FUZZY TOPSIS Application in Materials Analysis for Economic Production of Cashew Juice Extractor

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ABSTRACT
In this paper, a Multi-Criteria Decision-Making (MCDM) tool which combines Fuzzy Set Theory (FST) with TOPSIS (Fuzzy TOPSIS) is presented for selecting optimal material for the different components of the cashew juice extractor. The technique proposed utilise a broad multiple criteria methodology in finding optimal material from among alternative materials. The alternative materials are mild steel, stainless steel, galvanised steel, and alloy steel. To illustrate the applicability of the technique, a case study of the Auger material selection problem was used. The Auger was applied for the demonstration of the proposed method because it is the most critical component of the cashew juice extractor. The result of the analysis indicated that galvanised steel is the optimal material for the Auger. To validate the FUZZY TOPSIS method, the results obtained from it were compared with results obtained from FUZZY MOORA and FUZZY SAW methods. The comparative analysis indicated that FUZZY TOPSIS produces completely same result with the FUZZY SAW method and very similar results with the FUZZY MOORA method. This is an indication of the suitability of the proposed technique in resolving the material selection problem of the cashew juice extractor.

1. Introduction
The cashew tree (Anacardium occidentale) is an evergreen plant that yields cashew fruit comprising of cashew seed and apple [1]. The origin of the tree can be traced to Brazil and was introduced by Portuguese voyagers to Nigeria and other parts of the world [2]. The fruit produced by the cashew tree consisting of the cashew apple and a raw nut (seed), are of great economic importance. This is largely due to their nutritional and medicinal value. For example, the cashew apple contains ascorbic acid, niacin and vitamin C among other vitamins and minerals needed for human body wellbeing [3].

In the world categorisation of production of edible nut, the cashew industry was ranked third in the year 2000, with a production capacity of 2 million tonnes valued at over 2 billion US dollars [4]. Currently, the cashew global market is estimated to be 12 billion US dollars [5]. Brazil is rated as the highest exporter of cashew having 60% of world export whilst the highest importer is the United States also having 60% of the world import. The international
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The cashew apple cannot be preserved for a substantial interval of time due to their perishable nature and as such it is either eaten raw or processed into a juice drink. However, in many developing nations across the globe majority of the cashew apple produced are wasted due to mainly lack of effective and economic facility (juice extractor) to process it into juice by the rural dwellers where the bulk of the fruits are produced. To eliminate or reduce wastage to the barest minimum and also guarantee an all-time of year obtainability of the cashew juice in developing countries, researchers’ have developed a different variant of the cashew juice extractor.

Ogunsina and Lucas [3] produced a manually operated cashew juice extractor whose design was based on the principle of a screw press. The efficiency of the system was estimated to be 85.38%. Aviara et al. [7] developed an extractor with the capability of extracting juice from different fruit apple. In similar research work, Aremu and Ogunlade [8] developed and carried out performance evaluation of a multi-fruit juice extractor. Sylvester and Abugh [9] designed and constructed an extractor solely for orange juice extraction. The performance evaluation of juice extractors has been investigated in the literature. Olaniyan [10] investigated the performance of an orange juice extractor. Machine efficiency was estimated to be 57.4%. Adebayo et al. [11] studied the performance evaluation of a motorised pineapple juice extracting machine. The juice extraction efficiency of the machine was found to be 87.5%.

From the above, analysis although different variants of cashew juice extractor have been produced, most of the machines do not meet the requirement of the end-users in most developing nations. It is either the machine is too expensive for the end-users to purchase or the juice output quality from the machine is poor. This is due to majorly improper material selection for the production of the juice extractor. For example, if the auger of the juice extractor which squeezes out the juice from the cashew apple is made from mild steel or galvanised steel to reduce production cost, the juice will be contaminated and be unfit for human consumption. To assist researchers to design and produce machines that will be more appealing to local farmers and other end-users and for sustainable economic production, there is the need for a decision support system for material analysis. The support system will select optimal material from among different alternative materials whilst simultaneously considering different decision criteria such as cost and corrosion resistance for the production of the different components of the cashew juice extractor.

In the literature MCDM tools such as AHP, TOPSIS and VIKOR have been applied in selecting appropriate material in diverse fields. The tools are well-known for resolving multifaceted real-life problems due to their intrinsic capability to judge various alternatives with regard to different decision criteria to select the optimum alternative. Hussain and Mandal [12] adapted a combination of COPRAS and MOORA methods to select the optimum material for exhaust manifold which can give maximum performance at minimum cost. The authors chose the optimum material from among alternative materials such as carburised steel, nitrided steel, hardened alloy steel, and cast alloy steel with regard to certain decision criteria. Moradian et al. [13] utilised three different MCDM tools; MOORA, TOPSIS and VIKOR methods to select the most appropriate material for a braking system of a motor vehicle while considering temperature deflection, tensile strength, density and cost as decision criteria. Manalo and Magdaluyo [14] carried out a study to identify the best material for

cashew market is anticipated to remain strong even in the future due to the high demand for the cashew by-product such as cashew nut [6] and juice drink.
usage as an interlayer in laminated glass windshield and windows. The authors utilised the COPRAS method in resolving the material selection decision-making problem. Sen et al. [15] applied COPRAS, MOORA, TOPSIS, ARAS and VIKOR in selecting the optimum material for a connecting rod whilst using decision criteria such as tensile strength and fracture toughness machining.

