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Data-driven selection of indigenous rice varieties using a Pentapartitioned Neutrosophic decision model

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Abstract
In this study, five prominent indigenous rice varieties Karunkuruvai, Mappillai Samba, Karuppu Kavuni, Kattuyanam, and Kullakar were critically analyzed to assist the farming community in selecting the most suitable variety under multiple conflicting criteria. A novel Multi-Criteria Decision-Making (MCDM) framework is proposed by extending the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) into a Pentapartitioned Neutrosophic environment, allowing for a more realistic representation of uncertainty, ignorance, contradiction, and expert disagreement. To aggregate the opinions of diverse experts, we introduce a new operator termed the Pentapartitioned Neutrosophic Weighted Averaging (PNWA) operator. This enhanced decision model, referred to as PN-TOPSIS, is applied to real-world agricultural data involving key criteria such as yield, crop duration, seed cost, market demand, and seasonal stability. Based on the closeness coefficients derived from the model, Kullakar emerged as the most recommended rice variety, offering valuable insight to farmers interested in traditional rice cultivation. The results demonstrate the practical relevance and decision-support capabilities of the PN-TOPSIS method in agricultural planning.

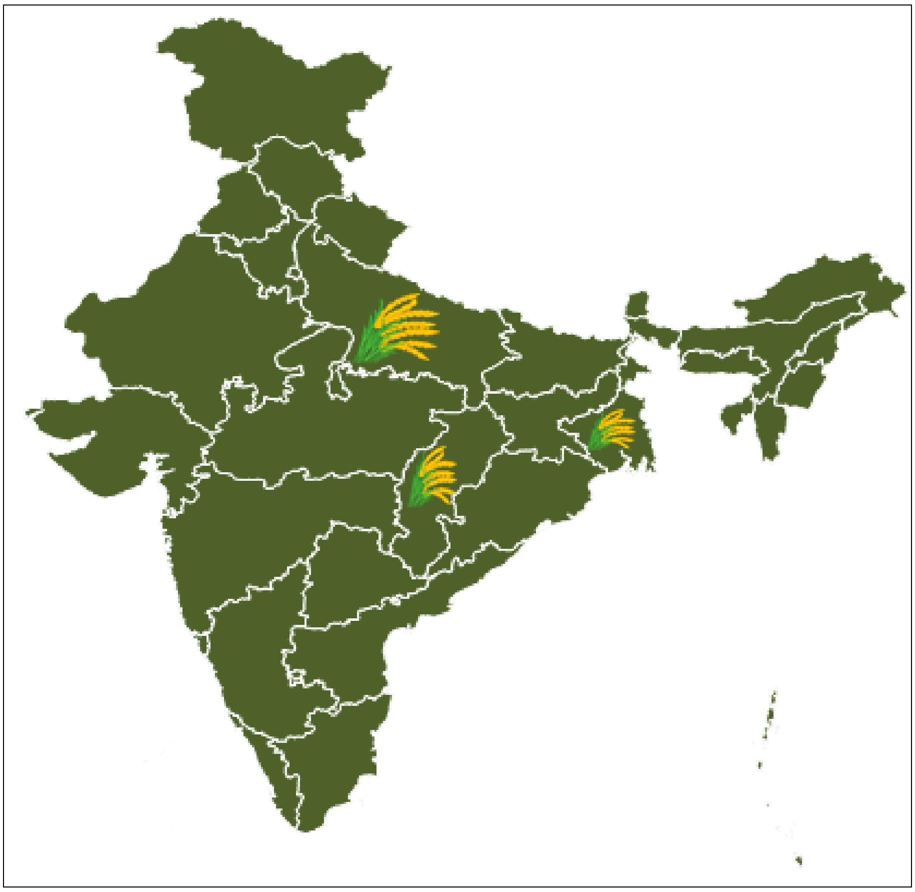
Keywords: Indigenous Rice Varieties, Pentapartitioned Neutrosophic Set, PN-TOPSIS, Multi-Criteria Decision Making, Agricultural Decision Support.

