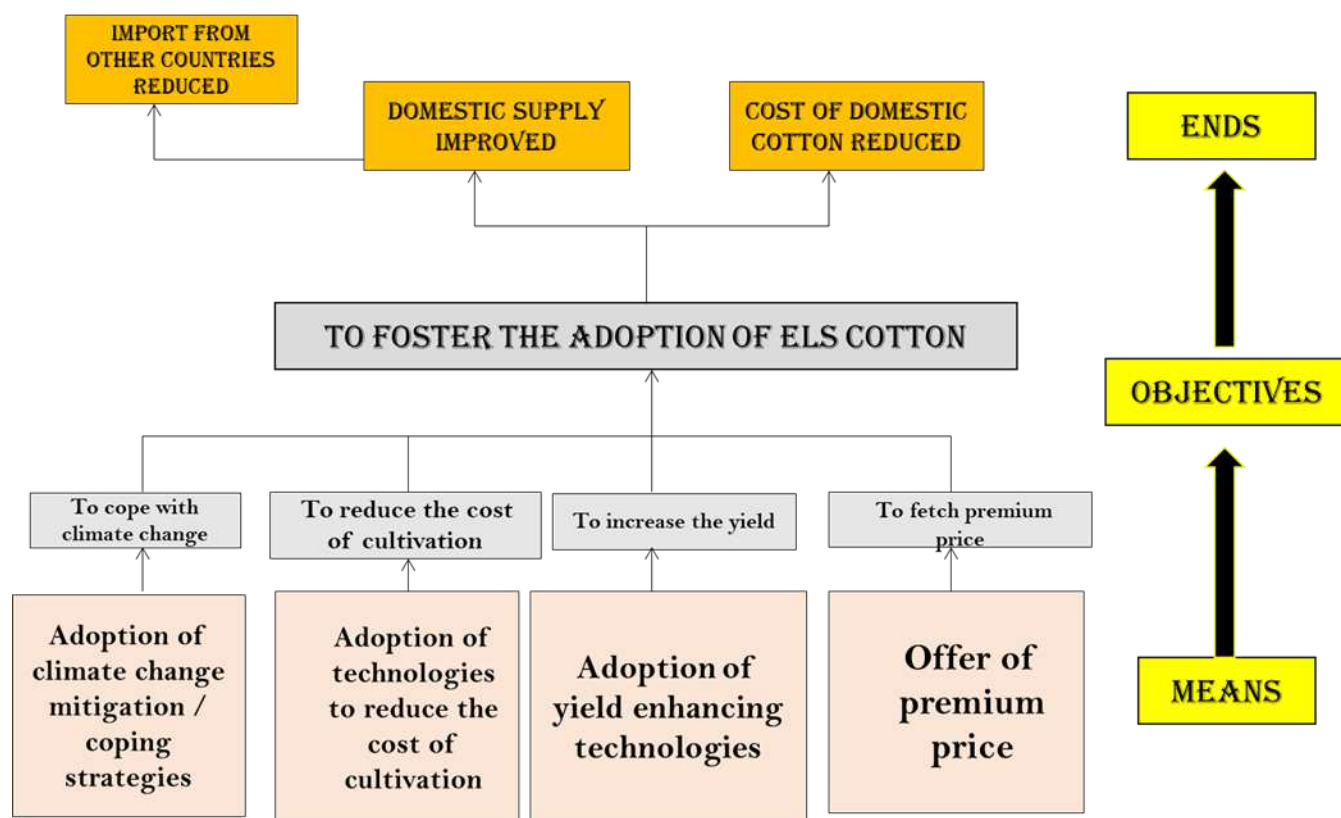


Fig. 2 Objective analysis on fostering the adoption of ELS cotton cultivation

Strategy analysis for improving the adoption of ELS cotton

The strategic analysis (Fig. 3) provided a comprehensive framework of both micro and macro level interventions required to enhance the adoption of ELS cotton cultivation among potential and traditional cotton growers. The strategies were identified through participatory FGDs involving farmers and other stakeholders and were formulated based on the key constraints and objectives identified during the problem and objective analyses.

To address climate related challenges affecting ELS cotton cultivation, stakeholders emphasized the dissemination of climate change mitigation technologies, climate adaptation strategies and conservation oriented production practices. The suggested interventions included promotion of drought and stress tolerant varieties, micro irrigation systems such as drip irrigation, rainwater

harvesting structures, mulching, conservation tillage, crop diversification and soil moisture conservation practices. In addition, climate coping strategies such as weather based agro advisories, contingency crop planning and climate smart nutrient and water management practices were considered essential for minimizing the adverse impacts of rainfall variability, drought, and temperature fluctuations on ELS cotton productivity.

