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Compromise Ranking Method to the Selection of Starch Source for the Production of Biodegradable Flexible Plastics

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Abstract

Plastics have been found to be useful all over the world. Its usage ranges from packaging to garbage bags, fluid containers, disposable fast food service items, and others. The disposal of plastics after their useful life poses great threat to both human and the environment because of their non-biodegradable nature. This has led to a search for alternative raw material for the production of flexible plastics that are biodegradable, environmentally friendly and renewable. Starches from cereals and tubers have been found to be useful for the production of biodegradable flexible plastics. Starches from these sources have different quality attributes and the choice of making the decision to select the best out of these alternatives is a multi-criteria problem. The purpose of this work is to use compromise ranking method to select starch source out of the numerous alternatives for the production of flexible biodegradable plastics.

Several starch sources were identifies from literature namely: rice(A_1), cassava (A_2), Irish potato (A_3), corn (A_4), yam (A_5), cocoyam (A_6) and sweet potato (A_7). The criteria upon which the performance of each starch source were evaluated were also identified from literature. They include: amylose content (C_1); gelatinization temperature: onset temperature (C_2), peak temperature (C_3), completion temperature (C_4); cost of production (C_5); availability (C_6); shelf life (C_7); crystallinity (C_8); tensile stress (C_9); percentage elongation (C_{10}); young modulus (C_{11}), and water absorption capacity (C_{12}). Information entropy weighting method was used to assign weight to reflect the relative importance of the criteria. VIKOR approach was used to rank the alternatives to identify the best among the starch sources for the production of biodegradable plastics.

The weight assigned to each of the criteria in a descending order is given as: C_1 (0.084067); C_6 (0.083847); C_8, (0.083839); C_{10} (0.083716); C_{12} (0.083634); C_{11} (0.083506); C_9 (0.083387); C_4 (0.083293); C_2 (0.083043); C_7 (0.082672); C_3 (0.082514); C_5 (0.082482). Ranking of the starch sources in descending order is: $A_5 \succ A_6 \succ A_4 \succ A_2 \succ A_1 \succ A_7 \succ A_3$. Starch from yam is the best compromise choice that is closest to the ideal solution. It has an amylose content of 25.2% and an average availability of 15 tons per hectare, a production cost ₦124129.7 and percentage elongation of 11%.

Keywords: VIKOR approach, Criteria weighting, starch sources selection criteria, best compromise solution and starch sources selection criteria.

1.0 INTRODUCTION

Plastics have become a product that the world cannot do without because of its wide range of application. It can be said that the world is tending to a plastic-age, flexible plastics are used all over the world in making retail and refuse bags, agricultural mulch, beverage rings, diaper linings, bottles and drums, disposable fast food service items (cup, food trays, dinner wares, etc), egg cartons, containers, as well as packaging of both edible and non-edible products (Funke *et al*., 1998; Tharanathan, 2003; Mondal, 2015).Despite this wide range of applications, the disposal of plastics after their useful life poses threat to human, aquatic animals and the environment because of their non-biodegradable nature. Synthetic plastics are known to be non-biodegradable, upon disposal, they remain unchanged for decades and pollute the environment (Roper and Koch, 1990; Funke *et al.*, 1998; Tokiwa et al., 2009 ; Mondal, 2015; Soomaree, 2016; Shamsuddin *et al*., 2017)

The environmental concern about the non-biodegradability of polymeric plastics led to a search for an alternative biodegradable and environmentally friendly source. The widely studied and capable raw material used in biodegradable plastics production is starch while others are cellulose, chitosan/chitin and other polypeptides. Owing to the fact that there are numerous sources from which this starch can be obtained, there is a need to select from this discrete alternatives the optimal that will meet the given application. In carrying out this selection process, the property of the resulting flexible plastics must be put into consideration such that the selection can be optimal. The key properties includes: amylose content, water absorption rate, peak temperature, mechanical properties like tensile strength, elongation at break/Young Modulus, degradation time, gelatinization, melting temperature, other requirements are availability, cost per hectare, cost of production, and others. None of the starch sources can fulfill/meet all of these criteria simultaneously, there has to be a trade-off among the various conflicting criteria. (Funke *et al*., 1998; Tharanathan, 2003; Santana & Meireles, 2014; Mondal, 2015; Omotoso *et al*., 2015a; Omotoso *et al*., 2015b).

