



Mapping Socio-economic and Entrepreneurial Diversity among Makhana Farmers in Bihar through Cluster Analysis

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HIGHLIGHTS

- Three distinct clusters of makhana farmers were identified, each with unique socio-economic and behavioural characteristics.
- Significant differences were found in landholding, annual income, and Makhana income across the clusters.
- Young and resource-limited farmers showed higher entrepreneurial traits, indicating their potential for targeted intervention.

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ABSTRACT

Makhana (*Euryale ferox*), a high-value aquatic crop, plays a pivotal role in the rural economy of Bihar, particularly in the Mithilanchal and Kosi regions. However, the socio-economic characteristics of makhana farmers are far from homogeneous, reflecting diverse livelihood strategies, access to resources, and market participation levels. The study presents a replicable protocol to classify socio-economic and entrepreneurial diversity among makhana farmers. A multistage stratified random sampling technique was used to collect primary data from 120 farmers across four major districts of Bihar during 2022-23. Ward's hierarchical clustering followed by k-means clustering identified three statistically distinct groups based on landholding, income, and entrepreneurial indicators. ANOVA and Levene's tests confirmed significant variation across the clusters. The findings support the development of targeted, group-specific extension strategies. The proposed framework serves as a replicable protocol for classifying farmer heterogeneity in similar agricultural contexts. The analysis revealed three distinct clusters of farmers viz., Well-capitalised Makhana Farmers, Progressive and Prosperous Farmers, and Traditional, Medium-Level Farmers—each with unique characteristics and development needs. The findings support the development of targeted, group-specific extension strategies. The proposed framework serves as a replicable protocol for classifying farmer heterogeneity in similar agricultural contexts.

INTRODUCTION

Popped makhana (foxnut) seeds – the edible product of *Euryale ferox* is an aquatic crop cultivated primarily in Bihar. These high-protein, low-fat nuts have gained superfood status globally. Bihar accounts for over 90 per cent of India's makhana production and approximately 85 per cent of global output (Singh & Agrawal, 2024). The Kosi and Mithilanchal region, including districts like Purnia, Katihar, Madhubani and Darbhanga, is a dominant zone for makhana cultivation due to its waterlogged conditions and traditional

knowledge systems (Sonu & Jha, 2025). Globally, makhana (*Euryale ferox*) is estimated to secure a valuation of USD 146.6 million in 2025 and is estimated to rise to USD 265.4 million by 2035. The market is anticipated to grow at a CAGR of 8.1 per cent during the forecast period (Future Market Insights Global, 2025). The Government of India has responded by announcing a “Makhana Board” for Bihar (2025 budget) and creating a GI tag for Mithila Makhana (2022) to improve processing, value addition and export potential (Times of India, 2025).

The total area under Makhana cultivation in India is around 15,000 hectares (ha), with an average production of 1.5 tonnes per hectare (t ha⁻¹). The total production of Makhana seeds is around 1,20,000 million tonnes (MT), which after processing becomes 40,000 MT of Makhana pop. Makhana production is projected to be worth Rs. 2.50 billion at the farmer's level, however, it earns Rs. 5.50 billion at the trader's level (Sonu & Jha, 2025). In Bihar, the area under Makhana cultivation is about 13,000 ha, contributing to 85 per cent of India's total production. Major producing districts include Darbhanga (7421.4 t), Sitamarhi (277.4 t), Madhubani (7280.7 t), Saharsa (5267 t), Supaul (5182.8 t), Araria (2639.95 t), Kishanganj (2000.25 t), Purnia (11652.9 t), and Katihar (11759 t). Darbhanga and Madhubani districts alone account for approximately 80 per cent of the processed Makhana production (Ahmad, 2020).

The agricultural sector in Bihar, India, exhibits significant socio-economic diversity, particularly among makhana (*Euryale ferox*) farmers, who play a crucial role in regional food security and rural livelihoods. Makhana cultivation, primarily practised in the floodplains of North Bihar, contributes substantially to the local economy but is marked by disparities in landholding, income, education, and access to resources. Understanding the dynamics of these heterogeneities is essential for designing targeted policies, improving resource allocation, and enhancing farmers' welfare. However, existing studies often treat makhana farmers as a homogeneous group, overlooking the nuanced variations that influence their productivity and decision-making (Singh & Pandey, 2020).