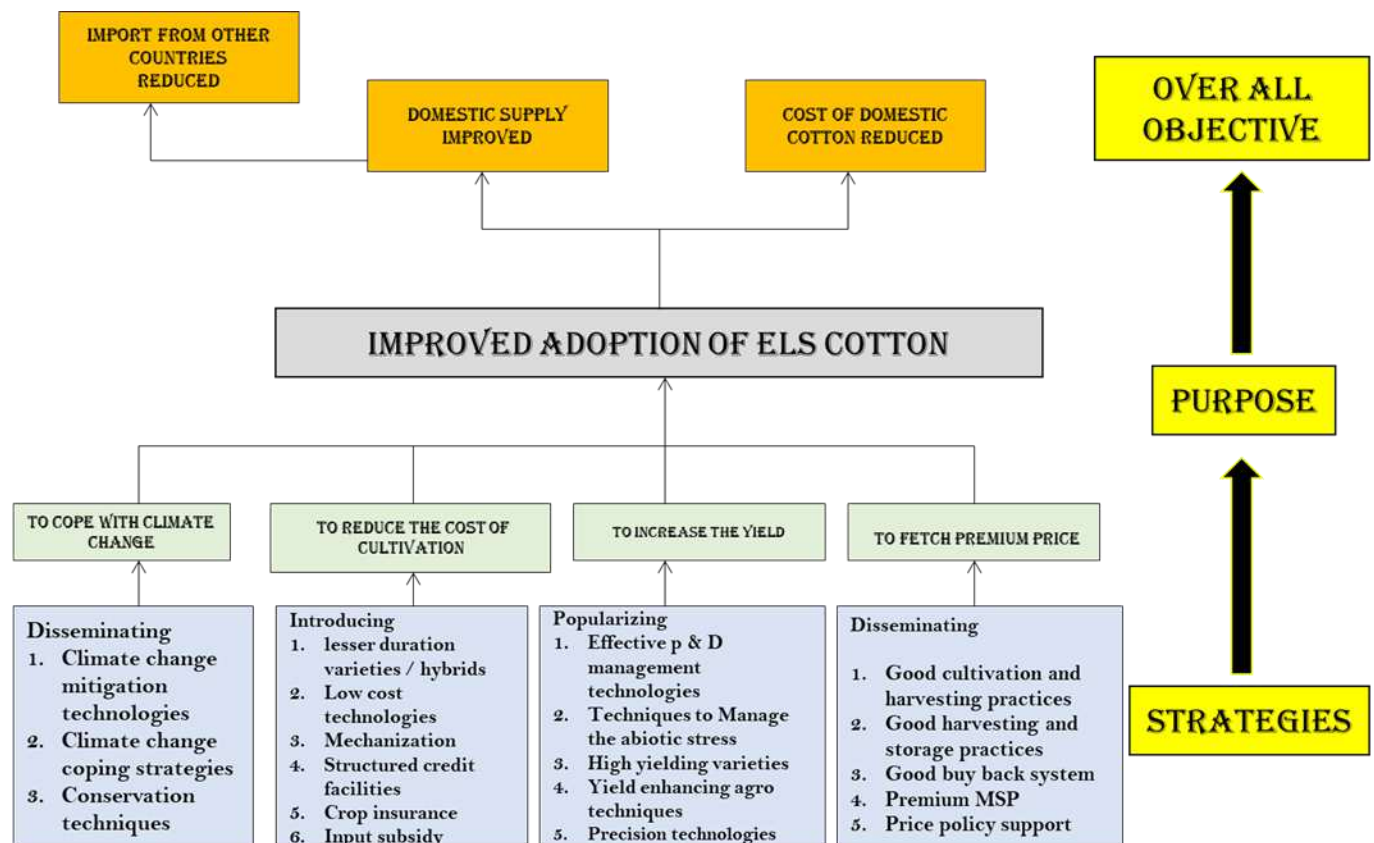


Fig. 3 Strategy analysis for improving the adoption of ELS cotton

Reducing the high cost of cultivation emerged as another major strategic priority. Stakeholders recommended the introduction and promotion of short duration ELS cotton varieties and hybrids to reduce crop duration and associated management costs. The adoption of cost effective and resource efficient technologies, including integrated nutrient management, precision input application and labour saving practices was also emphasized. Mechanization of labour intensive

320 operations through cotton pickers and mechanical harvesters was identified as a critical
321 intervention for overcoming labour scarcity and escalating wage costs. Participants further
322 highlighted the need for strengthening institutional credit delivery through nationalized and rural
323 banking systems to reduce farmers' dependence on informal money lenders and high interest loans.
324 Expansion of crop insurance coverage to safeguard farmers against climatic risks such as droughts
325 and floods, along with timely provision of input subsidies, was considered essential for reducing
326 financial vulnerability and encouraging technology adoption.

327 Strategies aimed at improving productivity focused primarily on strengthening technological
328 support systems for ELS cotton cultivation. Stakeholders emphasized the large scale dissemination
329 of Integrated Pest Management (IPM) practices, Integrated Disease Management (IDM)
330 approaches and abiotic stress management technologies to mitigate the crop's susceptibility to
331 biotic and environmental stresses. The introduction of high yielding and location specific ELS
332 cotton varieties, precision farming technologies, balanced nutrient management and improved
333 agronomic practices were also identified as important interventions for enhancing productivity.
334 Furthermore, the need for intensive awareness and capacity building programmes was emphasized
335 to improve farmers' technical knowledge and promote scientific cultivation practices.

336 Marketing and price related strategies were identified as critical for improving farmers' economic
337 confidence and sustaining long term adoption of ELS cotton cultivation. Stakeholders emphasized
338 the dissemination of good cultivation, harvesting and post harvest handling practices to improve
339 fibre quality and reduce trash content in seed cotton. Establishing efficient storage systems and
340 strengthening quality management practices were also suggested to enhance market acceptability.
341 In addition, participants strongly recommended the development of structured buy back
342 arrangements and contract farming mechanisms that directly link farmers with textile industries

and buyers to ensure assured market access and price realization. The provision of premium MSP, stable pricing policies and enhanced policy support for ELS cotton were identified as essential institutional measures to improve profitability and incentivize adoption.

The findings indicate that improving the adoption of ELS cotton cultivation requires an integrated strategy combining technological, financial, institutional and market oriented interventions. Effective implementation of these strategies is expected to significantly enhance the adoption of ELS cotton technologies among farmers. In the long term, improved adoption would contribute towards reducing dependence on imported ELS cotton, strengthening domestic production and supply systems and lowering the cost of domestically produced ELS cotton in India.

The strategic analysis further highlights the importance of a pluralistic extension framework involving coordinated participation of research institutions, extension agencies, financial institutions, private sector actors, Farmer Producer Organizations (FPOs) and policy support systems. Such an integrated and stakeholder driven approach is essential for addressing the multidimensional constraints limiting ELS cotton cultivation and for ensuring the sustainable expansion of ELS cotton production in India.

Table 1 Ranking of constraints using Garrett average score

S. No.	Constraints	Sum	Average score	Rank
1	Extended crop duration	21561	47.91	VII
2	High susceptibility to sucking pests, boll worms and severely to PBW	23756	52.79	III

3	Reduced fertility, poor boll opening and empty locules	20965	46.59	IX
4	Reduction in yield compared to the initial release period	20638	45.86	X
5	Labour intensive harvesting due to difficulty in picking from the locules	26491	58.87	I
6	Less suitable for rainfed cultivation because of its longer crop duration	20968	46.60	VIII
7	Susceptible to water logging and Magnesium deficiency	22015	48.92	VI
8	Competition from high value alternative crops and also within the species (<i>G.hirsutum</i>)	20545	45.66	XI
9	High production cost	23445	52.10	IV
10	Limited market demand and lack of price premium	24730	54.96	II
11	Yield limitations	22386	49.75	V

359

360 The Garrett ranking analysis (Table 1) of empirical data has identified the major constraints
361 limiting the cultivation of ELS cotton. Among them, high labour requirement for harvesting and
362 drudgery associated with picking cotton from compact locules emerged as the most severe
363 constraint recording the highest Garrett score (58.87). The harvesting of ELS cotton, particularly
364 variety Suvin, remains highly labour intensive due to the tight retention of lint within the bolls,

which increases harvesting time and costs. Increasing labour shortages, migration of rural workers to non-farm sectors and increasing wages rates have further reduced the economic viability of the crop (Pandya 2012; Deepika and Asokhan 2019; Mishra et al.2023; Kale et al. 2025). The second most important constraint was low and non-remunerative market price (54.96). Despite possessing superior fibre quality and premium spinning characteristics, farmers reported inadequate price realization because of weak quality based pricing mechanisms and limited access to specialized markets. Consequently, the additional investment required for ELS cotton cultivation is often not adequately compensated through market returns (Narayanamoorthy and Kalamkar,2006; Deepika and Asokhan 2019). High susceptibility to sucking pests, bollworms and particularly pink bollworms infestation ranked third (52.79). The longer crop duration exposes the crop to repeated pest cycles, increasing crop vulnerability and necessitating higher pesticide use, thereby escalating production costs and yield losses (Kranthi,2015; Naik et al.2018; Deepika and Asokhan 2019). Closely associated the pest incidence was the problem of high production cost, which secured the fourth rank (52.10). The requirement for greater investment in labour, irrigation, fertilizers and plant protection measures significantly reduces net profitability, especially among small and marginal farmers (Bennett et al.2004; Narayanamoorthy and Kalamkar,2006; Rao et al.2007; Gurjar et al.2013; Baskar and Jagannathan 2021).

