BRILL WAGENINGEN ACADEMIC

JOURNAL OF INSECTS AS FOOD AND FEED 11 (2025) 2695–2712

Journal of Insects as Food and Feed
brill.com/jiff

RESEARCH ARTICLE

Entwined evolution: how innovation networks foster collaborative growth in East Africa's edible insect value chain

N. Ndung'u[1*], *H. Isaboke*[1], *W. Nyarindo*[1], *M. Otieno*[2], *M. Gicheha*[3] *and J. Kinyuru*[4]

[1]Department of Agricultural Economics and Extension, University of Embu, Embu 60100, Kenya;
[2]Department of Water and Agricultural Resource Management, University of Embu, Embu 60100, Kenya;
[3]Department of Animal Science, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya;
[4]Department of Food Science and Technology, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya; *wamwitha.j@gmail.com

Received 23 October 2024 | Accepted 7 May 2025 | Published online 22 May 2025 |
Published in issue 1 November 2025

Abstract

The introduction of edible insects as a protein source has gained traction in East Africa, with various multidisciplinary initiatives promoting insect production and consumption. However, there remains a limited understanding of the innovation networks, roles of different actors, and linkages that influence the development of this sector. This study employed social network analysis and exponential random graph models (ERGMs) to examine data from 220 cricket farmers in Masaka, Uganda, and western Kenya, focusing on network structures and participation dynamics. Findings revealed a gap between market awareness and actual sales. The institutional network demonstrated high connectivity, with a density of 0.559 and complete reciprocity. The affiliation network showed eigenvector centrality values were 0.128 for Kenya and 0.112 for Uganda, highlighting the importance of key nodes. Masaka's farmer network was highly centralized (0.605), in contrast to Kisumu (0.478) and Siaya (0.244). While institutional networks exhibited strong cooperation, the affiliation networks revealed weak linkages, suggesting fragmentation among actors that hinders information flow and coordinated action. This study underscores the increasingly vital role of collaboration between research organizations and the private sector in fostering innovation and demand for cricket farming. Additionally, it contributes to network theory by empirically mapping a multi-actor system within an emerging food innovation context. The findings stress the importance of enhancing stakeholder interactions to facilitate adoption and scaling. Policies should promote best practices in production and processing, while also strengthening institutional support by engaging government agencies, NGOs, and research institutions to provide resources, technical assistance, and market linkages.

Keywords

centrality – ERGMs –linkages – network density – roles

1 Introduction

Food insecurity and malnutrition pose persistent challenges in developing countries, particularly in Sub-Saharan Africa (SSA) (FAO, 2024). The prevalence of undernourished individuals worldwide is increasing, with 22.3% of them residing in SSA (FAO *et al.*, 2024). Given the anticipated population growth, rising inco-

Published with license by Koninklijke Brill BV | DOI: 10.1163/23524588-BJA10233
 | ISSN: 2352-4588 (online)

mes, and shifts in consumer behaviour, the difficulties associated with food provision in SSA are projected to escalate (FAO *et al.*, 2024). Consequently, conventional methods of producing animal proteins are becoming untenable and/or need supplementation. The motivation to explore alternative food sources has led to the promotion of edible insects as a viable protein alternative (Alemu *et al.*, 2017; van Huis, 2020). Edible insects provide essential sources of proteins for human nutrition (Roos, 2018; Zhou *et al.*, 2022). In addition to provision of nutrients, they exhibit efficient feed conversion and demonstrate a reduced environmental impact, characterized by lower land and water usage as well as diminished greenhouse gas emissions (Ebenebe *et al.*, 2020) hence a more sustainable food resource.

There is a growing interest in promoting the consumption of edible insects in low and middle-income countries (Halloran *et al.*, 2018; Niassy *et al.*, 2018), especially in East Africa (Fiaboe and Nakimbugwe, 2017). The interventions and projects focus on basic research (Alemu *et al.*, 2017; Pambo *et al.*, 2018b), development of standards (Kinyuru and Ndung'u, 2022) and inclusion of insects in the food composition database (FAO/GoK, 2018), all of which are valuable steps in enhancing insects production, marketing and consumption. The multidisciplinary approaches and knowledge generated by these projects are contributing to new technologies and the development of the insect value chain. These efforts include documentation of edible insect species (Jongema, 2017), their nutritional attributes (Zhou *et al.*, 2022), assessing consumer acceptance products (Pambo *et al.*, 2018b), and exploring the potential of insect farming in food security (Tanga and Kababu, 2023).

While the global edible insect sector has garnered increasing scholarly interest, a substantial portion of the existing literature is very rich on wild harvesting systems (Manditsera *et al.*, 2022; Odongo *et al.*, 2018). In contrast, farmed insect systems – particularly in emerging markets such as East Africa (EA) – remain significantly underexplored. This study focuses on farmed edible insects, specifically crickets (*Acheta domesticus*, *Gryllus bimaculatus*), within the East African context. Central to these value chains are the farmers, who not only rear insects but also act as key innovators and knowledge brokers. Research indicates that they initiate informal networks of trade, technology exchange, and peer learning, thereby establishing the foundation for more formalized sector development (Musungu *et al.*, 2023; Van Peer and Van Miert, 2024; Verner *et al.*, 2021). Supporting these grassroots efforts are middlemen, who play a critical role in connecting producers to retailers and processors – especially in informal or semi-formal settings where structured supply chains are still developing (Kinyuru *et al.*, 2024). Retailers, including those marketing insect species such as mealworms, facilitate access to urban and rural markets, directly interfacing with consumers and shaping demand (Verner *et al.*, 2021), although the established retailers are for the harvested EI species (Donkor *et al.*, 2022a). In turn, food processors create value-added products, thereby expanding the market reach of edible insects and enhancing shelf life and safety.

The sector also benefits from the contributions of research institutions, which provide breeding stock, farming technologies, training, and applied research that drive continuous improvement (Kinyuru and Ndung'u, 2020; Verner *et al.*, 2021). Government and regulatory agencies are responsible for developing the legal and policy frameworks necessary to guide and legitimize insect farming. Nevertheless, gaps in legislation remain a significant obstacle to the growth and scalability of these systems (Niassy *et al.*, 2022; Okello *et al.*, 2023; Van Peer and Van Miert, 2024). Non-governmental organizations (NGOs) have been instrumental in addressing capacity gaps, raising awareness, and promoting insect consumption, particularly at the community level (Flying foods, 2018). Concurrently, the private sector – ranging from start-ups to large enterprises – has begun to invest in farming, processing, and commercializing insect-based products, thereby contributing to the development of a viable market (Tanga and Kababu, 2023; Van Peer and Van Miert, 2024; Verner *et al.*, 2021). Ultimately, the success of the edible insect value chain is contingent upon – acceptance, consumer behaviour – acceptance, demand, and willingness to purchase these novel products (Alemu and Olsen, 2018; Pambo *et al.*, 2018). However, realizing the full potential of the sector also hinges on access to financial capital, particularly for farmers and small businesses seeking to expand their operations. Studies underscore the importance of credit facilities and institutional financing in facilitating this scaling (Musungu *et al.*, 2023). Finally, development organizations continue to play a crucial role by supporting research, infrastructure development, and policy formulation. Their involvement ensures that the edible insect sector develops in a sustainable, inclusive, and well-regulated manner (Van Peer and Van Miert, 2024).

While global literature provides valuable insights, the East African context remains under-researched, particularly in understanding how local farmers integrate into value chains, how their roles evolve with formalization, and their linkages with traders, processors, and institutions. Comprehensive reviews mapping actors, roles, and networks in edible insect value chains are lacking, especially studies on traders in farmed insect sectors. This study addresses these gaps by mapping key actors – farmers, traders, processors, and institutional stakeholders – and analyzing their key roles. It examines the nature and strength of their relationships and both strong and weak interactions. It also uncovers the institutional, economic, and social structures that facilitate or hinder coordination, identifying missing or fragile links, such as limited farmer-trader collaboration, which may impede scalability.

There has been several developmental initiatives in East Africa, led by universities such as Makerere University, Jomo Kenyatta University of Agriculture and Technology (JKUAT), Jaramogi Oginga Odinga University of Science and Technology (JOOUST), as well as research organizations like the International Centre of Insect Physiology and Ecology (ICIPE), Non governmental organizations (NGO's) and development agencies including the International Development Research Centre (IDRC), the Danish International Development Agency (DANIDA), and the World Bank (Niassy *et al.*, 2018). Examples of such initiatives is introduction of cricket farming by Flying Foods (Flying foods, 2018) and other developmental projects such as The Africa Center of Excellence in Sustainable Use of Insects as Food and Feeds (INSEFOODS) and HEALTHYNSECT (Donkor *et al.*, 2022b). The initiatives have advanced the innovation of edible insects through various activities such as scientific validation, feasibility assessments, legislation (Kinyuru and Ndung'u, 2022), training for farmers and entrepreneurs, product development, and the establishment of small-scale production systems (Tanga and Kababu, 2023). However, despite these efforts, the insect value chain in the region is still in its infancy. Key challenges include a limited number of farmers involved in insect farming (Ayieko *et al.*, 2016), the low scale of operation and the restricted range of value-added edible insect products (Ebenebe *et al.*, 2020). As a result, insect products are not readily available in the common food retail outlets such as supermarkets or shops (Odongo *et al.*, 2018). To fully realize the anticipated benefits, there is a crucial need to elevate edible insect value chains from experimental stages to large-scale production and commercialization. This transition is highlighted as essential by various studies, emphasizing the importance of scaling up these initiatives (Alemu *et al.*, 2023; Kinyuru and Ndung'u, 2020).