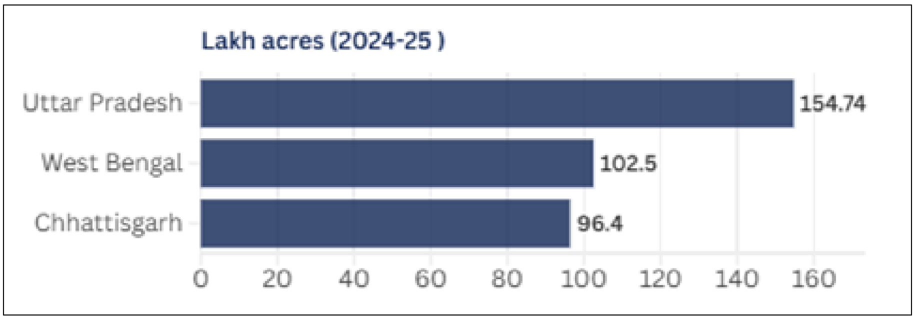
Introduction

Traditional rice varieties represent a vital reservoir of genetic diversity and cultural heritage in rice-producing regions like Tamil Nadu, India. Over centuries, local farming communities have preserved indigenous landraces including Karunkuruvai, Mappillai Samba, Karuppu Kavuni, Kattuyanam and Kullakar, each uniquely adapted to specific agroecological niches and cultivated through traditional practices. These landraces embody the resilience and ingenuity of smallholder farmers while conserving valuable traits such as drought tolerance, pest resistance and distinctive nutritional qualities. In recent years, their agronomic and socioeconomic importance has grown considerably due to rising health awareness and shifting consumer preferences. Traditional varieties are increasingly valued for their low glycemic index, making them suitable for diabetic and health-conscious populations. Additionally, they command premium prices in niche markets and contribute to the enhancement of rural livelihoods through value-added marketing and heritage branding initiatives [1, 2].

In Fig. 1, the dominance of rice cultivation in India's top rice-growing states based on area coverage during the 2024-25 season is depicted. Uttar Pradesh leads with an impressive 154.74 lakh acres, followed by West Bengal at 102.50 lakh acres and Chhattisgarh with 96.40 lakh acres. This geographic distribution reflects both the climatic suitability and agricultural focus of these regions, highlighting their critical role in sustaining India's overall rice economy [3].

Despite these advantages, many farmers remain hesitant to adopt Indigenous Rice cultivation due to uncertainties regarding yield performance, market demand, input costs, and seasonal adaptability. This underscores the need for robust, data-driven decision-support tools that can assist growers in selecting the most suitable varieties under complex, often conflicting, criteria.





Source: Department of Agriculture & Farmers Welfare, 2024

Fig. 1: National Dominance in Rice Cultivation: Top Three States by Area Coverage in 2024-25

In response to this challenge, the present study introduces a novel Multi-Criteria Decision-Making (MCDM) framework by extending the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) into a Pentapartitioned Neutrosophic environment. This approach enables a more nuanced representation of uncertainty, ignorance, contradiction, and expert disagreement in agricultural planning. By aggregating diverse expert opinions through the Pentapartitioned Neutrosophic Weighted Averaging (PNWA) operator, the proposed PN-TOPSIS model provides actionable insights for variety selection, validated through real-world data on key criteria such as yield, crop duration, seed cost, market demand, and seasonal stability. The findings offer practical guidance for farmers and policymakers aiming to revitalize traditional rice cultivation while navigating the complexities of modern agricultural systems.

Literature Review

Researchers have studied the theory of Neutrosophic sets in enormous detail to tackle uncertainty in our everyday lives. Smarandache F introduced the Neutrosophic Set [5] involving indeterminancy and inconsistent data as a mathematical tool for handling problems. Karabaevi *et al.* (2020) [4] introduced a novel MCDM method based on TOPSIS on SVNS. In 2023, Porchudar *et al* [11] developed an MCDM model for entrepreneurs and farmers using Neutrosophic Fuzzy SAW method. Rama Mallick and Surapati Pramanik [6] introduced the set called Pentapartitioned Neutrosophic Set and its properties in 2020. The Indeterminacy membership function is subdivided into three parts as contradiction, ignorance and unknown membership function. In 2021, R. Radha and A. Stanis Arul Mary [7] have proposed the concept of Pentapartitioned Neutrosophic Pythagorean Set. In 2022, Shio Gai Quek *et al.* [8] have introduced the concepts of pentapartitioned neutrosophic graphs (PPNGs) & have emphasized the effectiveness at extremely heterogeneous data in our daily life. In 2023, Yi-ming Li *et al.* [9] introduced pentapartitioned neutrosophic cubic set and also its operational laws. They have used these operators to check its applicability in some of the models, to detect the air pollution of cities in Pakistan. In 2024, Porchudar and Ajay [10] they developed decision making model for Oil seed cultivation under Complex Pentapartitioned Neutrosophic Set with Einstein

Aggregation operators.

