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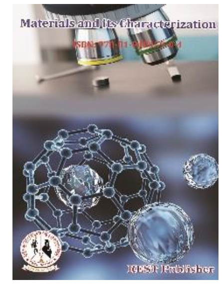

Bio-inspired Material selection with Integrated MPSI-AROMAN Decision Making Approach

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Abstract: *Material selection is the critical determinant of the quality of the products as it influences the performance, sustainability and cost-functionality of the products. In recent times, the consumers prefer eco-friendly and innovative products and this has stimulated the manufacturers to employ bio-inspired materials in product development. The bio-inspired materials are generally more environmentally compatible, however the existence of diverse materials of this kind is more in number with different characterization in terms of physical, mechanical, chemical properties, costs and other factors. This intricate decisioning circumstance calls for muti-criteria decision method to determine optimal solution to this challenge of material selection. This research work develops a hybrid method by fusing MPSI (Modified Preference Selection Index) and AROMAN (Alternative Ranking Order Method Accounting for Two-Step Normalization). The key criteria such as Strength, Density, Resistance, Cost, Reliability, Elasticity, Biodegradability and Recyclability are considered for this study. The bio-inspired materials such as Spider Silk, Lotus Leaf-inspired Coatings, Shark Skin-inspired Materials, Bone-like Composites, Chameleon-inspired Materials, Butterfly Wing-inspired Crystals, Gecko-inspired Adhesives and Cellulose-based Materials are considered as the alternatives. The method of MPSI is applied to find the criterion weights and the method of AROMAN is applied in ranking the alternatives. The results of this hybrid model facilitate and support the decision makers in making optimal decisions. This research work shall be extended by developing more such hybrid methods and also by discussing the proposed method with the representations of fuzzy and its extensions.*

Keywords: *Bio-inspired Materials, MSPI, AROMAN, Decision-making*

1. INTRODUCTION

In recent times, the manufacturing sectors are incorporating the aspect of sustainability into their production process and product design. The production of sustainable products is highly determined by the choice of the input materials contributing to sustainability. Bio-inspired materials are one such kind of materials which possess the characteristics of the natural materials. These sustainable driven materials possess the attributes of strength efficacy and adaptability. There are several bio-inspired materials available with different attributes which constraints the manufacturers in making optimal ranking decisions. In general, the multi-criteria decision-making methods (MCDM) are applied to resolve such decisioning challenges. A MCDM is characterized by alternatives, criteria and a suitable decisioning method. Different methods of finding the criterion weights and ranking of the alternatives are developed to deal with diverse decisioning circumstances. Researchers have also developed new decision-making methods encompassing various normalization techniques. This research work applies two recently developed methods namely MPSI and AROMAN in selection of bio-inspired materials considering the criteria of Strength, Density, Resistance, Cost, Reliability, Elasticity, Biodegradability and Recyclability. Gligori et al[1] introduced the method of modified preference selection index as an extension of the method developed by Maniya and Bhatt. This method is applied in finding the criterion weights. The method of AROMAN is developed by Boskovic et al[2] and it is employed in ranking the alternatives. This paper intends to develop a hybrid method by combining the methods of MPSI and AROMAN.

The methods of MPSI and AROMAN are applied in several decision-making scenarios. Some of the noteworthy and recent applications of MPSI and AROMAN are presented in Table 1. These methods are applied to handle intricate decision challenges.