Specifically, the study aims to categorise farmers using key variables such as landholding size, annual income, education level, and family size. These variables were selected based on previous research highlighting their significant influence on agricultural adoption and livelihood outcomes (Sonu & Jha, 2025). To achieve this classification, cluster analysis—a statistical method capable of grouping similar observations while maximising differences between groups—was employed (Everitt et al., 2011). This approach allows identification of latent patterns in the heterogeneous population, thus enabling more effective policy formulation and extension strategies tailored to the needs of distinct farmer.

METHODOLOGY

The study was conducted during the period 2022–24 in four major makhana-producing districts of Bihar, namely Darbhanga, Madhubani, Katihar, and Purnea. These districts were selected purposively due to their concentration of makhana cultivation and their representativeness of regional agro-ecological and socio-economic diversity. A multistage stratified random sampling technique was employed to select 120 makhana farmers, ensuring representation across key strata relevant to the study area. The strata were defined based on the highest production blocks (Purnea East from Purnia, Barari from Katihar, Bahadurpur from Darbhanga, and Jhanjharpur from Madhubani). Proportional samples were drawn from each stratum corresponding to their population share, which helped capture the diversity of farming practices and socio-economic conditions among makhana cultivators in the region. Primary data were collected from the sampled respondents using a

pre-tested semi-structured interview schedule. The interview schedule encompassed a broad range of variables, including demographic characteristics, economic indicators, knowledge levels, and entrepreneurial indicators (innovativeness, achievement motivation, production orientation, marketing orientation, risk-taking ability, and management orientation). To explore and classify the socio-economic diversity among makhana farming households in Bihar, a two-stage cluster analysis approach was adopted. In the first stage, Ward's hierarchical clustering method was applied to minimise within-cluster variance and determine the optimal number of clusters (Murtagh & Legendre 2011). Ward's method, a widely used agglomerative clustering technique, operates by minimising the total within-cluster variance at each step of the clustering process. The application of this method resulted in a dendrogram that provided a hierarchical visualisation of how the sampled farmers were grouped based on their socio-economic and behavioural characteristics. The dendrogram also aided in identifying the optimal cluster solution by pinpointing the stage with the greatest increase in linkage distance. Following this, the k-means clustering method—a non-hierarchical partitioning approach—was employed to refine the classification by assigning farming households to clusters based on their proximity to the respective cluster centroids (Burkardt, 2009). The integration of both Ward's method and k-means clustering ensured that the final clusters were internally homogeneous and externally heterogeneous. To validate the robustness of the cluster solution, one-way ANOVA was performed to test for statistically significant differences across the clusters in terms of key socio-economic variables. Additionally, Levene's test was applied to assess the equality of variances among the groups (Fox & Weisberg, 2019). This comprehensive and statistically grounded methodology facilitated the identification of distinct categories of makhana farmers, thereby enabling targeted policy formulation and effective intervention strategies.

RESULTS

The vertical axis in Figure 1 represented the dissimilarity or distance between clusters that were merged. A greater height on this axis indicated more heterogeneity between the clusters joined at that point. Initially, each farmer appeared as an individual unit at the base of the dendrogram. As the clustering algorithm progressed upward, these individual farmers were gradually grouped into larger clusters. At a specific height—around 15—a horizontal cut in the dendrogram revealed three distinct clusters, shown within red, green, and blue boxes. This grouping matched the earlier k-means clustering, where the number of clusters (k) was set to three. The branching patterns in the dendrogram clearly showed significant variability among the farmers, especially since the vertical distances between some merges were large at the top of the tree. This indicated that the farmer groups formed were not only statistically distinct but also meaningful in terms of their socio-economic characteristics.