Little is known about how social networks, market structures, and stakeholder interactions shape the production and distribution of insect-based products is limited. Addressing innovation challenges requires a clear understanding of actor roles, linkages, and readiness for scaling. The Agricultural Innovation System (AIS) framework provides a valuable lens for analyzing stakeholder engagement, knowledge flows, and institutional dynamics (Klerkx and Begemann, 2020; Sartas *et al.*, 2020). When combined with social network analysis, AIS is particularly suited to examining early-stage innovations and the structural factors shaping adoption (Weyori *et al.*, 2017). This study addresses existing gaps by applying Social Network Analysis (SNA) and Exponential Random Graph Models (ERGMs) to explore the social and market dynamics unique to East Africa, offering insights for both policy and practice.

While social networks have been studied, the application of SNA and ERGMs in the context of African agricultural and food systems has been limited. However, Nyantakyi-Frimpong *et al.* (2019) applied ERGMs to analyze smallholder farmers' social networks in Ghana, focusing on resource-conserving agricultural practices. Their findings offered valuable insights into farmer advisory roles and network clustering. Similarly, research by Walther *et al.* (2019) on West African food systems highlights the relationship between network position, structural embeddedness, economic performance, and gender dynamics. Another study used ERGMs to analyze the structural dynamics of collaborative networks, knowledge exchange channels, and influence frameworks within multi-stakeholder platforms (MSPs) (Hermans *et al.*, 2017). These studies illustrate that the methodologies used are part of an evolving trend of applying network approaches in African contexts.

The primary objective of this study was to investigate the roles of actors and network structural characteristics of edible insect value chains in East Africa. Specifically, the research aimed to measure and analyze the role of social networks in facilitating or impeding market access, knowledge exchange, and collaboration among stakeholders. Utilizing Social Network Analysis and ERGMs, we tested hypotheses related to network cohesion, information flow, and market integration, ultimately identifying the key factors that either constrain or promote the commercialization of edible insects within this context. This study contributes to the academic literature on alternative protein sources and informs policy-oriented strategies aimed at enhancing the development of the edible insect value chain.

2 Methodology

Study area and data collection

This study used data collected from farming households in Kenya and Uganda. The sampling methodology combined purposive, multi-stage cluster sampling and probability proportionate to size (PPS) sampling techniques to select the respondents. At first, specific regions were purposively selected based on their significant cricket production, namely Siaya and Kisumu counties in Western Kenya and Masaka District, Uganda. Next, an exploratory survey (S1) was conducted to gather information on cricket farmers within the areas where farming was most prevalent. Within the selected regions, a multi-stage cluster sampling was carried out to break down the area into smaller, more homogeneous clusters (based on geographic proximity). Finally, the study applied probability proportionate to size (PPS) sampling within each cluster to determine the number of respondents, ensuring that clusters with larger populations contributed proportionately more to the overall sample than those with smaller populations. This combination enabled the study to target critical areas while maintaining a level of representativeness across the cricket farming regions, enhancing the overall reliability of the findings. Comprehensive surveys (S2) were conducted in Uganda November 2022 and in Kenya March 2023, involving interviews with a total of 220 cricket-farming households and 457 non-cricket farming households. Data collection was facilitated through a structured questionnaire that covered various aspects including farming systems, household profiles, and socio-economic characteristics, and included both open-ended and Likert scale questions related to the adoption of insect farming. Additionally, ego network questions were included to explore interactions with individuals and organizations in the context of cricket farming. To enrich the primary data, supplementary information was obtained through secondary data sources. Prior to commencing the study, ethical approval was secured from the Mount Kenya University Research Ethics Committee (Approval no. 765), and registered with Kenya's National Council for Science, Technology, and Innovations (NACOSTI) for licensing. In Uganda, ethical clearance was granted by the Makerere University School of Social Sciences Research Ethics Committee (No. MAKSS REC 09.19.317) and the Uganda National Council for Science and Technology (UNCST, research no. SS 5182). Additionally, the questionnaire began with an introduction that explained confidentiality measures, outlined how the research findings would be reported, and provided a written request for voluntary consent to participate in the survey

Empirical models

In this paper, we utilize the Exponential Random Graph Model (ERGM), initially introduced by Frank and Strauss (1986) and later expanded by Wasserman and Pattison (1996). The model assigns probabilities to networks by considering local configurations, representing the underlying local network processes. We then depict the networks through graph configurations in which all ties are viewed as conditionally dependent, organizing into patterns influenced by underlying social processes (Bellotti *et al.*, 2016; Wang *et al.*, 2016). Thus, the probability of observing a network B (Farmers/producers) $B = \{B_{ij}\}$, where $B_{ij} = 1$ indicates a tie between nodes i and j, Network B is given as;

$$\Pr(B = b) = \frac{1}{k(\theta)} \exp\{\theta_Q z_Q(b) + \theta_2 z_2(b) + \theta_3 z_3(b) + \theta_4 z_4(b)\} \quad (1)$$

where θ = (arc, 1 = edge, 2 = closeness centrality, 3 = betweenness centrality, 4 = degree centrality)

Following (Wang *et al.*, 2016), macro-analysis for network A (Institutions) considers network density, average out-degree assortativity (popularity), centrality and reciprocity while eigenvector centrality and degree centrality to analyse the affiliation network C.

The Exponential Random Graph Model (ERGM) offers a statistical methodology for analysing social network structures (Snijders, 2011; Stivala *et al.*, 2020), making it suitable for understanding tie formation between individuals farmers and institutions. While there is presence of other models such as Multiple Correspondence Analysis (MCA), which is an exploratory technique used to uncover patterns in categorical data (Hjellbrekke, 2019), ERGM handles relational data and models the likelihood of specific network configurations. This distinction is crucial in social network analysis, where connections among actors are interdependent and influenced by factors like reciprocity, transitivity, and homophily (Sartas, 2018). While MCA reduces dimensionality and visualizes clustering, it does not account for relational aspects; it fails to model or explain the presence or absence of ties. In contrast, ERGM provides a probabilistic framework for assessing whether observed patterns – such as a tendency for individuals of the same gender to connect – are statistically significant, considering the inherent dependencies in network data.

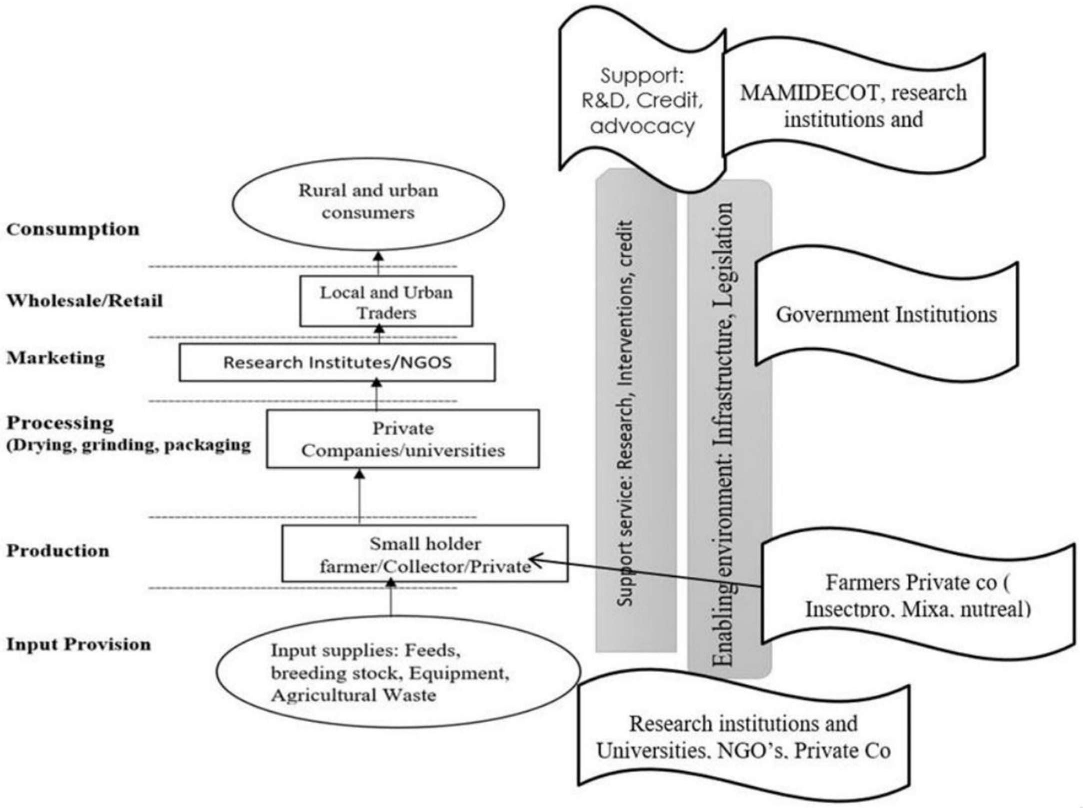

FIGURE 1 Edible insects value chain in East Africa and actors' roles.