However, there is no available research in the literature to the best of our knowledge that is concerned with the analysis of optimal material for sustainable economic production of the fruit juice extractor. Hence, in this paper, a Multi-Criteria Decision-Making (MCDM) tool is presented and recommended for optimal selection of material for economic production of the cashew juice extractor. The MCDM tool presented is an aggregation of FST and TOPSIS which is referred to as FUZZY TOPSIS methodology.

TOPSIS method was chosen because the process is quite simple and the solution procedure does not change irrespective of the number of decision criteria and alternatives. However, the vagueness of human judgment is a challenge in the use of the MCDM tool which makes it difficult for decision-makers to assign a precise numerical value [16]. To address the challenge of the vagueness of human judgment, the application of FUZZY Set Theory (FST) in conjunction with MCDM tools such as TOPSIS becomes imperative since the fuzzy system allows the use of linguistic variables which decision-makers are more at ease with than the use of numerical precise value. In the literature Fuzzy system has been applied in conjunction with other MCDM methods in solving multi-criteria decision problems in various fields. Chang [17] used a FUZZY VIKOR methodology to evaluate the quality of hospital service in Taiwan. Tolga et al. [18] utilised Fuzzy Tomada de Decisao Multicriterio (TODIM) technique in solving health care multi-criteria decision problem. The Fuzzy rule has also been combined with swarm intelligence to enhance its effectiveness [19]. For example, Anter et al. [19] applied the combination of Fuzzy logic with whale optimisation algorithms (WOA) and chaos theory for fault detection in a water treatment plant.

2. Methodology

Multi-Criteria Decision-Making (MCDM) is a systematic approach to finding the optimal option from among practicable alternatives. In most real-life problems daily encountered in the industries, hospitals, a tertiary institution among others, decision-makers are faced with the challenge of making the best decision from among different alternatives whilst considering various criteria. To solve problems of this nature, different MCDM tools such as TOPSIS and AHP are available for use.

However, each of the MCDM tools has one limitation or the other. For example, in the application of the Analytic Hierarchy Process (AHP) tool, as the number of decision-makers and criteria increases the complexity of the decision-making process also increases. The vagueness of the human judgment is also a challenge in the use of the MCDM tool which makes it difficult for decision-makers to assign a precise numerical value [16]. To address the challenge of the vagueness of human judgment, the application of Fuzzy Set Theory (FST) in conjunction with MCDM tools such as TOPSIS becomes imperative since the fuzzy system allows the use of linguistic variables which decision-makers are more at ease with.
2.1. FUZZY TOPSIS Method

FUZZY TOPSIS is a hybrid tool that combines the benefits of the FST with the TOPSIS technique for solving the multi-criteria problem. TOPSIS is an acronym for Technique for Order of Preference by Similarity to Ideal Solution and is an MCDM tool which was originated by Hwang and Yoon in 1981 [20]. It is a technique of compensatory combination that matches a set of alternatives solutions by ascertaining weights for each criterion [20]. In the TOPSIS methodology, the optimum alternative is the one having the shortest distance to the positive ideal solution and farthest from the negative ideal solution [21].

TOPSIS method was chosen because the process is quite simple and the solution procedure does not change irrespective of the number of decision criteria and alternatives. However, the technique is less efficient when the decision-makers are faced with uncertainty and vagueness generally involved in the multi-criteria decision-making process. Zadeh introduced the FST which utilises fuzzy numbers number which is more suitable for addressing problems that are very complex and not well defined than the crisp number [22,23]. The FST is the most important tool in modelling uncertainty and the area of production management it has aided research [24]. The tool has also made life easier today due to its ability in using the linguistic variables to model human reasoning thereby providing the solution to the problem in the past without a satisfactory solution [25]. In most multi-criteria problems, the criteria on the basis decision are made are often of incompatible dimensions which may create a challenge in the evaluation process and to avoid such difficulty, there is a need for the fuzzy system [26]. Aggregating FST in TOPSIS for criteria analysis makes the evaluation process simpler [26]. Therefore, FUZZY TOPSIS is a more realistic model for analysing optimal material for sustainable economic production of the fruit juice extractor.

The steps of the FUZZY TOPSIS algorithm can be expressed as follows [26].

Step 1: Construction of fuzzy decision matrix

Ratings are generally assigned to alternatives with regards to decision criteria using linguistic variables which are then translated into Triangular Fuzzy Numbers (TFN). The linguistic variables and the corresponding TFN are indicated in Table 1.