The respondents ranked low yield as the fifth major constraint (49.75). Farmers perceived that the productivity of traditional ELS cotton varieties has gradually declined and no longer competes favourably with modern cotton hybrids despite their superior fibre quality (Venugopalan et al.2011; Kranthi, 2018). Sensitivity to waterlogging and magnesium deficiency occupied the sixth position (48.92), indicating the greater susceptibility of ELS cotton to nutrient imbalances and environmental stresses, particularly under conditions of climatic variability like temperature

388 fluctuations and erratic rainfall (Pettigrew, 2008). The long duration of the crop was ranked
389 seventh (47.91). Farmers increasingly prefer short duration crops and hybrids that facilitate crop
390 diversification and reduce exposure to climate and pest related risks, making long duration cotton
391 less attractive under intensive farming systems (Sankaranarayanan et al.2010; Dhir et al.2024).
392 Similarly, limited suitability under rainfed conditions due to prolonged crop duration ranked eighth
393 (46.60). Dependence on assured irrigation limits the adaptability of these varieties in regions
394 characterized by rainfall uncertainty and water scarcity (Venkateswarlu & Shankar 2009; Blaise
395 and Kranthi,2019). The constraint of sterility, poor boll bursting and empty locules in few varieties
396 secured the ninth rank (46.59). Farmers associated these physiological abnormalities with lower
397 yields and reduced economic returns, which may result from genetic factors or environmental
398 stress conditions (Deepika and Asokhan 2019; Bista et al.2025). The issue of declining the yield
399 performance compared with the release period, particularly in Suvin, ranked tenth (45.86). Farmers
400 attributed these declines to varietal deterioration, evolving pest complexes and changing
401 environmental conditions over time.

402 Finally, competition from high value alternate crops and high yielding *Gossypium hirsutum*
403 hybrids was ranked eleventh (45.66) (Blaise and Kranthi 2019). Although comparatively less
404 severe, this constraint reflects changing farm economics, wherein farmers increasingly prefer crops
405 and enterprises that offer higher productivity, improved profitability, diversified risk and more
406 attractive market opportunities. The widespread adoption of high yielding *G. hirsutum* hybrids and
407 increasing interest in diversified and remunerative cropping systems illustrate this transition in
408 farmer preferences (Keller et al.2024; Thirukumaran et al.2024). The finding from the Garrett
409 ranking analysis closely corroborated the outcomes of the PRA exercises conducted in the study
410 villages, thereby validating the identified production challenges. Based on the PRA problem tree

analysis, the constraints were categorized into four major domains representing the underlying root causes:

1. Production related constraints, including low yield, poor boll bursting and varietal decline;
2. Climate and environmental constraints, comprising pest incidence, sensitivity to waterlogging, nutrient deficiencies and poor rainfed adaptability;
3. Economic and market related constraints, including high production costs, low and non-remunerative market prices; and
4. High cost of cultivation constraints, encompassing labor scarcity, harvesting drudgery, long crop duration and competition from alternative crops and hybrids.

Addressing these multidimensional challenges through a proposed pluralistic extension approach involving research institutions, extension agencies, market actors, farmer organizations and the private sector is crucial for revitalizing ELS cotton production systems in the future.

Discussions

Development of Pluralistic Extension Model

The findings from the FGDs and problem tree analysis revealed that ELS cotton farmers encounter multiple interrelated constraints that adversely affect productivity, profitability and overall livelihood outcomes. These constraints indicate the need for a comprehensive pluralistic extension model capable of integrating the efforts of diverse stakeholders and strengthening support services across the production system. Accordingly, the proposed model (Fig. 5) has been designed by considering key dimensions, including the identification of relevant actors, the establishment of functional linkages among stakeholders, the development of appropriate institutional mechanisms, and the formulation of an operational framework for implementation. Through coordinated

collaboration, knowledge sharing and resource convergence, the proposed model aims to enhance access to technical, institutional and market support, thereby improving adoption of recommended practices, mitigating production constraints and promoting sustainable development of the ELS cotton sector.

Actors

The proposed pluralistic extension model encompasses a diverse range of stakeholders operating at different levels of the ELS cotton production and marketing system. The actors involved in the pluralistic extension model were represented in the fig. 4. To facilitate effective coordination and functional integration, these stakeholders were categorized into three interrelated layers based on their primary roles and contributions.

The Knowledge and Technology Support Layer comprises institutions responsible for research, technology generation, capacity building and extension services delivery. This layer includes ICAR institutes, the State Department of Agriculture, State Agricultural Universities (SAUs), Krishi Vigyan Kendras (KVKs), and Non-governmental organizations (NGOs). These organizations play a pivotal role in developing, validating, disseminating and promoting improved production technologies and best management practices among ELS cotton farmers.

The Inputs and Service Support Layer consists of stakeholders that facilitate access to critical production resources, financial services, and collective action mechanisms. This layer includes private companies, financial institutions such as lead banks, Regional Rural Banks (RRBs) and the National Bank for Agriculture and Rural Development (NABARD), along with FPOs and Farmer Producer Companies (FPCs). These actors contribute to ensuring the timely availability of quality

inputs, credit support, advisory services, risk management mechanisms and institutional support necessary for enhancing farm productivity and profitability.

The Market and Value Chain Layer encompasses stakeholders involved in post-harvest management, value addition, processing and marketing of ELS cotton produce. This layer includes contract farming firms, the Cotton Corporation of India (CCI), ginning factories, regulated markets, spinning factories (lint processing), oil extraction units (seed processing), finishing factories (yarn production) and retailers. These actors facilitate efficient market linkages, value chain integration, price realization, product transformation and market access for cotton producers.