Data analysis

Before analysis, the data were rigorously prepared to ensure quality and uniformity. Records lacking values in essential variables were discarded, whereas gaps in less critical fields were addressed through median imputation. Potential outliers were identified using Z-scores and interquartile range (IQR) rules; extreme points were either excluded or transformed as necessary. Categorical variables – such as gender, age – were assigned explicit factor labels in R, while all continuous measures were converted to numeric formats. We analysed characteristics associated with innovation processes, network properties, and the specification of ERGMs using the 'statnet' package and the specialized 'ergm' package in R. The 'ergm' package specifically designed for network analysis was employed to estimate these models and the results were visually presented through graphical outputs. Descriptive statistics, including arithmetic means, frequencies, and percentages, for features linked to the edible insects' innovation processes, were summarized in tables. To guarantee the reliability and validity of the statistical model, it was essential to identify and address any issue of degeneracy. Therefore, the *statnet* suite in R (specifically the 'ergm' package) includes several built-in mechanisms were used to detect and prevent degeneracy. The Markov Chain Monte Carlo (MCMC) controlled proposal distributions and was optimized to avoid degenerate behaviour.

3 Results and discussion

In this section, we present key findings from the methodological approach discussed earlier, which provided a structured framework for understanding the social, institutional, and market dynamics that shape the cricket farming value chain in East Africa. Using both descriptive and network-based analyses, we highlight the influence of farmer characteristics, institutional support, and network interactions on the adoption and scaling of cricket farming.

Mapping of the value chain and actors' roles

This study focused more on delineating the value chain and acquiring an in-depth understanding of the roles undertaken by the various actors as presented in Figure 1. Farmers emerged as the primary producers of crickets, actively involved in the cultivation and breeding of cricket colonies. These included farmers who adopted and implemented recommended farming practices, including feeding, housing, disease management, harvesting, and processing. The findings exhibit similarities to those presented by Ayieko *et al.* (2016), wherein farmers played a significant role as key players in cricket production. Local trainers, most often the experienced farmers themselves, played a crucial role in guiding smallholder farmers in establishing their own small-scale cricket rearing stations. These farmers have played a role in peer-to- peer learning and knowledge sharing within their locality. Further, these trainers continuously sought to improve their knowledge of cricket farming techniques, production methods, and product development.

Research institutions, universities, and NGOs have played a key role in the value chain, as many farmers have benefited from their capacity-building efforts. These initiatives, which include providing starter kits (eggs, rearing equipment), training, and support in establishing market linkages, have been made possible through strategic collaboration with these organizations. This aligns with the findings of (Omollo *et al.*, 2019), wherein the researchers observed the influential role played by research institutions and NGOs in the fodder value chain development.

While research institutions in East Africa have contributed significantly to supporting research and farmer training initiatives, their efforts have not been as comprehensive as those of similar organizations elsewhere. For instance, Halloran *et al.* (2016), describe how Khon Kaen University in Thailand offers a holistic approach, encompassing classroom instruction on cricket farming and edible insects, on-campus and field-based training programs tailored for cricket farmers, and the utilization of social media platforms to address queries related to cricket farming practices. The university hosts an edible insect club managed by entomology students, and the Department of Agriculture has established demonstration sites dedicated to cricket farming through its Agricultural Technology Promotion Centers (Economic Insects). Additionally, research by (Durst and Hanboonsong, 2015) in Thailand and Laos revealed that Thai universities provide extensive training on insect production, marketing, product development, and nutrition while facilitating the establishment of marketing networks for cricket products. Thailand's success in integrating edible insects into mainstream food systems provides significant insights for East Africa, particularly in the areas of regulatory development, market expansion, and consumer acceptance. This case exemplifies the critical role of standardized rearing practices, safety certification, branding, coordinated value chains, and structured extension services that are specifically tailored to insect farming.

The study found that MAMIDECOT, a financial institution in Uganda supported farmers by offering credit and starter kits, training and assistance in bulking and marketing harvested crickets. Private companies, notably Mixa Foods, were also actively involved in cricket farming, processing cricket into various cricket-based products such as bread and cookies. Beyond production activities, these companies offer comprehensive training services to farmers, covering all aspects of cricket farming, production, input supply and product development. Government institutions, particularly KEBS (Kenya Bureau of Standards) and UNBS (Uganda National Bureau of Standards), played a crucial role in establishing and approving standards for insects as both food and feed (Fiaboe and Nakimbugwe, 2017; Kinyuru and Ndung'u, 2022). Their involvement in setting and endorsing these standards contributed to regulating and ensuring the quality and safety of insect-based products in the respective regions. Our study also noted that the media played a vital role in increasing awareness through coverage on national television and in print publications. This observation corroborates with the findings from other research highlighting the media's significant role, as exemplified in the work of (Suchiradipta and Raj, 2014).

However, we encountered difficulties in identifying significant retailers, buyers, or traders for farmed edible insects, despite the documented high demand for insects (Ebenebe *et al.*, 2020) and positive consumer acceptance (Alemu *et al.*, 2017; Homann *et al.*, 2017). This high consumer demand coexists with a low scale of farming, resulting in an inconsistent supply. This inconsistency, in turn, limits the participation of traders, despite their willingness to engage (Ndung'u *et al.*, 2025). The absence of government extension officers as significant participants in the insect value chain was observed in both Kenya and Uganda. This may be due to the predominant role played by research institutions, universities NGOs (especially Flying Foods), and development partners in driving this innovation. Agricultural education and extension services have traditionally offered farmers research-based information and supported the adoption of new technologies. However, in recent decades, governments have scaled back these services and increasingly depend on other actors for the implementation and distribution of innovations, often through Public-Private Partnerships (PPPs) (Akullo *et al.*, 2018). Moreover, as observed by (Odongo *et al.* (2018), we also identified that distribution systems, encompassing collection, transportation and storage, are not well-developed.

TABLE 1 Demographic characteristics of the cricket farmers

Variable	Categories	Percentage	Frequency (n = 186)
Gender	Male	33.33	62
	Female	66.67	124
Age (years)	18-25	9.68	18
	25-35	21.51	40
	35-50	30.65	57
	50-60	21.51	40
	Above 60	16.67	31
Education level	None	2.67	5
	Primary	33.87	63
	Secondary	39.97	74
	Tertiary College	19.35	36
	University	4.3	8
Marital status	Single	10.22	19
	Married	65.59	122
	Separated	3.76	7
	Widowed	19.35	36
	Divorced	1.08	2
	Mean	Standard deviation	
Household size	2.60	0.8005	

Demographic characteristics for cricket farmers

Table 1 illustrates the distribution of human capital factors among cricket farmers – namely gender, household size, marital status, education, and age – providing insights into the demographic characteristics associated with the adoption of cricket farming. The gender distribution reveals more females, who make up 66.67% of the cricket farming demographic, while males constitute 33.33%. This suggests that the majority of the cricket farmers are females emphasizing the prevalence of female participation in cricket farming.

This finding suggests that women are not only active participants in agriculture but also early adopters of innovative practices, such as insect farming, potentially due to their heightened involvement in household food security and income-generating activities. Similar findings were observed in Kenya with higher participation of women in cricket farming expecting to make higher income compared to other agricultural activities (Halloran *et al.*, 2018; Oloo *et al.*, 2021). The culture in the Lake Victoria region may contribute to this dynamic where women are generally tasked with household responsibilities and the management of small livestock maintained within a homestead (Oloo *et al.*, 2021). This further aligns with existing literature that emphasizes the critical role of women in adopting sustainable agricultural innovations (FAO, 2023). Verner *et al.* (2021), noted that insect farming could provide benefits to women by increasing their access to livelihoods and agricultural resources, as evidenced in Thailand, where the promotion of cricket farming among women has been perceived as a pathway to greater financial independence (Halloran *et al.*, 2017). Understanding this gender distribution in cricket farming holds implications for targeted interventions, that promote inclusivity and equitable economic benefits. Additionally, the data shows that farmers aged 35 years and above account for over 60% of the cricket farming population, indicating a lower participation rate among the youth. This finding suggests that the adoption of innovation in this context may be more prevalent among older farmers, who may possess greater resources, decision-making authority, or agricultural experience. This is supported by other studies on youth participation in the agricultural sector (Daxini *et al.*, 2018; Morais *et al.*, 2018), underscoring the necessity for targeted programs that promote innovation uptake among younger demographics through education, training, and entrepreneurship support.

Furthermore, marital status appears to influence the adoption of cricket farming, with 65.59% of adopters being married. This suggests that combined household resources and joint decision-making may play a role in the willingness to engage in new ventures. Similar observations were made in studies such as (Manditsera *et* *al.*, (2022), which also noted more participation among married individuals in the edible insect value chain. Additionally, regarding educational background, most farmers have at least a primary education, with only 2.67% lacking formal education and just 4.3% holding a university degree. The average household size of cricket farmers is 2.60, with a variability of approximately 0.8. The associations between human capital factors and participation in cricket farming yield significant insights into the socio-demographic profiles of innovation adopters and can inform the development of inclusive and targeted intervention strategies.

