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Unveiling Regional Disparities in Makhana Farming: A Multidimensional Analysis from Bihar

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HIGHLIGHTS

- Landholding size and perception levels significantly differentiate *Mithlanchal* and *Simanchal* Makhana growers.
- Multidimensional profiling using Multiple Correspondence Analysis (MCA) explained nearly half of the variance (49.38%), confirming robust separation between traditional and emerging Makhana production areas.
- Policy relevance emerges from the evidence-based identification of regional strengths and gaps, suggesting tailored interventions on resource enhancement in *Simanchal* and perception and technology orientation in *Mithilanchal* to promote balanced and inclusive sectoral development.

ARTICLE INFO

Keywords: Makhana cultivation, Regional disparities, Mann-Whitney U test, Multiple correspondence analysis, Permutation test, Bihar.

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ABSTRACT

Makhana (*Euryale ferox)* cultivation in Bihar accounts for 85% of India's total production of Makhana, exhibiting pronounced regional disparities driven by agro-ecological, socio-economic, and institutional factors. This study compares traditional (Darbhanga/Madhubani) and emerging (Purnea/Katihar) Makhana-growing zones to elucidate differences in farming practices, resource endowments, and socio-behavioural attributes. In a comparative cross-sectional design, 120 Makhana growers (60 per region) were surveyed using a structured interview schedule covering landholding size, income level, training, age, education level, perception, knowledge and attitude level of farmers. Mann-Whitney U tests ($\alpha = 0.05$) examined univariate regional differences; Multiple Correspondence Analysis and permutation testing (B = 999) assessed multidimensional separation and statistical significance of regional groupings. Univariate analysis revealed significant regional differences in landholding size, larger in traditional zones, perception scores higher in emerging zones, and income level. MCA showed robust grouping: the first two dimensions captured 49.38% of total variance. Though specific socio-economic and attitudinal factors appear similar, multidimensional profiling uncovers clear structural differences between traditional and emerging Makhana regions. These findings emphasize the need for region-tailored extension strategies, input support, and market interventions to foster equitable growth and resilience in Bihar's Makhana sector.

INTRODUCTION

Makhana (*Euryale ferox*), also known as fox nut or gorgon nut, is an aquatic crop of significant nutritional, economic, and cultural importance in eastern India, particularly in Bihar. It is widely consumed as a healthy snack due to high protein and low-fat content and is valued in traditional Ayurvedic medicine for its therapeutic properties. Bihar accounts for nearly 85% of India's Makhana production, with districts such as Darbhanga, Madhubani, Supaul and Saharsa forming the core of the Makhana belt (Sonu & Jha, 2025a; Kumar et al., 2011). The cultivation of Makhana offers livelihood support to thousands of marginal and small-scale farmers,

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many of whom rely on it as a primary or supplementary source of income. Despite its prominence, Makhana cultivation in Bihar is characterised by notable regional disparities in production inequality, economic, processing, agroecological and policy access disparities (Sonu & Jha, 2025c). While certain districts benefit from favourable natural conditions such as abundant ponds and marshy lands, others lag due to water scarcity, poor market access, or inadequate technical guidance. Consequently, variations exist not only in productivity and profitability but also in cultivation practices, adoption of improved inputs, and access to government schemes and services.

Historically, districts like Darbhanga and Madhubani have been the epicentre of traditional Makhana farming. Farmers in these regions often rely on inherited knowledge and indigenous practices passed down through generations. In contrast, regions like Purnea/Katihar are witnessing a shift towards commercial-scale pond-based cultivation, supported by scientific techniques such as pond rejuvenation, line sowing, improved seed varieties, and mechanized processing. These advancements, however, are not uniformly accessible across all regions, leading to an imbalance in economic returns and development opportunities among farmers (Warshini et al., 2025).

To address these growing disparities, it is important to undertake region-specific assessments that capture both the strengths and challenges of Makhana cultivation across different areas. Understanding regional patterns in input use, productivity levels, income, and socio-economic profiles of farmers is essential for designing policies that promote equitable agricultural growth. Moreover, such analysis can inform targeted interventions to improve technology dissemination, enhance value chain integration, and support the development of farmer collectives and cooperatives (Kumar et al., 2020).

This study aims to assess regional disparities in Makhana farming practices in Bihar by comparing two distinct Makhana-producing regions. It also assesses the impact of socio-economic factors, on farm outcomes. By employing both descriptive and inferential statistical techniques, the research seeks to identify significant differences and contributing factors to regional variability.