Owing to the fact that there are several alternatives, it requires that one should determine the optimal in order to safe cost, time and energy. VIKOR method has been chosen from various decision making techniques available. This is due to its efficiency in solving discrete decision problems with conflicting criteria, its evaluation with little computation load and because of it suitability for those circumstances in which decision makers want to gain maximum profit. In this work, VIKOR approach will be used using an objective weight determined from Information Entropy Weight (IEW) based on the information entropy of raw data to help select the best among all of the alternatives of starch source that will find application in the plastic production industry (El-Santawy, 2012; Opricovic and Tzeng, 2004).

2.0 LITERATURE REVIEW

Plastics are typically organic polymer of high molecular mass. The properties of polymer depend on the monomer(s) from which it is formed. Plastics are mostly derived from petrochemicals. Alternative sources arechitins/chitosan, collagen, starch from obtained from cereal, root crops, tuber, legumes, etc. (Santana & Meireles, 2014). Plastics can either be biodegradable or non-biodegradable depending on the source from which they are being produced.Plastic materials can be produced into rigid, flexible, serializable or isolating products (Omotoso(a) *et al*., 2015; Shamsuddin *et al*., 2017; Srichuwonga *et al*., 2005). The later paragraphs discuss: Biodegradable plastics, multi-criteria decision making (mcdm) and the VIKOR method.

Biodegradable plastics

Biodegradable plastics are plastics that degrade, or breakdown, upon exposure to sunlight or ultra-violet radiation, water or dampness, bacteria, enzymes or wind abrasion. In some instances, rodent, pest, or insect attack can also be considered as forms of biodegradation or environmental degradation. Whilst most plastics are produced from petrochemicals which has and is raising alarm for it to be banned due to its high rate of pollution, biodegradable plastics are essentially from renewable plant materials such as cellulose and starch which are environmental friendly. Biopolymers from agricultural feed stocks such as rice, yam, corn, potato, sweet potato, cassava and cocoyam have the ability upon blending and/ or processing to result in biodegradable plastics that are useful in packaging. Their functionality can be better expressed by combining them with other ingredients such as plasticizers and additives (Roper & Koch, 1990; Obasi and Igwe, 2014; Adewumi *et al*., 2015; Ezeoha and Ezenwanne, 2013).

Multi-criteria decision making (MCDM)

Multi-Criteria Decision Making (MCDM) is the problem of selecting the best alternative over a discrete number of alternatives described by several criteria. To select the best choice over a wide range of alternatives can be a very difficult task for a decision maker due to conflicting criteria, high number of alternatives and the presence of uncertainties. The presence of conflicting criteria in the design of a system makes a solution method that is able to compare the alternatives not obvious. If there are a high number of alternatives, a computationally efficient method that will be able to identify the optimal decisions is required (Mardani *et al*., 2016).

Several multi-criteria selection decision making (MCDM) techniques are available which been used alone or combined with another methods. They include TOPSIS (Srikrishna *et al*., 2014), VIKOR (Jahan *et al*., 2011 ; El-Santawy, 2012), PROMETHEE (Mareschal *et al*., 1984), ELECTRE (Sevkli, 2010), Compromise Programming (Adeyeye *et al*., 2015), AHP (Triantaphyllou and Mann, 1995), ANP (Saaty, 1996), COPRAS (Zavadskas and Antucheviciene, 2007), and several others. All of these various techniques and their Fuzzy have been used to solve several problems that involve selection of the best alternative which satisfies the evaluation criteria among a set of candidate solution. Weight assignments which reflect the relevance of each criterion can be determined using: Weighted Least Square method, Delphi method, Analytic Hierarchy Process method, Multi-objective programming, Principle element analysis or Information Entropy Weighing Method (El-Santawy and Ahmed, 2012; El-Santawy, 2012; Mardani *et al*., 2016; He *et al*., 2016).