Figure 2 revealed K-means clustering of the 120 makhana sampled farmers from three distinct groups. Cluster 1 (circle) comprised only a few farmers, but they stood out by having markedly different socio economic profiles: these farmers tended to have the smallest landholdings and the lowest annual and makhana incomes among the sample. In contrast, Cluster 2 (triangle) contained farmers

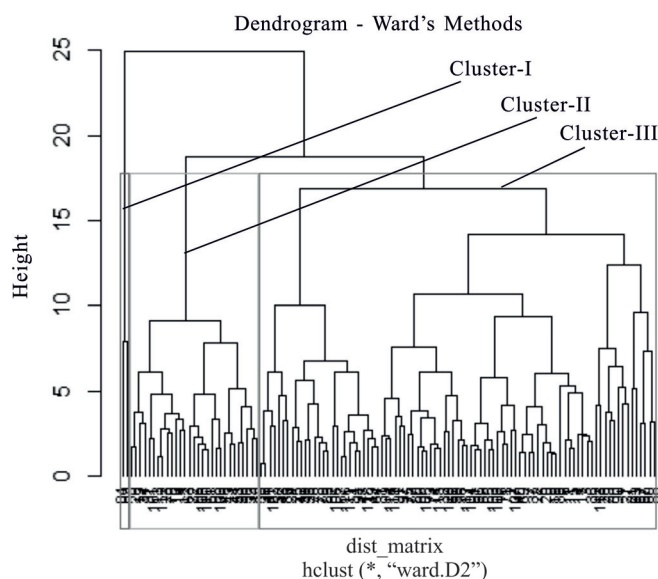


Figure 1. Dendrogram of socio-economic heterogeneity among makhana farmers in Bihar using Ward's method

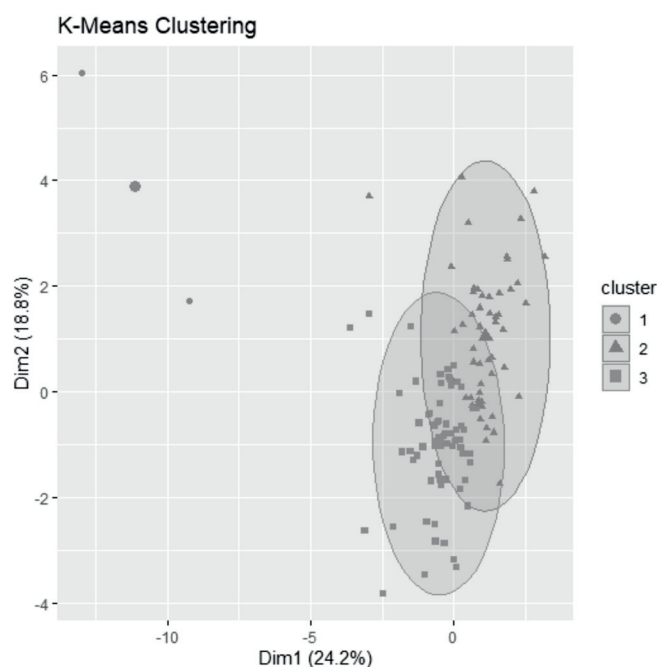


Figure 2. K-Means Clustering diagram of socio-economic heterogeneity among makhana farmers in Bihar

with larger landholdings and the highest mean annual and makhana incomes, suggesting they are relatively better off; this group also had higher average knowledge scores. Cluster 3 (rectangle) fell between these extremes, with moderate land size and incomes.

Cluster 1: Well-capitalised Makhana Farmers (N = 2)

Cluster 1 represented a small group of farmers (just 2 out of 120), characterised by extremely high landholding and income values, making them extreme outliers within the dataset. These farmers had an average landholding of 77.5 ha, which is nearly 20 times larger than the average for other clusters. Their average annual income

