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DIET FOOD RECOMMENDATION FOR DIABETIC PATIENTS BY AHP AND FUZZY AHP METHOD

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ABSTRACT

The Analytic Hierarchy Process (AHP) is used widely for analyzing decision made in various real world applications. This method counts both tangible and intangible factors in and this attribute fits to the subjectivity feature of real-world problems. Also this method used in choosing among several strategies for improving safety features in motor vehicles, Estimating cost and scheduling options for material requirements planning and etc. This paper proposes the AHP approach and Fuzzy AHP approach in recommendation of diet food for diabetic patients based on the food ingredients.

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Keywords: *The Analytic Hierarchy Process (AHP), Fuzzy AHP, Sugar Free Foods, Diabetes.*

INTRODUCTION

The Analytic Hierarchy Process (AHP), introduced by Thomas Saaty (1980), is an effective tool for dealing with complex decision making, and may aid the decision maker to set priorities and make the best decision. It is based on a hierarchical structure. Besides classical AHP, where a 1-9 scale is applied, fuzzy AHP which combines the classical AHP and the fuzzy set theory is often used in applications. Fuzzy AHP should be applied when the pairwise comparisons are imprecise because decision makers are unable to make exact preferences due to some unclear and indefinite information in the decision making process [4]. In fuzzy AHP, fuzzy sets and fuzzy numbers are used instead of crisp sets and crisp numbers. Pairwise comparisons are applied with linguistic scales and fuzzy numbers in fuzzy AHP method [6].

In this Paper consider three different sugars free foods viz., Brown rice, Wheat and Ragi and four ingredients of sugar free foods as multiple criteria. Carbohydrate content of the sugar free food is the most important and impactful criteria on human blood sugar level, which is followed by fats. Proteins and fiber present in sugar free food have very less impact as compared to carbohydrates and fats. AHP and Fuzzy AHP are used to get best sugar free food or combination of sugar free foods, based on nutritional information. The nutritional information collected from diabetic doctors at Salem in Tamilnadu to recommend for diabetics.

Formulation of the method

- **Analytical hierarchy process [2]**
- ✓ The first step is experts plot the hierarchy of the problem; goal, criteria and alternatives.
- ✓ The second step is constructing a pairwise comparison matrix of criteria with respect to the goal.

The values of relative importance of criteria or alternative are as per the developer of AHP (Pro. Saaty 1980) given in the following table. Diagonal of the pair wise matrix is 1. Because in i and j has the same criteria or alternative.

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Table-1: AHP Relative Preference Numbers [1]

AHP Scale of Importance for comparison pair (a_{ij})	Numeric Rating	Reciprocal(decimal)
Extreme Importance	9	1/9 (0.111)
Very strong to extremely	8	1/8 (0.124)
Very strong Importance	7	1/7 (0.143)
Strongly to very strong	6	1/6 (0.167)
Strong Importance	5	1/5 (0.200)
Moderately to strong	4	1/4 (0.250)
Moderately Importance	3	1/3 (0.333)
Equally to Moderately	2	1/2 (0.500)
Equal Importance	1	1 (1.000)

If criteria or alternative 1 has one of the above nonzero numbers assigned to it when compared with criteria or alternative j, then j has the reciprocal value when compared with i.

- Rank the criteria with respect to the goal flow. Some steps and realization of the pairwise matrix consistency also. Calculating Eigenvector and Eigenvalue ($\lambda_{\max}$), Consistency Index (CI), Consistency Ratio (CR) and verifying CR weather it's acceptable or not.
- Calculating Eigenvector
  i. Sum each column of criteria or alternative.
  ii. Divide each row by above sum (i).
  iii. Sum row wise and divide by number of criteria or alternative. This result is Eigenvector it is used to calculate Eigenvalue.
- Calculating Eigenvalue
  i. Multiply each column sum of pairwise matrix by each row Eigenvector and sum.
  ii. This value denoted by $\lambda_{\max}$ and used to drive CI. And the value is approximately number of criteria or alternative.
- Calculating CI=$\frac{\lambda_{max}-n}{n-1}$and Calculating CR = CI/RI. Where RI is consistency index.
- Calculating CR = CI/RI. Where RI is consistency index.