Basic Concepts

1. Definition: Fuzzy Set

A fuzzy set D defined on a universe of discourse R has the form $D = \{\langle \varepsilon_D(r) \rangle r \epsilon R\}$, where $\varepsilon_D(r): R \to [0,1]$. Here $\varepsilon_D(r)$ denote the membership function of each r.

2. Definition: Neutrosophic Set

Let S be the Universe. A Neutrosophic Set C on S can be defined as follows: $C = \{\langle m, T_C(m), I_C(m), F_C(m)\rangle; m \epsilon U\}$ each element $m \epsilon S$ has a degree of truth, false and indeterminancy membership in C. Where, $T_C(m), I_C(m)$ and $F_C(m)$ represent the degree of Truth, Falsity and Indeterminacy membership functions respectively. Which takes values in the unit closed interval satisfying the relation $0 \le T_C(m) + I_C(m) + F_C(m) \le 3$.

3. Definition: Pentapartitioned Neutrosophic Set

Let P be a non-empty set. A PNS D over P characterizes each element $\propto$ in P, by truth membership function T_D, Contradiction membership function C_D, Ignorance membership function G_D, Unknown membership function U_D and Falsity membership function F_D such that for each $\propto \epsilon P$, $T_D, C_D, G_D, U_D, F_D \epsilon [0,1]$ and $0 \le T_D(\propto) + C_D(\propto) + G_D(\propto) + U_D(\propto) + F_D(\propto) \le 5$.

4. Manhattan Distance

Let $X_1 = (\mu_1, \vartheta_1, \gamma_1, \tau_1, \sigma_1)$ and $X_2 = (\mu_2, \vartheta_2, \gamma_2, \tau_2, \sigma_2)$ be a Pentapartitioned Neutrosophic Numbers. The defined Seperation measure based on Manhattan Distance between X_1 and X_2.

$$\propto D_{Manh}(X_1, X_2) = |\mu_1 - \mu_2| + |\vartheta_1 - \vartheta_2| + |\gamma_1 - \gamma_2| + |\tau_1 - \tau_2| + |\sigma_1 - \sigma_2|$$

Algorithm: Proposed Pentapartitioned Neutrsophic-TOPSIS Method

Step 1: With regard to the decision makers' opinion, construct the aggregated Pentapartitioned Neutrosophic Decision Matrix.

$$D = (d_{ij})_{\substack{1\le i\le \emptyset \\ 1\le i\le \varphi}} = (T_{ij}, C_{ij}, G_{ij}, U_{ij}, F_{ij})_{\substack{1\le i\le \emptyset \\ 1\le i\le \varphi}}$$

In order to create a collective decision from individual decisions, it is necessary to derive an aggregated pentapartitioned neutrosophic decision matrix D. This aggregated matrix can be obtained by our proposed Pentapartitioned Neutrosophic Aggregation Operator:

$$D = \sum_{t=1}^{\epsilon} \delta_t D_t, \text{ where } D = d_{ij} = (T_{ij}, C_{ij}, G_{ij}, U_{ij}, F_{ij})$$

$$d_{ij} = \left[1 - \prod_{t=1}^{\epsilon}(1 - T_{ij}^t)^{\delta t}, 1 - \prod_{t=1}^{\epsilon}(1 - C_{ij}^t)^{\delta t}, \prod_{t=1}^{\epsilon}(G_{ij}^t)^{\delta t}, \prod_{t=1}^{\epsilon}(U_{ij}^t)^{\delta t}, \prod_{t=1}^{\epsilon}(F_{ij}^t)^{\delta t},\right]$$

