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Application of the ELECTRE I and ELECTRE IS Method to Optimize Maize Seed Selection in Cameroon: A Multi-Criteria Approach

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ABSTRACT

This study aims to help Cameroonian farmers choose the best maize seeds to improve their yields. To achieve this, we evaluated 15 varieties based on five essential criteria: cycle length, yield per hectare, cob quality, stem height, and grain weight. Using the ELECTRE I and ELECTRE IS multi-criteria decision-making methods, we selected four particularly high-performing varieties: CLH103, CMS8602, CMS9015, and CMS 8501. These seeds offer a good balance between productivity and adaptation to local conditions, with potential yields of up to 10 tons per hectare. In-depth analyses have confirmed the reliability of these results, assuring farmers of a robust and effective choice. These recommendations can help improve food security and the profitability of farms in Cameroon.

Keywords : *ELECTRE method, maize; choice; multi-criteria evaluation.*

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1. INTRODUCTION

Maize (Zea mays L.) is an essential staple crop for global food security, particularly in developing countries. The study by [1, 2] highlights that, in the savannahs of Central Africa, maize has become an essential market crop, contributing significantly to urban food security. It is a versatile cereal widely consumed and grown in Cameroon [3]. Its adaptability across the five agroecological zones makes it a staple food for both human consumption and livestock feed [4, 5]. Despite its importance, choosing appropriate seed varieties remains a challenge due to diverse agronomic and environmental conditions. Cameroonian researchers, under the direction of IRAD and MINRESI, have characterized 15 varieties [6, 7] of maize improved to optimize yields. The aim of this article is to define a coherent set of criteria for seed selection, assign weights to these criteria, identify the best maize varieties based on specific agronomic criteria, and apply AMCD to evaluate the seeds available in Cameroon. We will also seek to compare these two methods to determine their robustness in decision-making, and to formulate practical recommendations for farmers and policy-makers. In addition, this research highlights the importance of analysis.

Several decision support models have been proposed for seed selection using different Multi-Criteria Decision-Making (MCDM) methods. [8] used the AHP-TOPSIS hybrid approach for rice seed selection, but this method is sensitive to subjective judgments and struggles to handle conflicting criteria. [9] applied the WASPAS method for maize, but this method lacks robustness to extreme values and does not perform a systematic comparison of alternatives for each criterion. Other approaches, such as the exponential comparison method used by [10], also have limitations in dealing with conflicting criteria and lack intuition in their use. In comparison, the ELECTRE I and ELECTRE IS methods stand out for their ability to handle such conflicts effectively, thanks to outranking relations and veto thresholds. They thus offer a more robust alternative, adapted to complex agricultural contexts such as that of Cameroon.

2. METHODS

Cameroon has some fifteen improved seeds distributed over the five agro-ecological zones. To make this choice, we will identify the available and cultivable seeds, and then use the ELECTRE I and ELECTRE IS methods. To make this choice, we need a number of coherent and non-redundant criteria for evaluating these seeds. We also need these different seeds to represent the basic performance matrix, and then to model this matrix in data on which we will apply our two methods. The data used come from institutional sources (IRAD, MINADER) and [6, 7].

2.1. Definition of Evaluation Criteria

The selection of criteria was guided by their direct impact on the agronomic performance and productivity of maize varieties. Each criterion selected plays a key role in adapting seeds to local conditions and optimizing yields for farmers.

2.1.1. Growth cycle

The growth cycle is a fundamental criterion, as it enables the choice of seed to be adapted to local climatic conditions and agricultural calendars. A short cycle may be advantageous for areas with short rainy seasons, while a longer cycle is suitable for regions with high rainfall [11, 12].

2.1.2. Yield potential

Selection, as it has a direct impact on agricultural productivity and farm profitability. A variety offering good yield under optimal conditions guarantees better food and economic security [13].

2.1.3. Ear coverage

Good ear coverage reduces the risk of attack by pests and fungal diseases, thus contributing to better quality of harvested grain [14].

2.1.4. Plant heigh

Stem height influences resistance to bad weather (wind, storms) and ease of harvesting. Stems that are too tall increase the risk of lodging, while short stems can be less productive [15, 16].

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2.1.5. Weight of 100 kernels

The weight of kernels is an indicator of maize quality, influencing final yield and the market value of harvests [17, 18].

2.2. Justification for the absence of certain criteria

Certain criteria, although relevant in other contexts, have not been retained due to their subjectivity, their low direct influence on productivity or their dependence on exogenous factors such as the market or consumer preferences.

2.2.1. Seed color, seed texture

These are characteristics that influence aesthetic or commercial aspects rather than agronomic performance parameters. Their inclusion could introduce subjectivity that would distort rigorous evaluation based on objective criteria.

2.2.2. Utilization

The study aims to optimize seed selection based on objective agronomic criteria linked to variety productivity and resistance. The allocation of maize to a specific use (human consumption, animal feed, etc.) is a post-production decision that depends on the needs of producers and the market rather than on the intrinsic characteristics of the seed. In addition, many varieties are multi-purpose and can be used for both food and livestock. Consequently, classifying seeds according to their final destination could introduce unnecessary subjectivity into the evaluation [19].

2.2.3. Environmental influence and variability

Criteria linked to environmental conditions (disease resistance, drought tolerance, etc.) are essential, but they are highly dependent on local variations. However, this study aims at a multi-criteria evaluation applicable to different agro-ecological zones. Moreover, these aspects can be indirectly taken into account through agronomic criteria already integrated, such as yield potential and plant vigor.