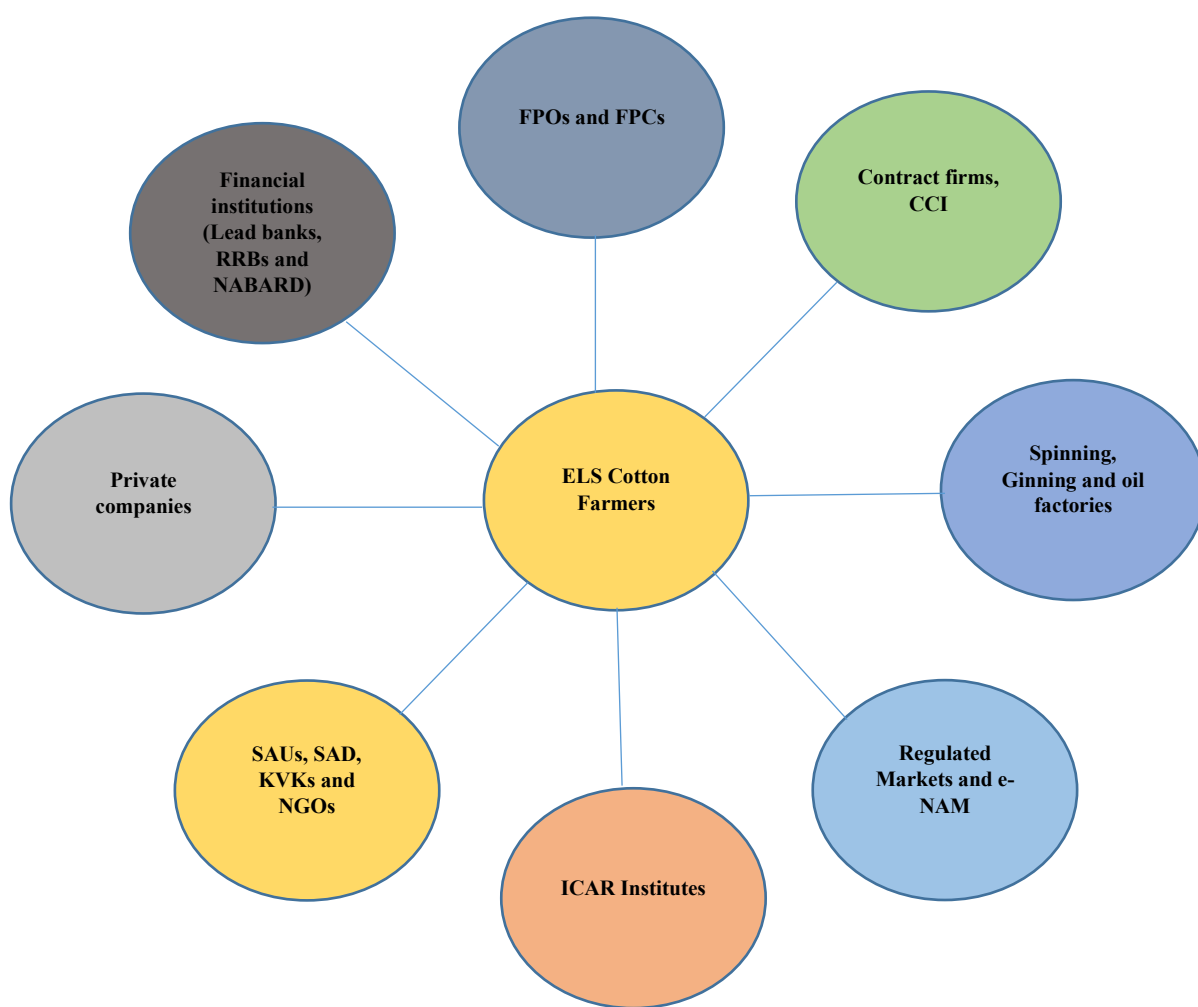


Fig. 4 Stakeholders involved in ELS cotton production system

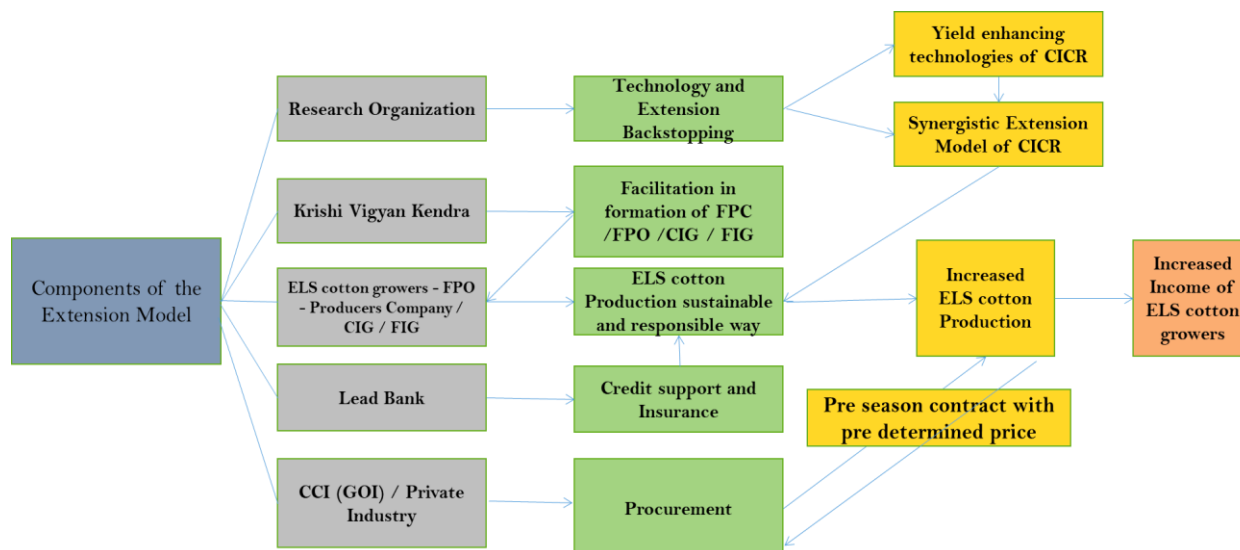


Fig 5. Conceptual framework of Pluralistic Extension Model for Fostering the Production of ELS cotton

Functional linkages

The success of the proposed pluralistic extension model depends not only on the participation of multiple stakeholders but also on the establishment of effective functional linkages that facilitate the continuous exchange of knowledge, technologies, inputs, financial resources, market intelligence and feedback across the ELS cotton value chain. These linkages promote coordination among stakeholders, enhance service delivery and ensure that farmers receive timely and need based support. Table 2 represents the actors and resources involved in functional linkages. The major functional linkages identified within the proposed model are discussed below.

506 **Table 2 Actors and resources involved in functional linkages**

S. No	Type of linkage	Actors involved	Resource flow
1.	Knowledge linkage/ Research-Extension-Farmer linkage	ICAR institutes, SAUs, KVKs and State Department of Agriculture (SDA)	Transfer of Technology, Training, Advisories
2.	Input linkage	Private firms, FPOs	Seeds, Fertilizers, pesticides and Mechanization (Tractors, Harvester)
3.	Financial linkage	Banks, NABARD	Credit, Insurance, Subsidies
4.	Institutional linkage	SDA, NGOs, FPOs	Coordination, governance
5.	Market linkage	CCI, Contract firms, Markets	Procurement, Price information, Market channel
6.	Value chain linkage	Ginners, Spinners, Retailers	Processing, Value addition
7.	Feedback linkage	Farmers and all actors	Need assessment, innovation

507
508 **Research-Extension-Farmer linkage**

509 The Research-Extension-Farmer linkage (fig. 6) constitutes the cornerstone of the pluralistic
510 extension model, serving as the primary pathway for the transfer of technology from research
511 institutions to farming communities. This linkage facilitates the effective dissemination of

scientific innovations and ensures that technological advancements reach the intended beneficiaries in a timely manner. Research institutions, including ICAR institutes and SAUs, play a critical role in generating locations specific technologies aimed at addressing the key constraints faced by ELS cotton farmers. Their contributions include the development of high yielding varieties / hybrids, drought tolerant cultivars, pest and disease resistant genotypes, climate resilient production technologies, improved crop management practices and development of cost effective technologies. These innovations are designed to enhance productivity, profitability and sustainability within ELS cotton production systems.

The extension system, comprising the State Department of Agriculture, KVKs, NGOs and other extension agencies, acts as the intermediary between research institutions and farmers. Its primary function is to disseminate newly developed technologies, improved varieties / hybrids and scientific recommendations by both conventional and digital extension approaches. Key activities include farmer training programmes, Front Line Demonstrations (FLDs), field days, capacity building initiatives and the dissemination of timely advisories through information and communication technologies (ICTs). These interventions enhance farmers' access to knowledge, strengthen their technical competencies and promote the rapid adoption of recommended practices.



Fig. 6 Research-Extension-Farmer linkage

By establishing a strong interface among researchers, extension personnel and farmers, this linkage bridges the gap between technology generation and field level adoption. Furthermore, it creates a two-way communication channel enabling farmers' experiences, production constraints and feedback to inform research priorities and the continuous refinement of technologies. Ultimately, this linkage strengthens farmers' knowledge, technical skills and decision making capacity, leading to improved productivity, technology adoption and resilience in ELS cotton cultivation.

Input supply linkage

The findings of the study revealed that insufficient availability of quality inputs and the escalating cost of production inputs are among the major constraints affecting ELS cotton cultivation. To address these challenges, the proposed pluralistic extension model incorporates robust input supply linkage involving private companies, FPOs, FPCs and the Department of Agriculture.