If CR > 0.1 the above work is perfect and rank the criteria or alternative from largest to smallest. If not go to pair wise matrix and reconstruct.

- ✓ The rating of each alternative is multiplied by the weights or criteria.
  These are the steps to do AHP for analysis of the best criteria or alternative for ranking and selection.

Table-2: Random consistency Index [2]

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

- ➢ **Fuzzy Analytical hierarchy process [3]**
- ✓ First compares the criteria or alternatives via linguistic terms shown in the following table.

Table-3: Linguistic terms and the corresponding triangular fuzzy number [3]

Fuzzy AHP Scale of Importance forcomparison pair	Fuzzy Triangular Scale
Equally important	(1,1,1)
Weakly important	(2,3,4)
Fairly important	(4,5,6)
Strongly important	(6,7,8)
Absolutely important	(9,9,9)
The intermittent values between two adjacent scale	(1,2,3), (3,4,5), (5,6,7), (7,8,9)

The pair wise contribution matrice is shown in the following equation, where $\tilde{d}_{ij}^{k}$ indicates the k^{th} decision maker's preference of i^{th} criterion over j^{th} criterion, via fuzzy triangular numbers. Here, "tilde" represents the triangular number demonstration.

$$\tilde{A}^k = \begin{bmatrix} \tilde{d}_{11}^k & \tilde{d}_{12}^k & \cdots & \tilde{d}_{1n}^k \\ \tilde{d}_{21}^k & \cdots & \cdots & \tilde{d}_{2n}^k \\ \cdots & \cdots & \cdots & \cdots \\ \tilde{d}_{n1}^k & \tilde{d}_{n2}^k & \cdots & \tilde{d}_{nn}^k \end{bmatrix} \quad (1)$$

- ✓ If there is more than one decision maker,preferences of each decision maker ($\tilde{d}_{ij}^k$) are averaged and ($\tilde{d}_{ij}$) is calculated as in the following equation.

$$\tilde{d}_{ij} = \frac{\sum_{k=1}^{K} \tilde{d}_{ij}^k}{K} \quad (2)$$

- ✓ According to averaged preference, pairwise contribution matrix is updated as shown in the following equation.

$$\tilde{A} = \begin{bmatrix} \tilde{d}_{11} & \cdots & \tilde{d}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{d}_{n1} & \cdots & \tilde{d}_{nn} \end{bmatrix} \quad (3)$$

- ✓ The geometric mean of fuzzy comparison values of each criterion is calculated as shown in the following equation. Here, $\tilde{r}_i$ still represents triangular values.

$$\tilde{r}_i = \left(\prod_{j=1}^{n} \tilde{d}_{ij} \right)^{1/n}, \text{ i=1, 2…n} \quad (4)$$

- ✓ Find the vector summation of each $\tilde{r}_i$ .Find $\tilde{r}_i^{-1}$, Replace the fuzzy triangular number, to make it in an increasing order.To find the fuzzy weight of criterion i ($\tilde{w}_i$), multiply each $\tilde{r}_i$ with this reverse vector.

$$\tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus ... \oplus \tilde{r}_n)^{-1} \text{ and } \tilde{w}_i = (lw_i, mw_i, uw_i) \quad (5)$$

- ✓ Since $\tilde{w}_i$ are still fuzzy triangular numbers, $M_i = \frac{lw_i + mw_i + uw_i}{3}$ (6)

- ✓ M_i is a non-fuzzy number, normalized by equation, $N_i = \frac{M_i}{\sum_{i=1}^{n} M_i}$ (7)

These steps are performed to find the normalized weights of both criteria and the alternatives. Then by multiplying each alternative weight with related criteria, the scores for each alternative is calculated. According to these results, the alternative with the highest score is suggested to the decision maker.