The VIKOR Method

The VIKOR method determines the compromise multi-criteria ranking index based on the particular measure of “closeness” to the “ideal” solution. All alternatives are evaluated in line with the identified criteria which carry equal or varying weight. The best is selected based on its closeness to ideal solution. The multi-criteria measure for compromise ranking is developed from the linear programming metric used as an aggregating function in a compromise programming method.

VIKOR is a helpful tool in MCDM, particularly in a situation where the decision maker is not able, or does not know how to express preference at the beginning of system design due to the conflicting criteria which cannot be achieved simultaneously and also because of its little computation load. The obtained compromise solution could be accepted by the decision makers because it provides a maximum group utility (represented by S^-) of the 'majority' and a minimum of individual regret (represented by R^-) of the 'opponent' (El-Santawy, 2012; Opricovic & Tzeng, 2002).

3.0 MATERIALS/METHODS

The situation considered here is a case where a manufacturer wants to select from a finite number of alternative raw materials to be used for the production of a particular product. There are m alternatives and n criteria upon which the alternatives will be evaluated. The procedure for achieving this is presented below:

- Identification of available raw materials for the specific application from which the most suitable will be selected
- Identification of the various criteria upon which the various material will be evaluated.
- Determination of the weight of the criteria to reflect their relative importance to the production of flexible biodegradable plastics using Information Entropy Weighting method
- Ranking of the alternatives using VIKOR

Model Description

MCDM problems have three levels, that is, the goal, criteria and the constraint.

Goal: what VIKOR will measure; minimize the level of regret/the distance of the alternative to the ideal.

Criteria: elements integral to attaining the goal, the desired properties for evaluation.

The alternatives: the organisms of concern We also have the constraint: these are restrictions on attributes and decision variables. They include:

i. The values of the attributes are all non-negative i.e. $f^-_j, f_{ij}, f^*_j \geq 0$
ii. The weights of the various attributes take values between 0 and 1, i.e. $0 \leq W_j \leq 1$
iii. The weights add up to 1 $\sum_i W_j = 1$

The model is expressed mathematically as follows:

Minimize $L_{p,j} = \left\{\sum_{i=1}^{n}\left[w_i\left(f_i^* - f_{ij}\right)/\left(f_i^* - f_i^-\right)\right]^p\right\}^{1/p} \quad 1 \leq p \leq \infty$

Subject to $f^-_j, f_{ij}, f^*_j \geq 0$

$\sum_i W_j = 1 ; \quad 0 \leq W_j \leq 1$

$i = 1,2,3 \ldots n \text{ and } j = 1,2,3 \ldots m$

Where: i = the alternatives

j = the criterion

$L_{1,i}$ = defined as the maximum group utility

$L_{\infty,i}$ =defined as the minimum individual regret of the opponent.