This linkage is designed to ensure the timely availability and accessibility of quality production inputs, including certified seeds, fertilizers, bio inputs, crop protection chemicals and other essential agricultural resources. FPOs and FPCs play a particularly significant role in this linkage by organizing collective procurement and distribution of agricultural inputs. Through bulk purchasing mechanisms, these institutions can reduce transaction costs, improve farmers' bargaining power and ensure the availability of inputs at competitive prices. In addition, collective procurement minimizes delays in input delivery and enhances farmers' access to reliable and quality assured products. By strengthening coordination among input suppliers, farmer organizations and extension agencies, this linkage effectively addresses the input related constraints identified in the study.

553 **Financial linkage**

554 The study identified inadequate access to timely and affordable credit as a major constraint in ELS
555 cotton cultivation. Farmers frequently experienced shortages of funds during cropping seasons and
556 lacked access to capital for purchasing agricultural machinery. Consequently, many relied on
557 informal moneylenders, resulting in the burden of high interest repayments. To address these
558 challenges, the proposed financial linkage integrates lead banks and RRBs. This linkage is
559 designed to facilitate farmers' access to pre-season crop loans, working capital support and credit
560 for mechanization. In addition, it supports crop insurance coverage to protect farmers against
561 natural calamities such as droughts and cyclones. By improving access to institutional finance and
562 risk management instruments, it reduces farmers' dependence on informal lenders and helps
563 alleviate the financial pressures faced during the cropping season.

564 **Farmer collective linkage**

565 The study also revealed that ELS cotton farmers incur high input costs due to individual input
566 procurement and receive lower prices when marketing their produce independently. This situation
567 is largely attributed to the predominance of smallholder farmers in ELS cotton cultivation. To
568 overcome these constraints, the proposed model promotes the formation and strengthening of
569 FPOs and FPCs involving ELS cotton growers. Through collective action, these organizations
570 enable farmers to procure agricultural inputs in bulk at competitive prices, aggregate seed cotton
571 efficiently and undertake collective marketing of Kapas. This collective marketing system enables
572 farmers to avoid distress sales, strengthens their bargaining power and improve price realization
573 in the market. Overall, the farmer collective linkage reduces transaction costs, enhances market
574 participation and contributes to better prices realization for ELS cotton producers.

575 **Market linkage**

576 Marketing related constraints emerged as one of the major challenges faced by ELS cotton farmers.
577 In many cases, farmers sell their produce directly to local traders at the farm gate, often at prices
578 lower than the prevailing market value. Furthermore, cotton prices often decline during the
579 harvesting season due to excess market arrivals. Although regulated markets provide an alternative
580 marketing channel, farmers are required to bear transportation costs and frequently experience
581 delays in receiving payments. To address these challenges, the proposed market linkage
582 incorporates stakeholders such as contract firms, the CCI and spinning mills.

583 Contract firms facilitate pre-season agreements with farmers, enabling them to secure relatively
584 stable prices for cotton irrespective of seasonal price fluctuations. Similarly, CCI and spinning
585 mills provide additional procurement channels, thereby expanding marketing opportunities for
586 farmers. This linkage system facilitates the procurement of Kapas, dissemination of market and
587 price information, provision of assured marketing channels and reduction of market uncertainty.
588 Overall, the market linkage is expected to improve price realization and enhance market access for
589 ELS cotton farmers.

590 **Value chain linkage**

591 The value chain linkage extends beyond conventional market linkages by connecting cotton
592 producers with downstream industries and end consumers. This linkage integrates key
593 stakeholders such as ginning factories, spinning factories, finishing factories within the textile
594 industry and retailers. Through these connections, farmers are better positioned to align their
595 production decisions with the quality and quantity requirements of the textile and spinning
596 industries. The linkage also facilitates communication regarding market demand between industry

597 stakeholders and producers, thereby improving responsiveness to market requirements.
598 Furthermore, it enhances the traceability of ELS cotton throughout the value chain. Overall, this
599 linkage strengthens the integration of farmers with downstream industries and promotes a more
600 market oriented production system. Furthermore, it creates opportunities for value addition
601 through production of silage, energy blocks, ornamental cotton products and biochar.

602 **Feedback linkage**

603 The feedback linkage represents the final and one of the most critical components of the proposed
604 pluralistic extension model. Under this system, extension agencies systemically collect feedback
605 from farmers on the technologies disseminated, their level of adoption and the challenges
606 encountered under field conditions. This information is subsequently communicated to research
607 institutions, enabling researchers to refine existing technologies and develop solutions to emerging
608 field level problems. The continuous exchange of information between farmers, extension agencies
609 and research organizations establish a complete cyclical process within the extension system. This
610 mechanism supports the continuous improvement of technologies and ensures that extension
611 interventions remain relevant to farmers' needs. The feedback linkage ensures that the model
612 remains adaptive and demand driven in nature.

613 **Institutional mechanisms**

614 Institutional mechanisms define the organizational arrangements, governance structures,
615 coordination platforms, accountability systems and resource sharing processes that enable
616 stakeholders to work collectively towards achieving common objectives. In the proposed
617 pluralistic extension model, stakeholders such as ICAR institutes, the State Department of
618 Agriculture, KVKs, NGOs, FPOs/FPCs, financial institutions, private companies, ginning

619 industries and textile industries perform distinct functions within the ELS cotton production
620 system. In the absence of an effective coordinating mechanism, the efforts of these stakeholders
621 may remain fragmented and less effective. Therefore, the institutional mechanisms incorporated
622 into the model are intended to facilitate stakeholder coordination, ensure role clarity and
623 accountability, promote participatory decision making, support resource mobilization, strengthen
624 monitoring and evaluation processes and enhance the long term sustainability of the extension
625 system.

626 **Governance structure**

627 The proposed pluralistic extension model is led by ICAR-CICR as the nodal agency, considering
628 its mandate, extensive field level network and responsibility for coordinating cotton development
629 programmes. The institute serves as the central coordinating body responsible for stakeholder
630 engagement, policy implementation and oversight of extension interventions within the ELS
631 cotton production system.

632 To facilitate effective stakeholder coordination, a regional level ELS cotton extension coordination
633 committee may be established. The committee should comprise representatives from ICAR
634 institutes, SAUs, KVKs, NGOs, FPOs/FPCs, financial institutions, private input suppliers, ginning
635 industries, textile industries and farmer representatives. Among these stakeholders, farmers
636 constitute the most important component of the model and should be represented through FPOs,
637 FPCs, village level farmer committees, progressive farmers and lead farmers. These
638 representatives should actively participate in the planning, implementation, monitoring and
639 evaluation of extension interventions. The regional level ELS cotton extension coordination
640 committee would be responsible for planning, coordinating, reviewing and monitoring extension

activities across the ELS cotton value chain, thereby ensuring effective collaboration among stakeholders and improving the overall functioning of the pluralistic extension system.

Decision making process

Decision making within the proposed pluralistic extension model should follow a participatory and evidence based approach. Seasonal planning meetings may be conducted prior to each cropping season, during which stakeholders collectively review production constraints, market trends, input requirements and technological needs. Decisions should be based on field level data, stakeholder consultations and feedback received from farmers. The priorities and needs of farmers may be identified through PRA, FGDs, farmer consultations, market assessments and periodic needs assessments. Such a process ensures that extension interventions remain demand driven rather supply driven and are aligned with the actual requirements of ELS cotton farmers.