METHODS AND MATERIALS

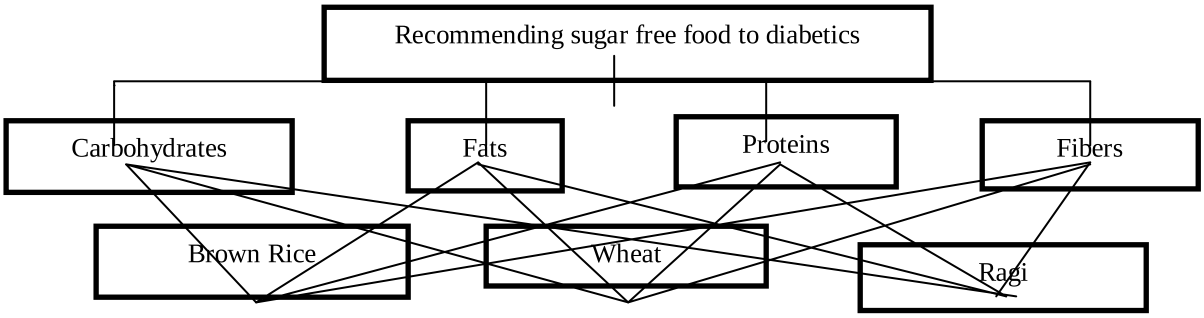
The following table lists out the nutritional values of the foods considered as alternatives. Which are collected from diabetic Doctors at Salem in Tamilnadu by face to face questions.

Table 4: Criteria and Alternatives for Recommending Sugar Free Foods

Attributes	Brown Rice	Wheat	Ragi
Carbohydrate	76	71	72.6
Fat	2.7	2.0	1.5
Protein	7.9	11.6	7.7
Fiber	1.0	2.0	3.6

Hierarchical structure of levels consisting of criteria and alternatives in analytic process is given in figure as below.

Figure-1: Hierarchical structure of proposed AHP and Fuzzy model



a) Analytical Hierarchy Process

Following are the paired comparisons for each criterion and alternatives for every individual criterion separately.

Table-5: AHP for Considered Sugar Free Foods (Alternatives)

Criteria preferences	Carbohydrates	Fats	Proteins	Fibers
Carbohydrates	1	3	5	7
Fats	1/3	1	3	5
Proteins	1/5	1/3	1	3
Fibers	1/7	1/5	1/3	1
Total	**176/105**	**68/15**	**28/3**	**16**

The Eigen values are calculated from the above table (5), where sum of each column is considered and this sum is then divided by individual element followed by addition of rows to obtain further results [5]. The weights for Carbohydrate, Fat, Protein and Fiber are also calculated. The Eigen values ($\lambda_{\max}$) can be calculated for criterions. The Eigen valuescan be calculated for criterions as $\lambda_{\max}$ = 4.1760.To find Consistency Index (CI), here n = 4 (size), CI = 0.0587. The Consistency Ratio (CR) is calculated as CR = 6.52%.The CR ratio must be under 10%. So as to assume the chosen criterion as a good one. In the same way, calculation of weights for alternatives is done which are food types as mentioned below. Similarly we can find the paired comparisons for each criterion.

Table-6: AHP for Carbohydrates

Alternatives	Brown Rice	Wheat	Ragi
Brown Rice	1	1/5	1/3
Wheat	5	1	3
Ragi	3	1/3	1

The obtained weights for Brown Rice = 0.1062, Wheat = 0.6333 and Ragi =0.2605.Based on these procedures, the weights of each alternative for each criterion are found and tabulated in below table.

