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EVALUATING THE PARAMETERS FOR SELECTING THE BEST METHOD FOR THE PREPARATION OF NANOCRYSTALS BY USING FUZZY ANALYTIC HIERARCHY PROCESS

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Keywords:

Nanocrystals, Sonoprecipitation, Fuzzy Analytic Hierarchy Process (AHP), Fuzzy Linguistic, α-cut-based method, Multi-Criteria Decision Making (MCDM)

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ABSTRACT: The aim of this paper is to select the best method for the preparation of nanocrystals by using the fuzzy analytic hierarchy process (Fuzzy-AHP) methodology. The commonly used methods for the preparation of nanocrystals are Hydrosol, sonoprecipitation, spray freezing into liquid, and Nanomorph®. There are several parameters to take into consideration for the selection of the best method like operational skill, technical information, benefits, expenditure, etc. To improve the traditional AHP, Fuzzy concepts are applied because it is well organized and logical compared to other decision making technique. In order to avoid the controversial of fuzzy ranking process, the α-cut-based method has been used. Based on the results of FAHP it is concluded that sonoprecipitation is the best method for the preparation of nanocrystals. The fuzzy approach gives a more apt and agreeable result compared to the traditional AHP. Our study shows that the FAHP is a suitable and constructive approach to select the best method for the preparation of Nanocrystals. This study reveals that sonoprecipitation method is the most appropriate technique for the preparation of nanocrystals.

INTRODUCTION: The majority of the pharmaceutical dosage forms are administered orally, and the bioavailability of such dosage forms are not upto the mark. So, in order to overcome this problem, many researchers developed an innovative drug delivery system called nanocrystals which is also a novel drug delivery system [1]. Today, Novel drug delivery systems (NDDS) are the cutting edge of research in the pharmaceutical field [2]. Pharmaceutical formulations with NDDS have been introduced with the aim of optimizing bioavailability by modulating the time course of the drug concentration in blood [3, 4].

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Nano drug delivery systems are nanoparticles, nanospheres, solid lipid nanoparticles, nanosponges, nanosuspensions, nanoemulsions, molecular system (inclusion complexes), and nanocrystals [5]. Nanocrystal technology is very useful to enhance the solubility of poorly soluble drug products, hence in this emerging field of nanocrystal technology, there is a need for the production of nanocrystals from lab scale to large scale. As there is number of methods for the preparation, the goal is to select the best method [6]. The overall goal is to select the best method for the preparation of nanocrystals with sufficient low cost and structural integrity. This is influenced by various factors such as operational skill, processing condition, consistency, flexibility, technical information *etc*.

Fuzzy set theory is a useful tool for solving the above problem. The fuzzy set theory is the body of concepts and techniques that gave a norm mathematical precision to human cognitive process, which in many ways are imprecise and ambiguous by the standards of classical mathematics. In the fuzzy set theory of concept and techniques, for instance, in AHP we use a 1 to 9 real number scale to describe the relative importance between criteria or alternative with respect to a criteria [7]. Since, the concept of relative importance such as strong importance is linguistically ambiguous, a triangular fuzzy 1 to 9 scale can be used to represent the fuzziness in criteria definitions as well as the uncertainty in subjective judgments and incomplete objective information. So, fuzzy multiple criteria decision-making techniques are a very useful tool for the selection of the best method for the preparation of nanocrystals.

The Fuzzy AHP presented in this paper applied for the triangular fuzzy number through symmetric triangular membership function, which is depicted in **Fig. 1**. In norm, fuzzy number is represented by a cap on top. A triangular fuzzy number is the special class of fuzzy number whose membership defined by three real numbers, expressed as (*l, m, u*).

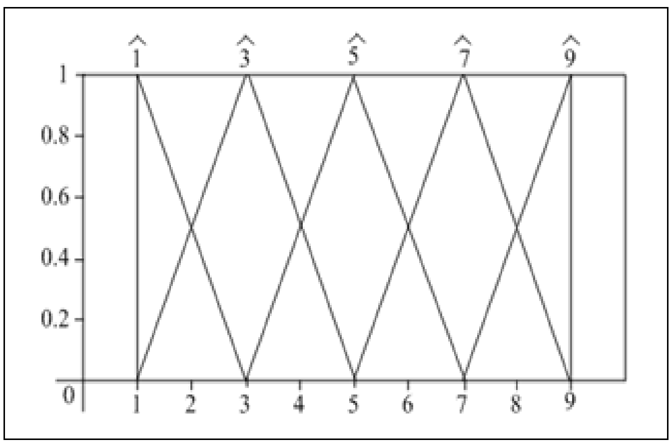

FIG. 1: SYMMETRIC TRIANGULAR MEMBERSHIP FUNCTION

The inability of traditional AHP to deal with the vagueness in the pairwise comparison process has been enhanced in Fuzzy AHP. Instead of a single crisp value, Fuzzy AHP used a range of value to incorporate decision maker's uncertainty [8].

The earliest work in fuzzy AHP appeared in van Laarhoven and Pedrycz [9], which compared fuzzy ratios described by triangular membership functions as shown in **Fig. 2**. A new approach for handling fuzzy AHP, for making pairwise comparison scale of fuzzy AHP with the use of fuzzy triangular numbers and also for extent analysis method for the synthetic extent values for making pairwise comparisons was introduced by Chang [10].

A method to evaluate different production cycle alternatives adding the mathematics of fuzzy logic to the classical AHP was presented by Weck [11]. For making a fuzzy weighted evaluation by obtaining the weights from AHP, a fuzzy objective and subjective method were used by Kahraman [12]. Deng [13] in a simple and straightforward manner presents a fuzzy approach for tackling qualitative multi-criteria analysis problems. A new method for evaluating weapon systems based on linguistic variable weight by analytical hierarchy process was proposed by Cheng [14]. The AHP is a theory for discussing complex socio-political, technological and economic problems [15, 16].

The present study was aimed on fuzzy analytic hierarchy process (FAHP) as a tool to select the best method among the various methods such as M1 Hydrosol, M2Sonoprecipitation, M3 Spray freezing into liquid and M4 Nanomorph® for preparation of nanocrystals.

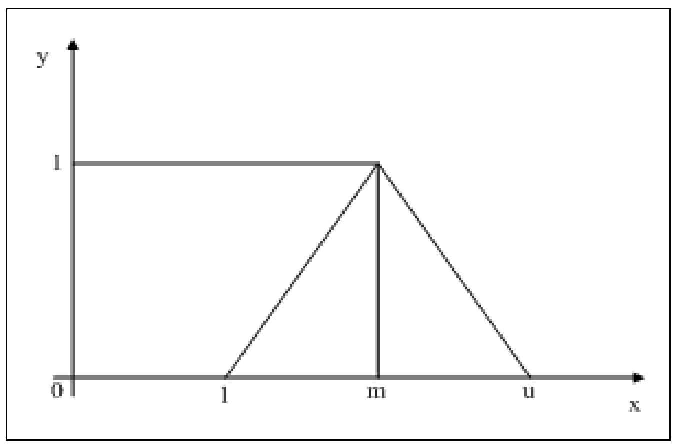

FIG. 2: TRIANGULAR MEMBERSHIP FUNCTION

Fig. 3 shows, a typical FAHP model consists of at least four hierarchical levels. The top-level explains the overall objective of the analysis. The second level includes all relevant and important evaluation criteria (in our study, Method information, Operation skill, Viability, and Technical information) that influence the overall objective. The third level sub-criteria is identified and structured into a hierarchy descending from the overall objective.