Processing, institutional and marketing factors influencing cricket farming

To understand the innovation dynamics within cricket farming, we analyzed variables related to processing practices, training and resource accessibility, market awareness, and institutional support, as presented in Table 2. These variables include processing methods, training and resource availability, market awareness, and institutional support. Acquiring a comprehensive understanding of these variables brings forth valuable insights into the enhancement of innovation processes along the cricket farming value chain. Our findings indicated that 50.36% of participants did not process harvested crickets, while the remaining 49.64% utilized various processing methods including drying, frying, a combination of drying and grinding, or the processing of cricket-based products. This indicates a lack of uniformity in post-harvest handling practices, hence a need for standardization and guidance regarding appropriate processing methods to ensure safety and quality EI products. Policies could prioritize the dissemination of best practices for processing, potentially through public- private partnerships since agricultural extension services are not well established within the EI value chain. Training programs by research institutions, universities and NGO's could emphasize the benefits of processing (e.g., extended shelf life, value addition), while equipping farmers with accessible and cost-effective processing techniques (Okello *et al.*, 2023). Additionally, promoting collaboration among farmers to establish shared processing facilities could be beneficial.

In terms of farmers' perceptions of the availability of processing technologies, 39.25% agreed and 13.44% strongly agreed. These responses collectively suggest a generally positive outlook among farmers regarding the existence of processing technologies. The response highlights the varying degrees of engagement and perspectives among cricket farmers concerning the adoption and availability of processing technologies in cricket farming practices. From the institutional factors associated with the innovation process, it was found that a significant majority of cricket farmers, 76.32%, did not receive support from institutions such as research organizations and NGOs. This highlights a significant gap in institutional support for cricket farmers. Specifically, 54.61% of respondents reported receiving training focused on edible insects, covering production systems, feed, farm management, product development, and processing. Trained farmers are reported to have increased their cricket yields (Musungu *et al.*, 2023). Thus, understanding farmer-institutional networks and collaboration is essential for identifying areas that require strengthening. Policies should enhance institutional support systems for the edible insect sector. This may involve government agencies, NGOs, and research institutions providing resources, technical assistance, and market connections. Additionally, stablishing multi-stakeholder platforms (MSPs) could also facilitate better coordination and delivery of support services to farmers (Sartas, 2018).

In terms of marketing variables related to innovation processes, 70.39% of the respondents reported a lack of market access for edible insects, while 29.61% expressed confidence in having access. Interestingly, 88.24% acknowledged the presence of a ready market for insects, with 56.45% falling into the agree and strongly agree categories, indicating a positive perception that edible insect products do indeed have a readily available market. However, despite the perceived ready market, the study observed that only 24.46% of cricket farmers sold their harvest in the previous 12 months. A similar study observed cricket farmers inability to reach the buyers (Halloran *et al.*, 2020). This is in contrast to the projected global market for edible insects, which is expected to reach USD 8 billion by the year 2030, with volumes expected to grow by 28% (MMRPL, 2019). Moreover, evidence shows that the supply of edible insects and their products is insufficient (Ebenebe *et al.*, 2020) and that trading volumes cannot meet processors' demand (Kinyuru and Kipkoech, 2018). Together, these shortfalls reveal critical supply-chain and market-dynamic challenges that must be resolved to harness the sector's projected growth.

This further implies that, even in the presence of demand, farmers may encounter challenges in accessing potential buyers or established markets, particularly with respect to distribution systems and marketing dynamics. Thus, social networks can play a pivotal role in addressing this challenge by establishing platforms

TABLE 2 Processing, institutional and marketing variables related to the innovation processes

Variable	Categories	Percentage	Frequency (n = 186)
Process harvested crickets*	No	50.36	70
	Yes	49.64	69
Processing technology available	Strongly Disagree	6.99	13
	Disagree	22.04	41
	Neutral	18.28	34
	Agree	39.25	73
	Strongly Agree	13.44	25
Institutional variables			
Receive support	No	76.32	142
	Yes	23.68	44
Receive training on edible insects	No	45.39	85
	Yes	54.61	101
Participate in community training	No	87.50	133
	Yes	12.50	19
Participate in group advocacy	No	96.71	142
	Yes	3.29	44
Training on handling insects	Strongly disagree	5.38	10
	Disagree	16.67	31
	Neutral	13.98	26
	Agree	41.40	77
	Strongly agree	22.58	42
Marketing variables			
Market access for edible insects	No	70.39	131
	Yes	29.61	55
Market readily available	No	11.76	22
	Yes	88.24	164
Sell edible insects in the last 12 months*	No	75.54	105
	Yes	24.46	34
Edible insects' products have a ready market	Strongly disagree	8.60	16
	Disagree	20.43	38
	Neutral	14.52	27
	Agree	28.49	53
	Strongly agree	27.96	52
Acceptance variable			n = 186
Willing to farm edible insects in the next 12 months	Strongly disagree	3.76	7
	Disagree	4.30	8
	Neutral	4.84	9
	Agree	42.25	79
	Strongly agree	44.62	83

* The frequency for these variables was 139 as it accounted for only farmers who harvested crickets

for direct interaction between farmers and potential buyers, including wholesalers, retailers, and end consumers. For example, a stakeholder association could develop an online marketplace that connects buyers with producers (Verner *et al.*, 2021). Such digital platforms have the potential to minimize geographic barriers and enhance market accessibility, thereby streamlining the process for buyers to locate sellers and vice versa. According to one farm-level survey, personal networks are the way 42% of farmers receive information

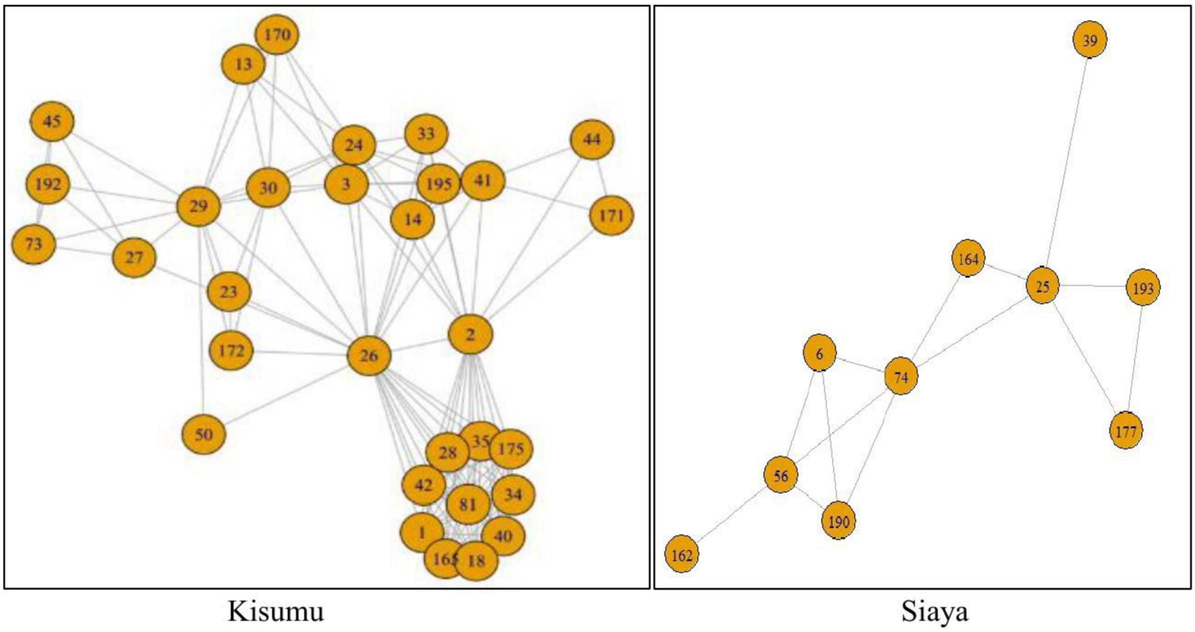

FIGURE 2 Cricket farmers network for Kisumu and Siaya counties.

on insect farming (Verner *et al.*, 2021). By leveraging these relational assets, social networks can aid in transforming latent market potential into actual economic engagement in East Africa.

Regarding the acceptance variable, particularly the willingness to engage in farming, a significant percentage, 42.25 and 44.62% respectively, indicated agreement and strong agreement. This demonstrates a noteworthy consensus among the respondents, indicating their positive predisposition and preparedness to take part in farming activities.

Network characteristics and linkages

From our analysis, exponential random graph models (ERGMs) results revealed distinct graphs featuring specific network characteristics for each level. The farmer networks analyzed in this study are region-specific – namely Masaka (Uganda), Kisumu, and Siaya (both in Kenya) – and reflect localized farmer-to-farmer interactions. Since the data is based on self-reported connections, it would be methodologically inappropriate to combine farmers from regions like Siaya and Kisumu who do not report any direct interaction. In contrast, institutional networks were analyzed collectively across both countries because many of the same institutions and initiatives operate regionally, engaging stakeholders in both Kenya and Uganda. Affiliation networks, however, remain country-specific, as they represent how farmers interact with institutions within their national context and organizational outreach.

