



RESEARCH ARTICLE

Social network analysis for mapping stakeholders of litchi supply chain in Bihar

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Abstract

Litchi, a sub-tropical fruit crop, plays a crucial role in supporting rural livelihoods in Bihar, which contributes nearly three-fourths of India's total litchi production. However, despite having considerable potential, its contribution to Bihar's economy remains limited owing to structural inefficiencies and weak coordination among stakeholders in the litchi supply chain. The highly perishable nature of the fruit, inadequate infrastructure and fragmented stakeholder linkages further constrain its economic performance. Therefore, understanding stakeholder interactions is essential for strengthening supply chain governance. This study applies social network analysis (SNA) using the Net-Map methodology to examine the structure, roles, power relations and interconnections among key stakeholders in the litchi supply chain of Muzaffarpur district, Bihar. A symmetric square matrix was created to establish linkages among stakeholders, along with an influence-power matrix that was tabulated to evaluate their relative influence and strategic positioning. Centrality measures, including degree, closeness, betweenness and eigenvector centrality, were computed using Gephi software to identify dominant and intermediary actors. The findings reveal that pre-harvest contractors and growers occupy central and highly influential positions within the network, while institutional actors such as government agencies and research institutes remain moderately connected. Weak integration between institutional and primary actors limits innovation diffusion and coordinated market expansion. Strengthening stakeholder collaboration through targeted policy interventions and improved network connectivity can enhance efficiency, reduce post-harvest losses and expand export potential. The study demonstrates the importance of SNA as a diagnostic and policy-support tool for improving agricultural value chains and boosting farmers' economic returns in Bihar.

Keywords: litchi; net-map; social network analysis; summated square matrix; supply chain

Introduction

Bihar is the second-largest producer of litchi in India, contributing nearly three-fourths of the country's total production (1). The fruit plays an important role in providing livelihood security and employment opportunities in rural areas of the state (2). However, the highly perishable nature of litchi and its short shelf life pose serious challenges for effective supply chain management (3). Despite favourable agro-climatic conditions, India's litchi productivity remains lower compared with other exporting countries, indicating scope for improvement in production practices as well as post-harvest and supply chain management (1).

Bihar accounts for nearly 45–50 % of India's total litchi production and remains the leading producer in the country (4). The state cultivates litchi on more than 35000 hectares with an annual production exceeding 300000 metric tonnes, with Muzaffarpur, Vaishali and Samastipur as major producing districts (5). Despite its

production advantage, productivity fluctuations due to climatic variability, pest incidence and inadequate post-harvest infrastructure reduce market competitiveness (6). Compared to other producing states such as West Bengal and Jharkhand, Bihar holds a comparative production advantage yet supply chain inefficiencies limit export potential and value realisation (7).

Stakeholders play a crucial role in the sustainable supply chain management of agricultural commodities (8). In the case of litchi, effective supply chain coordination is particularly essential because of its short shelf life (3). Marketing institutions, government agencies and extension workers currently play limited roles; however, they are expected to provide price assurance, productivity support and timely knowledge transfer to stakeholders (9). External stakeholders, including governmental and non-governmental organisations, facilitate sustainable agricultural practices and proactive engagement with them enhances organisational learning and capability development (10).

Collaborative supply chain management is critical in the litchi industry due to the fruit's highly perishable nature (11). Supply chain risk, quality management practices and business strategies have a significant impact on supply chain linkages and overall business performance in the litchi industry (12). Social network analysis (SNA) is a methodological approach used to study the structure and relationships within social networks (5). It conceptualises individuals and organisations as nodes connected through relational links that can be analysed using network and graph theory (13). Social networks are complex and self-organising systems that demonstrate emerging patterns as their size increases (14).

Despite multiple interventions, supply chain practices in the litchi value chain in Bihar remain underdeveloped. Hence, the present study employs the SNA-based Net-Map approach to map key stakeholders, analyse their roles and examine power relations that influence stakeholder collaboration and supply chain strengthening in Muzaffarpur district of Bihar (15). This research forms a basis for enhancing collaboration among stakeholders and informing policy interventions. Additionally, it addresses an important research gap as very few studies have focused on the litchi value chain in Bihar and none have applied the Net-Map-based SNA approach to analyse stakeholder relationships in this region.