Monitoring and Evaluation

A participatory monitoring and evaluation framework should be established to assess the outcomes and effectiveness of the proposed pluralistic extension model. Monitoring should be undertaken throughout the implementation process, from initiation to completion, through quarterly reviews and seasonal evaluations to ensure the proper execution of planned activities. Evaluation of the model should be carried out after its full implementation to assess its overall performance and impact.

Several indicators may be employed to evaluate the effectiveness of the model. Technology adoption indicators include the adoption rate of recommended ELS cotton cultivation practices, adoption of disseminated technologies and the number of farmers trained. Production indicators include improvements in yield and reductions in pest and disease incidence. Economic indicators

comprise farmers' net income and benefit cost ratio. Market indicators include the volume of collective marketing and improvements in prices. Institutional indicators encompass stakeholder participation, the functionality of FPOs/FPCs and the frequency of coordination meetings. Collectively, these indicators provide a comprehensive framework for assessing the performance and impact of the pluralistic extension model.

Sustainability of the model

The sustainability of the proposed model can be ensured through its integration with existing extension systems and government programmes. Long term sustainability may further be strengthened through diversified funding support from government schemes, NABARD and industry partnerships. Active participation of farmers through FPOs and FPCs, continuous technological support from ICAR institutes, SAUs and KVKs and enhanced marketing support are also critical for sustaining the model over time.

Furthermore, strengthening FPC as local extension and marketing hubs can reduce long term dependence on external agencies and enhance the self reliance of farming communities. These measures collectively contribute to the institutional, financial, technical and operational sustainability of the pluralistic extension model. Collectively, these institutional mechanisms provide the governance foundation necessary for the effective implementation and long term sustainability of the proposed pluralistic extension model for the ELS cotton production system.

Operational framework of the model

The operational framework of the proposed pluralistic extension model explains the functional implementation of the system across the cotton production cycle. A well defined operational framework is essential to ensure that the model is not merely conceptual but practically

implementable. Accordingly, the operational framework is structured into three interrelated phases, namely the pre-production phase, production phase and post production phase.

Pre-Production phase

The initial activity in the pre-production phase (fig. 7) involves the formation of an ELS cotton FPC with the support of ICAR-CICR, NABARD, the Small Farmers' Agribusiness Consortium (SFAC) and ICAR-KVKs. Subsequently, consultations and meetings between ELS cotton farmers, extension personnel and research representatives are conducted to identify prevailing field level constraints. Based on the root causes identified through PRA, appropriate solutions are formulated and implemented through the coordinated efforts of the relevant stakeholders within the proposed pluralistic extension model.

During this phase, pre-season crop loans are facilitated through credit service providers such as Primary Agricultural Cooperative Societies (PACS), lead banks and RRBs to meet financial requirements and reduce dependence on informal money lenders charging high interest rates. Quality seeds are produced and distributed among ELS cotton farmers with the support of ICAR-CICR, SAUs, private organizations and procurement agencies, based on the requirements of FPOs/FPCs. Agricultural inputs such as fertilizers and pesticides are supplied at competitive prices through input service providers such as PACS and local agri clinics. Labour scarcity and high labour costs, identified as major constraints limiting farm profitability, are addressed through the convergence of Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) (now VB - G RAM G) workers with agricultural operations, facilitated by the District Collectorate, Block Development Offices (BDOs) and village panchayats. Pre-season training programmes are conducted for farmers with the support of technology service providers such as ICAR-CICR and

707 KVKs to disseminate climate resilient production technologies, conservation practices and climate
708 change adaptation strategies.

709 In addition, pre-season awareness campaigns are organized to enhance farmers' knowledge
710 regarding improved technologies and crop insurance schemes, with support from information
711 service providers, crop insurance agencies, KVKs, SDA and NGOs. To address marketing
712 constraints and price fluctuations during the harvesting period, pre-season contract agreements are
713 established with procurement firms and or the CCI. These interventions implemented during the
714 pre-production phase will help the farmers to address the underlying causes of production
715 constraints, enhance their preparedness for cultivation and promote sustainable and responsible
716 ELS cotton production.

717 The implementation of this phase is expected to ensure the timely availability of quality inputs to
718 ELS cotton farmers, improved preparedness to climate related risks, enhanced access to
719 institutional credit and increased knowledge and awareness regarding improved technologies and
720 government schemes.

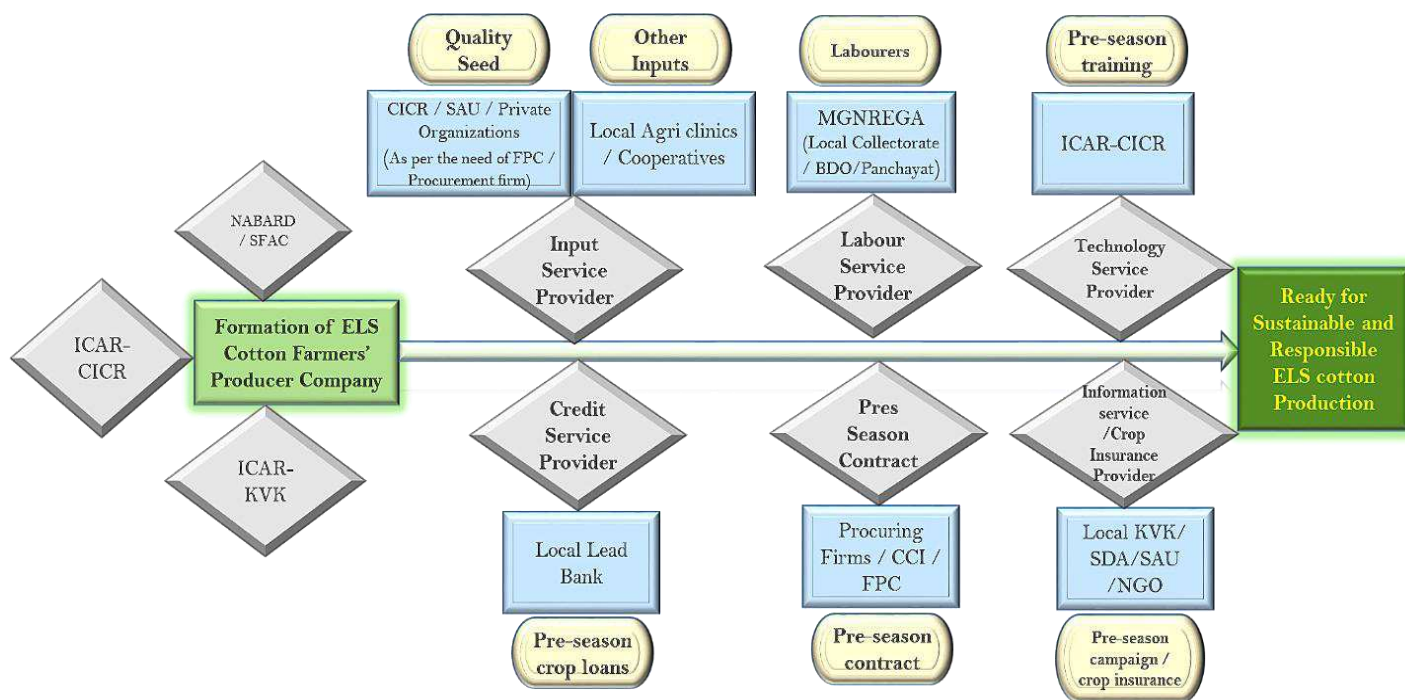


Fig. 7 Operational framework for the Pre-Production Phase in Pluralistic Extension Model