Step 2: We now aggregate the weighted Pentapartitioned Neutrosophic decision matrix as,

$$D^w = D \otimes W$$

Step 3: We evaluate the Positive and Negative Ideal Solution namely Pentapartitioned Neutrsophic Positive Ideal Solution (PNPIS) and Pentapartitioned Neutrosophic Negative Ideal Solution (PNNIS)

$$Q_{PN}^+ = (d_1^{w^+}, d_2^{w^+}, \dots, d_n^{w^+})$$
$$T_j^{w^+} = \{(max_i\{T_{ij}^{wj} | j \epsilon E\})(min_i\{T_{ij}^{wj} | j \epsilon F\})\}$$
$$C_j^{w^+} = \{(max_i\{C_{ij}^{wj} | j \epsilon E\})(min_i\{C_{ij}^{wj} | j \epsilon F\})\}$$
$$G_j^{w^+} = \{(min_i\{G_{ij}^{wj} | j \epsilon E\})(max_i\{G_{ij}^{wj} | j \epsilon F\})\}$$
$$U_j^{w^+} = \{(min_i\{U_{ij}^{wj} | j \epsilon E\})(max_i\{U_{ij}^{wj} | j \epsilon F\})\}$$
$$C_j^{w^+} = \{(min_i\{F_{ij}^{wj} | j \epsilon E\})(max_i\{F_{ij}^{wj} | j \epsilon F\})\}$$
$$Q_{PN}^- = (d_1^{w^-}, d_2^{w^-}, \dots, d_n^{w^-})$$
$$T_j^{w^-} = \{(min_i\{T_{ij}^{wj} | j \epsilon E\})(max_i\{T_{ij}^{wj} | j \epsilon F\})\}$$
$$C_j^- = \{(min_i\{C_{ij}^{wj} | j \epsilon E\})(max_i\{C_{ij}^{wj} | j \epsilon F\})\}$$
$$G_j^{w^-} = \{(max_i\{G_{ij}^{wj} | j \epsilon E\})(min_i\{G_{ij}^{wj} | j \epsilon F\})\}$$
$$U_j^{w^-} = \{(max_i\{U_{ij}^{wj} | j \epsilon E\})(min_i\{U_{ij}^{wj} | j \epsilon F\})\}$$
$$C_j^{w^-} = \{(max_i\{F_{ij}^{wj} | j \epsilon E\})(min_i\{F_{ij}^{wj} | j \epsilon F\})\}$$

Step 4: Calculate the Separation measure [1] of each alternative from PNPIS and PNNIS

$$D_{Manh}^{j+}(d_{ij}^{wj}, d_{ij}^{wj}) = \begin{cases} |T_{ij}^{wj}(x) - T_{ij}^{w+}(x)| + \\ |C_{ij}^{wj}(x) - C_{ij}^{w+}(x)| + \\ |G_{ij}^{wj}(x) - G_{ij}^{w+}(x)| + \\ |U_{ij}^{wj}(x) - U_{ij}^{w+}(x)| + \\ |F_{ij}^{wj}(x) - F_{ij}^{w+}(x)| \end{cases}$$

$$\text{PNS}_i^+ = \sum_{j=1}^{\varphi} D_{Manh}^{j+}(d_{ij}^{wj}, d_{ij}^{w+}) \text{ with } i = 1,2,\dots,\varphi$$