Farmers network characteristics

To identify a more suitable set of networks, we examined the networks of farmers (at the micro-level) who work as cricket producers. The study specifically focused on three regions. Figures 2 and 3 display the networks of Kenyan farmers in Kisumu and Siaya counties, and Masaka district in Uganda, respectively. In Figure 2, we show the closeness centrality, betweenness centrality, degree centrality, total degree centralization, and clustering coefficient for farmers' networks in Kenya. Closeness centrality refers to the average proximity of an individual farmer to all other farmers in the network, measured as the inverse of the sum of geodesic distances (Pinto, 2020; Wasserman and Faust, 1994). A farmer with a high closeness centrality can reach every other farmer through fewer relational "steps." Such individuals are able to acquire new information rapidly (such as rearing techniques and buyer contacts) and can disseminate their own knowledge efficiently. Betweenness centrality, on the other hand, measures the proportion of the shortest paths in the network that pass through a particular farmer (Pinto, 2020; Wasserman and Faust, 1994). Farmers with a high betweenness centrality score function as bridges or brokers between otherwise disconnected groups, such as those spanning different counties or farmer associations. These individuals can exert control over information flow and often serve as informal gatekeepers for resources, such as starter colonies or training opportunities. Degree centrality is defined as the total number of direct ties that a farmer possesses, which includes both in-degree and

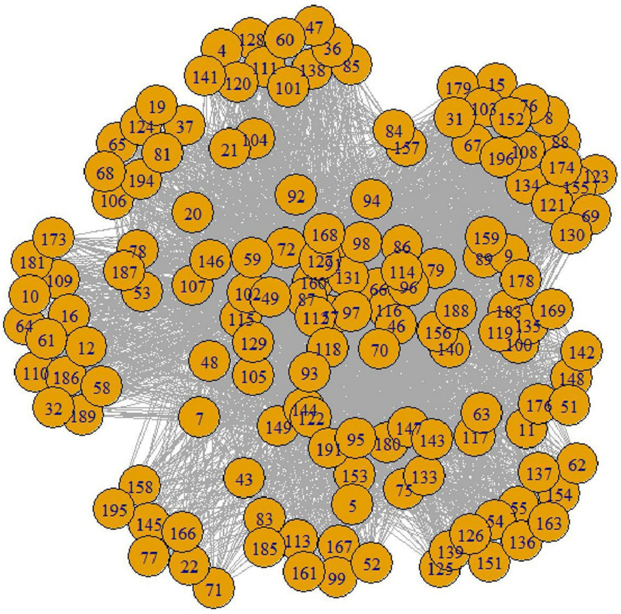

FIGURE 3 Masaka district crickets' farmers' network.

out-degree in a directed graph (Pinto, 2020; Wasserman and Faust, 1994). A farmer with a high degree centrality is characterized by high visibility and strong integration within the network, thereby receiving numerous peer inquiries and invitations. While degree centrality indicates a level of popularity, it provides less insight into the strategic position of a farmer compared to betweenness or closeness centrality.

Within the Kisumu network, there is an average closeness among individual farmers (closeness centrality: 0.018), and certain farmers serve as important intermediaries in connecting others (betweenness centrality: 13.677). Consistent with the findings by Johny *et al.* (2017) on degree centrality, our observed degree centrality is relatively high (8.645), indicating that some farmers have a notable number of direct connections to other farmers. However, the total degree centralization is moderate (0.478), with an eigenvector centrality of 0.424, suggesting a distributed rather than highly centralized network. The numerous connections we observed within the network potentially indicate a greater ability to receive and disseminate information. Nevertheless, the moderate correlation with eigenvector centrality implies that these connections may not necessarily lead to highly central nodes in the network. Moreover, the clustering coefficient is high (0.882), indicating the formation of closely-knit groups or clusters within the network.

In Siaya, the farmers' network, shows moderate average closeness among individuals (closeness centrality: 0.056), with certain farmers playing a role in connecting others (betweenness centrality: 4.8). The degree centrality is moderate (2.8), indicating a reasonable number of direct interactions among farmers. The total degree centralization is relatively low (0.244), suggesting a more distributed network. The high clustering coefficient (0.763) implies that farmers in the network tend to form closely interconnected groups, indicating a strong sense of cohesion and collaboration within the community.

As shown in Figure 3, closeness centrality for farmers in Masaka district stands at 0.0043, indicating that, on average, individual farmers in the network are not closely connected. The betweenness centrality is 44.432, signifying the crucial role of specific farmers in connecting others. The degree centrality is notably high at 58.135, suggesting a substantial number of direct connections for farmers in Masaka. The clustering coefficient, reflecting tightly interconnected groups, is 0.835. The total degree centralization is 0.605, indicating a moderately centralized distribution of direct connections within the network. The findings highlight that the Masaka district farmers' network demonstrates a high betweenness centrality pattern, signifying the presence of influential farmers who act as bridges, connecting others within the network. Furthermore, the high degree centrality and clustering coefficient suggest a network characterized by influential and closely-knit farmers. However, the relatively low closeness centrality implies that, on average, the connections among farmers in the Masaka District network are somewhat weak. Nonetheless, the identification of key farmer actors in a similar study by Aguirre-López *et al.* (2020) indicates their roles as intermediaries within the network.

Table 3 summarizes the network characteristics of farmer networks, holding significant implications for interventions and the dissemination of information regarding cricket farming technologies. Centrality measures are indicative of influence and popularity and have an impact on innovation processes and inform on the key actors in knowledge diffusion (Pinto, 2020). Siaya County's farmers' network displays distributed influence, characterized by a low total degree centralization, indicating that influence and interactions are spread across farmers. For effective interventions and information dissemination, it may be beneficial to involve a broader group of farmers rather than concentrating efforts on specific individuals.

By contrast, Kisumu exhibits a centralized influence, suggesting that a few farmers have a substantial number of direct connections, thus interventions towards these central individuals could leverage their influence in spreading information effectively. Masaka district

TABLE 3 Network characteristics for the farmer networks

	Kenya		Uganda
	Kisumu County	Siaya County	Masaka District
Network density	0.288	0.311	0.395
Closeness centrality	0.018	0.056	0.004
Betweenness centrality	13.677	4.8	44.432
Degree centrality	8.645	2.8	58.135
Total degree centralization	0.478	0.244	0.605
Eigenvector centrality	0.424	0.537	0.477
Clustering coefficient	0.882	0.763	0.835

demonstrates pronounced centralization, with an even higher total degree centralization, signifying that influence is concentrated among a smaller group of farmers. Effective interventions in Masaka may benefit from close collaboration with influential subsets and key individuals to ensure the successful adoption of new practices. The exceptionally high betweenness centrality in Masaka indicates that certain farmers play a critical role as intermediaries, acting as bridges in the flow of information. Interventions may benefit from closely collaborating with these key individuals, as they are pivotal in facilitating the spread of information across the network. The moderate betweenness centrality in Kisumu suggests that some farmers serve as intermediaries, connecting different parts of the network. While not as pronounced as Masaka, identifying and involving these individuals in interventions can enhance the dissemination of information. Siaya has a lower betweenness centrality compared to Masaka and Kisumu, indicating fewer individuals playing intermediary roles. Thus, interventions in Siaya may involve a more direct approach, engaging a broader group of farmers rather than relying heavily on specific intermediaries. Similar to other studies, value chain development interventions are not only used to increase knowledge and opportunities for small-scale holders, social welfare such as economic empowerment, employment creation and poverty eradication (Devaux *et al.*, 2016), but also strengthen policy and institutional environments (Springer-Heinze, 2018).

Institutional network

Wang *et al.* (2016) recommended augmenting farmers' micro-network measures with whole-network statistics for the institutional layer (Network A-Institutions). Network density illustrates the saturation of the tie structure; a high-density value indicates significant collaboration potential but also the possibility of redundancy. Average out-degree assortativity denotes whether well-connected institutions are more likely to form connections with other well-connected institutions (positive assortativity) or with smaller entities (negative assortativity), thereby influencing the stratification of information. Additionally, centralization (degree/eigenvector) assesses whether influence is concentrated within a limited number of hubs (such as research institutes) or is more evenly distributed across the network. Reciprocity represents the proportion of mutual ties, which signals the presence of trust and facilitates balanced knowledge exchange. In Figure 4, we illustrate the macro-level (institutional) networks, showcasing institutions that collaborated in various activities related to edible insects, including training, projects, workshops and symposiums.

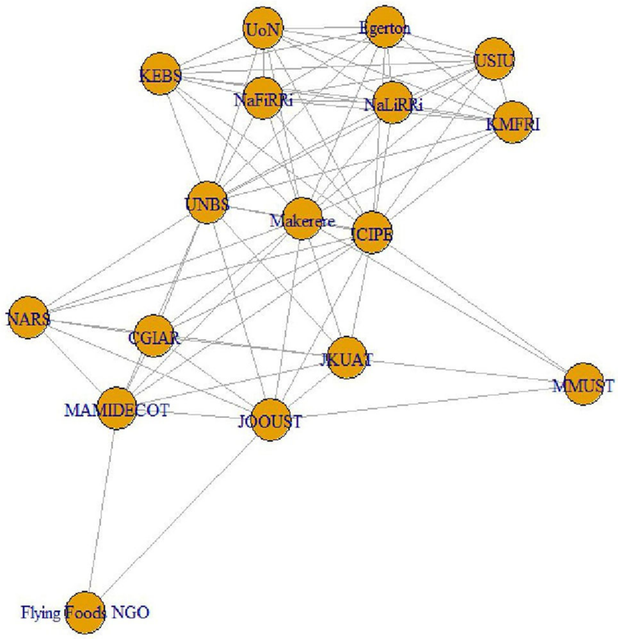

FIGURE 4 Institutional networks for Kenya and Uganda.