Table-7: The weights of each alternative for each criterion

Alternatives	Carbohydrate	Fat	Protein	Fiber
Brown Rice	0.1062	0.0738	0.1741	0.0833
Wheat	0.6333	0.2828	0.7225	0.1932
Ragi	0.2605	0.6434	0.1033	0.7235

By using the weights of criterionsand alternatives, individual scores of each alternative for each criterion are presented in below table.

Table-8: Aggregated results for each alternative according to each criterion

Criteria		Scores of Alternatives with respect to related Criterion		
	Weights	**BrownRice**	**Wheat**	**Ragi**
Carbohydrate	0.5579	0.1062	0.6333	0.2605
Fat	0.2633	0.0738	0.2828	0.6434
Protein	0.1218	0.1741	0.7225	0.1033
Fiber	0.0569	0.0833	0.1932	0.7235
Total		0.1046	**0.5268**	0.3685

Depending on this result, Alternative 2 has the largest total score. Therefore, it is recommended as the best sugar free food among 3 of them with respect to 4 criterions.

b) Fuzzy Analytical Hierarchy Process

Following are the paired comparisons for each criterion and alternatives for every individual criterion separately [3].

Table-9: Fuzzy AHP for Considered Sugar Free Foods (Alternatives)

Alternatives	**Carbohydrate**	**Fat**	**Protein**	**Fiber**
Carbohydrate	(1,1,1)	(2,3,4)	(4,5,6)	(6,7,8)
Fat	(1/2,1/3,1/4)	(1,1,1)	(2,3,4)	(4,5,6)
Protein	(1/4,1/5,1/6)	(1/2,1/3,1/4)	(1,1,1)	(2,3,4)
Fiber	(1/6,1/7,1/8)	(1/4,1/5,1/6)	(1/2,1/3,1/4)	(1,1,1)

The geometric mean of fuzzy comparison values of each criterion is calculated by equation (4).

$\tilde{r}_i$ = [2.6321;3.2011; 3.7224]

Hence, the geometric means of fuzzy comparison values of all criteria are shown in below table. In addition, the total values and the reverse values are also presented. In the last row of below table, since the fuzzy triangular number should be in increasing order, the order of the numbers is changed [3].

Table-10: Geometric means of fuzzy comparison values

Criteria	$\tilde{r}_l$		
Carbohydrate	2.6321	3.2011	3.7224
Fat	1.4142	1.4953	1.5651
Protein	0.7071	0.6687	0.6389
Fiber	0.3799	0.3124	0.2686
Total	5.1333	5.6775	6.1950
Reverse (power of -1)	0.1948	0.1761	0.1614
Increasing Order	0.1614	0.1761	0.1948

In the seventh step, the fuzzy weight of carbohydrate criterion ($\tilde{w}_1$) is found by the help of equation (5), $\tilde{w}_1$ = [0.4248; 0.5637; 0.7251]. Hence the relative fuzzy weights of each criterion are given in below table.

Table-11: Relative fuzzy weights of each criterion

Criteria	$\tilde{w}_l$		
Carbohydrate	0.4248	0.5637	0.7251
Fat	0.2283	0.2633	0.3049
Protein	0.1141	0.1178	0.1245
Fiber	0.0613	0.0550	0.0523

In the eighth step, the relative non-fuzzy weight of each criterion (M_i) is calculated by taking the average of fuzzy numbers for each criterion. In the ninth step, the normalized weights of each criterion are calculated and tabulated in below table [3].

Table-12: Averaged and normalized relative weights of criteria

Criteria	M_i	N_i
Carbohydrate	0.5712	0.5646
Fat	0.2655	0.2624
Protein	0.1188	0.1174
Fiber	0.0562	0.0556

In the same way, calculation of weights for alternatives is done which are food types as mentioned below.