METHODOLOGY

The present study was conducted to assess regional disparities in Makhana cultivation practices, productivity, and socio-economic factors among farmers in two selected regions of Bihar, one representing a traditional Makhana-growing zone (Darbhanga/Madhubani designated as Mithilanchal) and the other an emerging cultivation area (Purnea/Katihar designated as Simanchal). A total of 120 Makhana farmers were purposively selected, with 60 respondents from each region, ensuringhighly localised and practised by a specialised group of farmers possessing unique knowledge of aquatic crop management. A comparative cross-sectional research design was adopted, enabling simultaneous analysis of differences between regions during the 2023-24. Data were collected using a pre-tested, structured interview schedule covering variables such as age, education, landholding size, annual income, input usage, yield (kg ha^{-1}), gross income (Rs. ha^{-1}), knowledge and attitude towards improved practices. Interviews were conducted in local dialects to ensure clarity and accuracy. Primary data were coded and entered into Microsoft Excel, then analysed using SPSS v27 for descriptive statistics and R (Facto Mine R package) for advanced multivariate analysis.

Given that many variables did not meet the assumption of normality (tested via Shapiro–Wilk), the Mann-Whitney U test was used to compare medians between regions:

$$U = n_1 n_2 + \frac{n_1 (n_1 + 1)}{2} R_1$$

where n_1 and n_2 are the sample sizes of Region A and Region B, and R_1 is the sum of ranks for Region A. Statistical significance was set at $p<0.05$.

To explore multidimensional relationships, Multiple Correspondence Analysis (MCA) was applied to categorical variables from socio-economic, knowledge, and attitude dimensions. Socio-economic and knowledge/attitude indicators were treated as active variables, while *region* was included as a supplementary variable to enable between-group comparisons without distorting the factorial space (Greenacre & Blasius, 2006; Husson & Josse, 2014). The barycenter for each region was calculated as:

$$G_k = \frac{1}{n_\kappa} \sum_{i \epsilon k} x_i$$

where G_k is the barycenter of group κ, n_k the number of individuals in group κ, and x_i is the coordinate vector of individual i.

Lebart test values were computed to identify variables most associated with regional separation. A permutation test with 999 replications was conducted to assess whether the observed separation between regions in MCA space exceeded that expected by chance (Husson & Josse, 2014). The test statistic was:

$$P = \frac{\{\delta^* \geq \delta_{obs}\}}{B + 1}$$

where δ_{obs} is the observed inter-group distance, δ^* are permuted distances, and B=999.

Bootstrapping (n = 500) was performed to generate 95% confidence ellipses around regional barycenters, enabling visual interpretation of variability and overlap in the MCA factorial map.

RESULTS

The Mann-Whitney U test results the regional variations between Mithlanchal and Simanchal Makhana growers across multiple socio-economic and behavioural parameters (Table 1). The analysis identified a statistically significant difference in income levels (U = 2208.5, p = 0.023); however, the direction of the effect indicated no substantial practical difference between the two regions. Landholding size also varied significantly (U = 2223.5, p = 0.021), with growers in Mithlanchal possessing comparatively larger agricultural holdings than their counterparts in Simanchal.

Perception score presented the most pronounced difference between the groups (U = 1132, p < 0.001), with Simanchal growers exhibiting more favourable perceptions toward Makhana cultivation and associated technological practices. In contrast, other variables including knowledge level (p = 0.057), training received (p = 0.422),

Table 1. Mann-Whitney U Test of regional differences across different variables of makhana growers

Variable	U Statistic	P Value	Significant	Effect Direction
Income Level	2208.5	0.023471	Yes	No difference
Land Holding	2223.5	0.021114	Yes	Mithlanchal > Simanchal
Knowledge Level	2075	0.057091	No	No difference
Perception Score	1132	4.90E-05	Yes	Simanchal > Mithlanchal
Training Received	1920	0.421637	No	No difference
Attitude level	1890.5	0.537416	No	No difference
Farm Location	2084	0.112355	No	No difference
Age Group	1801.5	0.995111	No	No difference
Education Level	1478.5	0.081637	No	Simanchal > Mithlanchal

attitude level (p = 0.537), farm location (p = 0.112), age group (p = 0.995), and education level (p = 0.082) did not display statistically significant differences between the two regions. Nevertheless, the education data indicated a non-significant trend towards higher educational attainment among growers from Simanchal.