TABLE 1. Application of MPSI and AROMA

MPSI	
Authors & Year	**Areas of Application**
Chakraborty, S., Chatterjee, P. et al.,(2024)[3]	Multi-Criteria Decision-Making in Manufacturing
Sintaro, S. (2024) [4]	Best Sales Selection
Windarto, A. P., Mesran, M. et al., (2024) [5]	Coffee Shop Selection
Pamucar, D., Ulutaş, A., et al.,(2024) [6]	Green Supplier Selection in Textile Industry
Van Dua, T. (2024) [7]	MEPSI:Enhanced PSI Method for Alternative Ranking
Ren, J., &Esangbedo, M. O. (2024) [8]	University Dormitory Renovation Design
Wibisono, K., Dama, H., et al., (2024)[9]	Rice Genotype Selection under Drought Stress
Sudianto, L., Buna, A. et al., (2024) [10]	Decision Support System for Farmer Assistance
Ayangda, A. S.,Pakpahan, et al., (2024) [11]	Facilitator Performance Evaluation
Sari, F., & Mahmud, S. F. (2024) [12]	AI-Based Math Learning Media Selection
Barus, T., Syahra et al., (2024) [13]	Employee Performance Evaluation
Ritonga, H. M.,Yunizar, Z. et al., (2024) [14]	Coin Selection in Cryptocurrency
Wardana, A., & Putri, R. A. (2024) [15]	Courier Partner Recruitment
Adhicandra, I., Hutahaean, et al., (2024) [16]	IT Staff Selection
Putra, A., Siswanto, S. et al., (2024) [17]	Village Staff Performance Evaluation
Roy, D., Mitra, S.,et al., (2024)[18]	MCDM Selection Problem
AROMAN	
Author & Year	**Area of Application**
Seidman, L. S. (1978) [19]	National health insurance and food crisis
Ambangan, M. A. (2008) [20]	Traditional land use norms and development program policies
Dobrodolac, M., et al.,(2024) [21]	Sustainable delivery model selection
Nikolić, I.,Milutinović,et al., (2023) [22]	Sustainability improvement in postal networks in rural areas
Bošković, S., Švadlenka et al., (2023) [23]	Cargo bike delivery concept selection
Bošković, S., Švadlenka, et al., (2023) [24]	Electric vehicle selection problem
Thinh, H. X., & Van Dua, T. (2024) [25]	Understanding ranking changes with variations in user coefficients
Kiptum, C. K., Bouraima et al., (2024) [26]	Supply chain management in national oil corporations in developing countries
Kara, K., Yalçın, G. C., et al., (2024) [27]	Sustainable competitiveness levels in Turkey
Bouraima, M. B., Jovčić et al., (2024) [28]	Sustainable healthcare system devolution strategy selection
Čubranić-Dobrodolac, et al., (2023) [29]	Professional driver selection using hybridized fuzzy–AROMAN approach
Dündar, S. (2024) [30]	Evaluation of entrepreneurship training across regions
Bošković, S., Švadlenka et al.,(2024) [31]	Propulsion technology selection for penultimate mile delivery
Alrasheedi, A. F., Mishra,et al., (2024) [32]	Wastewater treatment technology selection
Rani, P., Mishra, A. R. et al.,. (2023) [33]	Sustainable human resource management evaluation in manufacturing firms
Kara, K., Yalçın et al.,(2024) [34]	Sustainability performance benchmarking of wind energy power plants
Olteanu, A. L., Ionașcu,et al.,(2024) [35]	Prioritization of European investment sectors based on ESG factors
Hu, L., Yu, Q., Jana et al., (2024) [36]	Sports event management
Anjum, M., Simic, et al.,(2024) [37]	Intelligent transportation systems integration with metaverse technologies
Macit, N. Ş. (2023) [38]	Evaluation of macroeconomic performance of European and Central Asian countries
Song, M., Stević, Ž., et al., (2024) [39]	Public acceptance assessment of autonomous vehicles
Güçlü, P. (2024) [40]	Comparative analysis of hybrid MCDM methods with normalization techniques in sustainable competitiveness assessment

The applications of both MPSI and AROMAN presented in Table 1 exhibits the efficacy and diverse applications of both the methods to the readers. Also, the combinations in which these methods are used are presented in Table 2 to identify the research gaps and to demonstrate the novel contributions of this work.

TABLE 2. Combination of methods used in MPSI and AROMA

MPSI	• Combined Compromise Solution • Fermatean Fuzzy Framework • Mutriss Enhanced Preference Selection Index (MEPSI) • Grey Preference Selection Index
AROMAN	• BWM-AROMAN • Fuzzy AROMAN • Interval Type-2 Fuzzy AROMAN • FullEX-AROMAN • MEREC-AROMAN • Interval-Valued Intuitionistic Fuzzy AROMAN • RANCOM-AROMAN • Spherical Fuzzy DIBR II-AROMAN • Intuitionistic Fuzzy SWARA-AROMAN • Pythagorean Fuzzy CRITIC-AROMAN • CILOS-Based AROMAN • IRN PIPRECIA-IRN AROMAN • DNMARCOS-AROMAN

The Table 2 shows that the combination of MPSI and AROMAN is not explored and this motivates the authors to evolve a new method with the combination of the above said methods. Also, neither of the methods is applied in decision making on bio-inspired materials in specific. To bridge these gaps, this research work attempts to conceptualize the development of this hybrid method and apply the same in criterion weight computations and ranking of the alternatives. The remaining of the paper is structured in to the following sections. Section 2 presents the methodology of MPSI and AROMAN. Section 3 describes the decision-making problem considered for this study. Section 4 discusses the results and the last section concludes the work.