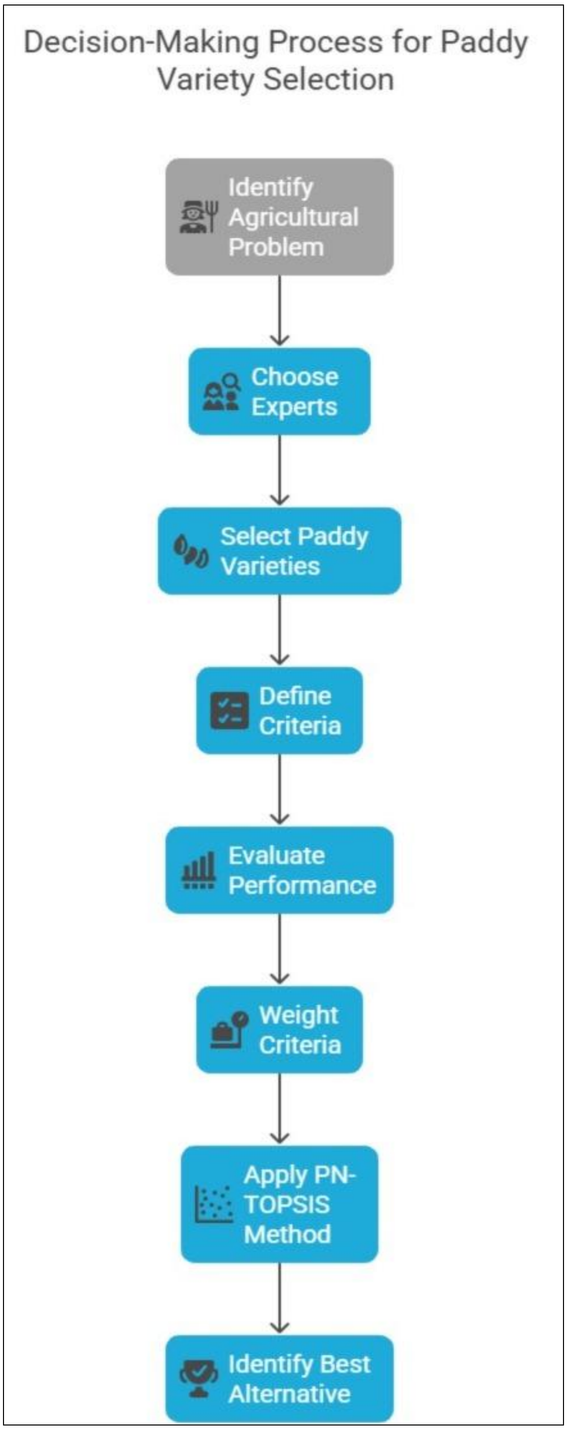
$$D_{Manh}^{j-}(d_{ij}^{wj}, d_{ij}^{w-}) = \begin{cases} |T_{ij}^{wj}(x) - T_{ij}^{w-}(x)| + \\ |C_{ij}^{wj}(x) - C_{ij}^{w-}(x)| + \\ |G_{ij}^{wj}(x) - G_{ij}^{w-}(x)| + \\ |U_{ij}^{wj}(x) - U_{ij}^{w-}(x)| + \\ |F_{ij}^{wj}(x) - F_{ij}^{w-}(x)| \end{cases}$$

$\mathrm{PNS}_i^{+} = \sum_{j=1}^{\varphi} D_{Manh}^{j-}(d_{ij}^{wj}, d_{ij}^{w-})$ with i = 1,2,…,φ

Step 5: We derive Closeness Coefficient for PNSs.

$$C_k^* = \frac{PN_i^-}{PN_i^+ + PN_i^-}; k = 1,2, \dots \epsilon$$

Finally, we rank the alternatives based on the Closeness coefficient values C_k^*.



Numerical Illustration

In this section an Agricultural Problem is applied to PN-TOPSIS method in order to help and motivate farmers towards Indigenous Rice Cultivation. We choose four Experts DM1-Agronomy Student, DM2 - Organic Farmer(A), DM3 - Organic Farmer(B), DM4 -Naturopathic Doctor to analyse the best alternative for farmers who aspire to succeed in Indigenous Rice cultivation. Five Indigenous Rice Varieties are chosen as alternatives: A1-Karunkuruvai, A2 - Mappilai Samba, A3 - Karuppu Kavuni, A4 - Kattuyanam, A5 -Kullakar. Seven Criteria are classified and basic qualities are considered and analyszed to assist a farmer to choose the suitable rice variety. The list of criteria taken: C1- Yeild Rate, C2- Seed Cost, C3 - Duration of Crop, C4 - Resistance Rate, C5 - Stability over Season, C6 - Paddy Straw, C7 - Market Demand. Decision Makers have utilized the linguistic variables to weight the performance of each criterion over the selected Indigenous Rice varieties taken for evaluation. The following Table 1 explains the transformation of linguistic variables to corresponding Pentapartitioned Neutrosophic Numbers.