The MCA was carried out to examine multidimensional relationships among the socio-economic, attitudinal, and behavioural attributes of growers in the two regions. Table 2 presented the eigenvalues and variance contributions for the five extracted dimensions. The first dimension yielded the highest eigenvalue (0.298), accounting for 28.59% of the total variance. This axis primarily differentiated growers based on economic indicators, perception levels, and landholding size, making it the most influential factor in distinguishing regional profiles.

Table 2. MCA Eigenvalues and Variance patterns distinguishing the regional groups

Dimension	Eigenvalue	Explained Variance (%)	Cumulative (%)
Dim 1	0.298216	28.59464	28.59464
Dim 2	0.216823	20.79022	49.38486
Dim 3	0.180723	17.32876	66.71362
Dim 4	0.176319	16.90652	83.62013
Dim 5	0.170827	16.37987	100

The second dimension explained 20.79% of the total variance, raising the cumulative contribution of the first two dimensions to 49.38%. This indicated that nearly half of the total variability in the dataset was explained by these two dimensions, making them the most relevant for visual interpretation. The third dimension accounted for 17.33% of the variance and appeared to represent variations related to education level and access to training programmes. The fourth dimension contributed 16.91% of the variance, reflecting diversity in farm location and age group characteristics. The fifth dimension explained 16.38% of the variance, bringing the cumulative explained variance to 100% and confirming that the extracted dimensions fully summarised the variability present in the dataset.

The barycenter values obtained from the MCA revealed clear positional differences between the two regions on the first two dimensions, as shown in Table 3. Mithlanchal growers recorded negative coordinates on both axes (Dim1: –0.108, Dim2: –0.082), indicating that their overall profile was positioned on the opposite side of the factorial space compared to Simanchal growers. In contrast, Simanchal barycenters were positive on both dimensions (Dim1: 0.108, Dim2: 0.082), reflecting a distinct grouping pattern.

Table 3. Regional Barycenters of different region of Makhana growers

Region	Dim1	Dim2	n
Mithlanchal	-0.10846	-0.08171	60
Simanchal	0.108457	0.081711	60

Both regions had an equal sample size (n = 60), ensuring that the observed differences were not a result of unequal representation but instead reflected genuine contrasts in growers' characteristics. This separation along the two primary dimensions reinforced the interpretation that regional factors played a significant role in shaping technology adoption and entrepreneurial behaviour among makhana farmers.

The Multiple Correspondence Analysis (MCA) plot illustrated the spatial differentiation between makhana growers from the Mithlanchal and Simanchal regions based on their multidimensional characteristics (Figure 1). The two primary dimensions (Dim 1 and Dim 2) accounted for 28.59% and 20.79% of the total variance, respectively, together explaining a substantial proportion of the variation in the dataset. The plot displayed two distinct yet partially overlapping clusters.

Growers from Mithlanchal, represented by blue points, were predominantly positioned in the negative quadrant of Dimension 1, with their barycenter (marked as a diamond) located at approximately -0.108 on Dim 1 and -0.082 on Dim 2. In contrast, growers from Simanchal, represented by red points, were generally situated in the positive quadrant of Dimension 1, with their barycenter (diamond) at approximately 0.108 on Dim 1 and 0.082 on Dim 2. This mirrored positioning along Dim 1 indicated a clear directional contrast in the underlying variables influencing each group.

The shaded ellipses represented the 95% confidence intervals for the regional group distributions. While some overlap was observed, suggesting shared characteristics, the centers were separated by an inter-group distance of 0.27 (p = 0.01), confirming statistically significant regional differences. This separation likely reflected variations in socio-economic profiles, access to inputs, adoption of improved cultivation practices, and market linkages between the two regions.

Figure 2 illustrated the distribution of socio-economic, attitudinal, and perceptual variables among Makhana growers across