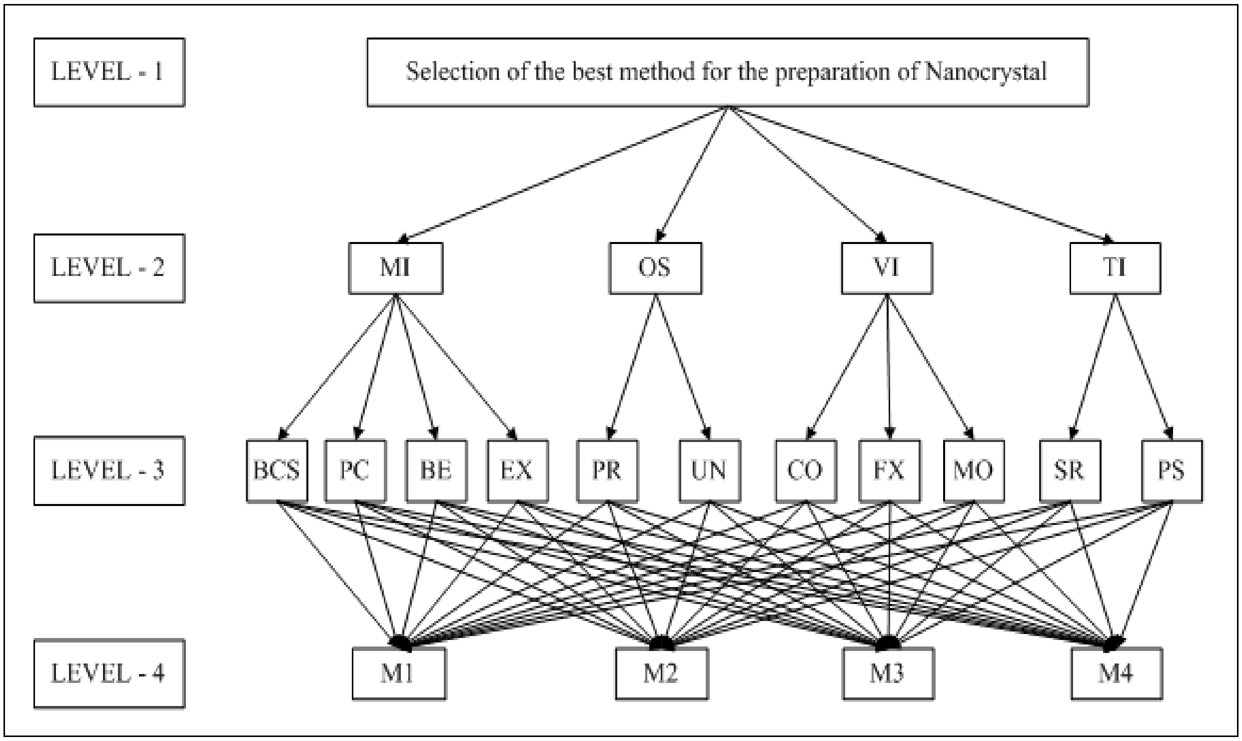

FIG. 3: SELECTION OF THE BEST METHOD FOR THE PREPARATION OF NANOCRYSTALS

First, the objective is presented at the top level of the hierarchy that is to select the most suitable method for the preparation of nanocrystals.

The main criteria can be classified into four aspects: Method Information (MI), Operational Skill (OS), Viability (VI), and Technical Information (TI).

The sub-criteria are represented at the third level of the hierarchy. There are four sub-criteria that refer to Method information: BCS (Biopharmaceutical Classification system), Classification of drugs (BCS), Processing conditions (PC), Benefits (BE) and Expenditure (EX). Performance (PR) and Understanding (UN) add value for Operational Skill. Consistency (CO), Flexibility (FX) and Monotonous (MO) are the subcriteria that add values to Viability. Size reduction (SR) and Processing steps (PS) are the subcriteria that add values to Technical Information respectively.

Finally, at the lowest level of the hierarchy, the alternative methods (M) for nanocrystals preparation are identified, which are the decision alternatives: M1 Hydrosol, M2 Sonoprecipitation, M3 Spray freezing into liquid and M4 Nanomorph®.

To indicate preferences and to make pairwise comparisons between pairs of criteria and between pairs of alternatives, a standard 9-unit scale is used. The matrix derived from the pairwise comparison using a Saaty's or nine-point scale is called judgment matrix [17].

Methodology of Fuzzy AHP: The Fuzzy-AHP methodology extends Saaty's AHP (Saaty's scale expressed in fuzzy numbers shown in **Table 1**) by combining it with the fuzzy set theory. In the Fuzzy- AHP to indicate the relative strength of the factors in the corresponding criteria, fuzzy ratio scales are used. Therefore, a fuzzy judgment matrix can be constructed. Using the triangular fuzzy method from the judgment matrix, normalization value is calculated from weight vectors. The sum of normalization value gives rank for all alternatives, which gives the choice of selection of best method for the preparation of nanocrystals [18].

TABLE 1: SAATY'S SCALE EXPRESSED IN FUZZY NUMBERS

Relative importance	Definition
1	Equal importance
3	Weak importance
5	Strong importance
7	Demonstrated importance over the other
9	Absolute importance

Fuzzy AHP Workflow: The workflow of Fuzzy AHP is depicted below **Fig. 4**.