2. METHODOLOGY OF INTEGRATED MPSI-AROMAN [40]

This section presents the steps involved in the integrated method of MPSI and AROMAN. The method of MPSI is applied in computing the criterion weights and the method of AROMAN is applied in ranking of the alternatives.

Step 1: Construct the initial decision-making matrix M

The initial decision-making is constructed where m denotes alternatives and n denotes criteria as follows.

$$M = [x_{ij}]_{mxn} = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix}$$

Step 2: Obtain the normalized decision matrix R.

Linear normalization technique normalizes the initial decision matrix elements, and normalized matrix R is formed as follows using linear max-min

Benefit criteria $$n_{ij} = \frac{x_{ij} - min\, x_{ij}}{max\, x_{ij} - min\, x_{ij}}$$

Cost criteria $n_{ij} = \frac{maxx_{ij} - x_{ij}}{maxx_{ij} - minx_{ij}}$

$$R = [r_{ij}]_{mxn} = \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mn} \end{bmatrix}$$

Step 3: Calculate each criterion's mean normalized value v alt j.m

$$v_j = \frac{\sum_{i=1}^{m} r_{ij}}{m}, \qquad j = 1,2, \ldots \ldots . . n$$

Step 4: Calculate the preference variation value (p_j) of criteria.

$$p_j = \sum_{i=1}^{m} (r_{ij} - v_j)^2 \text{ ,} j = 1,2, \ldots \ldots . n$$

Step 5: Calculate the criteria weights (w_j).

$$w_j = \frac{p_j}{\sum_{j=1}^{n} p_j}$$

Step 6 : Normalize the matrix again using Vector normalization methods

Benefit criteria $n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}$

Cost criteria $n_{ij} = 1 - \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}$

Step 7: Aggregated Normalization Value

The aggregated average normalization values are calculated by

$$t_{ij}^{norm} = \frac{\beta t_{ij} + (1-\beta) t_{ij}^{*}}{2} i = 1,2, \ldots . m; j = 1,2, \ldots . . n$$

β denotes the weight of the linear normalization methods, varies between 0 and 1.

Step 8: Weighted normalized matrix

The normalized matrix is converted to weighted normalized form using the weights obtained in step 5.

$$\hat{t}_{ij} = W_{ij} . t_{ij}^{norm} i = 1,2, \ldots . m; \quad j = 1,2, \ldots n$$

Step 9: The sum weighted normalized values of criteria are calculated by separating their types (max and min)

$$L_i = \sum_j \hat{t}_{ij}^{(\min)} \quad i = 1,2, \dots . m; \quad j \in costcriteria$$

$$A_i = \sum_j \hat{t}_{ij}^{(\max)} \quad i = 1,2, \dots . m; \quad j \in benefitcriteria$$

Step 10: The final values of criteria function (R_i) are computed.

$$R_i = L_i^{\lambda} + A_i^{(1-\lambda)} \quad i = 1,2, \dots \dots . . m$$

Step 11: Rank the R_i values by decreasing order. The highest value of R_i denotes the best alternatives.

The algorithmic framework of the above steps is presented graphically in Fig.1.