Table 1. Fuzzy linguistic terms and corresponding TFN for each criterion and alternatives [26,27].

| Importance                  | Abbreviation | TFN  |
|-----------------------------|--------------|------|
| Very low/very poor          | VL           | 1,1,3|
| Low/poor                    | L            | 1,3,5|
| Medium/fair                 | M            | 3,5,7|
| High/good                   | H            | 5,7,9|
| Very high/very good         | VH           | 7,9,9|

The ratings of m, alternatives with respect to n, criteria by K number of experts are then applied to form a decision matrix, $X^k$, expressed as:

$$X^k = \begin{bmatrix} x_{11}^k & x_{12}^k & \cdots & x_{1n}^k \\ x_{21}^k & x_{22}^k & \cdots & x_{2n}^k \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1}^k & x_{m2}^k & \cdots & x_{mn}^k \end{bmatrix} \quad (1)$$
\(x_{ij}^k\) is the \(k\)-th expert defined rating of alternative \(i\) with respect to criterion \(j\) and \(x_{ij}^k = (a_{ij}^k, b_{ij}^k, c_{ij}^k)\)

**Step 2. Evaluation of the combined group decision matrix**

The rating by \(K\) number of decision-makers can be aggregated with Equation (2) to form a combined group decision matrix, \(\hat{X}_{ij}\) as follows:

\[
a_{ij} = \min_k (a_{ij}^k), \quad b_{ij} = \frac{1}{K} \sum_{k=1}^{K} b_{ij}^k, \quad c_{ij} = \max_k (c_{ij}^k)
\]

(2)

The combined group decision matrix, \(\hat{X}_{ij}\) is represented as follows:

\[
\hat{X}_{ij} = \begin{bmatrix}
\hat{x}_{11} & \hat{x}_{12} & \ldots & \hat{x}_{1n} \\
\hat{x}_{21} & \hat{x}_{22} & \ldots & \hat{x}_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
\hat{x}_{m1} & \hat{x}_{m2} & \ldots & \hat{x}_{mn}
\end{bmatrix}
\]

(3)

where \(\hat{x}_{ij} = (a_{ij}, b_{ij}, c_{ij})\)

**Step 3: Computing the normalised fuzzy decision matrix, \(\tilde{p}_{ij}\)**

In this phase, the beneficial criteria and the non-beneficial criteria are identified. For example, yield strength, thermal conductivity, and corrosion resistance are beneficial criteria while the cost is a non-beneficial criterion where the minimum value is desired.

For the benefit criteria, normalisation is expressed as follows:

\[
\tilde{p}_{ij} = \left( \frac{a_{ij}}{c_j^+}, \frac{b_{ij}}{c_j^+}, \frac{c_{ij}}{c_j^+} \right), \text{ if } j \in G, c_j^+ = \max_i (c_{ij})
\]

(4)

While for the non-beneficial criteria, normalisation is performed as follows:

\[
\tilde{p}_{ij} = \left( \frac{a_j^+}{a_{ij}}, \frac{b_j^+}{a_{ij}}, \frac{c_j^-}{c_{ij}} \right), \text{ if } j \in H, a_j^- = \min_i (a_{ij})
\]

(5)

where \(G\) and \(H\) denotes beneficial and cost criteria respectively.

**Step 4: Computation of the weighted normalised fuzzy decision matrix, \(\tilde{v}_{ij}\)**

\(\tilde{v}_{ij}\) is computed by multiplying the normalised matrix with the criteria weight as follows:

\[
\tilde{v}_{ij} = \tilde{p}_{ij} \times w_j
\]

(6)

where \(w_j\) is the fuzzy importance weight for criterion \(j\) and in a scenario involving more than one decision-maker in categorising the degree of importance of criteria, it is referred to as combined group criteria weight. For example, if there are \(K\) number of decision-makers in a group decision-making process, the group criteria weight is represented as follows:

\[
W_j^k = [w_j^1, w_j^2, w_j^3, \ldots, w_j^K]
\]

(7)

where \(w_j^k\) is the fuzzy weight of criterion \(j\) assigned by \(k\)th decision-maker and \(w_j^k = (a_j^k, b_j^k, c_j^k)\).
The combined group criteria weight is derived as follows [28]:

\[ a'_j = \min_k (a'_j^k), b'_j = \frac{1}{K} \sum_{k=1}^{K} b'_j^k, c'_j = \max_k (c'_j^k) \] (8)

Therefore, the combine fuzzy weight of criterion \( j \) is expressed as \( w_j = (a'_j, b'_j, c'_j) \)

**Step 5: Evaluation of the fuzzy positive ideal solution, \( A^+ \) and fuzzy negative ideal solution, \( A^- \)**

The selection of \( A^+ \) and \( A^- \) is performed as follows:

\[ A^+ = (\tilde{v}^+_1, \tilde{v}^+_2, \ldots, \tilde{v}^+_n), \text{ where } \tilde{v}^+_j = \max_i (\tilde{v}_{ij}) \] (9)

\[ A^- = (\tilde{v}^-_1, \tilde{v}^-_2, \ldots, \tilde{v}^-_n), \text{ where } \tilde{v}^-_j = \min_i (\tilde{v}_{ij}) \] (10)

**Step 6: Computation of the distance from each alternative to \( A^+ \) and \( A^- \)**

Applying the vertex method, the distances between each alternative and \( A^+ \) and \( A^- \) can be determined [29]. Since \( \tilde{v}_{ij} = (a_{ij}, b_{ij} \text{ and } c_{ij}) \) and \( \tilde{v}^+_j = (a^+_j, b^+_j \text{ and } c^+_j) \) the distance between them \( d(\tilde{v}_{ij}, \tilde{v}^+_j) \) can be expressed as follows [26]:

\[ d(\tilde{v}_{ij}, \tilde{v}^+_j) = \sqrt{\frac{1}{3} \left[ (a_{ij} - a^+_j)^2 + (b_{ij} - b^+_j)^2 + (c_{ij} - c^+_j)^2 \right]} \] (11)