Materials and Methods

Study area

The study was conducted in Muzaffarpur district of Bihar during 2024. Among the 38 districts of Bihar, Muzaffarpur was selected due to its prominence in litchi production.

Research design

A mixed-method research approach was adopted to conduct the study. Stakeholders were selected based on their knowledge, experience and involvement in the litchi supply chain to ensure diverse representation.

Stakeholder identification and Net-Map procedure

The Net-Map methodology was employed to identify stakeholders, visualise linkages and assess power relations. A stakeholder meeting was organised on 5 May 2024 involving 30 progressive growers and experts from Dr. Rajendra Prasad Central Agricultural University (RPCA). Participants identified 15 key stakeholders. Influence was rated using a nine-point Likert scale and visualised through influence towers.

Data collection and matrix development

Qualitative and relational data were triangulated through interviews with 10 key informants. A symmetric square matrix was constructed in Microsoft Excel where linkages were coded as 1 (presence) and 0 (absence).

Network analysis

Gephi (version 0.10) was used to generate network diagrams and compute centrality measures including degree, closeness, betweenness and eigenvector centrality.

Results and Discussion

Stakeholders in litchi supply chain

A total of 15 stakeholders were identified in the litchi supply chain and their respective roles are presented in Table 1. The major stakeholders include growers, pre-harvest contractors, input suppliers and traders, all of whom play significant roles in the movement of litchi from production to consumption. The stakeholder network reflects strong interdependence among actors, indicating that efficient supply chain functioning relies on coordinated actions (16).

Stakeholder analysis was used as a methodological framework to understand the litchi supply chain system comprehensively in the study area (Fig. 1). The objective was to improve supply chain efficiency while exploring export potential. Consequently, stakeholders mapping assessed influence, interest and scope of action across the entire spectrum of activities (17).

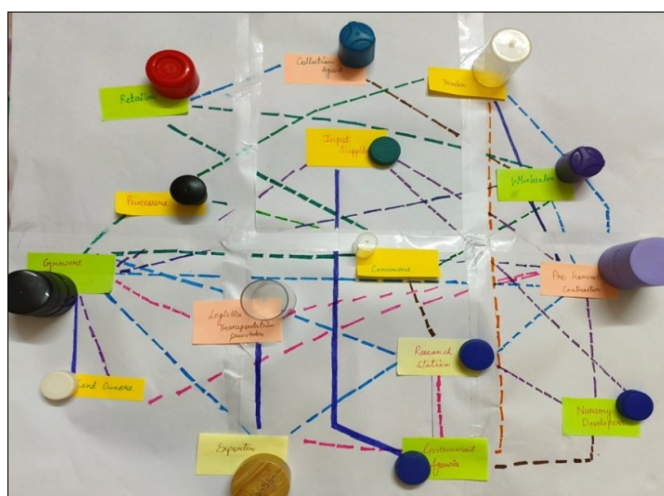


Fig. 1. Sample net map.

Table 1. Roles of potential stakeholders in litchi supply chain

Sl. No.	Stakeholders	Role/function
1.	Nursery developers	Quality litchi seedlings or graft for farmers.
2.	Input suppliers	Fertilizers, pesticides and irrigation equipment's.
3.	Growers	Cultivate and harvest
4.	Land owners	Orchard owners who lease out land on contract basis
5.	Pre harvest contractor/traders	Takes orchard for lease on contract basis
6.	Collection agent	Owners of individual collection unit. Direct purchases of litchi are made from producers.
7.	Traders	Buy litchi from farmers and sell to wholesalers or exporters.
8.	Wholesalers	Purchase large quantities from collectors and supply to retailers or processors.
9.	Retailers	Sell litchi directly to consumers through various channels.
10.	Processors	Engage in value addition activities like canning, juicing or drying litchi.
11.	Exporters	Ship litchi to international markets.
12.	Logistics and transportation providers	Facilitates the movement of litchi throughout the supply chain.
13.	Government agencies	Regulates quality standards, provide support to farmers and monitor exports.
14.	Research institutes	Develop new varieties, improve farming practices and address pest/ diseases issues.
15.	Consumers	The end users who purchase and consume litchi.