was Rs. 2.14 million, and makhana income was Rs. 2.085 million, indicating heavy reliance on and success in makhana-based agriculture. Despite their exceptional economic standing, these farmers showed very low educational attainment (average: 0.5 years of schooling)—suggesting that success in this context may not be education-driven but could be due to inherited land assets, long-standing experience, or specialised knowledge not captured by formal education. Demographically, these farmers were also significantly older (average age: 67.5 years), and they had the largest family sizes (average: 8.5 members), likely contributing to labour availability on their large landholdings. Their entrepreneurial traits showed moderate scores across indicators such as knowledge (29), innovativeness (19.5), and perception (9), though their perception score was notably lower than in other clusters. These traits might reflect traditional but successful farming methods with limited openness to new ideas. Statistical tests confirmed that this cluster was significantly different from the others in terms of landholding and income ($p < 0.001$), but not in education ($p = 0.172$). However, due to the small number of observations, generalisations must be made cautiously. Nonetheless, this cluster illustrates the presence of a niche group of elite farmers who dominate makhana production economically but are not necessarily formally educated or highly innovative.

Cluster 2: Progressive and Prosperous Farmers (N = 53)

Cluster 2 comprised the most populous and economically well-off group among the mainstream farmers. These farmers had moderate to high landholding sizes (mean: 3.75 ha) and were characterised by the highest average scores in multiple entrepreneurial and psychological dimensions, including knowledge (24.7), innovativeness (21.5), achievement motivation (19.4), and perception (12.77). Their annual income averaged Rs. 1,36,000, and income from makhana was Rs. 85,293, placing them above average but not in the elite bracket of Cluster 1.

The farmers in this cluster were relatively young and had small-to-moderate family sizes (5.85 members), possibly indicating a shift toward nuclear families or a focus on economic efficiency. Educational attainment was moderate (average: 1.62 years), though still low in absolute terms, and not significantly different from other clusters (ANOVA $p = 0.172$). Interestingly, despite the low formal education, their higher entrepreneurial traits suggested a willingness to adopt innovations and scientific practices, contributing to higher productivity and income. In terms of the distribution of districts, this cluster included significant membership from Madhubani (18), Katihar (14), and Darbhanga (12), with a smaller representation from Purnea (9). The concentration of such farmers in these districts indicated regional pockets of progressive farming practices and better access to markets, infrastructure, or support services. ANOVA tests revealed that Cluster 2 differed significantly from Clusters 1 and 3 in landholding ($p < 0.001$), annual income ($p < 0.001$), and makhana income ($p < 0.001$). Levene's test also confirmed heterogeneity of variance in these variables ($p < 0.01$), implying that variability in farm size and income was high even within this relatively uniform group. This cluster is vital for targeted interventions as these farmers represent the future of scalable and sustainable makhana entrepreneurship.

Table 1. Characteristics of Selected Clusters of Farm Households and P-value of one-way analysis of variance

Variables	Cluster 1	Cluster 2	Cluster 3	Cluster Mean	Cluster SD	P-Value
Age	67.5	43.58	45.85	52.31	13.20	<0.001
Education	0.5	1.62	1.27	1.13	0.57	0.172
Family Size	8.5	5.84	7.36	7.23	1.33	-
Land Holding	77.5	3.75	4.22	28.49	42.44	<0.001
Annual Income	2144250	135727.2	148705.90	809561	1155892.8	<0.001
Makhana Income	2084750	85293.25	94444.38	754829	1151754.3	<0.001
Scientific Orientation	17.5	16.33	16.50	16.77	0.63	-
Perception	9	12.77	11.76	11.17	1.95	-
Knowledge	29.0	24.69	25.00	26.23	2.40	-
Entrepreneurial Behaviour						
Innovativeness	19.5	21.54	20.95	20.66	1.04	-
Achievement Motivation	16.0	19.35	16.60	17.31	1.78	-
Production Orientation	17.0	20.49	17.60	18.36	1.86	-
Marketing Orientation	22.0	22.83	21.64	22.15	0.61	-
Risk-taking ability	16.0	19.35	16.66	17.33	1.77	-
Management Orientation	22.0	22.86	21.64	22.16	0.62	-

Cluster 3: Traditional, Medium-Level Farmers (N = 65)

Cluster 3 included a relatively large group of farmers who may be considered typical or average makhana growers. They had moderate landholdings (mean: 4.22 ha) and earned Rs. 1,49,000 annually, with makhana income averaging Rs. 94,444, which was relatively higher than Cluster 2 in this regard, despite lower entrepreneurial traits. Their educational level was 1.27 years on average, and their family sizes were higher (7.37 members), possibly suggesting a reliance on traditional family-based labour systems.