Following the same approach, the distance between each alternative and \( A^- \) can be evaluated as follows:

\[ d(\tilde{v}_{ij}, \tilde{v}^-_j) = \sqrt{\frac{1}{3} \left[ (a_{ij} - a^-_j)^2 + (b_{ij} - b^-_j)^2 + (c_{ij} - c^-_j)^2 \right]} \] (12)

Therefore, with regard to the whole decision criteria, the distance of each alternative to \( A^+ \) and \( A^- \) can be determined respectively as follows [16]:

\[ Y^+_i = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}^+_j), i = 1, 2, \ldots, m; j = 1, 2, \ldots n \] (13)

\[ Y^-_i = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}^-_j), i = 1, 2, \ldots, m; j = 1, 2, \ldots n \] (14)

**Step 7: Compute the closeness coefficient \( (CC_i) \) for each alternative**

The closeness coefficient \( (CC_i) \) for each alternative is evaluated as follows:

\[ CC_i = \frac{Y^-_i}{Y^-_i + Y^+_i} \] (15)

The alternatives are ranked based on the \( CC_i \) values and the best choice is the alternative with the highest value.
3. Case Study

The cashew juice extractor consists of different components such as the Hopper, Chopping unit frame, Auger and perforation screen. For sustainable economic production of the machine, the most appropriate material whilst considering multiple decision criteria must be selected for the various components.

The Auger conveyor which is an assembly of the shaft and screw is the most critical component of the cashew juice extractor. The function is to provide the shearing and compressing force requires for the crushing of the cashew apple and squeezing the juice out. The Auger is applied to illustrate how suitable is the FUZZY TOPSIS method in selecting optimal material for the sustainable and economic production of the whole machine. In the application of the Auger in demonstrating the applicability of the FUZZY TOPSIS method, two cases are considered in the decision-making process; (1) the use of a group of decision-makers in obtaining an optimal material for the Auger and, (2) the use of a single decision-maker in selecting the appropriate material for the component.

3.1. Case Study 1

3.1.1. Group Decision-Making Data Collection

In this case study, a group of three decision-makers (DM1, DM2, and DM3) was used to determine the optimal material for Auger from among four alternatives (alloy steel, galvanised steel, stainless steel, and mild steel) based on certain decision criteria. The various criteria are; yield strength (C1), thermal conductivity (C2), corrosion resistance (C3), and cost (4). To obtain data for the FUZZY TOPSIS analysis, the three decision-makers were asked to assign a level of importance to the alternative materials using the linguistic variable scale in Table 1. The assigned linguistic variable to the alternatives by DM1, DM2, and DM3 are presented in Tables 2–4 respectively. The linguistic variable ratings in Tables 2–4 are then replaced with the corresponding TFN and results are indicated in Tables 5–7. The degree of importance of the four decision criteria was however ascertained by a single decision-maker. The ratings assigned to the decision criteria by the decision-maker are presented in Table 8.

3.1.2. Group Decision-Making Data Analysis

The rating obtained from the three decision-makers in Tables 5–7 are aggregated by applying Equation (2) and the group combine decision matrix generated is indicated in Table 9.

The application of Equation (2) is demonstrated with the result for, A1C1, as follows: 

\[ a_{11} = \min (7,5,7) = 5; \]
\[ b_{11} = \frac{1}{3} (9 + 7 + 9) = 8.3333; \]
\[ c_{11} = \max (9,9,9) = 9. \]

| Table 2. Decision-maker 1 (DM1). |
|---------------------------------|
| **Alternatives**               | **Criteria** |
| Alloy steel (A1)                | VH | H | H | VH |
| Galvanised steel (A2)           | H  | H | M | VL |
| Stainless steel (A3)            | L  | L | VH | VH |
| Mild steel (A4)                 | M  | H | L | L  |
Table 3. Decision-maker 2 (DM2).

| Alternatives | C1 | C2 | C3 | C4 |
|--------------|----|----|----|----|
| A1           | H  | VH | H  | VH |
| A2           | H  | M  | H  | L  |
| A3           | VL | L  | VH | VH |
| A4           | L  | H  | M  | M  |

Table 4. Decision-maker 3 (DM3).

| Alternatives | C1 | C2 | C3 | C4 |
|--------------|----|----|----|----|
| A1           | VH | VH | H  | VH |
| A2           | H  | H  | H  | VL |
| A3           | VL | L  | H  | VH |
| A4           | L  | H  | L  | M  |

Table 5. Fuzzy number representation for DM1.

| Alternatives | C1 | C2 | C3 | C4 |
|--------------|----|----|----|----|
| A1           | 7  | 9  | 5  | 7  |
| A2           | 5  | 7  | 5  | 3  |
| A3           | 1  | 3  | 5  | 3  |
| A4           | 3  | 5  | 7  | 1  |

Table 6. Fuzzy number representation for DM2.

| Alternatives | C1 | C2 | C3 | C4 |
|--------------|----|----|----|----|
| A1           | 5  | 7  | 9  | 9  |
| A2           | 5  | 7  | 9  | 5  |
| A3           | 1  | 3  | 1  | 5  |
| A4           | 1  | 3  | 5  | 1  |

Table 7. Fuzzy number representation for DM3.

| Alternatives | C1 | C2 | C3 | C4 |
|--------------|----|----|----|----|
| A1           | 7  | 9  | 5  | 7  |
| A2           | 5  | 7  | 9  | 5  |
| A3           | 1  | 3  | 5  | 3  |
| A4           | 1  | 3  | 5  | 1  |

Having obtained the combined group decision matrix, next, the matrix is normalised using Equations (4) and (5) and the normalised matrix is shown in Table 10. The normalised matrix is then multiplied with decision criteria weight in Table 8 using Equation (6) to produce a weighted normalised matrix. The weighted normalised matrix is presented in Table 11. Equations (9) and (10) are then applied to data in Table 11 respectively, to determined $A^+$ and $A^-$ and the results produced are indicated in Table 12.