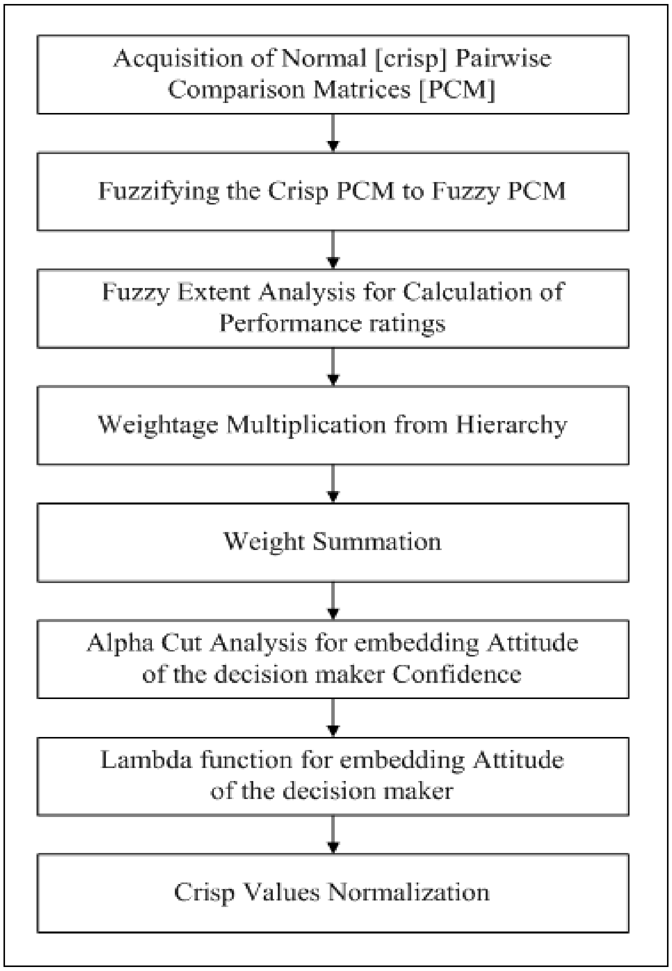

FIG. 4: FUZZY ANALYTICAL HIERARCHY PROCESS (AHP) WORKFLOW

Acquisition of Crisp PCM and Fuzzyfying the Crisp PCM to Fuzzy PCM: In the fuzzy AHP, for the fuzzification of the crisp PCM, the triangular fuzzy number is used. For a crisp PCM *A* (eq. 1), having values ranging from 1/9 to 9, by using the triangular fuzzy number $f = (l,m,u)$, the crisp PCM is fuzzified, which fuzzified the original PCM using the conversion number as shown in **Table 2**. Decision-maker represents the range in the form of *l* (lower bound) and *u* (upper bound).

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{1n} \\ a_{21} & a_{22} & a_{2n} \\ \cdot & \cdot & \cdot \\ \ddots & \vdots & \vdots \\ a_{m1} & a_{m2} & a_{mn} \end{bmatrix} \text{(eq. 1)}$$

The fuzzy PCM, $\tilde{A}$ is as follows,

$$\tilde{A} = \begin{bmatrix} (a_{11l} a_{11m} a_{11u}) & (a_{12l} a_{12m} a_{12u}) & \cdots & (a_{1nl} a_{1nm} a_{1nu}) \\ (a_{21l} a_{21m} a_{21u}) & (a_{22l} a_{22m} a_{22u}) & \cdots & (a_{2nl} a_{2nm} a_{2nu}) \\ \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdots & \cdot \\ (a_{m1l} a_{m1m} a_{m1u}) & (a_{m2l} a_{m2m} a_{m2u}] & \cdots & (a_{mnl} a_{mnm} a_{mnu}) \end{bmatrix} \text{(eq. 2)}$$

Fuzzy Extent Analysis for Calculation of Performance Ratings, Weight Multiplication, and Summation: In order to obtain fuzzy performance matrix, fuzzy extent analysis is applied on the above fuzzy PCM. By solving the fuzzified reciprocal PCMs, we can obtain criteria importance and alternative performance, and this is the main purpose of applying the Fuzzy extent analysis. The Fuzzy extent analysis is applied after obtaining the fuzzified pairwise comparison matrices, and it is as follows:

For the fuzzified pairwise comparison

The total sum of the whole fuzzy PCM:

Left = add all the left values of rows and columns of fuzzified pairwise comparison (b_1)

Middle = add all the middle values of rows and columns of fuzzified pairwise comparison (b_2)

Right = add all the right values of rows and columns of fuzzified pairwise comparison (b_3)

The first-row sum

Left = add all the left values of the first row of fuzzified pairwise comparison (a_1)

Middle = add all the middle values of the first row of fuzzified pairwise comparison (a_2)

Right = add all the right values of the first row of fuzzified pairwise comparison (a_3)

First-row sum / total sum =

Left = a_1 / b_3

Middle = a_2 / b_2

Right = a_3 / b_1

The second-row sum

Left = add all the left values of the second row of fuzzified pairwise comparison (a_1)

Middle = add all the middle values of the second row of fuzzified pairwise comparison (a_2)

Right = add all the right values of the second row of fuzzified pairwise comparison (a_3)

Second row sum / total sum =

Left = a_1 / b_3

Middle = a_2 / b_2

Right = a_3 / b_1

The third-row sum

Left = add all the left values of third row of fuzzified pairwise comparison (a_1)

Middle = add all the middle values of third row of fuzzified pairwise comparison (a_2)

Right = add all the right values of third row of fuzzified pairwise comparison (a_3)

Third row sum / total sum =

Left = a_1 / b_3

Middle = a_2 / b_2

Right = a_3 / b_1

The fourth-row sum

Left = add all the left values of the fourth row of fuzzified pairwise comparison (a_1)

Middle = add all the middle values of the fourth row of fuzzified pairwise comparison (a_2)

Right = add all the right values of the fourth row of fuzzified pairwise comparison (a_3)

Fourth-row sum / total sum =

Left = a_1 / b_3

Middle = a_2 / b_2

Right = a_3 / b_1

To get the weighted performance of the left alternative (P) in the context of sub-criteria, multiply the left value of the overall weight of criteria with the left value of overall weight of the sub-criteria and also with the left value of overall weight of the alternative.

To get the weighted performance of the middle alternative (P) in the context of sub-criteria, multiply the middle value of the overall weight of criteria with the middle value of the overall weight of sub-criteria and also with the middle value of overall weight of the alternative.

To get the weighted performance of the right alternative (P) in the context of sub-criteria multiply the right value of overall weight of criteria with the right value of the overall weight of sub-criteria and also with the right value of the overall weight of alternative.

(P) = weighted performance of the respective alternatives.

To get the total weighted performance of all the alternatives to add all the values of particular alternative, that is to get the total weighted performance of the left value of a particular alternative adds the left values of particular alternative from the weighted performance of each alternative in the context of sub-criteria.

Similarly, to get the total weighted performance of all the alternatives to add all the values of a particular alternative to get the total weighted performance of middle value of particular alternative add the middle values of particular alternative from the weighted performance of each alternative in the context of sub-criteria.

Similarly, to get the total weighted performance of all the alternatives to add all the values of a particular alternative, that is to get the total weighted performance of the right value of a particular alternative, add the right values of particular alternative from weighted performance of each alternatives in the context of sub-criteria.

Check Fuzzy Ranking with Alpha-Cuts-Based Method 1: For checking and comparing fuzzy number in order to make a crisp choice among the alternatives, alpha-cuts-based method 1 is needed according to Wang[19]. The alpha-cuts-based method 1 stated that if let A and B be fuzzy numbers with α-cuts, $A_\alpha = [a_\alpha^-, a_\alpha^+]$ and $B_\alpha = [b_\alpha^-, b_\alpha^+]$. If say A is smaller than B, denoted by $A \leq B$, if $a_\alpha^- < b_\alpha^-$ and $a_\alpha^+ < b_\alpha^+$ for all $\alpha \in (0.1]$. The advantage of this method is less controversial. So, here the alpha cut analysis is applied to the total weighted performance matrices under different alpha level circumstances for checking ranking consistency for each alternative.

Alpha Cut Analysis for Confidence Level Representation: Total weighted performance matrices are transformed into interval performance matrices by applying alpha cut analysis. In the fuzzy range chosen, alpha cut is to account for the uncertainty and the decision maker expresses the confidence range between 0 and 1 that is least confidence to the most confidence. The alpha cut analysis will give two values, namely Alpha_Left (minimum range) (equation 3) and Alpha_Right (maximum range) (equation 4).