Farmers in this cluster were slightly older (mean age: 45.6 years) than those in Cluster 2 but much younger than Cluster 1, representing a transitional generation. Entrepreneurial indicators were relatively modest: knowledge (25), innovativeness (20.95), achievement (16.6), and perception (11.77), indicating a group with decent traditional knowledge but less proactive behaviour toward innovation or risk-taking compared to Cluster 2. Scientific orientation and risk management scores were also moderate. District-wise, this group largely represented Purnea (19) and Darbhanga (18), suggesting these regions are home to many farmers who maintain traditional practices with limited external support. These farmers may benefit from targeted training or extension programs designed to improve access to modern cultivation and marketing techniques. Like Cluster 2, this group showed significant variation in income and landholding ($p < 0.001$) compared to others, but not in education. Levene's test supported significant variance differences, particularly in income and land size.

The one-way ANOVA was conducted to examine whether there were statistically significant differences in landholding, annual income, makhana income, and education levels among the identified clusters shown in Table 2. The results indicated significant differences between clusters for landholding (217.1, $p < 0.001$), annual income (265.3, $p < 0.001$), and makhana income (271.5, $p < 0.001$). These findings suggest that the clusters differ substantially in terms of landholding size and income variables, both overall and specifically from makhana production. In contrast, no significant difference was found among clusters for education levels (1.79, p

Table 3. Levene's test of socio-economic heterogeneity among makhana farmers in Bihar

Variables	F value	P Value	Significance
Land Holding	5.851	0.003	Significant
Annual Income	6.947	0.001	Significant
Makhana Income	7.671	0.000	Significant
Education	0.279	0.757	Non-Significant

= 0.172), indicating that educational attainment was relatively homogeneous across the groups.

Table 3 demonstrated that Levene's test rejected the null hypothesis of equal variances for Land Holding, Annual Income and Makhana Income, but not for Education. Specifically, Land Holding ($F = 5.851$, $p = 0.003$), Annual Income ($F = 6.947$, $p = 0.001$) and Makhana Income ($F = 7.671$, $p < 0.001$) all yielded p-values well below the 0.05 threshold. By convention, this indicates significant variance heterogeneity among the clusters for these variables. In contrast, Education ($F = 0.279$, $p = 0.757$) reflected a high p-value (>0.05), so the null hypothesis of homogeneity of variance was not rejected for education. In practical terms, a significant Levene test ($p < 0.05$) means at least one cluster's variance differs from the others whereas a non-significant result means variances are statistically indistinguishable. Thus, the clusters of makhana farmers were markedly heterogeneous in landholding and income (the dispersion of these traits differs across clusters) but homogeneous in educational attainment.

Table 4 revealed that the entrepreneurial profiling of makhana farmers revealed notable variation across six key attributes. Among

Table 2. ANOVA of socio-economic heterogeneity among makhana farmers in Bihar

Variables	F value	P Value	Significance
Land Holding	217.1	<0.001	Significant
Annual Income	265.3	<0.001	Significant
Makhana Income	271.5	<0.001	Significant
Education	1.789	0.172	Non-Significant

Table 4. Entrepreneurial attribute scores and rankings across the makhana farmers

S.No.	Entrepreneurial attributes	Mean Score	Rank
1	Production orientation	22.86	I
2	Marketing orientation	22.16	II
3	Management orientation	21.83	III
4	Risk-taking ability	17.8	IV
5	Achievement motivation	15.8	V

these, production orientation received the highest average score (22.86), securing the top rank, indicating farmers' strong focus on increasing yield and optimising cultivation practices. Marketing orientation (22.16) and management orientation (21.83) followed as the second and third highest-ranked attributes, respectively. These results suggest that farmers are relatively proactive in accessing markets and organising farm operations efficiently. On the other hand, attributes such as risk-taking ability (17.80), achievement motivation (15.80), and innovativeness (15.11) were ranked lower, indicating a more cautious or traditional mindset in entrepreneurial behaviour.