The distance of each alternative material from $A^+$ is then evaluated by using data in Tables 11 and 12 as input to Equation (11) and the results obtained are presented in Table 13. The application of Equations 11 is illustrated with results obtained for, A1C1, A1C2,
Table 8. Decision criteria rating.

| Decision criteria       | Linguistic rating | Fuzzy number |
|-------------------------|-------------------|--------------|
| Yield strength          | H                 | 5, 7, 9      |
| Thermal conductivity    | M                 | 3, 5, 7      |
| Corrosion resistance    | H                 | 5, 7, 9      |
| Cost                    | VH                | 7, 9, 9      |

Table 9. Combined group decision matrix.

| Alternatives | C1  | C2  | C3  | C4  |
|--------------|-----|-----|-----|-----|
| A1           | 5   | 8.3333 | 9   | 5   |
| A2           | 5   | 7    | 9   | 3   |
| A3           | 1   | 1.6667 | 5   | 3   |
| A4           | 1   | 3.6667 | 7   | 9   |

Table 10. Normalised fuzzy decision matrix based on group decision-making.

| Alternatives | C1  | C2  | C3  | C4  |
|--------------|-----|-----|-----|-----|
| A1           | 0.5556 | 0.9259 | 1.0000 | 0.5556 |
| A2           | 0.5556 | 0.7778 | 1.0000 | 0.3333 |
| A3           | 0.1111 | 0.1852 | 0.5556 | 0.1111 |
| A4           | 0.1111 | 0.4074 | 0.7778 | 0.5556 |

Table 11. Weighted normalised fuzzy decision matrix based on group decision-making.

| Alternatives | C1  | C2  | C3  | C4  |
|--------------|-----|-----|-----|-----|
| A1           | 2.7778 | 6.4815 | 9.0000 | 1.6667 |
| A2           | 2.7778 | 5.4444 | 9.0000 | 1.0000 |
| A3           | 0.5556 | 1.2963 | 5.0000 | 0.3333 |
| A4           | 0.5556 | 2.8519 | 7.0000 | 1.6667 |

Table 12. Fuzzy positive ideal solution $A^+$ and negative ideal solution $A^−$ based on group decision-making.

$A^+$

| Alternatives | C1  | C2  | C3  | C4  |
|--------------|-----|-----|-----|-----|
| A1           | 2.7778 | 6.4815 | 9.0000 | 1.6667 |
| A2           | 2.7778 | 5.4444 | 9.0000 | 1.0000 |
| A3           | 0.5556 | 1.2963 | 5.0000 | 0.3333 |
| A4           | 0.5556 | 2.8519 | 7.0000 | 1.6667 |

$A^−$

| Alternatives | C1  | C2  | C3  | C4  |
|--------------|-----|-----|-----|-----|
| A1           | 0.5556 | 1.2963 | 5.0000 | 0.3333 |
| A2           | 0.5556 | 2.8519 | 7.0000 | 1.6667 |
| A3           | 0.5556 | 1.2963 | 5.0000 | 0.3333 |
| A4           | 0.5556 | 2.8519 | 7.0000 | 1.6667 |

and A1C3 respectively in Table 13 as follows:

\[
d(\tilde{v}_{11}, \tilde{v}_1^+) = \sqrt{\frac{1}{3}[(2.7778 - 2.7778)^2 + (6.4815 - 6.4815)^2 + (9 - 9)^2]} = 0.000
\]

\[
d(\tilde{v}_{12}, \tilde{v}_2) = \sqrt{\frac{1}{3}[(1.6667 - 1.6667)^2 + (4.6296 - 4.6296)^2 + (7 - 7)^2]} = 0.000
\]

\[
d(\tilde{v}_{13}, \tilde{v}_3^+) = \sqrt{\frac{1}{3}[(2.7778 - 2.7778)^2 + (5.4444 - 6.4815)^2 + (9 - 9)^2]} = 0.5987
\]

To calculate the distance of each alternative from $A^−$, Equation (12) is applied to data in Tables 11 and 12 and the computed results are indicated in Table 14. The application of Equation (12) is demonstrated with results obtained for A1C1, A1C2, and A1C3 respectively.
Table 13. Distance of each alternative from $A^+$ based on group decision-making.

| Alternatives | C1     | C2     | C3     | C4     |
|--------------|--------|--------|--------|--------|
| A1           | 0.0000 | 0.0000 | 0.5987 | 5.6569 |
| A2           | 0.5987 | 1.1759 | 1.6826 | 0.0000 |
| A3           | 2.5337 | 3.9000 | 0.0000 | 3.6389 |
| A4           | 5.1753 | 0.9623 | 2.8698 | 1.1547 |