Alpha Cuts Analysis

α_{Left} = [α * (Middle_fuzzy – Left_fuzzy)] + Left_fuzzy (equation 3)

α_{Right} = Right_fuzzy – [[α * (Right_fuzzy – Middle_fuzzy)] (equation 4)

Lambda Function and Crisp Values Normalization: From the above alpha cut analysis, we get two values namely Alpha_Right and Alpha_Left. Alpha_Right represents the maximum range and Alpha_Left represents the minimum range and these values need to be converted into a crisp value (using equation 5) by applying the Lambda function, which represents the attitude of the decision-maker. Decision-makers with an optimistic attitude will take the maximum value and the pessimistic person will take the minimum value of the range. To obtain the crisp output (using equation 6), the concept of optimism index λ, is introduced.

Crisp_value = λ * α_{Right} + [(1– λ) * α_{Left}] (equation 5)

$C_\lambda = \lambda * P_{r\alpha} + (1-\lambda) * P_{l\alpha}$ (equation 6)

Where λ = [0, 1]

The elements of the pairwise comparison matrices do not have the same scale, so crisp values need to be normalized. It is important to note that elements can be compared if they have a uniform scale.

Crisp value after normalization = crisp value/sum of the crisp values.

RESULTS:

Assessment Using Traditional AHP: Final scores and ranking for each alternative can be obtained by performing the traditional AHP operations from the values given in **Table 3-7**. It is required to perform consistency index (CI) and consistency ratio (CR) to check the consistency of the pairwise comparison matrix. A pairwise comparison matrix of criteria and sub-criteria is given.

The degree of consistency is satisfactory because the Consistency Ratio (CI/CR) is <0.10. Therefore, the decision maker's comparison is almost consistent enough to use. The scores of Alternatives are given in **Table 8**.

TABLE 3: PAIRWISE COMPARISON OF CRITERIA WITH RESPECT TO OVERALL GOAL

Goal	MI	OS	VI	TI
Method Information (MI)	1	3	A=5	5
Operation Skill (OS)	1/3	1	3	3
Viability (VI)	1/5	1/3	1	3
Technical Information (TI)	1/5	1/3	1/3	1
Total Column	1.73	4.66	9.33	12

Note: λ_{max} = 4.18; Consistency Index (CI) = 0.06; Given random Index, RI, n = 4; RI = 0.90; Consistency Ratio (CR) = CI/ RI = 0.06/0.90 = 0.06

TABLE 4: CONSISTENCY TEST FOR SUB-CRITERIA

G/MI	BCS	PC	BE	EX
BCS	1	3	3	5
PC	1/3	1	1/3	3
BE	1/3	3	1	3
EX	1/5	1/3	1/3	1

Note: λ_{max}=4.18; Consistency index (CI) = 0.06; Given random Index, RI, n = 4; RI = 0.90; Consistency ratio (CR) = CI/ RI = 0.06

TABLE 5: CONSISTENCY TEST FOR SUB-CRITERIA

G/OS	PR	UN
PR	1	5
UN	1/5	1

Note: λ_{max}=1.998; Consistency index (CI) = 0.000; Consistency ratio (CR) = 0.000

TABLE 6: CONSISTENCY TEST FOR SUB-CRITERIA

G/VI	CO	FX	MO
CO	1	3	5
FX	1/3	1	3
MO	1/5	1/3	1

Note: λ_{max} =3.036; Consistency index (CI) = 0.018; Given random Index, RI, n = 4; RI = 0.90; Consistency ratio (CR) = CI/ RI = 0.02.

TABLE 7: CONSISTENCY TEST FOR SUB-CRITERIA

G/TI	SR	PS
SR	1	3
PS	1/3	1

Note: λ_{max} = 2.000; Consistency index (CI) = 0.000; Consistency ratio (CR) = 0.000.

TABLE 8: SCORE OF EACH ALTERNATIVE

Alternative	Score	Rank
M1	0.239	3
M2	0.263	1
M3	0.225	4
M4	0.258	2

TABLE 9: FUZZIFIED PAIRWISE COMPARISON (PCM) OF CRITERIA

Criteria	MI	OS	VI	TI
MI	(1,1,1)	(1,3,5)	(3,5,7)	(3,5,7)
OS	(1/5,1/3,1/1)	(1,1,1)	(1,3,5)	(1,3,5)
VI	(1/7,1/5,1/3)	(1/5,1/3,1/1)	(1,1,1)	(1,3,5)
TI	(1/7,1/5,1/3)	(1/5,1/3,1/1)	(1/5,1/3,1/1)	(1,1,1)

Assessment Using Fuzzy AHP: To perform Fuzzy AHP operations, the original crisp Pairwise Comparison should be fuzzified by referring to the fuzzy number conversion **Table 2**. The fuzzified pairwise comparison (PCM) of Criteria is shown in **Table 9**.

After obtaining fuzzified pairwise comparison matrices, the Fuzzy extent analysis is applied as follows:

For the fuzzified pairwise comparison of criteria,

Total sum of the whole fuzzy PCM:

Left = (1+1+3+3+1/5+1+1+1+1/7+1/5+1+1+1/7+ 1/5+1/5+1) = 15.085(b_1)

Middle = (1+3+5+5+1/3+1+3+3+1/5+1/3+1+3+1/5 +1/3+1/3+1) = 27.733(b_2)

Right = (1+5+7+7+1/1+1+5+5+1/3+1/1+1+5+1/3 +1/1+1/1+1) = 42.666(b_3)

The first row sum (for MI)

Left = 1+1+3+3 = 8(a_1)

Middle = 1+3+5+5 = 14(a_2)

Right = 1+5+7+7 = 20(a_3)

First row sum / total sum =

Left = a_1 / b_3 = 8 / 42.666 = 0.187

Middle = a_2 / b_2 = 14 / 27.733 = 0.504

Right = a_3 / b_1 = 20 / 15.085 = 1.325

The second row sum (for OS)

Left = 1/5+1+1+1 = 3.20 (a_1)

Middle = 1/3+1+3+3 = 7.33 (a_2)

Right = 1/1+1+5+5 = 12 (a_3)

Second row sum / total sum =

Left = a_1 / b_3 = 3.20 / 42.666 = 0.075

Middle = a_2 / b_2 = 7.33 / 27.733 = 0.264

Right = a_3 / b_1 = 12 / 15.085 = 0.795

The third-row sum (for VI)

Left = 1/7+1/5+1+1 = 2.342 (a_1)

Middle = 1/5+1/3+1+3 = 4.533 (a_2)

Right = 1/3+1/1+1+5 = 7.33 (a_3)

Third-row sum / total sum =

Left = a_1 / b_3 = 2.342 / 42.666 = 0.054

Middle = a_2 / b_2= 4.533 / 27.733 = 0.163

Right = a_3 / b_1 = 7.33 / 15.085 = 0.486

The fourth-row sum (for TI)

Left = 1/7+1/5+1/5+1 = 1.542 (a_1)

Middle = 1/5+1/3+1/3+1 = 1.866 (a_2)

Right = 1/3+1+1+1 = 3.333 (a_3)

Fourth-row sum/total sum =

Left = a_1 / b_3 = 1.542 / 42.666 = 0.036

Middle = a_2 / b_2= 1.866/ 27.733 = 0.067

Right = a_3 / b_1 = 3.333 / 15.085 = 0.220

The same calculation above applies to other criteria also that is for Method information (MI), Operational skill (OS), Viability (VI) and Technical information (TI). The same calculation applies to sub-criteria also that is for Method information (MI) the sub-criteria are BCS (Bio-pharmaceutical Classification system), Classification of drugs (BCS), Processing conditions (PC), Benefits (BE) and Expenditure (EX). Performance (PR) and Understanding (UN) add value for Operational Skill. Consistency (CO), Flexibility (FX) and Monotonous (MO) are the subcriteria that add values to Viability. Size reduction (SR) and Processing steps (PS) are the subcriteria that add values to Technical Information, respectively.