Table 1: Linguistic Variables

Linguistic Terms	PNN's
Extermely Productive	(0.9,0.8,0.2,0.1,0.1)
Highly Productive	(0.7,0.7,0.3,0.2,0.2)
Moderatly Productive	(0.6,0.6,0.3,0.4,0.4)
Productive	(0.5,0.5,0.5,0.5,0.5)
Little Productive	(0.4,0.4,0.5,0.6,0.6)
Lowly Productive	(0.3,0.3,0.7,0.8,0.8)
Extermely low Productive	(0.1,0.1,0.8,0.9,0.9)

The Pentapartitioned Neutrosophic Weight of each criterion is in Table 2 and the weight vector for the decision makers in Table 3 are presented respectively.

Table 2: Criteria Pentapartitioned Neutrosophic Weight

	C_1	C_2	C_3	C_4
w_i	(0.811, 0.705, 0.271, 0.189, 0.189)	(0.578, 0.489, 0.431, 0.422, 0.422)	(0.547, 0.496, 0.459, 0.453, 0.453)	(0.551, 0.500, 0.459, 0.449, 0.449)
	C_5	C_6	C_7	-
w_i	(0.496, 0.458, 0.418, 0.524, 0.524)	(0.367, 0.355, 0.600, 0.680, 0.680)	(0.867, 0.757, 0.237, 0.133, 0.133)	-

We denote the weight vectors by δ = [δ1, δ2, δ3, δ4]

Table 3: Weight of the Decision Makers

δ	δ1	δ2	δ3	δ4
Weight	0.249	0.292	0.292	0.167

Step:1 Based on the experts' opinion we constructed an Aggregated Pentapartitioned Neutrosophic Decision Matrix.

Step:2 Using the Criteia weights in table 2, we have aggregated the weighted Pentapartitioned Neutrosophic decision matrix and have tabulated it in table 4 and 5.

Table 4: Aggregated Weighted PN Decision Matrix

	$\tilde{A}1$	$\tilde{A}2$
C_1	(0.398,0.349,0.606,0.556,0.367)	(0.771,0.378,0.542,0.556,0.367)
C_2	(0.549,0.262,0.625,0.600,0.178)	(0.562,0.291,0.629,0.624,0.201)
C_3	(0.356,0.291,0.636,0.621,0.191)	(0.531,0.267,0.673,0.664,0.211)
C_4	(0.271,0.242,0.707,0.729,0.280)	(0.531,0.257,0.673,0.709,0.260)
C_5	(0.357,0.250,0.617,0.663,0.139)	(0.472,0.208,0.695,0.780,0.256)
C_6	(0.222,0.189,0.772,0.806,0.126)	(0.357,0.216,0.748,0.774,0.094)
C_7	(0.501,0.363,0.564,0.499,0.365)	(0.860,0.452,0.519,0.387,0.253)

Table 5: Aggregated Weighted PN Decision Matrix

	A˜3	A˜4	A˜5
C_1	(0.352 0.362 0.556 0.556 0.284)	(0.447 0.353 0.542 0.454 0.256)	(0.441 0.375 0.548 0.559 0.371)
C_2	(0.338 0.395 0.542 0.489 0.300)	(0.448 0.335 0.602 0.619 0.130)	(0.274 0.219 0.697 0.736 0.314)
C_3	(0.279 0.243 0.676 0.663 0.240)	(0.336 0.280 0.660 0.664 0.212)	(0.336 0.263 0.660 0.664 0.212)
C_4	(0.253 0.256 0.692 0.673 0.221)	(0.322 0.293 0.636 0.678 0.229)	(0.340 0.276 0.692 0.660 0.211)
C_5	(0.377 0.300 0.647 0.641 0.192)	(0.262 0.224 0.662 0.773 0.249)	(0.262 0.224 0.642 0.757 0.233)
C_6	(0.316 0.264 0.601 0.674 0.143)	(0.262 0.231 0.716 0.771 0.091)	(0.243 0.216 0.731 0.789 0.109)
C_7	(0.370 0.434 0.497 0.500 0.366)	(0.573 0.468 0.486 0.427 0.294)	(0.553 0.437 0.526 0.447 0.314)

Step:3 Pentapartitioned Neutrosophic Positive Ideal Solution (PNPIS) and Pentapartitioned Neutrosophic Negative Ideal Solution(PNNIS) were evaluated using Eq.8 and Eq.9, PNPIS and PNNIS were calculated.