f^*_j = the best normalized value of a criterion function

f^-_j = the worst normalized value of a criterion function

f_{ij} = the normalized criterion value corresponding to alternative i

f_{ij} = the normalized criterion value j corresponding to alternative i

f^*_i = the best normalized criterion value corresponding to alternative i

f^-_i = the worst normalized criterion value corresponding to alternative i

n = number of criteria

m= number of alternatives

w_j = weight of jth criterion

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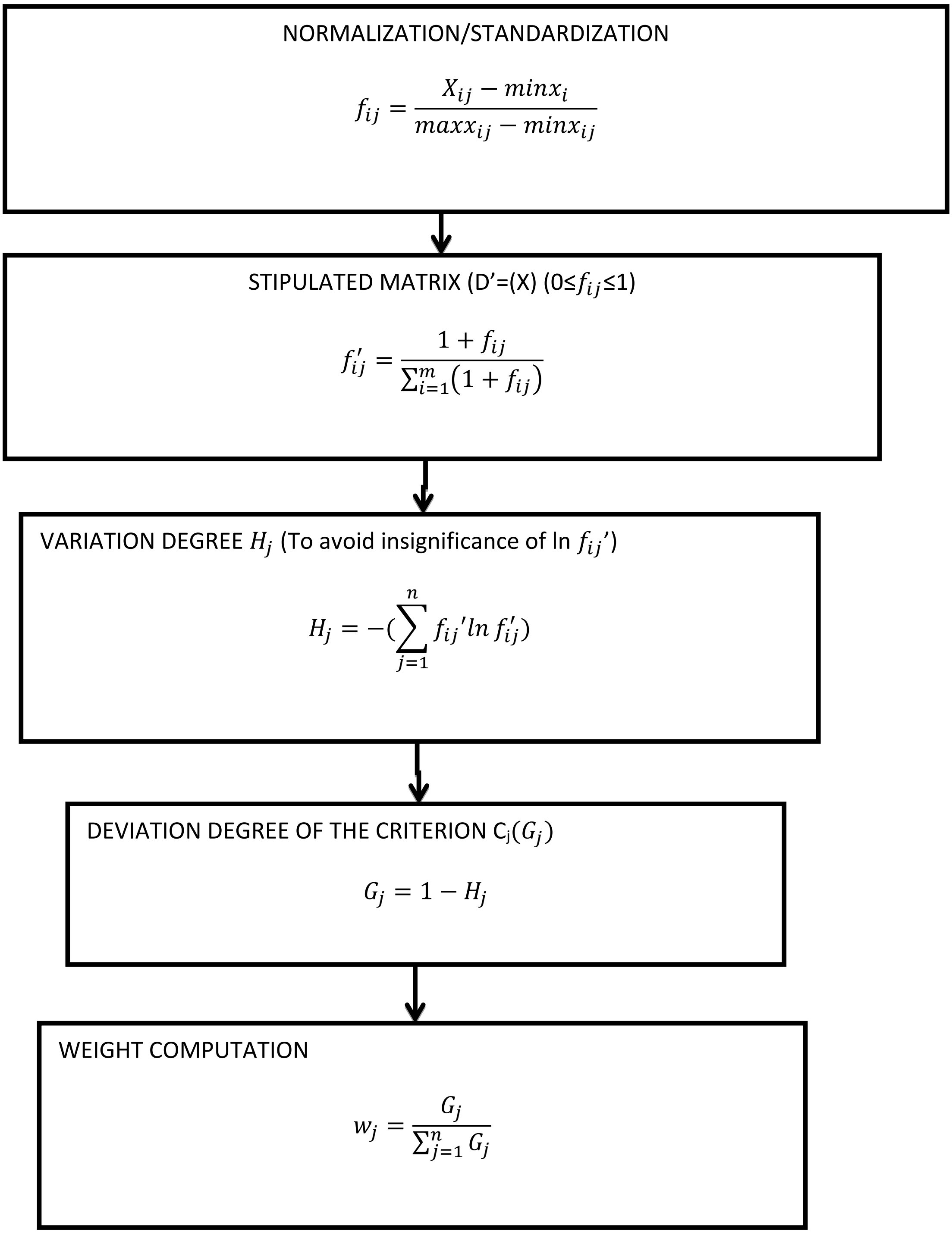

Figure 3.1: Information Entropy Weighting Method.

Source: El-Santawy (2012).