DISCUSSION

This methodological approach yielded three distinct clusters based on empirical differences in key variables: landholding size, annual income, makhana income, and entrepreneurial attributes. The clustering technique facilitated the delineation of distinct farmer groups, thereby moving beyond descriptive profiling to generate actionable classification. Results from Tables 1 and 2 confirmed significant variation across clusters in landholding ($p < 0.001$), annual income ($p < 0.001$), and makhana income ($p < 0.001$), but not in educational attainment ($p = 0.172$). Levene's test (Table 3) further validated heterogeneity of variances for landholding and income variables, reinforcing the robustness of the cluster distinctions.

Larger landholdings and higher income were often associated with increased adoption of agricultural technologies and practices. For instance, Wang et al., (2023) noted that professional farmers with high education levels, large-scale farmland operations, and high levels of agricultural mechanization participated in digital finance, which played a more significant role in promoting their total household income. This suggests that farmers with larger landholdings may have better access to financial resources and technology. Interestingly, the cluster's low education levels contrast with the general trend observed. Aman et al., (2024) indicated that "education alone does not have a noticeable impact, signifying that specialised training can be more effective in improving adoption rates among small farmers with limited formal education" (Aman et al., 2024). This implies that formal education may not always be a determining factor in agricultural success. The older age and larger family size of the cluster align with some observations. Kibona & Yuejie (2021) mentioned that the average age of the interviewees was 53.73 years with a family size of 13.11. This suggests that older farmers with larger families are common in certain agricultural contexts. Extension efforts could involve capacity-building workshops, subsidies for micro-irrigation systems, and community-based water management models to improve the adoption of these practices (Kumar et al., 2020; Pundir et al., 2025).

The production orientation of the respondents, measured through entrepreneurial attributes, attained the highest mean score of 22.86, securing the first rank, followed by marketing orientation, which recorded a mean score of 22.16 and ranked second. Management orientation with a mean score of 21.83 ranked 3rd. Finally, risk-taking ability ranked 4th with a mean score of 17.80. The lower innovativeness score reflects limited engagement with novel practices or technologies, which may hinder productivity growth and adaptation to market changes. These findings align with the cluster-based analysis, where Cluster 2 exhibited higher entrepreneurial scores across most dimensions. The results underscore the need for tailored interventions—enhancing innovation training and achievement-oriented incentives, particularly for clusters with lower entrepreneurial indices. Strengthening entrepreneurial capabilities, especially in innovation and risk-taking, could significantly improve resilience and profitability among makhana farmers, thereby supporting more dynamic agricultural entrepreneurship in Bihar's aquatic crop sector. These results were consistent with previous studies conducted by Chandrashekhar (2010); Parthiban et al., (2018); Afros et al., (2021) & Afros et al., (2022) where the motivation for entrepreneurs had a higher utility. The insights gained from this research can be invaluable in shaping future training programs to better align with the specific needs and expectations of agripreneurs, also aligned with Kumari et al., (2024).

CONCLUSION

The study classified 120 makhana farmers in Bihar into three distinct clusters based on landholding, income, and entrepreneurial traits, achieving its objective to reveal socio-economic diversity. Cluster II, with the highest innovativeness and achievement motivation, shows strong potential for adopting new technologies and market linkages. Cluster III, despite moderate resources, had lower entrepreneurial engagement, indicating a need for capacity-building and input support. Cluster I, though economically well-off, exhibited low education and entrepreneurship levels, highlighting the need for customised extension strategies. The findings contribute to academic knowledge by demonstrating the utility of cluster analysis in farmer classification. For practitioners and policymakers, the study offers actionable insights for the precise targeting of extension programs and efficient resource use. Future research could examine the long-term impacts of cluster-specific interventions and include socio-cultural factors for a comprehensive understanding of makhana farmers' adoption behaviour, thereby supporting sustainable agricultural development in flood-prone regions.

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