The importance-influence matrix (Table 2) ranks stakeholders based on their relative influence within the litchi supply chain. Pre-harvest contractors recorded the highest influence score, indicating their dominant role in the supply chain. They are responsible for orchard management during critical pre-harvest periods and lease orchards from landowners, managing irrigation, fertilisation and pest control operations. Their decisions directly affect both the quality and volume of litchi entering the supply chain (4). Growers remain central actors whose production practices strongly influence output quantity and quality. To maximise yield, growers depend on input suppliers and pre-harvest contractors.

Table 2. Attribute sheet for importance influence matrix of stakeholders

Sl. No.	Stakeholders	Influence	Relative influence	Goals
1.	Pre harvest contractor (PHC)	45	1	1
2.	Trader	37	0.82	1
3.	Commission agent	26	0.57	1
4.	Wholesaler	30	0.66	1
5.	Consumers	0	0	-
6.	Growers	38	0.84	1
7.	Retailers	30	0.66	1
8.	Exporters	15	0.33	3
9.	Processors	20	0.44	3
10.	Logistics and transportation providers	30	0.66	1
11.	Input supplier	15	0.33	3
12.	Research institutes	21	0.46	2
13.	Land owners	22	0.48	3
14.	Government agencies	20	0.44	2
15.	Nursery developers	15	0.33	3

Government agencies and research institutes showed moderate influence. Although their direct involvement is limited, they play an important role in policy formulation, regulatory enforcement and technical innovation. Similar observations have been reported in other agricultural value chain studies (16).

Social network analysis amongst stakeholders in litchi supply chain

The SNA of the stakeholders involved in the litchi supply chain, depicting various actors interconnected through relationships involving supply, services and information exchange (18) (Fig. 2). Growers are central players in the network, directly engaged in cultivating and producing litchi and other agricultural produce. Their relationships extend to numerous stakeholders, including input suppliers, retailers, processors and government agencies. Input suppliers and nursery developers assist growers by providing essential resources such as seedlings, fertilisers and other inputs critical for litchi cultivation. Pre-harvest contractors provide operational support to growers including land preparation, planting, crop management and irrigation (19). Their connections with

multiple stakeholders highlight their reliance on both upstream (suppliers and growers) and downstream actors (processors, traders and retailers). Pre-harvest contractors act as intermediaries connecting growers to processors, retailers and wholesalers. Government agencies maintain extensive linkages with processors, exporters, traders and research institutions. Consumers are linked directly to retailers and indirectly to growers and pre-harvest contractors, representing the destination of the supply chain. The connecting lines between nodes represent different types of relationships and exchanges among stakeholders. Overall, the complexity of interactions within the litchi supply chain demonstrates the interdependence of stakeholders in facilitating the movement of produce from farms to end consumers (20).