These institutions encompassed a diverse range, including research organizations (such as International Centre of Insect Physiology and Ecology (ICIPE), Kenya Marine and Fisheries Research Institute (KMFRI), universities (Jaramogi Oginga Odinga University of Science and Technology (JOOUST), Jomo Kenyatta University of Agriculture and Technology (JKUAT), Makerere), government organizations (Kenya Bureau of Standards (KEBS), Uganda National Bureau of Standards (UNBS), and non-governmental organizations (NGOs) like Flying Foods. The network density for institutional networks was calculated as 0.559, the average out-degree assortativity (popularity) was found to be −0.184, and the reciprocity was 1. In accordance with (Kolaczyk and Csardi, 2014), the network density is a metric that signifies the proportion of actual connections within institutional networks relative to the total possible connections.

The relatively high network density observed implies a significant degree of interconnectedness among these institutions. Such interconnectedness is advantageous for information sharing, as a dense network facilitates efficient communication and collaboration between the institutions in question. Additional research supports the notion that there exists a positive correlation between knowledge sharing and the number of organizational connections within an institutional network (Hermans *et al.*, 2017). The average out-degree assortativity (popularity), in this case, −0.184, reflects the tendency of nodes with similar popularity (out-degree) to connect (Kolaczyk and Csardi, 2014). The negative assortativity indicates that institutions with differing levels of popularity or influence are more likely to connect. In the realm of information exchange, this notion suggests that collaborative efforts encompass both influential and less influential institutions, thereby fostering development of the value chain.

The results unveiled a reciprocity value of 1, signifying the probability of reciprocal associations between institutions within the edible insect value chain. A value of 1 indicates that if node (actor) A is linked to node B, then it is highly probable for node B to be reciprocally connected to node A (Schweinberger *et al.*, 2020). This finding points to a strong level of cooperation within the institutional network, indicating a tendency for institutions to engage in reciprocal relationships. Reciprocity enhances the effectiveness and success of agricultural value chains by establishing institutional networks. By fostering trust, cooperation, and collaboration, reciprocity plays a key role in building strong relationships within these chains (Giller and Andersson, 2018). This strong reciprocal collaboration among research organizations, universities, and NGOs can foster a supportive environment for research, development, and the establishment of policy frameworks necessary for the growth of the edible insect sector. This will facilitate the exchange of valuable information, resources, and ideas, leading to informed decision-making, comprehensive projects, and innovation within the chain.

Affiliation networks

In the analysis for affiliation networks, the study delved into two affiliation networks illustrated in Figures 5 and 6, offering valuable insights, particularly regarding the total degree centralization and eigenvector centrality. In the bipartite affiliation network C (farmers × institutions), eigenvector and degree centrality analy-

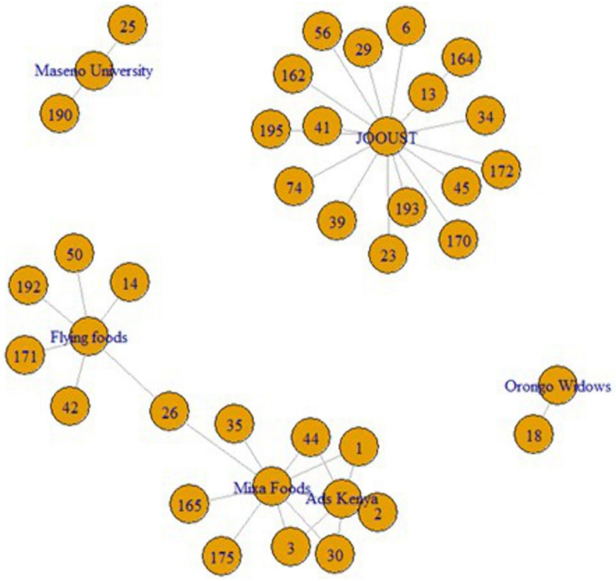

FIGURE 5 Affiliation network for farmers and institutions for Kenya.

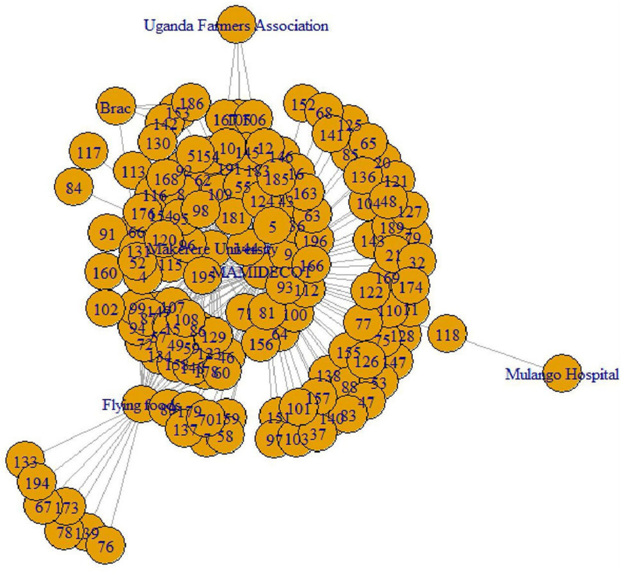

FIGURE 6 Affiliation networks for farmers and institutions in Masaka District, Uganda.

ses showed the actors positioned at the intersection of farmer-institution collaboration, which is essential for programs designed to expedite the adoption of edible insects (Pinto, 2020; Wasserman and Faust, 1994). The affiliation network in Kenya demonstrated a total degree centralization value of 0.368, suggesting a moderate concentration of connections among the nodes. Notably, the JOOUST node exhibited a higher number of connections and is crucial in facilitating communication and collaboration, compared to Maseno University, flying foods, Mixa Foods, and Ads Kenya. The eigenvector centrality value, documented as 0.128, emphasizes the influence of specific nodes – such as JOOUST, Mixa Foods, and Flying Foods – based on both the number and significance of their connections.

The affiliation networks involving farmers and institutions in Masaka district, Uganda, reveal a notable total degree centralization with a value of 0.876. This high value indicates a concentration of connections, particularly highlighting that MAMIDECOT and Makerere University nodes possess a significantly greater number of connections compared to others. This contributes to a centralized network structure, implying that information or influence may predominantly flow through this limited set of nodes. This concentration has the potential to significantly impact the overall connectivity and communication dynamics within the network. Furthermore, the eigenvector centrality value of 0.112 highlights that MAMIDECOT and Makerere University nodes hold influence based on both the number and importance of their connections. These nodes occupy strategic positions, playing crucial roles in conveying or controlling information within the network. The distributed influence, as indicated by the relatively low value, implies that multiple nodes contribute to the network dynamics, but the identified nodes play key roles in shaping the overall information flow and interactions. The eigenvector centrality in the affiliation network showed the importance of specific nodes in Kenya and Uganda. This suggests that certain key organizations exert a higher degree of influence within the network, potentially functioning as critical hubs for information dissemination and the promotion of innovative practices. Leveraging on them can speed up scale-out of insect-farming practices. There is a need for developing and evaluating interventions to strengthen linkages within the affiliation network, promoting collaboration and knowledge exchange among farmers, private sector actors, and other stakeholders.

Integrating the three network levels for a functional innovation system

The interaction between farmer-to-farmer networks, affiliations, and institutional networks is crucial for establishing a robust cricket farming innovation system. Farmer networks enable the bottom-up spread of knowledge tailored to local contexts, while institutional actors provide top-down support through training, research, and resources. However, the affiliation network remains the weakest link, creating a bottleneck in the transfer of institutional support into actionable knowledge at the grassroots level. This disconnect can hinder the adoption of research findings and the effective tailoring of institutional support to the specific needs and contexts of cricket farmers. The Agricultural Innovation Systems (AIS) framework highlights the importance of interactions among actors, institutional arrangements, and socio-economic contexts in promoting innovation. These multilevel networks are essential tools within the AIS framework that enhance collaboration, knowledge exchange, and collective action. To improve the effectiveness of networks in the cricket sector, it is vital to strengthen connections at all levels, particularly between farmers and institutions. The inclusion of diverse stakeholders, especially farmers and private sector actors, is also necessary to ensure that innovations are relevant, scalable, and responsive to market demands. Understanding these network dynamics and customizing interventions to fit regional and structural specifics will be critical for fostering sustainable growth in the cricket farming sector, thereby enhancing its contribution to food security and economic development in East Africa.

4 Conclusion

The primary aim of this research was to analyse the innovation networks within the emerging edible insect value chain in East Africa, focusing on the roles and linkages of various actors and how these network characteristics influence the sector's development. Our findings reveal a significant gap between the expressed positive interest in cricket farming and actual market engagement. Additionally, while strong reciprocal ties exist within the institutional network, connections in the broader affiliation network are weaker, indicating a potential disconnect among stakeholders. Furthermore, this study highlights the promising opportunities created by early collaborations between research organizations and the private sector to stimulate demand and accelerate innovation. These findings contribute to network theory by providing an empirical characterization of a multi-connection network system within an early-stage food innovation sector and introducing a novel methodological approach to understanding the complex interplay of actors.