Table-13: Comparison matrices of alternatives with respect to carbohydrate criterion

Alternatives	Brown Rice	Wheat	Ragi
Brown Rice	(1,1,1)	(1/4,1/5,1/6)	(1/2,1/3,1/4)
Wheat	(4,5,6)	(1,1,1)	(2,3,4)
Ragi	(2,3,4)	(1/2,1/3,1/4)	(1,1,1)

Similar to criterion clculation methodology, the geometric means of fuzzy comparison values ($\tilde{r}_l$) and relative fuzzy weights of alternatives for each criterion ($\tilde{w}_l$) are tabulated in below table.

Table-14: Geometric means ($\tilde{r}_l$) and fuzzy weights ($\tilde{w}_l$) of alternatives with respect to carbohydrate Criterion

Alternatives	$\tilde{r}_l$			$\tilde{w}_l$		
Brown Rice	0.5	0.4055	0.3467	0.1182	0.1047	0.0991
Wheat	2	2.4662	2.8845	0.4726	0.6370	0.8241
Ragi	1	1	1	0.2363	0.2583	0.2857
Total	3.5	3.8717	4.2312			
Reverse (power of -1)	0.2857	0.2583	0.2363			
Increasing Order	0.2363	0.2583	0.2857			

The non-fuzzy M_i and normalized N_i values are obtained shown in below table.

Table-15: Averaged and normalized relative weights of each alternative with respect to carbohydrate criterion

Alternatives	M_i	N_i
Brown Rice	0.1073	0.1060
Wheat	0.6446	0.6370
Ragi	0.2601	0.2570

Based on these procedures, the normalized relative weights of each alternative for each criterion are found and tabulated in below table.

Table-16: Normalized non-fuzzy relative weights of each alternative for each criterion

Alternatives	Carbohydrate	Fat	Protein	Fiber
Brown Rice	0.1060	0.0720	0.1680	0.0820
Wheat	0.6370	0.2798	0.7260	0.1868
Ragi	0.2570	0.6483	0.1059	0.7312

By using Table 12 and Table 16, individual scores of each alternative for each criterion are presented in below table.

Table-17: Aggregated results for each alternative according to each Criterion

Criteria		Scores of Alternatives with respect to related criterion		
	Weight	**Brown Rice**	**Wheat**	**Ragi**
Carbohydrate	0.5646	0.1060	0.6370	0.2570
Fat	0.2624	0.0720	0.2798	0.6483
Protein	0.1174	0.1680	0.7260	0.1059
Fiber	0.0556	0.0820	0.1868	0.7312
Total		**0.1030**	**0.5287**	**0.3683**

Depending on this result, Alternative 2 has the largest total score. Therefore, it is recommended as the best sugar free food among 3 of them, with respect to 4 criteria and the fuzzy preferences of decision makers.

Table-18: Results of AHP and Fuzzy AHP

Alternatives	AHP	Fuzzy AHP
Brown Rice	0.1046	0.1030
Wheat	**0.5268**	**0.5287**
Ragi	0.3685	0.3683

AHP and Fuzzy AHP recommended the same food. Hence alternative 2 (wheat) is the best sugar free food for diabetic patients.

CONCLUSION

Analytic Hierarchy Process model can be effectively used to recommend the sugar free foods to diabetics. Since, Wheat has less carbohydrate content than others, it is preferred and recommended the most, and hence its rank is obtained as 52.68%. This is followed by Ragi sugar free food with rank of 36.85% that is the second most recommended sugar free product. Brown Rice is the highest to contain carbohydrates and hence AHP ranks it as 10.46% to be least preferred among those sugar free products. Similarly Fuzzy AHP recommended the sugar free foods to diabetics. Through the Fuzzy AHP, Wheat is recommended most and its rank is 52.87%. Ragi is second recommended food and its rank is 36.83%. Finally Brown Rice to be least preferred among those sugars free foods. The results of AHP and fuzzy AHP are slightly differed. Finally AHP and Fuzzy AHP methods recommended the same food to diabetic patients. Hence wheat is the best sugar free food for diabetic patients.

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