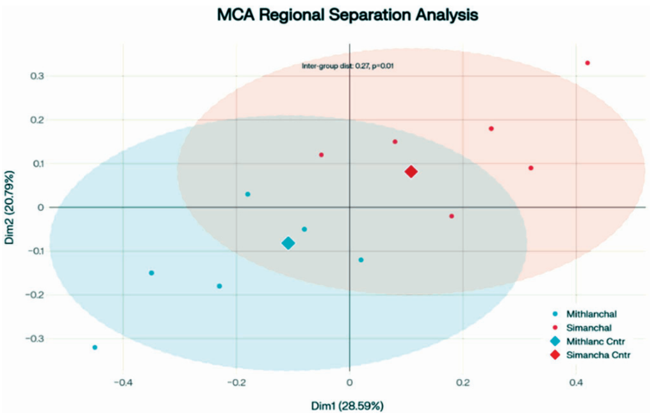


Figure 1. MCA Factorial Map showing regional separation between Mithlanchal and Simanchal

the two principal dimensions. Dimension 1 accounted for 11.98% of the total variance, while Dimension 2 explained an additional 8.84%, jointly capturing a substantial portion of the structural variation in the dataset. In the plot, each black point represented an individual respondent, whereas labelled coordinates denoted categorical variable categories. The positioning of categories along Dimension 1 and Dimension 2 indicated their relative association with respondents' profile. Respondents located on the right-hand side of Dimension 1 were predominantly associated with larger landholdings, higher income brackets (>2.4L), postgraduate education, and high knowledge and attitude levels. This cluster also reflected stronger adoption-related indicators, suggesting that these individuals were socio-economically advantaged and more receptive to innovation. Conversely, the left-hand side of Dimension 1 was characterised by marginal and small landholders, lower income categories (80K), and lower perception scores. These respondents were associated with lower adoption levels and limited resource access, highlighting structural constraints in production capacity.

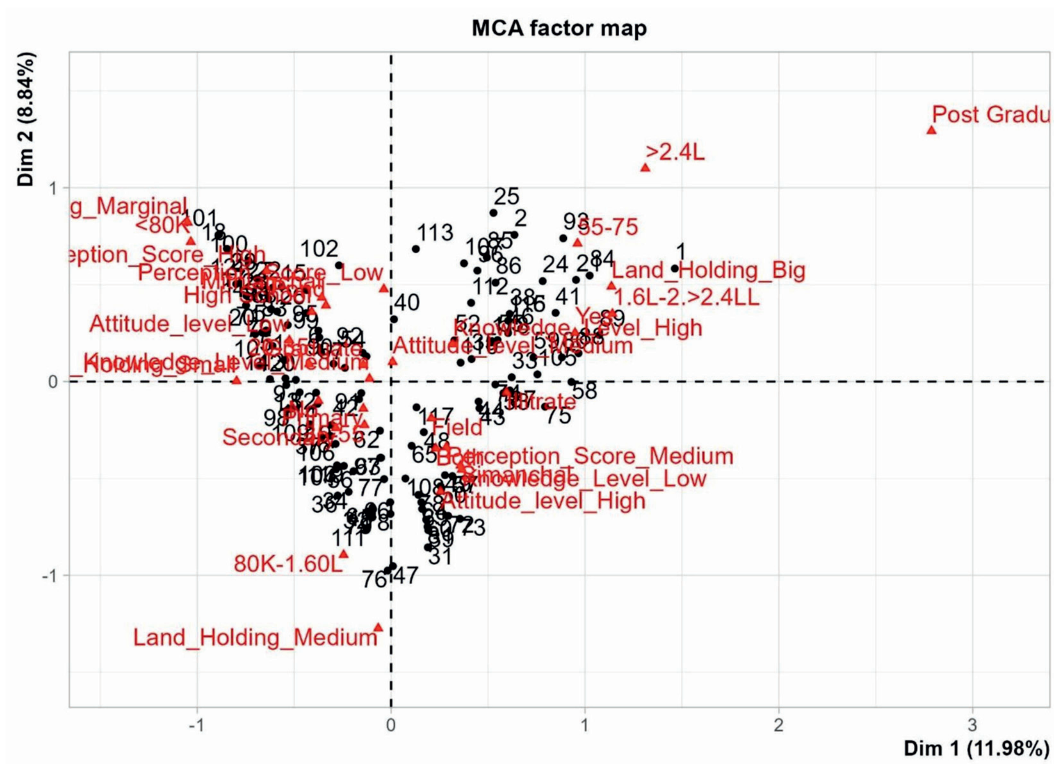
Along Dimension 2, the upper section contained respondents with very high perception scores and landholding extremes, while the lower section included categories such as medium landholding sizes, medium income levels (80K-1.60L), and mixed perception and knowledge scores. The vertical spread suggested variation in perception and attitude across income and landholding groups, independent of pure economic status. The mirrored positioning of adoption-related variables, such as high knowledge and attitude levels, against low and medium categories along Dimension 1, supported the interpretation of systematic socio-economic and attitudinal contrasts between different farmer groups. Furthermore, the clustering patterns implied that landholding size, income, and education had a stronger alignment with Dimension 1, whereas perception and knowledge distribution contributed more to separation along Dimension 2.