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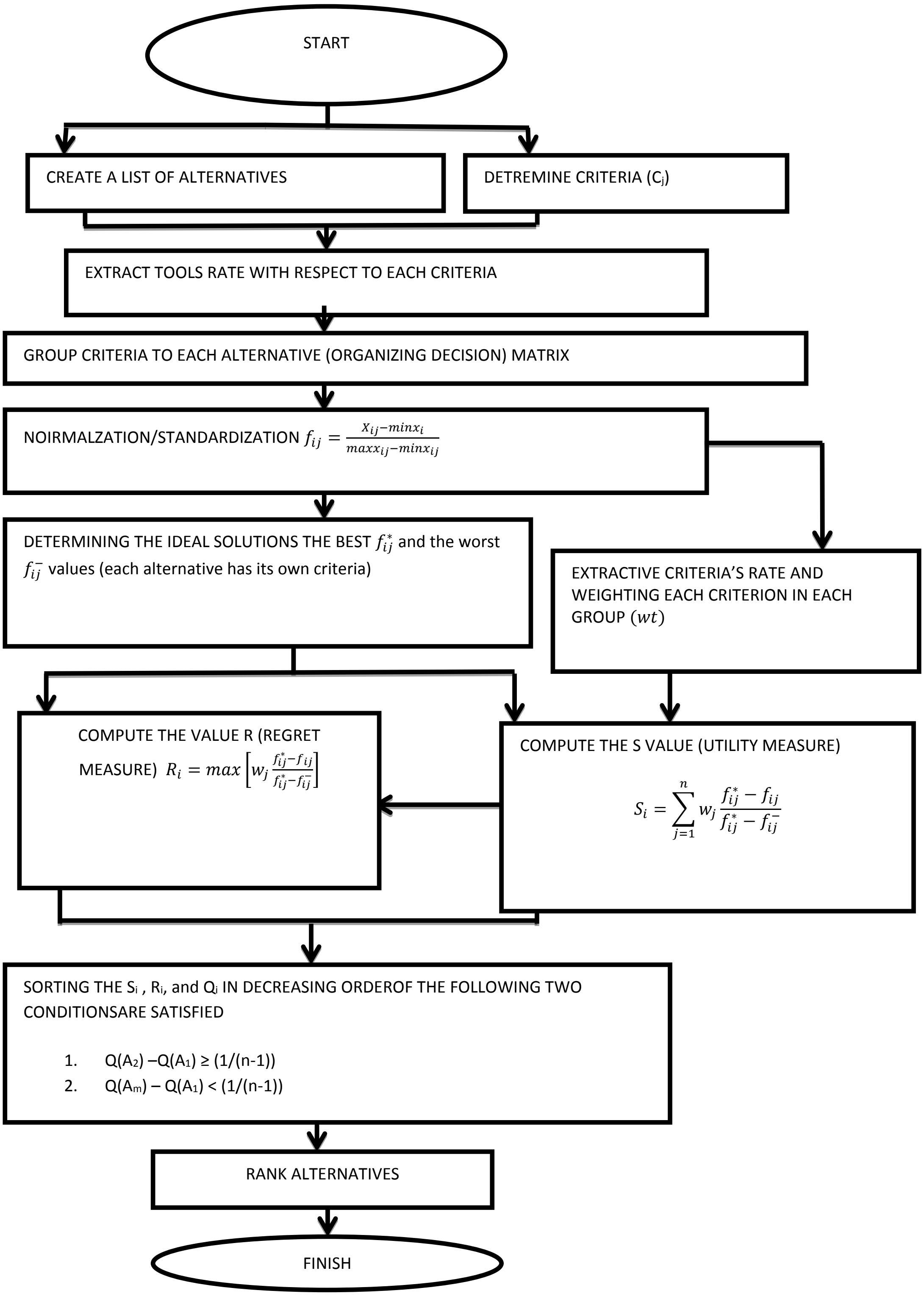

Figure 3.2: VIKOR Approach. *Source:* Mardani *et al*. (2016).

Information Entropy Weighting Method

The Information Entropy Weighting Method model used for assigning weight is presented in Figure 3.1.

The VIKOR Approach

It has been established that the compromise ranking algorithm VIKOR follows some procedure shown in Figure 3.2.

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Application

The procedures described in the section above were achieved as follows:

Step 1

Starch from the following sources were identified from literature

i. Rice, (A_1)
ii. Cassava, (A_2)
iii. Potato, (A_3)
iv. Maize, (A_4)
v. Yam, (A_5)
vi. Cocoyam, (A_6)
vii. Sweet potato, (A_7)

Table 3.1: Criteria and Computation Units

Criteria index	Criteria description	Computation units	
C_1	Amylose content	%	Beneficial
C_2	Gelatinization onset temperature	°C	Non-beneficial
C_3	Gelatinization peak temperature	°C	Non-beneficial
C_4	Gelatinization conclusion temperature	°C	Non-beneficial
C_5	Cost of production	₦	Non-beneficial
C_6	Availability per hectre	Ton	Beneficial
C_7	Shelf life	Months	Beneficial
C_8	Crystallinity	%	Non-beneficial
C_9	Tensile stress	MPa	Beneficial
C_{10}	Elongation	%	Beneficial
C_{11}	Young Modulus	MPa	Beneficial
C_{12}	Water Absorption Capacity	%	Non-beneficial

Step 2

Relative criteria for evaluation of the starch source were also identified from literature. Presentation of these criteria is as shown in Table 3.1.