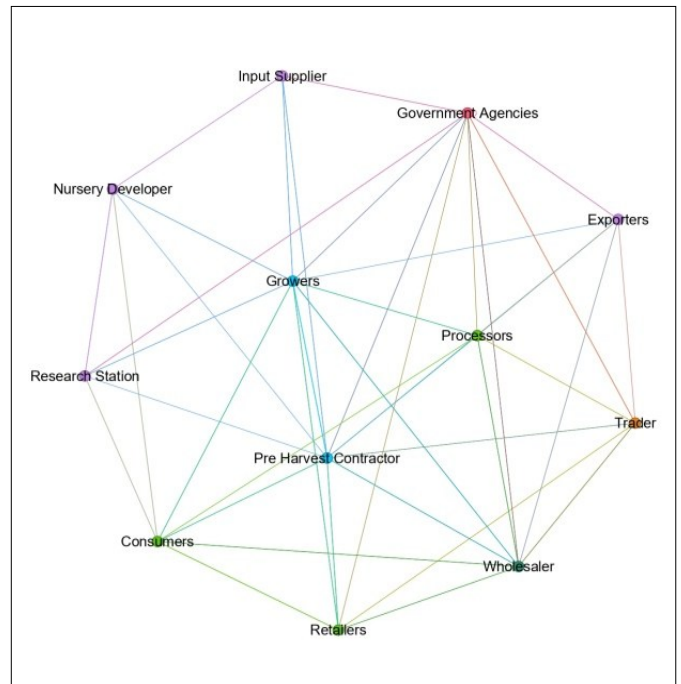


Fig. 2. Social network analysis (SNA) among litchi stakeholders.

A measure is defined as a unit used to describe a specific characteristic of a stakeholder within the network. These measures help in understanding the structural position and relative importance of individual stakeholders (21).

Degree centrality values presented in Table 3 were calculated to characterise stakeholder positions in the litchi supply chain (1). Degree centrality represents the number of direct connections maintained by each stakeholder in the network. Growers and pre-harvest contractors exhibit the highest degree centrality, indicating that they are directly connected to 19 other stakeholders. High degree centrality implies a greater potential to

Table 3. Centrality measures to typify the positions of identified stakeholders in litchi supply chain

Sl. No.	Stakeholders	Degree centrality	Closeness centrality	Betweenness centrality	Eigenvector centrality
1.	Growers	19	1.0	0.14	1.0
2.	Pre harvest contractor	8	0.61	0.005	0.52
3.	Input supplier	9	0.69	0.003	0.57
4.	Trader	8	0.65	0.007	0.49
5.	Research station	10	0.69	0.002	0.63
6.	Processors	8	0.68	0.001	0.51
7.	Exporters	10	0.69	0.02	0.61
8.	Consumers	18	0.84	0.08	0.48
9.	Government agencies	10	0.68	0.008	0.65
10.	Retailers	8	0.65	0.008	0.43
11.	Nursery developers	15	0.77	0.037	0.87
12.	Wholesalers				

exchange information and resources within the network. Closeness centrality measures the average distance between a stakeholder and all other stakeholders and reflects how quickly information can flow through the network (2). The pre-harvest contractor recorded the highest closeness centrality, suggesting strong accessibility to other actors. Exporters and processors showed comparatively lower centrality values, possibly due to infrastructure constraints and the highly perishable nature of litchi requiring rapid logistics (22).

Betweenness centrality captures the frequency with which a stakeholder lies on the shortest path between other stakeholders and indicates potential control over information or product flow. Pre-harvest contractors displayed the highest betweenness centrality, signifying their critical intermediary role in the supply chain (9). Eigenvector centrality measures the influence of a stakeholder based on connections with other influential actors in the network. A higher eigenvector value indicates a more dominant position. The pre-harvest contractor achieved the highest eigenvector score, confirming its central and influential role within the litchi supply chain network (23).

Growers are central, maintaining direct links with nearly all stakeholders, including pre-harvest contractors, input suppliers, traders, processors and exporters, while also engaging with research stations and government agencies. Processors and exporters contribute through value addition and expanding market reach (14). Consumers influence the supply chain through demand patterns, while government agencies provide regulatory and policy support across stakeholders. This intricate network highlights the collaborative effort required to move litchi from producers to consumers (24).

Despite the presence of multiple stakeholders, coordination challenges persist within the litchi supply chain. Growers often face information asymmetry regarding market prices, quality standards and export requirements (8). Limited cold storage facilities, inadequate transportation infrastructure and weak institutional linkages contribute to significant post-harvest losses (25). Furthermore, the absence of structured communication platforms among growers, traders and exporters restricts collective marketing and value addition opportunities (10).

This matrix of linkages highlights the interdependencies among stakeholders, with growers, traders and government agencies emerging as pivotal actors in ensuring effective coordination across the litchi supply chain (Table 4). Strengthening linkages can enhance efficiency, reduce losses and improve overall product quality. These findings are consistent with earlier Net-Map-based studies (26). Although government agencies and research institutes demonstrate comparatively lower direct influence, they remain essential for long-term supply chain sustainability. The matrix and centrality measures indicate scope for stronger integration between these institutional actors and primary stakeholders to address infrastructure and market linkage gaps (27).