The fuzzified Pairwise Comparison (PCM) of Criteria, Sub-criteria, and Alternatives in the context of respective Sub-criteria and calculation of Overall Weight of each Criteria, sub-criteria, and Alternative in the context of respective Sub-criteria (after Fuzzy Extent Analysis) values are shown in **Table 10-40**.

TABLE 10: OVERALL WEIGHT OF EACH CRITERION (AFTER FUZZY EXTENT ANALYSIS)

Criteria	Overall Weight		
	Left	Middle	Right
MI	0.187	0.504	1.325
OS	0.075	0.264	0.795
VI	0.054	0.163	0.486
TI	0.036	0.067	0.220

TABLE 11: FUZZIFIED PAIRWISE COMPARISON (PCM) OF SUB-CRITERIA

Sub-criteria	BCS	PC	BE	EX
BCS	(1,1,1)	(1,3,5)	(1,3,5)	(3,5,7)
PC	(1/5,1/3,1/1)	(1,1,1)	(1/5,1/3,1/1)	(1,3,5)
BE	(1/5,1/3,1/1)	(1,3,5)	(1,1,1)	(1,3,5)
EX	(1/7,1/5,1/3)	(1/5,1/3,1/1)	(1/5,1/3,1/1)	(1,1,1)

TABLE 12: OVERALL WEIGHT OF EACH SUB-CRITERION (AFTER FUZZY EXTENT ANALYSIS)

Sub-criterion	Overall Weight		
	Left	Middle	Right
BCS	0.145	0.463	1.369
PC	0.058	0.180	0.608
BE	0.077	0.283	0.913
EX	0.037	0.071	0.253

TABLE 13: FUZZIFIED PAIRWISE COMPARISON (PCM) OF SUB-CRITERIA

Sub-criteria	PR	UN
PR	(1,1,1)	(3,5,7)
UN	(1/7,1/5,1/3)	(1,1,1)

TABLE 14: OVERALL WEIGHT OF EACH SUB-CRITERION (AFTER FUZZY EXTENT ANALYSIS)

Sub-criteria	Overall Weight		
	Left	Middle	Right
PR	0.428	0.833	1.555
UN	0.122	0.166	0.259

TABLE 15: FUZZIFIED PAIRWISE COMPARISON (PCM) OF SUB-CRITERIA

Sub-criteria	CO	FX	MO
CO	(1,1,1)	(1,3,5)	(3,5,7)
FX	(1/5,1/3,1/1)	(1,1,1)	(1,3,5)
MO	(1/7,1/5,1/3)	(1/5,1/3,1/1)	(1,1,1)

TABLE 16: OVERALL WEIGHT OF EACH SUB-CRITERION (AFTER FUZZY EXTENT ANALYSIS)

Sub-criteria	Overall Weight		
	Left	Middle	Right
CO	0.223	0.605	1.521
FX	0.098	0.291	0.819
MO	0.060	0.103	0.273

TABLE 17: FUZZIFIED PAIRWISE COMPARISON (PCM) OF SUB-CRITERIA

Sub-criteria	SR	PS
SR	(1,1,1)	(1,3,5)
PS	(1/5,1/3,1/1)	(1,1,1)

TABLE 18: OVERALL WEIGHT OF EACH SUB-CRITERION (AFTER FUZZY EXTENT ANALYSIS)

Sub-criteria	Overall Weight		
	Left	Middle	Right
SR	0.250	0.750	1.875
PS	0.150	0.249	0.625

TABLE 19: FUZZIFIED PAIRWISE COMPARISON (PCM) OF ALTERNATIVES IN THE CONTEXT OF BCS

Alternatives	M1	M2	M3	M4
M1	(1,1,1)	(1/5,1/3,1/1)	(1/7,1/5,1/3)	(1/7,1/5,1/3)
M2	(1,3,5)	(1,1,1)	(1/5,1/3,1/1)	(1/7,1/5,1/3)
M3	(3,5,7)	(1,3,5)	(1,1,1)	(1/5,1/3,1/1)
M4	(3,5,7)	(3,5,7)	(1,3,5)	(1,1,1)

TABLE 20: OVERALL WEIGHT OF EACH ALTERNATIVE IN THE CONTEXT OF BCS (AFTER FUZZY EXTENT ANALYSIS)

Alternatives	Overall Weight		
	Left	Middle	Right
M1	0.033	0.058	0.156
M2	0.053	0.153	0.430
M3	0.118	0.315	0.822
M4	0.181	0.472	1.174

TABLE 21: FUZZIFIED PAIRWISE COMPARISON (PCM) OF ALTERNATIVES IN THE CONTEXT OF PC

Alternatives	M1	M2	M3	M4
M1	(1,1,1)	(1/5,1/3,1/1)	(1,3,5)	(3,5,7)
M2	(1,3,5)	(1,1,1)	(1,3,5)	(3,5,7)
M3	(1/5,1/3,1/1)	(1/5,1/3,1/1)	(1,1,1)	(1,3,5)
M4	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/5,1/3,1/1)	(1,1,1)

TABLE 22: OVERALL WEIGHT OF EACH ALTERNATIVE IN THE CONTEXT OF PC (AFTER FUZZY EXTENT ANALYSIS)

Alternatives	Overall Weight		
	Left	Middle	Right
M1	0.121	0.336	0.928
M2	0.140	0.432	1.193
M3	0.056	0.168	0.530
M4	0.034	0.062	0.176

TABLE 23: FUZZIFIED PAIRWISE COMPARISON (PCM) OF ALTERNATIVES IN THE CONTEXT OF BE

Alternatives	M1	M2	M3	M4
M1	(1,1,1)	(1,1,3)	(1/5,1/3,1/1)	(1/5,1/3,1/1)
M2	(1,1,3)	(1,1,1)	(1/5,1/3,1/1)	(1,1,3)
M3	(1,3,5)	(1,3,5)	(1,1,1)	(1,3,5)
M4	(1,3,5)	(1,1,3)	(1/5,1/3,1/1)	(1,1,1)

TABLE 24: OVERALL WEIGHT OF EACH ALTERNATIVE IN THE CONTEXT OF BE (AFTER FUZZY EXTENT ANALYSIS)