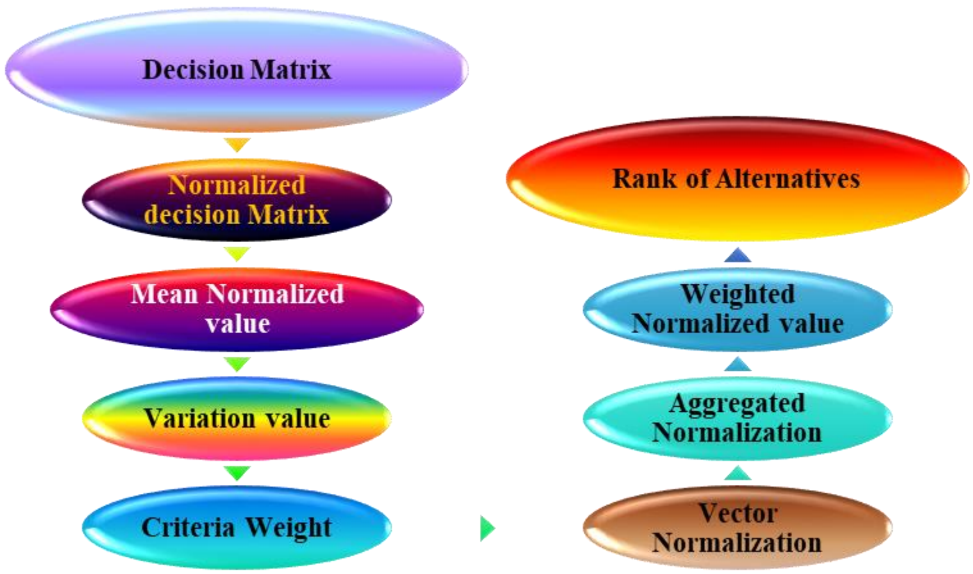

FIGURE 1. Overview of the Algorithmic Framework

3. APPLICATION OF THE INTEGRATED MPSI-AROMAN IN BIO-INSPIRED MATERIAL SELECTION

Problem Definition:
Let us consider a managerial situation, where a manufacturing firm decides to produce products with the inputs of bio-inspired materials; however, the firm is not sure of the choice of the materials. The research and development department has collected the possible data of the characteristics of different bio-inspired materials and it is presented in Table 3.

TABLE 3. Characteristics of Various Bio-inspired Materials

Material	Description
Spider Silk (BM1)	A lightweight, highly elastic, and exceptionally strong material produced by spiders, known for its tensile strength and energy-absorbing capacity.
Lotus Leaf-inspired Coatings (BM2)	Materials that mimic the hydrophobic surface of lotus leaves, offering self-cleaning and water-repellent properties for protective applications.
Shark Skin-inspired Materials(BM3)	Textured materials designed to reduce drag and resist microbial adhesion, inspired by the micro-patterns on shark skin.
Bone-like Composites(BM4)	Synthetic materials replicating the structure and properties of natural bone, providing high strength, stiffness, and biocompatibility.
Chameleon-inspired Materials (BM5)	Materials that mimic the color-changing ability of chameleons, often used for adaptive camouflage and responsive surface applications.
Butterfly Wing-inspired Crystals(BM6)	Photonic materials inspired by butterfly wings, known for their iridescent colors and high optical efficiency in light manipulation.
Gecko-inspired Adhesives(BM7)	Sticky materials that replicate the microscopic hair structures on gecko feet, enabling strong adhesion to smooth surfaces without glue.
Cellulose-based Materials(BM8)	Eco-friendly materials derived from natural cellulose, valued for their renewability, biodegradability, and diverse mechanical properties.

The criteria considered for decision making are presented in Table 4.

TABLE 4. Criteria for Decision making

Criteria	Strength (C1)	Density (C2)	Resistance (C3)	Cost (C4)	Reliability (C5)	Elasticity (C6)	Biodegradability (C7)	Recyclability (C8)

The initial decision making matrix of order 8 × 8 is formulated with each of the entries represent the percentage of the alternatives satisfying the criteria.

Step 1: Formulation of initial decision -making matrix
The Table 5 comprises the initial decision-making matrix based on the expert's opinion.

TABLE 5. Initial decision-matrix

Alternatives	**Max**	**Max**	**Max**	**Min**	**Max**	**Max**	**Max**	**Max**
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**
BIM1	65	65	85	35	100	95	80	75
BIM2	5	55	95	65	85	20	70	90
BIM3	15	60	95	80	95	10	40	90
BIM4	95	100	80	45	100	55	90	100
BIM5	10	65	90	100	80	95	30	50
BIM6	55	55	95	75	90	35	30	90
BIM7	40	60	100	65	100	45	70	100
BIM8	35	50	85	20	95	20	90	100

Step 2: Linear Normalization of matrix
The linear normalization matrix values are presented in Table 6.

TABLE 6. Linear Normalization matrix

Alternatives	C1	C2	C3	C4	C5	C6	C7	C8
BIM1	0.684211	0.65	0.85	0.571429	1	1	0.888889	0.75
BIM2	0.052632	0.55	1	0.307692	0.894737	0.210526	0.736842	0.947368
BIM3	0.157895	0.6	1	0.25	1	0.105263	0.421053	0.947368
BIM4	1	1	0.842105	0.444444	1.052632	0.578947	0.947368	1.052632
BIM5	0.105263	0.65	0.947368	0.2	0.842105	1	0.315789	0.526316
BIM6	0.578947	0.55	1	0.266667	0.947368	0.368421	0.315789	0.947368
BIM7	0.421053	0.6	1.052632	0.307692	1.052632	0.473684	0.736842	1.052632
BIM8	0.368421	0.5	0.894737	1	1	0.210526	0.947368	1.052632

Step 3: Mean normalized value

Using the values from the linear normalized matrix, we can calculate the mean normalized value for each criterion. The mean values are shown in Table 7

TABLE 7. Mean normalized value

vj	0.421053	0.6375	0.948355	0.418491	0.973684	0.493421	0.663743	0.909539

Step 4 : Preference variation value of criteria

The preference variation value for each criterion values are presented in table 8.