Production phase

The pre-production phase is followed by the production phase (figure 8), which constitutes the core implementation stage of the pluralistic extension model. The major activities in this phase include technology backstopping and extension backstopping for ELS cotton farmers organized under FPC. Technology backstopping is facilitated through the dissemination of ICAR-CICR Good Agricultural Practices, while extension backstopping is implemented through the CICR Synergistic Extension Model. Both forms of backstopping are delivered in a systematic and stage wise manner covering pre sowing, sowing, intercultural operations, plant protection, harvesting and post-harvest management. During the pre-sowing and sowing stages, CICR recommended practices such as suitable varieties or hybrids for specific agro climatic conditions, seed rate,

733 spacing and planting methods including normal planting or closer planting or High Density
734 Planting Systems (HDPS) are communicated to FPC farmers. These are disseminated through pre-
735 season training programmes, on farm varietal demonstrations, Decision Support Systems (DSS),
736 result demonstrations of new varieties or hybrids and method demonstrations.

737 During intercultural operations, best management practices are disseminated through multiple
738 extension tools, including field visits, booklets, voice SMS, web advisories, radio/television
739 programmes, WhatsApp messages, mobile applications and field days. These interventions aim to
740 enhance awareness and improve the adoption of recommended intercultural practices among
741 farmers. In the plant protection phase, Good Agricultural Practices related to IPM and IDM are
742 disseminated through video films, field visits, voice SMS, web advisories, radio/television
743 programmes, WhatsApp groups, mobile applications and field days. These strategies are designed
744 to promote timely and effective pest and disease management.

745 During harvesting and post harvesting stages, best practices such as clean harvesting, proper
746 storage of Kapas, hygienic transportation, market oriented handling and value addition are
747 communicated through method demonstrations, video films and web/mobile based market
748 advisories. This integrated system of technology dissemination and extension backstopping
749 promotes the adoption of improved cultivation practices among ELS cotton farmers. Continuous
750 follow up is carried out through progressive and lead farmers to monitor the adoption of
751 recommended technologies. In addition, a dedicated communication platform is established to
752 facilitate timely interaction among FPC farmers, scientists, KVKs and SAUs enabling the prompt
753 resolution of farmers' queries and strengthening technical support. Overall, this production phase
754 operational framework contributes to sustainable and responsible ELS cotton production through
755 continuous technical support and participatory extension mechanisms.

756

757 **Post production phase**

758 The post production phase (fig. 9) represents the final stage of the operational framework of the
759 pluralistic extension model. This phase involves post-harvest operations and marketing activities
760 following the completion of production. The harvested seed cotton is aggregated through FPC and
761 subsequent post-harvest activities such as storage, grading, packing and labelling are undertaken
762 within this phase. After completion of post-harvest operations, seed cotton is marketed either
763 through pre contract arrangements with procurement firms or the CCI, based on prior agreements.
764 Assistance for such transactions is provided by various actors within the model. In cases, where
765 pre contract agreements are not established, farmers may sell seed cotton to ginning factories or
766 regulated markets, depending on convenience and prevailing market conditions. Real time market
767 price updates are disseminated to FPC farmers through digital platforms such as WhatsApp and
768 SMS services, thereby enhancing market awareness and decision making.

769 Following the sale of produce, profits are distributed among FPC member farmers based on the
770 quantity of seed cotton contributed by each farmer. This system enables ELS cotton farmers
771 organized under FPC to maximize returns while minimizing individual transaction efforts, thereby
772 improving overall profitability and market efficiency.

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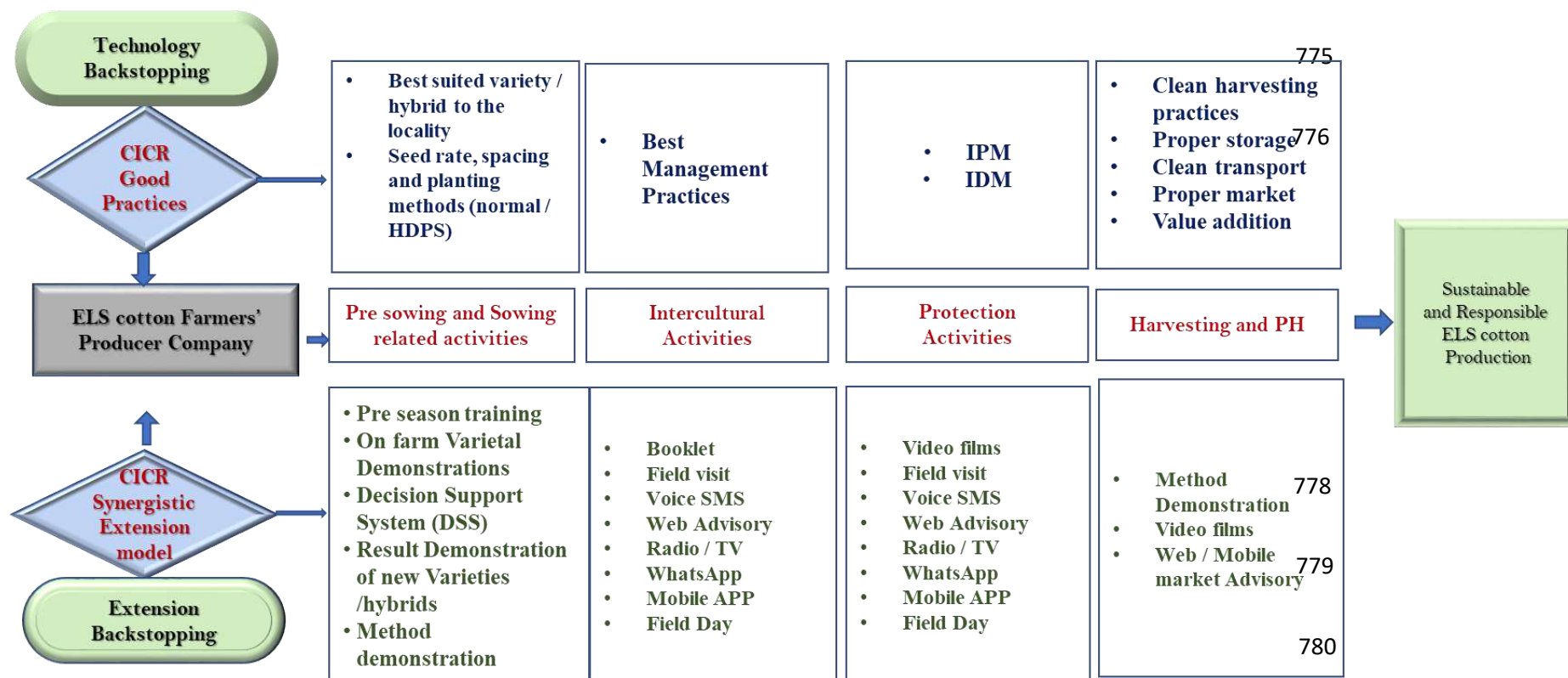


Fig. 8 Operational framework for the Production Phase in Pluralistic Extension Model