The identification of structural features such as network density and centrality across different regions (Masaka, Kisumu and Siaya) provides valuable insights into the variability of network configurations and their potential impact on innovation diffusion and value chain development. From an Agricultural Innovation Systems (AIS) perspective, this research emphasizes the critical roles of diverse actors (farmers, researchers, the private sector, etc.) and the importance of their linkages for sector growth. The observed weaknesses in the affiliation network, despite strong institutional cooperation, indicate a need for strategies that foster broader systemic interactions, a key element of AIS thinking. The study also makes methodological contributions to early-stage food innovation sectors by demonstrating the utility of Social Network Analysis and Exponential Random Graph Models in empirically assessing the structure and dynamics of emerging value chains.

Building on the insights generated by this study, policies should focus on promoting best practices in production and processing while strengthening institutional support through collaboration with government agencies, NGOs, and research institutions to deliver resources, technical expertise, and market access. Future research should prioritize several critical areas to foster a more resilient and sustainable edible insect value chain in East Africa. First, there should be a strong focus on market development and consumer engagement to bridge the gap between awareness and actual sales. This can be addressed through enhancing infrastructure – such as storage and collection centres, – integrating the value chain by strengthening connections between producers, processors, and traders, providing access to market information on trends and consumer preferences and investing in capacity building and training. Secondly, strengthen actor linkages and reinforce network structures, particularly given the observed weak affiliation networks. Efforts to explore models for enhancing coordination among farmers, institutions, NGOs and private sector actors to scale the EI sector should be given attention. Lastly, while market engagement and network strengthening are important for short-term progress, long-term sustainability depends on improving production systems. Efforts should therefore focus on optimizing cricket farming practices to enhance productivity and reduce costs for smallholder farmers to ensure a reliable and scalable supply chain that meets the demands of traders and processors. Future efforts can therefore build on the findings of this study to create a more dynamic, inclusive, and sustainable edible insect value chain in East Africa, ultimately contributing to economic development and food security.

Supplementary materials

Data is available on https://doi.org/10.1163/23524588-bja10233 under Supplementary Materials.

Acknowledgement

We thank LEAP-Agri for funding this study under Enhancing food and nutrition security through promotion of edible insects' value chain in Eastern Africa (Ento-Economy) project.

Conflict of interest

The authors assert the absence of any conflict of interest.

References

Aguirre-López, J.M., Díaz-José, J., Chaloupková, P. and Guevara-Hernánd, F., 2020. Unraveling innovation networks in conservation agriculture using social network analysis. In: Ragozini, G. and Vitale, M.P. (eds.) Challenges in Social Network Research: Methods and Applications. Springer, Cham, pp. 133-148.

Akullo, D., Maat, H. and Wals, A.E.J., 2018. An institutional diagnostics of agricultural innovation; public-private partnerships and smallholder production in Uganda. NJAS – Wageningen Journal of Life Sciences 84: 6-12.

Alemu, M.H., Halloran, A., Olsen, S.B., Anankware, J.P., Nyeko, P., Ayieko, M., Nyakeri, E., Kinyuru, J., Konyole, S., Niassy, S., Egonyu, J.P., Malinga, G.M., Ng'ang'a, J., Ng'ong'a, C.A., Okeyo, N., Debrah, S.K., Kiiru, S., Acur, A. and Roos, N., 2023. Promoting insect farming and household consumption through agricultural training and nutrition education in Africa: A study protocol for a multisite cluster-randomized controlled trial. PLoS ONE 18: e0288870. https://doi.org/10.1371/journal.pone.0288870

Alemu, M.H. and Olsen, S.B., 2018. Kenyan consumers' experience of using edible insects as food and their preferences for selected insect-based food products. In: Halloran, A., Vantomme, P., Flore, R. and Roos, N. (eds.) Edible Insects in Sustainable Food Systems. Springer, Cham, pp. 363-374.

Alemu, M.H., Olsen, S.B., Vedel, S.E., Kinyuru, J. and Pambo, K.O., 2017. Can insects increase food security in developing countries? An analysis of Kenyan consumer preferences and demand for cricket flour buns. Food Security 9: 471-484.

Ayieko, M.A., Ogola, H.J. and Ayieko, I.A., 2016. Introducing rearing crickets (gryllids) at household levels: adoption, processing and nutritional values. Journal of Insects as Food and Feed 2: 203-211.

Bellotti, E., Guadalupi, L. and Conaldi, G., 2016. Comparing fields of sciences: multilevel networks of research collaborations in Italian academia. In: Lazega, E. and Snijders, T.A.B. (eds.) Multilevel network analysis for the social sciences: theory, methods and applications. Springer, Cham, pp. 213-244.

Daxini, A., O'Donoghue, C., Ryan, M., Buckley, C., Barnes, A.P. and Daly, K., 2018. Which factors influence farmers' intentions to adopt nutrient management planning? Journal of Environmental Management 224: 350-360.

Devaux, A., Torero, M., Donovan, J. and Horton, D. (eds.), 2016. Innovation for inclusive value-chain development: successes and challenges. International Food Policy Research Institute, Washington, DC.

Donkor, E., Mbeche, R. and Mithöfer, D., 2022a. Gender differentials in value addition and lean season market participation in the grasshopper value chain in Uganda. Food and Energy Security 11: e411. https://doi.org/10.1002/fes3.411

Donkor, E., Mithöfer, D., Mbeche, R., Nakimbugwe, D., Kinyuru, J., Broeck, J.V., Ndung'u, N., Ssepuuya, G. and Fombong, T.F., 2022b. Technical Report EntoEconomy Project.

Durst, P.B. and Hanboonsong, Y., 2015. Small-scale production of edible insects for enhanced food security and rural livelihoods: experience from Thailand and Lao People's Democratic Republic. Journal of Insects as Food and Feed 1: 25-31.

Ebenebe, C.I., Ibitoye, O.S., AmobiI, I.M. and Okpoko, V.O., 2020. African edible insect consumption market. In: Mariod, A.A. (ed.) African edible insects as alternative source of food, oil, protein and bioactive components. Springer, Cham, pp. 19-51.

FAO, 2023. The status of women in agrifood systems. FAO, Rome.

FAO, 2024. The state of food and agriculture 2024 – value-driven transformation of agrifood systems. FAO, Rome. https://doi.org/10.4060/cd2616en

FAO, IFAD, UNICEF, WFP and WHO, 2024. The state of food security and nutrition in the World 2024 – financing to end hunger, food insecurity and malnutrition in all its form. FAO, Rome. https://doi.org/10.4060/cd1254en.

FAO/GoK, 2018. Kenya food composition tables. FAO, Nairobi.

Fiaboe, K. and Nakimbugwe, D., 2017. INSFEED-integrating insects in poultry and fish feed in Kenya and Uganda. Available online at https://idl-bnc-idrc.dspacedirect.org/items/e8815c00-1b21-4156-b734-67f591f5b81b

Flying foods, 2018. Flying Food – Insect Africa, Cricket Rearing, Nutritious Crickets Insect food. Available online at https://www.flyingfoodproject.com/ (accessed 22 March 2018).

Giller, K.E. and Andersson, J.A., 2018. Enhancing the role of institutional networks in agricultural innovation. Agricultural Systems 165: 1-10.

Halloran, A., Ayieko, M., Oloo, J., Konyole, S.O., Alemu, M.H. and Roos, N., 2020. What determines farmers' awareness and interest in adopting cricket farming? A pilot study from Kenya. International Journal of Tropical Insect Science 41: 2149-2164.

Halloran, A., Megido, R.C., Oloo, J., Weigel, T., Nsevolo, P. and Francis, F., 2018. Comparative aspects of cricket farming in Thailand, Cambodia, Lao People's Democratic Republic, Democratic Republic of the Congo and Kenya. Journal of Insects as Food and Feed 4: 101-114.

Halloran, A., Roos, N., Flore, R. and Hanboonsong, Y., 2016. The development of the edible cricket industry in Thailand. Journal of Insects as Food and Feed 2: 91-100.

Halloran, A., Roos, N. and Hanboonsong, Y., 2017. Cricket farming as a livelihood strategy in Thailand. The Geographical Journal 183: 112-124.

Hermans, F., Sartas, M., Van Schagen, B., Van Asten, P. and Schut, M., 2017. Social network analysis of multi-stakeholder platforms in agricultural research for development: Opportunities and constraints for innovation and scaling. PLoS ONE 12: 1-21.

Hjellbrekke, J., 2019. Multiple correspondence analysis for the social sciences. Routledge, New York, NY. https://doi.org/10.4324/9781315516257

Homann, A.M., Ayieko, M.A., Konyole, S.O. and Roos, N., 2017. Acceptability of biscuits containing 10% cricket (*Acheta domesticus*) compared to milk biscuits among 5-10-year-old Kenyan schoolchildren. Journal of Insects as Food and Feed 3: 95-103.

Johny, J., Wichmann, B. and Swallow, B.M., 2017. Characterizing social networks and their effects on income diversification in rural Kerala, India. World Development 94: 375-392.