TABLE 8. Variation Value

pj	0.736842	0.16875	0.042714	0.485947	0.038781	0.847299	0.523306	0.238032

Step 5: Computation of Criterion Weights

Using the preference variation values, we can calculate the criterion weight for each criterion, as presented in Table 9.

TABLE 9. Criterion Weight

	C1	C2	C3	C4	C5	C6	C7	C8
wj	0.239105	0.054759	0.013861	0.157689	0.012584	0.274948	0.169812	0.077241

Step 6 : Vector Normalization

Normalize the matrix obtained in step 1 again using vector normalization methods and the values are presented in Table 10.

Table 10. Vector Normalization matrix

	C1	C2	C3	C4	C5	C6	C7	C8
BIM1	30.29472	22.84618	28.11795	-5.63132	37.85734	56.82398	33.82505	22.51351
BIM2	0.179259	16.35733	35.12311	-21.8713	27.35193	2.518514	25.8973	32.41946
BIM3	1.613328	19.46657	35.12311	-33.6452	34.16625	0.629629	8.456263	32.41946
BIM4	64.71239	54.07381	24.90725	-9.96197	37.85734	19.04626	42.80983	40.02402
BIM5	0.717035	22.84618	31.52324	-53.1332	24.2287	56.82398	4.756648	10.00601
BIM6	21.6903	16.35733	35.12311	-29.4499	30.66444	7.71295	4.756648	32.41946
BIM7	11.47256	19.46657	38.91758	-21.8713	37.85734	12.74998	25.8973	40.02402
BIM8	8.783676	13.51845	28.11795	-1.16533	34.16625	2.518514	42.80983	40.02402

Step 7: Aggregate Normalization of the Matrix
The aggregated value of the normalized matrix is shown in table 11.

TABLE 11. Aggregated Normalization Matrix

	C1	C2	C3	C4	C5	C6	C7	C8
BIM1	7.740346	5.786546	7.091987	-1.22727	9.714335	14.45599	8.664596	5.753378
BIM2	0.044815	4.114332	8.968278	-5.3706	6.900482	0.65904	6.640993	8.304864
BIM3	0.43111	4.916643	8.968278	-8.35576	8.729062	0.157407	2.155732	8.304864
BIM4	16.4281	13.76845	6.226812	-2.33772	9.714335	4.893919	10.95246	10.25601
BIM5	0.193148	5.786546	8.005809	-13.2833	6.057174	14.45599	1.189162	2.501501
BIM6	5.561464	4.114332	8.968278	-7.29304	7.791111	2.001767	1.189162	8.304864
BIM7	2.965361	4.916643	9.979394	-5.3706	9.714335	3.290436	6.640993	10.25601
BIM8	2.279252	3.379613	7.091987	-0.06911	8.729062	0.65904	10.95246	10.25601

Step 8: Weighted Normalization Matrix
The values of the weighted normalization matrix are presented in Table 12.

TABLE 12. Weighted Normalization Matrix

	C1	C2	C3	C4	C5	C6	C7	C8
BIM1	1.850753	0.316867	0.098299	-0.19353	0.12225	3.974645	1.471356	0.444398
BIM2	0.010715	0.225298	0.124306	-0.84689	0.086839	0.181202	1.127723	0.641479
BIM3	0.10308	0.269232	0.124306	-1.31761	0.10985	0.043279	0.36607	0.641479
BIM4	3.928034	0.75395	0.086307	-0.36863	0.12225	1.345573	1.859864	0.792187
BIM5	0.046182	0.316867	0.110965	-2.09464	0.076226	3.974645	0.201935	0.193219
BIM6	1.329772	0.225298	0.124306	-1.15003	0.098047	0.550382	0.201935	0.641479
BIM7	0.709032	0.269232	0.13832	-0.84689	0.12225	0.904698	1.127723	0.792187
BIM8	0.54498	0.185065	0.098299	-0.0109	0.10985	0.181202	1.859864	0.792187

The final values of the criteria function have been computed. The values are ranked in decreasing order, with the highest value representing the best alternatives are presented in Table 13.