The SNA and stakeholder mapping underscore the importance of interconnectedness within the litchi supply chain, where each stakeholder supports others. Such interconnected networks facilitate smoother supply chain functioning and greater adaptability to market changes (28). Strengthening linkages between growers, government agencies and traders can enhance public-private partnerships, improve productivity and scale up innovations for smallholders. Ultimately, a coordinated multi-

Table 4. Symmetric square matrix

	Growers	Pre harvest contractor	Input supplier	Trader	Research station	Processors	Exporters	Consumers	Government agencies	Retailers	Nursery developers	Wholesalers
Growers	0	1	1	1	1	1	1	1	1	1	1	1
Pre harvest contractor	1	0	1	1	0	1	0	1	1	1	0	1
Input Supplier	1	1	0	0	0	0	0	0	1	0	1	0
Trader	0	1	0	0	0	1	1	0	1	1	0	1
Research station	1	1	0	0	0	0	0	1	1	0	0	0
Processors	1	1	0	0	0	0	1	1	0	0	0	1
Exporters	1	1	0	0	0	1	0	0	1	0	0	1
Consumers	1	1	0	0	0	1	0	0	0	1	0	1
Government agencies	1	1	1	1	1	1	1	0	0	0	0	1
Retailers	1	1	0	0	0	0	0	1	1	0	0	1
Nursery developers	1	1	1	0	1	0	0	1	0	0	0	0
Wholesalers	1	1	0	1	0	1	0	1	1	1	0	0

stakeholder approach is essential for improving the efficiency and quality of the litchi supply chain to meet both domestic and export market demand (29).

The SNA results provide strategic insights for strengthening the litchi supply chain. Identifying central actors such as pre-harvest contractors and growers enables targeted interventions to improve coordination and information dissemination (30). Strengthening linkages with research institutions and government agencies can enhance technology transfer and quality compliance (10). Improved coordination is expected to reduce post-harvest losses, improve export readiness and enhance overall supply chain efficiency (8), thereby contributing to income enhancement for farmers (3).

Social network analysis employs quantitative metrics to understand stakeholder positioning within a network (11). Degree centrality measures the number of direct connections an actor maintains, reflecting immediate influence (31). Closeness centrality indicates how efficiently an actor can interact with others in the network. Betweenness centrality identifies stakeholders who act as bridges between otherwise disconnected actors, highlighting brokerage power (30). Eigenvector centrality measures influence based on connections to other highly connected actors, thereby reflecting structural prominence (11).

Conclusion

The study demonstrates that social network analysis (SNA) is an effective tool for diagnosing structural gaps and power dynamics within the litchi supply chain in Bihar. The analysis reveals that pre-harvest contractors and growers dominate network interactions, while institutional stakeholders require stronger integration. Policy interventions should focus on strengthening cold storage infrastructure, promoting public-private partnerships, facilitating direct market linkages and enhancing extension support. Government initiatives aimed at improving logistics, export facilitation and digital market platforms can significantly enhance value realisation. By improving stakeholder coordination and reducing inefficiencies, the supply chain can become more resilient and market oriented. Ultimately, better integration and informed policy action will enhance income stability, reduce post-harvest losses and improve livelihood security for litchi farmers in Bihar.

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Authors' contributions

SP conceptualised the research idea, designed the methodology and drafted the manuscript. BS¹ carried out data interpretation, concise writing, reviewing and copy editing. TK assisted in methodology and performed the statistical analysis. AS contributed for literature review. SS carried out in the preparation of reference list and formation. BS² and SL carried out identification of research gaps. SK¹ and SK² in literature review. All authors have read and approved the final manuscript [BS¹- Bineeta Satpathy and BS²- Biswanath Sahoo; SK¹- Shweta Kumari and SK²- Swati Kumari].

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used Gephi; Symmetric square matrix and influence -power matrix for identification of stakeholders; establishing the linkages and identification of power and influence of stakeholders.

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