Alternatives	Overall Weight		
	Left	Middle	Right
M1	0.060	0.124	0.468
M2	0.080	0.156	0.625
M3	0.100	0.468	1.250
M4	0.080	0.249	0.781

TABLE 25: FUZZIFIED PAIRWISE COMPARISON (PCM) OF ALTERNATIVES IN THE CONTEXT OF EX

Alternatives	M1	M2	M3	M4
M1	(1,1,1)	(1,3,5)	(1,3,5)	(3,5,7)
M2	(1/5,1/3,1/1)	(1,1,1)	(1,3,5)	(1,3,5)
M3	(1/5,1/3,1/1)	(1/5,1/3,1/1)	(1,1,1)	(1,1,3)
M4	(1/7,1/5,1/3)	(1/5,1/3,1/1)	(1,1,3)	(1,1,1)

TABLE 26: OVERALL WEIGHT OF EACH ALTERNATIVE IN THE CONTEXT OF EX (AFTER FUZZY EXTENT ANALYSIS)

Alternatives	Overall Weight		
	Left	Middle	Right
M1	0.145	0.489	1.291
M2	0.077	0.298	0.860
M3	0.058	0.108	0.430
M4	0.056	0.103	0.382

TABLE 27: FUZZIFIED PAIRWISE COMPARISON (PCM) OF ALTERNATIVES IN THE CONTEXT OF PR

Alternatives	M1	M2	M3	M4
M1	(1,1,1)	(1,1,3)	(1,3,5)	(1,1,3)
M2	(1,1,3)	(1,1,1)	(1,3,5)	(1,3,5)
M3	(1/5,1/3,1/1)	(1/5,1/3,1/1)	(1,1,1)	(1,1,3)
M4	(1,1,3)	(1/5,1/3,1/1)	(1,1,3)	(1,1,1)

TABLE 28: OVERALL WEIGHT OF EACH ALTERNATIVE IN THE CONTEXT OF PR (AFTER FUZZY EXTENT ANALYSIS)

Alternatives	Overall Weight		
	Left	Middle	Right
M1	0.100	0.300	0.882
M2	0.100	0.400	1.029
M3	0.060	0.133	0.441
M4	0.080	0.166	0.588

TABLE 29: FUZZIFIED PAIRWISE COMPARISON (PCM) OF ALTERNATIVES IN THE CONTEXT OF UN

Alternatives	M1	M2	M3	M4
M1	(1,1,1)	(1/5,1/3,1/1)	(1,1,3)	(1,1,3)
M2	(1,3,5)	(1,1,1)	(1,3,5)	(1,1,3)
M3	(1,1,3)	(1/5,1/3,1/1)	(1,1,1)	(1,1,3)
M4	(1,1,3)	(1,1,3)	(1,1,3)	(1,1,1)

TABLE 30: OVERALL WEIGHT OF EACH ALTERNATIVE IN THE CONTEXT OF UN (AFTER FUZZY EXTENT ANALYSIS)

Alternatives	Overall Weight		
	Left	Middle	Right
M1	0.080	0.178	0.555
M2	0.100	0.428	0.972
M3	0.080	0.178	0.555
M4	0.100	0.214	0.694

TABLE 31: FUZZIFIED PAIRWISE COMPARISON (PCM) OF ALTERNATIVES IN THE CONTEXT OF CO

Alternatives	M1	M2	M3	M4
M1	(1,1,1)	(1,1,3)	(3,5,7)	(1,3,5)
M2	(1,1,3)	(1,1,1)	(1,3,5)	(1,3,5)
M3	(1/7,1/5,1/3)	(1/5,1/3,1/1)	(1,1,1)	(1,1,3)
M4	(1/5,1/3,1/1)	(1/5,1/3,1/1)	(1,1,3)	(1,1,1)

TABLE 32: OVERALL WEIGHT OF EACH ALTERNATIVE IN THE CONTEXT OF CO (AFTER FUZZY EXTENT ANALYSIS)

Alternatives	Overall Weight		
	Left	Middle	Right
M1	0.145	0.431	1.085
M2	0.096	0.344	0.949
M3	0.056	0.109	0.361
M4	0.058	0.114	0.407

TABLE 33: FUZZIFIED PAIRWISE COMPARISON (PCM) OF ALTERNATIVES IN THE CONTEXT OF FX

Alternatives	M1	M2	M3	M4
M1	(1,1,1)	(5,7,9)	(1,3,5)	(1,3,5)
M2	(1/9,1/7,1/5)	(1,1,1)	(1,1,3)	(1,1,3)
M3	(1/5,1/3,1/1)	(1,1,3)	(1,1,1)	(1,1,3)
M4	(1/5,1/3,1/1)	(1,1,3)	(1,1,3)	(1,1,1)

TABLE 34: OVERALL WEIGHT OF EACH ALTERNATIVE IN THE CONTEXT OF FX (AFTER FUZZY EXTENT ANALYSIS)

Alternatives	Overall Weight		
	Left	Middle	Right
M1	0.185	0.588	1.142
M2	0.071	0.131	0.411
M3	0.074	0.139	0.456
M4	0.074	0.139	0.456

TABLE 35: FUZZIFIED PAIRWISE COMPARISON (PCM) OF ALTERNATIVES IN THE CONTEXT OF MO

Alternatives	M1	M2	M3	M4
M1	(1,1,1)	(1,1,3)	(1,3,5)	(3,5,7)
M2	(1,1,3)	(1,1,1)	(1,1,3)	(1,3,5)
M3	(1/5,1/3,1/1)	(1,1,3)	(1,1,1)	(1,3,5)
M4	(1/7,1/5,1/3)	(1/5,1/3,1/1)	(1/5,1/3,1/1)	(1,1,1)

TABLE 36: OVERALL WEIGHT OF EACH ALTERNATIVE IN THE CONTEXT OF MO (AFTER FUZZY EXTENT ANALYSIS)

Alternatives	Overall Weight		
	Left	Middle	Right
M1	0.145	0.431	1.085
M2	0.096	0.258	0.814
M3	0.077	0.229	0.678
M4	0.037	0.080	0.226

TABLE 37: FUZZIFIED PAIRWISE COMPARISON (PCM) OF ALTERNATIVES IN THE CONTEXT OF SR

Alternatives	M1	M2	M3	M4
M1	(1,1,1)	(1,1,3)	(1,3,5)	(3,5,7)
M2	(1,1,3)	(1,1,1)	(1,1,3)	(3,5,7)
M3	(1/5,1/3,1/1)	(1,1,3)	(1,1,1)	(1,3,5)
M4	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/5,1/3,1/1)	(1,1,1)

TABLE 38: OVERALL WEIGHT OF EACH ALTERNATIVE IN THE CONTEXT OF SR (AFTER FUZZY EXTENT ANALYSIS)

Alternatives	Overall Weight		
	Left	Middle	Right
M1	0.140	0.398	0.958
M2	0.140	0.319	0.839
M3	0.075	0.212	0.599
M4	0.034	0.069	0.159