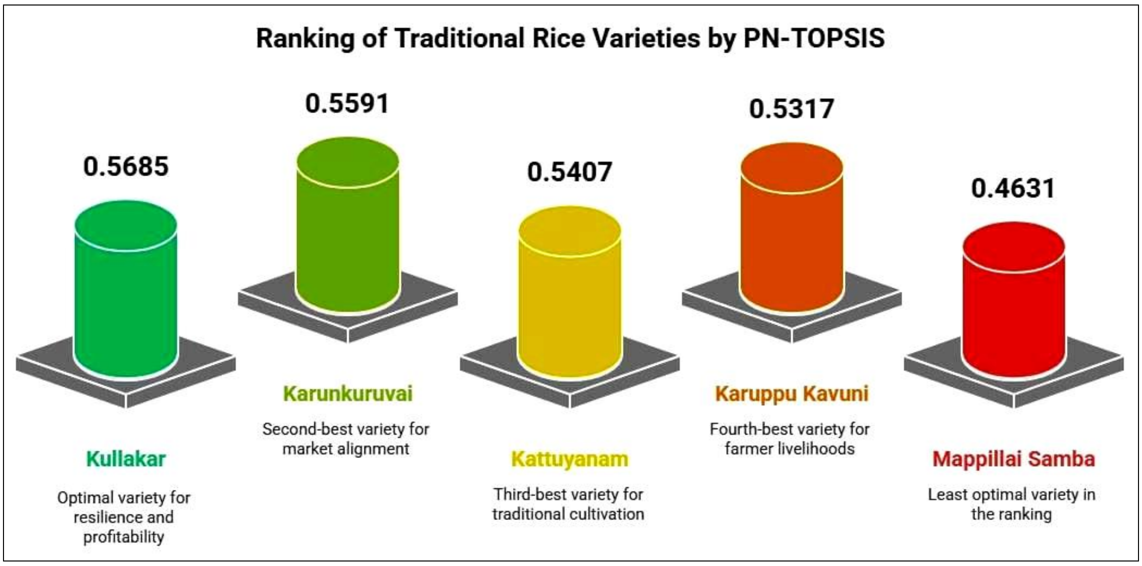
Step:4 The separation measures is calculated and tabulated in table 6 for each alternative using the positive and negative ideal solution using Eq.(10 and 11).

Step:5 And finally the Closeness Coefficient for all the alternative are been calculated and displayed (table 9) using Eq. (10).

Table 6: Separation Measures and Closeness Coefficient

Alternative	PN^-	PN^+	CC	Ranking
A˜1	0.515	0.653	0.5591	2
A˜2	1.004	0.866	0.4631	5
A˜3	1.018	1.156	0.5307	4
A˜4	0.778	0.916	0.5407	3
A˜5	0.434	0.572	0.5685	1

Alternative	A˜1	A˜2	A˜3	A˜4	A˜5
Closeness coefficient	0.5591	0.4631	0.5317	0.5407	0.5685
Rank	II	V	IV	III	I



Conclusion

This study introduced the Pentapartitioned Neutrosophic Weighted Averaging (PNWA) operator and advanced a novel Pentapartitioned Neutrosophic TOPSIS (PN-TOPSIS) framework to address multi-criteria decision-making challenges in Indigenous Rice Cultivation. By integrating expert opinions under conditions of uncertainty, ignorance, and contradiction, the model evaluated five traditional varieties—Karunkuruvai, Mappillai Samba, Karuppu Kavuni, Kattuyanam, and Kullakar—against critical agronomic and economic criteria: yield, crop duration, seed cost, market demand, and seasonal stability.

The PN-TOPSIS analysis revealed Kullakar as the optimal variety (closeness coefficient: 0.5685), followed by Karunkuruvai (0.5591), Kattuyanam (0.5407), Karuppu Kavuni (0.5317), and Mappillai Samba (0.4631). This ranking provides actionable guidance for farmers prioritizing resilience, profitability, and mark*et al*ignment in traditional rice cultivation. The PN-TOPSIS method demonstrates robust decision-support capabilities, bridging empirical data with practical agricultural planning. Future research should expand this framework to other crops, regional contexts, and sustainability metrics, reinforcing the role of computational tools in preserving agrobiodiversity while enhancing farmer livelihoods.

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