DISCUSSION

The present study examined regional differences in socio-economic, attitudinal, and behavioural variables among makhana growers in Mithilanchal and Simanchal, Bihar, and findings offer insights into the structural and perceptual variations that underpin technology adoption and entrepreneurial orientation in the makhana value chain.

The application of the Mann-Whitney U test proved effective in identifying clear regional differences in Makhana cultivation between traditional and emerging production zones. This choice of test aligns well with the nature of agricultural data, which often deviates from normality assumptions, making non-parametric methods more appropriate (Macfarland & Yates, 2016). The results revealed that farmers in Mithlanchal generally possess larger

Figure 2. MCA Factor Map showing different variables of Mithanchal and Simanchal region



landholdings compared to those in Simanchal (U = 2223.5, p = 0.021). This disparity can be attributed to long-standing historical land tenure patterns and the presence of well-established irrigation infrastructure in traditional growing areas (Singh et al., 2015). Such structural advantages have allowed Mithlanchal farmers to cultivate Makhana on a larger scale, reinforcing their dominant position in production.

Interestingly, while Simanchal farmers tend to operate on smaller plots, they recorded higher perception scores regarding Makhana cultivation and innovation adoption (Sonu & Jha, 2025a,b or c). This openness to new practices suggests that perception and willingness to adapt may be just as important if not more so than physical resources in driving agricultural transformation. Similar observations have been reported in other contexts, where farmer attitudes and readiness to embrace innovation often outweigh objective factors like land size in determining success (Datta et al., 2022; Vallury et al., 2024).

The Multiple Correspondence Analysis (MCA) provided further insight into these regional differences. The first two dimensions of the MCA accounted for 49.38% of the total variance, with a statistically significant separation between the two regions (inter-group distance = 0.27, p = 0.01). Such a high proportion of variance explained by only two dimensions indicates strong underlying structural contrasts (Hoffman & Leeuw, 1992; Roux & Rouanet, 2021). The positioning of the regional barycenters along Dimension 1, Mithlanchal at –0.108 and Simanchal at 0.108 reflects systematic socio-economic and technological adoption differences. This mirrored arrangement reinforces the argument for region-specific intervention strategies rather than a uniform policy approach.

A notable finding is the absence of significant differences in knowledge levels, training participation, and attitudes toward Makhana cultivation across the two regions (Sonu & Jha, 2025b). This suggests that while institutional support systems such as training programs and advisory services are available in both areas, their utilization and impact differ. This uneven uptake could be linked to the way local cooperatives operate or farmers perceived security and trust in institutional support, both of which strongly influence their willingness to adopt transformative agricultural practices (Masi et al., 2022).

One factor that stands out as a clear differentiator is market access. The study highlights that infrastructure connectivity, such as transportation networks and proximity to marketplaces plays a decisive role in shaping income potential and the adoption of innovative practices. Farmers with better access to markets are more likely to invest in quality improvements, adopt post-harvest innovations, and integrate into value chains. Conversely, inadequate connectivity can limit opportunities even for farmers with high awareness and willingness to adopt.

CONCLUSION

Larger landholdings in Mithlanchal reflect structural advantages, yet Simanchal's stronger perception scores highlight a readiness to adopt innovative practices despite resource constraints. While knowledge and training levels are comparable, the interplay between resource endowment and perception emerge as a central determinant of regional profiles. Strengthening market linkages, promoting farmer collectives, and facilitating targeted training could foster equitable development across regions. Addressing both structural and perceptual gaps is essential for sustainable growth in Bihar's makhana sector, enabling farmers to capitalize on market opportunities and strengthen the resilience of this high-value crop's value chain. The findings also provide valuable insights into the spatial heterogeneity of Makhana cultivation, enabling policymakers, researchers, and extension agencies to design region-specific interventions that promote inclusive and sustainable growth of this vital sector. Bridging regional disparities will not only enhance productivity and profitability but also strengthen the resilience, equity, and long-term competitiveness of Makhana farming in Bihar.

DECLARATIONS

Ethics approval and informed consent: Informed consent was sought from the respondents regarding the study during the course of the data collection.

Conflict of interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The authors declare that during the preparation of this work, they thoroughly reviewed, revised, and edited the content as needed. The authors take full responsibility for the final content of this publication.

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