TABLE 39: FUZZIFIED PAIRWISE COMPARISON (PCM) OF ALTERNATIVES IN THE CONTEXT OF PS

Alternatives	M1	M2	M3	M4
M1	(1,1,1)	(1,3,5)	(1,3,5)	(3,5,7)
M2	(1/5,1/3,1/1)	(1,1,1)	(1,1,3)	(3,5,7)
M3	(1/5,1/3,1/1)	(1,1,3)	(1,1,1)	(1,3,5)
M4	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/5,1/3,1/1)	(1,1,1)

TABLE 40: OVERALL WEIGHT OF EACH ALTERNATIVE IN THE CONTEXT OF PS (AFTER FUZZY EXTENT ANALYSIS)

Alternatives	Overall Weight		
	Left	Middle	Right
M1	0.140	0.454	1.133
M2	0.121	0.277	0.755
M3	0.075	0.202	0.629
M4	0.034	0.065	0.167

To get the weighted performance of the alternative, multiply the left value of MI overall weight of criteria **Table 10** with the left value of BCS overall weight of sub-criteria **Table 12** and also with the left value of M1 BCS overall weight of alternative **Table 20**.

= 0.187 * 0.145 * 0.033 = 0.0008

To get the weighted performance of the alternative, multiply the middle value of MI overall weight of criteria **Table 10** with the middle value of BCS overall weight of sub-criteria **Table 12** and also with the middle value of M1 BCS overall weight of alternative **Table 20**.

= 0.504 * 0.463 * 0.058 = 0.0135

To get the weighted performance of the alternative, multiply the right value of MI overall weight of criteria **Table 10** with the right value of BCS overall weight of sub-criteria **Table 12** and also with the right value of M1 BCS overall weight of alternative **Table 20**.

= 1.325 * 1.369 * 0.156 = 0.2829

To get the weighted performance of the alternative multiply the left value of MI overall weight of criteria **Table 10** with the left value of BCS overall weight of sub-criteria **Table 12** and also with the left value of M2 BCS overall weight of alternative **Table 20**.

= 0.187 * 0.145 * 0.053 = 0.0014

To get the weighted performance of the alternative, multiply the middle value of MI overall weight of criteria **Table 10** with the middle value of BCS overall weight of sub-criteria **Table 12** and also with the middle value of M2 BCS overall weight of alternative **Table 20**.

= 0.504 * 0.463 * 0.153 = 0.0357

To get the weighted performance of the alternative, multiply the right value of MI overall weight of criteria **Table 10** with the right value of BCS overall weight of sub-criteria **Table 12** and also with the right value of M2 BCS overall weight of alternative **Table 20**.

= 1.325 * 1.369 * 0.430 = 0.7799

To get the weighted performance of the alternative, multiply the left value of MI overall weight of criteria **Table 10** with the left value of BCS overall weight of sub-criteria **Table 12** and also with the left value of M3 BCS overall weight of alternative **Table 20**.

= 0.187 * 0.145 * 0.118 = 0.0031

To get the weighted performance of the alternative, multiply the middle value of MI overall weight of criteria **Table 10** with the middle value of BCS overall weight of sub-criteria **Table 12** and also with the middle value of M3 BCS overall weight of alternative **Table 20**.

= 0.504 * 0.463 * 0.315 = 0.0736

To get the weighted performance of the alternative, multiply the right value of MI overall weight of criteria **Table 10** with the right value of BCS overall weight of sub-criteria **Table 12** and also with the right value of M3 BCS overall weight of alternative **Table 20**.

= 1.325 * 1.369 * 0.822 = 1.4910

To get the weighted performance of the alternative, multiply the left value of MI overall weight of criteria **Table 10** with the left value of BCS overall weight of sub-criteria **Table 12** and also with the left value of M4 BCS overall weight of alternative **Table 20**.

= 0.187 * 0.145 * 0.181 = 0.0049

To get the weighted performance of the alternative, multiply the middle value of MI overall weight of criteria **Table 10** with the middle value of BCS overall weight of sub-criteria **Table 12** and also with the middle value of M4 BCS overall weight of alternative **Table 20**.

= 0.187 * 0.145 * 0.181 = 0.0049

To get the weighted performance of the alternative, multiply the right value of MI overall weight of criteria **Table 10** with the right value of BCS overall weight of sub-criteria **Table 12** and also with the right value of M4 BCS overall weight of alternative **Table 20**.

= 1.325 * 1.369 * 1.174 = 2.1290

The above calculation applies for all the steps.

The weighted performance of each alternative in the context of respective sub-criteria values are shown in **Table 41-51**.

To get the total weighted performance of all the alternatives, add all the values of a particular alternative that is to get the total weighted performance of left value of M1 alternative add the left values of M1 from **Table 41** to **Table 51** that is

0.0008+0.0013+0.0008+0.0010+0.0032+0.0007+0.0017+0.0009+0.0004+0.0012+0.0007 =0.0127.

Similarly, to get the total weighted performance of middle value of M1 alternative, add the middle values of M1 from **Table 41** to **Table 51** that is

0.0135+0.0304+0.0176+0.0174+0.0659+0.0078+0.0425+0.0278+0.0072+0.0199+0.0075 =0.2575

Similarly, to get the total weighted performance of right value of M1 alternative to add the right values of M1 from **Table 41** to **Table 51** that is

0.2829+0.7481+0.5661+0.4327+1.0903+0.1138+0.8020+0.4545+0.1439+0.3951+0.1557 =5.1851.

Similarly, to get the total weighted performance values of left, middle, and right for alternatives M2, M3 and M4 same procedure is followed and the results are shown in **Table 52**.

TABLE 41: WEIGHTED PERFORMANCE OF EACH ALTERNATIVE IN THE CONTEXT OF BCS

Alternatives	Left	Middle	Right
M1	0.0008	0.0135	0.2829
M2	0.0014	0.0357	0.7799
M3	0.0031	0.0736	1.4910
M4	0.0049	0.1101	2.1290

TABLE 42: WEIGHTED PERFORMANCE OF EACH ALTERNATIVE IN THE CONTEXT OF PC

Alternatives	Left	Middle	Right
M1	0.0013	0.0304	0.7481
M2	0.0015	0.0391	0.9610
M3	0.0006	0.0152	0.4269
M4	0.0003	0.0056	0.1417

TABLE 43: WEIGHTED PERFORMANCE OF EACH ALTERNATIVE IN THE CONTEXT OF BE

Alternatives	Left	Middle	Right
M1	0.0008	0.0176	0.5661
M2	0.0011	0.0222	0.7560
M3	0.0014	0.0667	1.5121
M4	0.0011	0.0355	0.9447

TABLE 44: WEIGHTED PERFORMANCE OF EACH ALTERNATIVE IN THE CONTEXT OF EX

Alternatives	Left	Middle	Right
M1	0.0010	0.0174	0.4327
M2	0.0005	0.0106	0.2882
M3	0.0004	0.0038	0.1441
M4	0.0003	0.0036	0.1280