TABLE 13. Ranking of Bio-inspired Materials

Alternatives	**BIM1**	**BIM2**	**BIM3**	**BIM4**	**BIM5**	**BIM6**	**BIM7**	**BIM8**
Final Score Values	3.317168	2.46867	2.435234	3.588454	3.665402	2.853188	2.936062	2.046414
Rankings	3	6	7	2	1	5	4	8

4. RESULTS AND DISCUSSION

The ranking results obtained using different the integrated approach of MPSI and AROMAN are compared with 3 other ranking results obtained using the combinations of Equal weights-AROMAN, CRITIC-AROMAN and MEREC-AROMAN. The comparison of ranking results is shown in Table 14.

TABLE 14. Comparison of Ranking results

Alternatives	**BM1**	**BM2**	**BM3**	**BM4**	**BM5**	**BM6**	**BM7**	**BM8**
Equal weights-AROMAN								
Scores	3.160377	3.030738	3.199187	3.612149	3.632158	3.249866	3.363704	2.432144
Ranks	6	7	5	2	1	4	3	8
CRITIC-AROMAN								
Scores	3.16337	3.033489	3.165836	3.489595	3.683203	3.201179	3.347834	2.419708
Ranks	6	7	5	2	1	4	3	8
MEREC-AROMAN								
Scores	3.151955	3.161283	3.329162	3.558769	3.587602	3.333034	3.484318	2.586861
Ranks	7	6	5	2	1	4	3	8

The different score values and ranking results obtained using three other combinations of criterion weights with AROMAN ranking method is presented above. For better understanding the score values are presented graphically as in Fig.2.

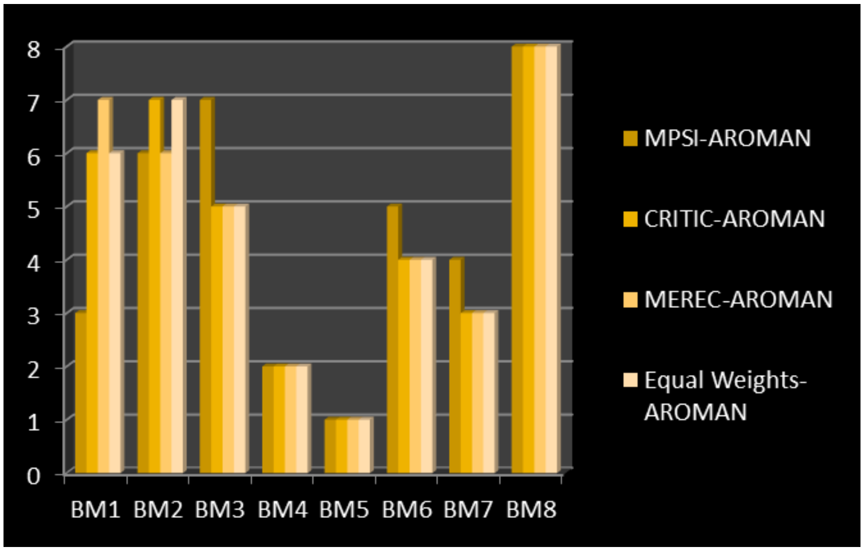

FIGURE 2. Score values Graph

The fig.2. represents the rankings of alternatives (BM1 to BM8) across four methods.
The Table 15 presents the rank correlation to determine the consistency of the ranking results.

Table 15. Rank Correlation Results

Alternatives	MPSI-AROMAN	CRITIC-AROMAN	MEREC-AROMAN	Equal Weights-AROMAN
MPSI-AROMAN	1	0.80952	0.738095	0.809524
CRITIC-AROMAN		1	0.976190	1
MEREC-AROMAN			1	0.976190
Equal Weights-AROMAN				1

From the above table, the efficacy of MPSI-AROMAN in capturing the distinctive nuances is inferred and it is not much completely reflected by CRITIC, MEREC, or Equal Weights approaches. The combination of MPSI-AROMAN produces rankings aligned with the other methods introducing certain distinctiveness in prioritizing the alternatives.

5. CONCLUSION

A hybrid decision making method by combining MPSI and AROMAN is developed in this research work. This hybrid decision approach is applied in ranking the alternatives of bio-inspired materials with the computation of core criterion weights. The results obtained are compared with other different combinations and it is found that the ranking results are more consistent and compatible. The proposed hybrid decision method shall be applied to other managerial decision-making challenges. This research work has more scope as it provides room for evolving diverse methods of decisioning and extending the applications of MCDM methods.

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