The beneficial indicates the desirable criterion/property which implies the more the better while the non-beneficial indicates a non-desirable property or criterion which implies the less the better.

Presented in Table 3.2 is the performance evaluation of each criterion obtained from literature.

Step 3

The weight assigned using the Information Entropy Weighting model presented in Figure 3.1 is presented in Table 3.3.

Step 4

The ranking of the alternative in order to select the most suitable starch source for the specific application is presented in Table 3.4.

Table 3.2: Decision Matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
A_1	13.2	61.6	67.3	80	212950	2	96	37.1	5.16	8.5	60	192
A_2	17.9	59.3	65.7	79.6	32214	25	3	35.8	5.33	8	97.5	100
A_3	18	61.4	65.5	77.7	248280.8	10	10	29.8	5.77	3	191.33	60
A_4	23.4	62.6	66.7	81.3	30000	4	12	31	5.2	5	104.6	120
A_5	25.2	77.9	80.2	89.9	124129.7	15	5	34.2	5.1	11	49.3	120
A_6	22.5	74.3	77.2	87.3	171760	10	3	33.2	1.15	23.61	4.867	100
A_7	19.8	66	74	86.6	31330.9	10	3	34.4	0.272	6.46	4.209	196.5

Table 3.3: Weights Assignment

Criteria	W_j
C_1	0.084067
C_2	0.083043
C_3	0.082514
C_4	0.083293
C_5	0.082482
C_6	0.083847
C_7	0.082672
C_8	0.083839
C_9	0.083387
C_{10}	0.083716
C_{11}	0.083506
C_{12}	0.083634

Table 3.4: VIKOR Approach

	A_1	A_2	A_3	A_4	A_5	A_6	A_7
C_1	0.084067	0.051141	0.05044	0.004345	0	0.018915	0.03783
C_2	0.072774	0.083043	0.073667	0.066605	0	0.016073	0.05313
C_3	0.072411	0.081392	0.082514	0.074999	0	0.01684	0.034802
C_4	0.06759	0.070321	0.083293	0.055872	0	0.017751	0.02253
C_5	0.013351	0.081646	0	0.082482	0.047944	0.028915	0.081979
C_6	0.083847	0	0.054683	0.075712	0.037256	0.054683	0.054683
C_7	0	0.082672	0.076449	0.073746	0.082672	0.082672	0.082672
C_8	0	0.01493	0.083839	0.068463	0.034038	0.044791	0.031009
C_9	0.009252	0.006673	0	5.89E-09	0.010385	0.07007	0.083387
C_{10}	0.061375	0.063406	0.083716	0.074652	0.052346	0	0.069662
C_{11}	0.058608	0.041873	0	0.033523	0.064776	0.083213	0.083506
C_{12}	0.002757	0.059126	0.083634	0.042619	0.047902	0.059126	0
S_i	0.526032	0.636223	0.672235	0.65302	0.37732	0.493047	0.635189
R_i	0.084067	0.083043	0.083839	0.082482	0.082672	0.083213	0.083506
Q_i	0.752141	0.615852	0.928058	0.467545	0.059845	0.426647	0.760267
Ranking	**5TH**	**4TH**	**7TH**	**3RD**	**1ST**	**2ND**	**6TH**

4.0 RESULTS AND DISCUSSION

Starch from rice, A_1, Cassava, A_2, potato, A_3, maize, A_4, yam, A_5, cocoyam, A_6, sweet potato, A_7, are applicable in the production of flexible biodegradable plastics.

Information entropy weighting method

The criteria and the weight assigned in a descending order is presented in Table 4.1

From the objective weight obtained using the information entropy weighting method, it can be observed that amylose content (C_1)is the most important criterion followed by availability (C_8), availability (C_6)and then crystallinity (C_8)and so on. The least important is cost of production (C_5). In the selecting starch source for the production of biodegradable flexible plastics, the amylose content of the raw material should be given topmost priority so as to ensure suitable rheology for the processing of the flexible plastics which in turn enhance the mechanical property and prevent retrogradation (ageing) of the resulting flexible plastics (Ashogbon, 2014; Mondal, 2015).