TABLE 45: WEIGHTED PERFORMANCE OF EACH ALTERNATIVE IN THE CONTEXT OF PR

Alternatives	Left	Middle	Right
M1	0.0032	0.0659	1.0903
M2	0.0032	0.0879	1.2720
M3	0.0019	0.0292	0.5451
M4	0.0025	0.0365	0.7269

TABLE 46: WEIGHTED PERFORMANCE OF EACH ALTERNATIVE IN THE CONTEXT OF UN

Alternatives	Left	Middle	Right
M1	0.0007	0.0078	0.1138
M2	0.0009	0.0187	0.1993
M3	0.0007	0.0078	0.1138
M4	0.0009	0.0093	0.1423

TABLE 47: WEIGHTED PERFORMANCE OF EACH ALTERNATIVE IN THE CONTEXT OF CO

Alternatives	Left	Middle	Right
M1	0.0017	0.0425	0.8020
M2	0.0011	0.0339	0.7015
M3	0.0006	0.0107	0.2668
M4	0.0006	0.0112	0.3008

TABLE 48: WEIGHTED PERFORMANCE OF EACH ALTERNATIVE IN THE CONTEXT OF FX

Alternatives	Left	Middle	Right
M1	0.0009	0.0278	0.4545
M2	0.0003	0.0062	0.1635
M3	0.0003	0.0065	0.1815
M4	0.0003	0.0065	0.1815

TABLE 49: WEIGHTED PERFORMANCE OF EACH ALTERNATIVE IN THE CONTEXT OF MO

Alternatives	Left	Middle	Right
M1	0.0004	0.0072	0.1439
M2	0.0003	0.0043	0.1079
M3	0.0002	0.0038	0.0899
M4	0.0001	0.0013	0.0299

TABLE 50: WEIGHTED PERFORMANCE OF EACH ALTERNATIVE IN THE CONTEXT OF SR

Alternatives	Left	Middle	Right
M1	0.0012	0.0199	0.3951
M2	0.0012	0.0160	0.3460
M3	0.0006	0.0160	0.2470
M4	0.0003	0.0034	0.0655

TABLE 51: WEIGHTED PERFORMANCE OF EACH ALTERNATIVE IN THE CONTEXT OF PS

Alternatives	Left	Middle	Right
M1	0.0007	0.0075	0.1557
M2	0.0006	0.0046	0.1038
M3	0.0004	0.0033	0.0864
M4	0.0001	0.0010	0.0229

TABLE 52: TOTAL WEIGHTED PERFORMANCE OF ALL THE ALTERNATIVES

Alternatives	Left	Middle	Right
M1	0.0127	0.2575	5.1851
M2	0.0121	0.2792	5.6791
M3	0.0102	0.2312	5.1046
M4	0.0114	0.2240	4.8132

TABLE 53: FUZZY RANKING CHECK THROUGH α-CUT-BASED METHOD 1

α Level	M1		M2		M3		M4	
	α_{Left}	α_{Right}	α_{Left}	α_{Right}	α_{Left}	α_{Right}	α_{Left}	α_{Right}
0.1	0.0371	4.6924	0.0388	5.1392	0.0323	4.6173	0.0326	4.3543
0.2	0.0616	4.1996	0.0655	4.5992	0.0544	4.1300	0.0539	3.8954
0.3	0.0861	3.7069	0.0922	4.0592	0.0765	3.6426	0.0751	3.4365
0.4	0.1106	3.2141	0.1189	3.5192	0.0986	3.1553	0.0964	2.9776
0.5	0.1351	2.7213	0.1456	2.9792	0.1207	2.6679	0.1177	2.5186
0.6	0.1595	2.2286	0.1723	2.4392	0.1428	2.1806	0.1389	2.0597
0.7	0.1840	1.7358	0.1990	1.8992	0.1649	1.6933	0.1602	1.6008
0.8	0.2085	1.2431	0.2257	1.3592	0.1870	1.2059	0.1814	1.1419
0.9	0.2330	0.7503	0.2524	0.8192	0.2091	0.7186	0.2027	0.6830

TABLE 54: RESULT OF FUZZY AHP THROUGH ALPHA CUT AND LAMBDA FUNCTION

Alternatives	Alpha Cut (α = 0.5)		Crisp Value		Crisp Value (after normalization)		Rank
	α_{Left}	α_{Right}	λ = 0.5	λ = 0.7	λ = 0.5	λ = 0.7	
M1	0.1351	2.7213	1.4281	1.9454	0.2504	0.2501	2
M2	0.1456	2.9792	1.5624	2.1290	0.2739	0.2737	1
M3	0.1207	2.6679	1.3942	1.9037	0.2444	0.2448	3
M4	0.1177	2.5186	1.3181	1.7983	0.2311	0.2312	4

TABLE 55: COMPARISON OF TRADITIONAL AHP AND FUZZY AHP RESULTS

Alternatives	Traditional AHP	Fuzzy AHP (α = 0.5)	
		λ = 0.5	λ = 0.7
M1	0.239	0.2504	0.2501
M2	0.263	0.2739	0.2737
M3	0.225	0.2444	0.2448
M4	0.258	0.2311	0.2312

Fuzzy Ranking Check through α-cut-based Method 1: The results of fuzzy Ranking Check through α-cut-based Method 1 are shown in **Table 53**.

$Crisp\_value = \lambda * \alpha_{Right} + [(1 - \lambda) * \alpha_{Left}]$

For M1 (λ = 0.5) = 0.5*2.7213+ [(1-0.5)*0.1351]

1.3606+0.065=1.4281

(λ = 0.7) = 0.7*2.7213+ [(1-0.7)*0.1351]

1.9049+0.0405=1.9454.

Similar calculation applies for M2, M3 and M4.

Crisp value after normalization= crisp value/ sum of the crisp values.

Sum of the crisp value (λ = 0.5)= 1.4281+ 1.5624+ 1.3942 +1.3181= 5.7028.

Crisp value after normalization = 1.4281/5.7028 = 0.2504.

Similar calculation applies for M2, M3 and M4.

DISCUSSION: Based on the results of α-cut-based Method 1, it is very clear that M2 has the highest fuzzy ranking at all alpha levels when compared to M1, M3, and M4. The result of fuzzy AHP through Alpha Cut and Lambda Function are shown in **Table 54**. **Table 55** shows the results of AHP and Fuzzy AHP and it is confirmed that M2 scores the highest value. Hence, from both the approaches, it is concluded that M2 is the alternative that can be used for the preparation of nanocrystals.

CONCLUSION: The selection of the best method for the preparation of nanocrystals is complicated because it involves a considerable amount of fuzziness, vagueness, ambiguity, or uncertainty in the modeling and decision-making process. So, in order to avoid this uncertainty, FAHP has been employed to give the most unfailing decision. FAHP methodology is a viable alternative when compared to the traditional AHP method for the selection of nanocrystals preparation because it incorporates partly known information and gives the best inference. The method involves making a fuzzy judgment matrix for criteria, sub-criteria, alternatives, and then weight multiplication, summation, and performance ratings for the alternatives.

Our study shows that the FAHP is a suitable and constructive approach to select the best method for the preparation of nanocrystals. This study reveals that sonoprecipitation method is the most appropriate technique for the preparation of nanocrystals.

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