Table 14. Distance of each alternative from $A^-$ based on group decision-making.

| Alternatives | C1     | C2     | C3     | C4     |
|--------------|--------|--------|--------|--------|
| A1           | 6.6732 | 4.3647 | 3.5168 | 0.0000 |
| A2           | 5.9037 | 3.6409 | 2.9518 | 5.6569 |
| A3           | 0.0000 | 0.0000 | 4.3382 | 0.0000 |
| A4           | 2.1924 | 3.9000 | 0.0000 | 3.6389 |

Table 15. $CC_i$ and corresponding alternatives ranking based on group decision-making.

| Alternatives | $Y^+_i$ | $Y^-_i$ | $(CC_i)$ | Rank |
|--------------|---------|---------|----------|------|
| A1           | 6.2556  | 14.5547 | 0.6994   | 2    |
| A2           | 3.4573  | 18.1533 | 0.8400   | 1    |
| A3           | 10.0726 | 4.3382  | 0.3010   | 4    |
| A4           | 10.1620 | 9.7312  | 0.4892   | 3    |

in Table 14 as follows:

\[
 d(\tilde{v}_{11}, \tilde{v}_{1^-}) = \sqrt{\frac{1}{3}[(2.7778 - 0.5556)^2 + (6.4815 - 1.2963)^2 + (9 - 5)^2]} = 6.6732
\]

\[
 d(\tilde{v}_{12}, \tilde{v}_{2^-}) = \sqrt{\frac{1}{3}[(1.6667 - 0.3333)^2 + (4.6296 - 1.6667)^2 + (7 - 3.8889)^2]} = 4.3647
\]

\[
 d(\tilde{v}_{13}, \tilde{v}_{3^-}) = \sqrt{\frac{1}{3}[(2.7778 - 0.5556)^2 + (5.4444 - 2.8519)^2 + (9 - 7)^2]} = 3.5168
\]

Finally, utilising Equations (13)–(15), $Y^+_i$, $Y^-_i$ and $CC_i$ are calculated respectively and the results produced are shown in Tables 15. The various materials alternatives are ranked based on $CC_i$ values and the rankings are also indicated in Table 15 and Figure 1.

From Table 15 and Figure 1, the alternative with the ranking of 1 is the galvanised steel (A2), hence it is optimal material suitable for the Cashew juice extractor Auger. The least suitable material for the system is stainless steel (A3) having rank 4 among all alternative materials. The result of the analysis of the FUZZY TOPSIS is dependent on several factors such as the quality of the decision-makers, degree of importance attached to different decision criteria. In the production of juice extracting machine, in most cases, parts having direct contact with the fruits are fabricated from stainless steel. The galvanised steel (A2) outcome of this FUZZY TOPSIS analysis was intending to produce a prototype machine at the barest minimum cost. However, production for commercial purposes more consideration should be given to the quality of juice produced from the machine rather than a cost criterion that was given the highest importance in this paper.
3.1.3. Comparison of Methods Based on Group Decision-Making

To validate the FUZZY TOPSIS technique for application in materials analysis for economic production of cashew juice extractor, the method was compared with two other MCDM approaches; FUZZY MOORA and FUZZY SAW. The three methods are very useful tools in investigating the multi-criteria decision-making problem. The comparative analysis results of the three approaches are indicated in Table 16 and Figure 2.

From Table 16 and Figure 2, the FUZZY TOPSIS and FUZZY SAW method produces the same ranking for the four alternative materials. On the other hand, the FUZZY TOPSIS and FUZZY MOORA methods produce very similar results having the same ranking for alternative materials, A3 and A4 and a rank difference of one between A1 and A2. From, the
comparative analysis it is obvious that the proposed technique is a viable tool for solving the material selection problem for the cashew juice extractor. Although the approach was applied in analysing material selection problem for the cashew juice extractor, the technique is also capable of solving other multi-criteria decision problem. The Spearman rank correlations test has also been used by different authors in the literature to show the degree of similarity among the various MCDM tools see the work of [30,31]. On this basis, the Spearman rank correlation test was carried out. The evaluated Spearman rank correlation coefficient between FUZZY TOPSIS and FUZZY MOORA; FUZZY TOPSIS and FUZZY SAW of 0.8095 and 1 respectively further indicated the viability of the proposed FUZZY TOPSIS methodology.

3.2. Case Study 2

3.2.1. Data Collection

In many real-life problems, multiple decision-makers are generally involved in the decision-making process, however, in some scenarios, a single decision-maker is utilised in obtaining the appropriate solution. This case study is used to demonstrate analysis involving a single decision-maker. In case study 1, a group of three decision-makers (DM1, DM2, and DM3) was used to ascertain the best material for the Auger from among four alternatives with respect to four decision criteria. Since, case study 2 involves the use of a single decision-maker in the decision-making process, DM1 data in Table 5 is utilised as input data for the FUZZY TOPSIS method analysis. The rating assigned to the decision criteria (C1, C2, C3, and C4) in Table 8 used for the FUZZY TOPSIS analysis in case study 1 is also used as criteria weights in case study 2.