Jongema, Y., 2017. List of edible insects of the World (April 2017). Available online at https://www.wur.nl/en/research-results/chair-groups/plant-sciences/laboratory-of

-entomology/edible-insects/worldwide-species-list.htm (accessed 30 March 2024).

Kinyuru, J. and Kipkoech, C., 2018. Production and growth parameters of edible crickets: experiences from a farm in a high altitude, cooler region of Kenya. Journal of Insects as Food and Feed 4: 247-251.

Kinyuru, J. and Ndung'u, N., 2022. Edible insects regulatory national standards in Kenya: an incentive or a deterrent? Journal of Agriculture Science and Technology 21: 1-3.

Kinyuru, J. and Ndung'u, N.W., 2020. Promoting edible insects in Kenya: Historical, present and future perspectives towards establishment of a sustainable value chain. Journal of Insects as Food and Feed 6: 51-58.

Kinyuru, J., Ng'ang'a, J. and Ndung'u, N., 2024. History of edible insects and future perspectives. In: García-Vaquero, M. and García, C.Á. (eds.) Insects as food and food ingredients: technological improvements, sustainability, and safety aspects. Academic Press, San Diego, CA, pp. 255-263.

Klerkx, L. and Begemann, S., 2020. Supporting food systems transformation: The what, why, who, where and how of mission-oriented agricultural innovation systems. Agricultural Systems 184: 102901.

Kolaczyk, E.D. and Csardi, G., 2014. Statistical Analysis of Network Data with R. International Statistical Review. Springer, New York, NY.

Manditsera, F.A., Mubaiwa, J., Matsungo, T.M., Chopera, P., Bhatasara, S., Kembo, G., Mahlatini, H., Ruzengwe, F.M., Matutu, F., Grigor, J., Fiore, A. and Macheka, L., 2022. Mopane worm value chain in Zimbabwe: Evidence on knowledge, practices, and processes in Gwanda District. PLoS ONE 17: e0278230. https://doi.org/10.1371/journal.pone.0278230

MMRPL, 2019. Edible insects market by product type (whole insect, insect powder, insect meal, insect type (crickets, black soldier fly, mealworms), application (animal feed, protein bar and shakes, bakery, confectionery, beverages) – global forecast to 2030. Market Research, Rockville, MD).

Morais, M., Borges, J.A.R. and Binotto, E., 2018. Using the reasoned action approach to understand Brazilian successors' intention to take over the farm. Land Use Policy 71: 445-452.

Musungu, A.L., Muriithi, B.W., Ghemoh, C.J., Nakimbugwe, D. and Tanga, C.M., 2023. Production, consumption, and market supply of edible crickets: insights from East Africa. Agricultural and Food Economics 11: 1-23.

Ndung'u, N., Isaboke, H., Nyarindo, W., Otieno, M., Gicheha, M. and Kinyuru, J., 2025. Understanding gender dynamics on the intentions of small-scale traders to trade in edible insects in Kenya. Journal of Agricultural Science, in press.

Niassy, S., Musundire, S., Ekesi, S. and van Huis, A., 2018. Edible insect value chains in Africa. Journal of Insects as Food and Feed 4: 119-201.

Niassy, S., Omuse, E.R., Roos, N., Halloran, A., Eilenberg, J., Egonyu, J.P., Tanga, C., Meutchieye, F., Mwangi, R., Subramanian, S., Musundire, R., Nkunika, P.O.Y., Anankware, J.P., Kinyuru, J., Yusuf, A. and Ekesi, S., 2022. Safety, regulatory and environmental issues related to breeding and international trade of edible insects in Africa. Scientific and Technical Review 41: 117-131.

Nyantakyi-Frimpong, H., Matouš, P. and Isaac, M.E., 2019. Smallholder farmers' social networks and resource-conserving agriculture in Ghana: a multicase comparison using exponential random graph models. Ecology and Society Resilience Alliance 24: 2-14.

Odongo, W., Okia, C.A., Nalika, N., Nzabamwita, P.H., Ndimubandi, J. and Nyeko, P., 2018. Marketing of edible insects in Lake Victoria basin: the case of Uganda and Burundi. Journal of Insects as Food and Feed 4: 285-293.

Okello, A.O., Otieno, D.J., Nzuma, J.M., Kidoido, M.M. and Tanga, C.M., 2023. Smallholder farmers' willingness to pay for commercial insect-based chicken feed in Kenya. International Food and Agribusiness Management Review 26: 67-87.

Oloo, J.A., Halloran, A. and Nyongesah, M.J., 2021. Socio economic characteristics of cricket farmers in Lake Victoria region of Kenya. International Journal of Tropical Insect Science 41: 2165-2173.

Omollo, E.O., Jawuoro, S.O., Wasonga, O.V. and Simatele, D., 2019. Mapping and characterization of stakeholders in the fodder value chain in Southern Rangelands of Kenya: Understanding their roles, interactions and influences. Journal of Agricultural Science and Practice 4: 151-164.

Pambo, K., Okello, J.J., Mbeche, R.M. and Kinyuru, J.N., 2018a. Means-end chain approach explains motivations to consume insect-based foods: the case of cricket-scones in Kenya. In: Halloran, A., Flore, R., Vantomme, P. and Roos, N. (eds.) Edible insects in sustainable food systems. Springer, Cham, pp. 401-420.

Pambo, K., Okello, J.J., Mbeche, R.M., Kinyuru, J.N. and Alemu, M.H., 2018b. The role of product information on consumer sensory evaluation, expectations, experiences and emotions of cricket-flour-containing buns. Food Research International 106: 532-541.

Pinto, C., 2020. A DEA-based network formation model. micro and macro analysis. In: Ragozini, G. and Vitale, M.P. (eds.) Challenges in Social Network Research: Methods and applications. Springer, Cham, pp. 93-114.

Roos, N., 2018. Insects in Human Nutrition. In: Halloran, A., Flore, R., Vantomme, P. and Roos, N. (eds.) Edible insects in sustainable food systems. Springer, Cham, pp. 83-91.

Sartas, M., 2018. Do multi-stakeholder platforms work?: contributions of multi-stakeholder platforms to the performance of research for development interventions. Thesis. Wageningen University, Wageningen.

Sartas, M., Schut, M., Proietti, C., Thiele, G. and Leeuwis, C., 2020. Scaling Readiness: Science and practice of an approach to enhance impact of research for development. Agricultural Systems 183: 1-12.

Schweinberger, M., Stewart, J.R., Krivitsky, P.N. and Butts, C.T., 2020. Exponential-family models of random graphs: inference in finite, super, and infinite population scenarios exponential-family models of random graphs: inference in finite, super and infinite population scenarios. Statistical Science 35: 627-662.

Snijders, T.A.B., 2011. Statistical models for social networks. Annual Review of Sociology 37: 131-153.

Springer-Heinze, A., 2018. ValueLinks 2.0 Manual on sustainable value chain development. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), Bonn.

Stivala, A., Robins, G. and Lomi, A., 2020. Exponential random graph model parameter estimation for very large directed networks. PLoS ONE 15: e0227804. https://doi.org/10.1371/journal.pone.0227804.

Suchiradipta, B. and Raj, S., 2014. Agricultural innovation systems (AIS): a study of stakeholders and their relations in system of rice intensification (SRI). Journal of Agricultural Education and Extension 21: 343-368.

Tanga, C.M. and Kababu, M.O., 2023. New insights into the emerging edible insect industry in Africa. Animal Frontiers 13: 26-40.

van Huis, A., 2020. Importance of insects as food in Africa. In: Mario, A. (ed.) African edible insects as alternative source of food, oil, protein and bioactive component. Springer, Cham, pp. 1-17.

Van Peer, M. and Van Miert, S., 2024. Current status of insect farming for food application. In: García-Vaquero, M. and García, C.Á. (eds.) Insects as food and food ingredients: technological improvements, sustainability, and safety aspects. Academic Press, San Diego, CA, pp. 13-27.

Verner, D., Roos, N., Halloran, A., Surabian, G., Tebaldi, E., Ashwill, M., Vellani, S. and Konishi, Y., 2021. Insect and hydroponic farming in Africa: the new circular food economy 2021. World Bank Publications, Washington, DC.

Walther, O.J., Tenikue, M. and Trémolières, M., 2019. Economic performance, gender and social networks in West African food systems. World Development 124: 1-14.

Wang, P., Robins, G. and Matous, P., 2016. Multilevel network analysis using ERGM and its extensions. In: Lazega, E. and Snijders, T.A.B. (eds.) Multi-level network analysis for the social sciences: theory, methods and applications. Springer, Cham, pp. 125-144.

Wasserman, S. and Faust, K., 1994. Social network analysis: methods and applications. Cambridge University Press, New York, NY.

Weyori, A.E., Amare, M., Garming, H. and Waibel, H., 2017. Agricultural innovation systems and farm technology adoption: findings from a study of the Ghanaian plantain sector. Journal of Agricultural Education and Extension 24: 65-87.

Zhou, Y., Wang, D., Zhou, S., Duan, H., Guo, J. and Yan, W., 2022. Nutritional composition, health benefits, and application value of edible insects: a review. Foods 11: 3961. https://doi.org/10.3390/foods11243961