Also, in selecting any raw material, availability is crucial. This was reflected in the result obtained. When raw material goes into extinct, production may seem impossible or one may have to find another readily available source. Therefore, in selecting a raw material for the production of biodegradable flexible plastics, the availability of such material must be put into consideration.

When quality of a product is paramount in production process, cost may not be a thing of much concern. Although one is expected to select a material that is economical and yet not play down on vital criteria which enhance the quality of the resulting plastics.

The VIKOR approach

The ranking of the various starch sources for the specified application is presented in descending order in Table 4.2

Conditions to be fulfilled:

1. Condition 1: Acceptable Advantage:
$$Q(A'') - Q(A') \geq \left[\frac{1}{(n-1)}\right]$$
Where n is the number of alternatives
$$Q(A'') - Q(A') = 0.426647 - 0.059845 = 0.366802$$
$$\left[\frac{1}{(n-1)}\right] = \frac{1}{(7-1)} = 0.16$$
The first condition is satisfied. Therefore, the one close to the ideal solution, the best solution (alternative) is A_5, that is yam.

2. Condition 2: Acceptable stability: Alternative A' must be the best ranked in S or/and R. from the result obtained in Table 5.2, Alternative 5, (A_5) is ranked the best in Q and S. Thus, the best solution (El-Santawy, 2012). The ranking is of the order: $A_5 > A_6 > A_4 > A_2 > A_1 > A_7 > A_3$.

The two conditions stated in VIKOR were satisfied based on the evaluation presented in step 4. This shows that the best starch source for the production of biodegradable flexible plastics is Yam (A_5).

Table 4.1: Weights Assigned to Criteria

Criteria	**W_j**
C_1, amylose content	0.084067
C_6, availability	0.083847
C_8, crystallinity	0.083839
C_{10}, percentage elongation	0.083716
C_{12}, water of absorption	0.083634
C_{11}, young modulus	0.083506
C_9, tensile strength	0.083387
C_4, conclusion temperature	0.083293
C_2, on set temperature	0.083043
C_7, shelf life	0.082672
C_3, peak temperature	0.082514
C_5, cost of production	0.082482

Table 4.2: Ranking List

	S_i	R_i	Q_i	Ranking
A_5	0.37732	0.082672	0.059845	1^{ST}
A_6	0.493047	0.083213	0.426647	2^{ND}
A_4	0.65302	0.082482	0.467545	3^{RD}
A_2	0.636223	0.083043	0.615852	4^{TH}
A_1	0.526032	0.084067	0.752141	5^{TH}
A_7	0.635189	0.083506	0.760267	6^{TH}
A_3	0.672235	0.083839	0.928058	7^{TH}

5.0 CONCLUSION

VIKOR method combined with Information Entropy Weighting method was presented to solve the MCDM problem which is the selection of starch source for the production of biodegradable plastics. Rice, cassava, potato, maize, yam, cocoyam, and sweet potato where the various alternatives of consideration and the criteria include: amylose content, gelatinization characteristics (onset temperature, peak temperature and conclusion temperature), cost of farming/production of each of the alternatives, availability in tons/hectre, shelf life, crystallinity, mechanical properties (tensile stress, elongation and young modulus), and water absorption capacity. The objective weights of the criteria were determined based on the data obtained from literature. Amylose content from the evaluation weighed more than other criteria. The computation and ranking of the various alternatives showed that starch from yam with amylose content of 25.2% and an average availability of 15tons per hectare, a production cost ₦124129.7 and percentage elongation of 11% is the best compromise that is close to the ideal solution. The resulting biodegradable plastics will be the most effective, efficient, reliable, save and economical. The following recommendations will be useful for further studies.

1. The MCDM problem should be reformulated and solved if any parameter or alternative is added or deleted because of its sensitivity to any change.
2. Characterization of these alternatives can be done locally because of geographical effect on the crops.
3. Other MCDM techniques may be used in further research.

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