3.2.2. Data Analysis

The FUZZY TOPSIS analysis for a decision-making process involving a single decision-maker starts with decision matrix normalisation as opposed to the group decision-making process which begins with individual rating aggregation. Applying Equations (4) and (5) to data in Table 5, the normalised matrix is generated and the result is shown in Table 17. The weighted normalised matrix is then obtained by applying Equation (6) to data in Tables 8 and 17 and the result produced is presented in Table 18. Having evaluated the weighted normalised matrix, the Fuzzy positive idea solution and Fuzzy Negative solution are obtained by applying Equation 9 and 10 to data in Table 18 respectively, and the results generated are presented in Table 19. The distances of each alternative from $A^+$ and $A^-$ are then obtained by applying Equations (11) and (12) to data in Tables 18 and 19 respectively and the results produced are shown in Tables 20 and 21. Finally, $Y^+_i$, $Y^-_i$ and $CC_i$ are evaluated by applying Equations (13)–(15) to data in Tables 20 and 21 and the results obtained

### Table 16. Ranking of different methods based on group decision-making.

| Alternatives | FUZZY TOPSIS | FUZZY MOORA | FUZZY SAW |
|--------------|--------------|-------------|-----------|
| A1           | 2            | 1           | 2         |
| A2           | 1            | 2           | 1         |
| A3           | 4            | 4           | 4         |
| A4           | 3            | 3           | 3         |
### Table 17. Normalised decision matrix.

| Alternatives | C1    | C2    | C3    | C4    |
|--------------|-------|-------|-------|-------|
| A1           | 0.7778| 1.0000| 1.0000| 0.5556|
| A2           | 0.5556| 0.7778| 1.0000| 0.5556|
| A3           | 0.1111| 0.3333| 0.5556| 0.5556|
| A4           | 0.3333| 0.5556| 0.7778| 0.7778|

### Table 18. Weighted normalised matrix.

| Alternatives | C1    | C2    | C3    | C4    |
|--------------|-------|-------|-------|-------|
| A1           | 3.8889| 7.0000| 9.0000| 1.6667|
| A2           | 2.7778| 5.4444| 9.0000| 1.6667|
| A3           | 0.5556| 2.3333| 5.0000| 1.6667|
| A4           | 1.6667| 3.8889| 7.0000| 1.6667|

### Table 19. Fuzzy positive ideal solution $A^+$ and negative ideal solution $A^-$.

$A^+ = \begin{bmatrix} 3.8889 & 7.0000 & 9.0000 & 1.6667 \\ 2.7778 & 5.4444 & 9.0000 & 1.6667 \\ 0.5556 & 2.3333 & 5.0000 & 1.6667 \\ 1.6667 & 3.8889 & 7.0000 & 1.6667 \end{bmatrix}$

$A^- = \begin{bmatrix} 0.5556 & 2.3333 & 5.0000 & 0.3333 \\ 1.6667 & 3.8889 & 0.5556 & 2.3333 \\ 4.0367 & 2.3333 & 0.0000 & 2.3333 \\ 2.4910 & 0.0000 & 4.0367 & 2.3333 \end{bmatrix}$

### Table 20. Distance of each alternative from $A^+$.

| Alternatives | C1    | C2    | C3    | C4    |
|--------------|-------|-------|-------|-------|
| A1           | 0.0000| 0.0000| 1.1036| 5.8875|
| A2           | 1.1036| 0.0000| 2.4910| 0.0000|
| A3           | 4.0367| 2.3376| 0.0000| 5.8875|
| A4           | 2.4910| 0.0000| 4.0367| 3.5325|

### Table 21. Distance of each alternative from $A^-$.

| Alternatives | C1    | C2    | C3    | C4    |
|--------------|-------|-------|-------|-------|
| A1           | 4.0367| 2.3376| 3.1945| 0.0000|
| A2           | 3.1945| 2.3376| 1.5972| 5.8875|
| A3           | 0.0000| 0.0000| 4.0367| 0.0000|
| A4           | 1.5972| 2.3376| 0.0000| 3.6804|

are presented in Table 22 and Figure 3. The different materials alternatives are ranked with respect to $CC_i$ values and the rankings produced are also shown in Table 22 and Figure 3.

It is obvious from Table 22 and Figure 3, the optimum material is galvanised steel, A2, having rank 1 while the worst material is stainless steel, A3, having rank 4 among the four alternative materials. This result generated whilst utilising a single decision-maker, in the decision-making process is completely the same result previously obtained when three
decision-makers were used in the decision-making process. This could be attributed to the similarity of the rating assigned to the four alternative materials against the four decision criteria by the three decision-makers; DM1, DM2, and DM3 as DM 1 rating were applied as input data for TOPSIS analysis in case study 2. If the degree of similarity of the rating assigned by the three decision-makers was low there would have been a difference in the results obtained from the single decision-makers decision-making scenario; case study 2 and the group decision-makers decision-making scenario; case study 1.

### 3.2.3. Comparison of Methods

To further validate the FUZZY TOPSIS methodology for the analysis of material selection for cashew juice extractor, the results obtained from the single decision-maker rating are compared with FUZZY MOORA and FUZZY SAW methods. The results of the comparative analysis are shown in Table 23.