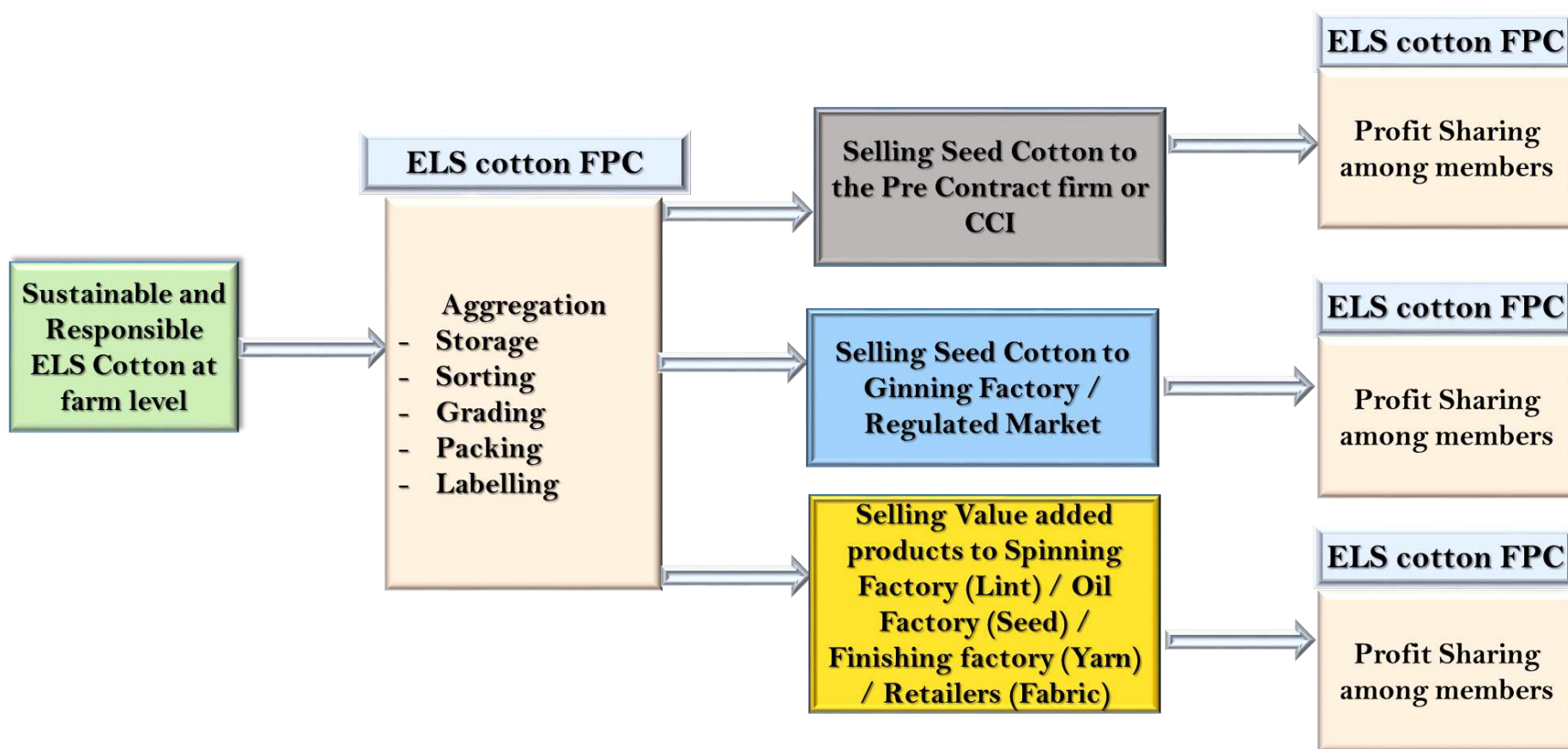


Fig. 9 Operational framework for the Post Production Phase in Pluralistic Extension Model

Conclusion

The present study demonstrated that the challenges confronting ELS cotton cultivation in South India extend beyond agronomic production constraints and are deeply embedded within broader climatic, economic, institutional and market systems. The participatory analyses conducted through problem tree analysis, FGDs and Garrett ranking provided complementary evidence that the low adoption of ELS cotton and its technologies is the outcome of multiple interrelated factors rather than isolated technical constraints. The findings revealed that high labour requirements for harvesting, non-remunerative market prices, pest susceptibility, high production costs, declining productivity, climatic vulnerabilities and weak market incentives constitute the major barriers limiting the expansion of ELS cotton cultivation. The PRA exercises further enables these constraints to be traced to four fundamental root cause domains, namely production related constraints, climate and environmental constraints, economic and market constraints and high cost of cultivation constraints. The close convergence between qualitative participatory assessments and quantitative Garrett ranking results strengthens the reliability and validity of the findings and highlights the multidimensional nature of the ELS cotton production system.

The study further demonstrated that conventional linear extension approaches are inadequate for addressing such complex and interconnected challenges. In response, a participatory pluralistic extension model grounded in AIS principles was developed to integrate the complementary strengths of research institutions, extension agencies, farmer organizations, financial institutions, private enterprises, market actors and value chain stakeholders. The proposed model emphasizes collaborative problem solving, functional stakeholder linkages, institutional coordination, continuous feedback mechanisms and farmer centred decision making across the entire production and marketing continuum. The operational framework developed under the model provides a

practical roadmap for strengthening ELS cotton production through coordinated interventions during pre-production, production and post production phase. By improving access to quality inputs, climate resilient technologies, institutional credit, mechanization services, market intelligence, collective marketing and value chain integration, the model has the potential to enhance technology adoption, improve productivity and profitability, reduce production risks and strengthen farmers' livelihood security.

From a policy perspective, revitalizing ELS cotton cultivation in India will require simultaneous investments in varietal improvement, labour saving technologies, climate adaptation measures, premium pricing mechanisms, farmer collectives and institutional innovations that strengthen linkages among stakeholders. Such interventions are essential not only for improving farm level outcomes but also for reducing dependence on imported ELS cotton and enhancing the competitiveness of the domestic textile sector. The study contributes to the emerging discourse on pluralistic extension and AIS by providing an empirically grounded and operationally feasible framework for addressing commodity specific constraints through coordinated stakeholder action. The proposed model offers considerable potential for replications and adaptation in other high value and complex agricultural commodity systems where sustainable intensification depends upon the effective integration of technology, institutions, markets and policy support.

835 **Declarations**

836 **Ethics approval and consent to participate**

837 Formal ethical approval was not required for this study under the institutional guidelines because
838 the research involved voluntary surveys, focus group discussions and participatory rural appraisal
839 with adult farmers and did not involve any medical intervention, collection of biological samples
840 or sensitive personal information. Informed consent was obtained from all participants before data
841 collection. Participants were informed about the objectives of the study, their voluntary
842 participation, the confidentiality of the information provided and their right to withdraw from the
843 study at any time.

844 **Consent for publication**

845 Not applicable

846 **Availability of data and materials**

847 The datasets generated and analysed during the current study are available from Dr. S. Usha Rani
848 on reasonable request.

849 **Competing interests**

850 The authors declare that they have no competing interests.

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853 Research

854

855 **Authors' contributions**

856 UR conceptualized and designed the study, guided the research process, and SG prepared the
857 original draft of the manuscript. PV, MA, DK, AS, KSN, SM, MS and AHP contributed to the
858 development of the research framework, assisted in data collection and analysis, and provided
859 critical inputs in reviewing, editing, and refining the final manuscript. All authors read and
860 approved the final manuscript.

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