From Table 23 and Figure 4, the three techniques rank alternative materials A3 and A4 the same, representing 50% of the overall materials having the same ranking. Comparing the FUZZY TOPSIS and FUZZY SAW methods, it can be observed that the duo produces the same ranking for all alternative materials. On the other hand, comparing FUZZY TOPSIS and FUZZY MOORA methods, it is obvious that the results produce by both techniques are very similar with both methodologies having the same rank for alternative materials, A3 and

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**Figure 3.** Alternatives, $C_{ij}$ values, and corresponding rank.

**Table 23.** Ranking of the proposed method in comparison with other methods.

| Alternatives | FUZZY TOPSIS | FUZZY MOORA | FUZZY SAW |
|--------------|--------------|--------------|-----------|
| A1           | 2            | 1            | 2         |
| A2           | 1            | 2            | 1         |
| A3           | 4            | 4            | 4         |
| A4           | 3            | 3            | 3         |
A4 and a rank difference of one between A1 and A2. The Spearman rank correlation coefficient between FUZZY TOPSIS and FUZZY MOORA; FUZZY TOPSIS and FUZZY SAW were also evaluated and results obtained are 0.8095 and 1 respectively. This has further shown that the proposed FUZZY TOPSIS methodology is capable of addressing the material selection analysis problem of the cashew juice extractor.

4. Discussion of Results

Improper material selection may lead to the requirement of customers and manufacturers not being satisfied [32]. It can also lead to failure of an assembly and reduction in product performance, thus efficiency and profitability affected adversely and organisation reputation damaged [33]. To properly select materials for sustainable cashew juice extractor production and also produce a machine that will meet the requirement of the end-users of the product in developing countries, this paper presented a FUZZY TOPSIS methodology for solving a material selection problem. The technique proposed uses a multi-criteria methodology in finding optimal material from among alternative materials. The ‘Auger’ which is the most critical component of the cashew juice extractor was utilised to illustrate the applicability of the FUZZY TOPSIS method. In the application, two cases were considered in the decision-making process. In Case 1 three decision-makers were involved in the decision-making process while in case 2 a single decision-maker was used in the decision-making process. The results obtained from the analysis of the FUZZY TOPSIS technique in case 1, indicated that galvanised steel (A2) is the optimum materials for the Auger having the highest performance value of 0.8400 while stainless steel (A3) is the least suitable material having the lowest performance value of 0.3010. The results of the analysis of the TOPSIS method were compared with that of the FUZZY MOORA and FUZZY SAW method to validate the proposed methodology. The comparative analysis indicated that FUZZY TOPSIS produces completely the same result with FUZZY SAW methods and very similar results with the FUZZY MOORA method and this is an indication of the viability of the proposed
methodology for the analysis of material selection problem of the cashew juice extractor. On the other hand, the result obtained from case 2 also showed that the best material for the Auger is the galvanised steel (A2) having the highest performance value of 0.7836 while the worst material is stainless steel (A3) having the lowest performance index of 0.2477. A comparative analysis was also carried out and the result of the analysis showed that FUZZY TOPSIS produced completely the same result with the FUZZY SAW method while it produces a very similar result to the FUZZY MOORA method. The ideal choice for the Auger would have been either the stainless steel or alloy steel since the Auger has direct contact with juice in the extraction process. However, the poor choice of material in the two case studies is as a result of the input data used in the analysis of the FUZZY TOPIS method. The decision-makers targeted galvanised steel and assigned the highest ratings to it with respect to almost all decision criteria including cost criterion. This is because their major consideration was reducing cost of production to the barest minimum without actually putting into consideration juice output quality. However, when producing for commercial purpose more consideration should be given to the quality of juice produced from the machine rather than a cost criterion that was given the highest importance in this paper. It could be concluded that the result of the FUZZY TOPSIS method and other similar techniques in the literature is dependent on the quality of decision-makers, the number of decision-makers and weight attached to the different decision criteria among other.

5. Conclusion

In many developing nations across the globe, the majority of fruits produced are wasted due to mainly lack of economic facility to process it into juice and other by-products by the rural dwellers where the bulk of the fruits are produced. In this paper, a methodology that combines FST with TOPSIS referred to as FUZZY TOPSIS is presented for selecting the optimal material for economic production of the cashew juice extractor. The applicability of the technique was illustrated with a case of the Augur one of the most critical components of the cashew juice extractor. The investigation result showed that Galvanised steel is the optimal material for the production of cashew juice extractor Auger. To ascertain the suitability of the FUZZY TOPSIS method, the results obtained from it was compared with FUZZY MOORA and FUZZY SAW technique. The comparative analysis results indicated that the FUZZY TOPSIS method produces completely same result with the FUZZY SAW method and very similar results with the FUZZY MOORA method. However, the result of analysis using the proposed technique and other techniques in the literature is dependent on the quality of decision-makers, the number of decision-makers and weight attached to the different decision criteria. It is therefore recommended that excellent decision-makers should be engaged to achieve an optimal result. Although in this paper, the FUZZY TOPSIS method was specifically designed for analysing cashew juice extractor material selection problem, in practice, the approach can be implemented in solving other multi-criteria material selection problems. For future work, the application of other MCDM tools such as ELECTRE, PROMETHEE, and TODIM in conjunction with FST could be exploited for analysing material selection problem of the cashew juice extractor. Furthermore, sensitivity analysis can be carried out to determine the impact of ranking parameter changes on the optimum solution.
Disclosure statement

No potential conflict of interest was reported by the authors.

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