An excessive selection of criteria increases the complexity of the decision model, which may hinder its readability and applicability by farmers and decision-makers. Since the aim is to provide effective decision support, it is preferable to focus on a limited set of relevant, measurable criteria. In conclusion, the elimination of these criteria ensures a more focused and pragmatic analysis, guaranteeing that seed selection is based on factors essential to agricultural productivity and sustainability.

2.3. Modeling Approach

The approach adopted is based on a combination of the ELECTRE I & IS methods for maize seed selection. This approach makes it possible to integrate several decision criteria, taking into account outranking relationships and veto thresholds, thus offering better management of conflicts between criteria.

2.4. Data Pre-Processing

As part of data pre-processing, a crucial step will be to transform ordinal data into numerical scores and interval data into a single score.

2.4.1. Cycle (in days), potential yield (in tons) and height (in centimeters)

the values obtained represent the results of the median values of the intervals for each variety. For example, for the variety CHC 201, whose cycle is between 120 and 130 days, the median value is equal to 125 days: $\frac{120+130}{2} = 125$;

2.4.2. Ear coverage

These data are ordinal, including "$good$", "$average$". We therefore assigned grades to these values as follows: grade 5 for $very\ good$, 4 $for\ good$, 3 $for\ average$, 2 $for\ poor$ and 1 for $very\ poor$;

2.4.3. Weight of 100 seeds

The data remained unchanged.

NB. Missing data were imputed using linear regression, a method deemed effective in reducing bias, as shown in [20], which compares different imputation techniques.

2.5. Applying of MCDM Methods

The method used to make the choice is the ELECTRE method (Elimination et Choix Traduisant la Réalité), developed by ROY, BERTIER, HUGONNARD, BOUYSSOU and SKALKA from 1968 onwards [21, 22]. This is a family of methods, two of which, ELECTRE I and ELECTRE IS in particular, are designed for the problem of choice, the selection procedure. They require little information, are easily accessible to decision-makers and provide solid results [23, 24]. The choice of these two methods is justified by the fact that they are among the most widely used methods [25].

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2.5.1. ELECTRE I

The ELECTRE I method is a multi-criteria decision support approach developed by Bernard Roy in 1968 [23, 24]. It is particularly useful for evaluating and comparing several alternatives, taking into account various criteria, both qualitative and quantitative [21]. It works with real criteria and makes systematic comparisons between actions in order to determine agreement and disagreement. Its principle: to make this choice, it is necessary to partition the set A of potential actions into two complementary subsets N and $A\backslash N$, such that: any action belonging to A\ is outclassed by at least one action belonging to N by eliminating the element-actions; the actions belonging to N are incomparable with each other because they are the actions which do not outclass each other [21]. This method seeks to establish an outranking relationship between the actions (seed) and uses the true criteria, i.e. a small difference is translated by a strict preference and there is indifference if there is equality between the criteria translated by $g(a) = g(b)$ (Rousval, 2005). Thus, to establish an outranking relation, it relies on the notion of preference and indifference [24]. It follows the following steps:

Fixing boundary scores according to the importance of each criterion, then calculating the transformed evaluation matrix noted $Mt = Slope * (MtPerf - MinCriteria) +$ BoundaryScore with $Slope = \frac{ScoreAm}{CriteriaAm}$ where :

a. $MinCriteria$: minimum criterion, refers to a performance threshold which must be reached by a seed on a given criterion for it to be considered acceptable;
b. $BoundaryScore$: refers to a performance threshold which determines whether a seed is deemed acceptable or not in relation to a given criterion,
c. Slope: represents the relationship between the importance of a seed ($AmNote$) and the importance of a specific criterion ($AmCritere$). This is used to assess how an alternative compare to others, taking into account the relevance of the criteria.
d. $MatPerf$: is a matrix that summarises the performance of the different seeds in relation to the five evaluation criteria.

We then move on to the concordance test, in which we seek to determine whether two seeds agree on a given criterion. It therefore uses the notion of concordance between seeds in the form of a matrix and is noted as follows C_{ik} with $C_{ik} = \frac{P^+(S_i,S_k)+P^=(S_i,S_k)}{P}$ where $P^+(S_i,S_k)$ is the sum of the weights of the criteria belonging $J^+(s_i,s_k)$ with all the criteria for which S_i seed is preferred to seed S_k and $P^=(S_i,S_k)$ the sum of the weights of the criteria belonging to $J^=(S_i,S_k)$ with all the criteria for which the S_i seed is equivalent to S_k seed;

Indices of disagreement between two seeds on a given criterion. Here we are looking to see if there is disagreement on the fact that seed S_i is preferred to S_k. It is noted D_{ik} and expressed by: $D_{ik} = 0$ if $J^-(S_i,S_k) = \emptyset$ where $J^-(S_i,S_k)$ is the set of criteria for which the seed $S_k$is preferred to the seed S_i .

The outranking relationship: once the index of concordance and discordance between the seed pairs on each criterion has been obtained, the decision-maker must set two values called the concordance threshold noted c and the discordance threshold noted d. Thresholds above which this value is exceeded, the seed hypothesis S_i concord with S_k seed is accepted ($C_{ik} > c$ and d expresses the maximum disagreement between the two seeds ($D_{ik} \leq d$. If these two conditions are met, then the hypothesis that seed S_i outclasses seed S_k is accepted.

Each criterion used to evaluate the seeds has a weight that indicates its relative importance in the decision. A higher weight means that this criterion has more importance in the seed selection. Example: A criterion with a weight of 8 (for example, yield) will be much more important in the decision-making than a criterion with a weight of 1 (for example, stem height). Weights are therefore numbers assigned to each criterion to reflect their relative importance in choosing the best seed.

The range of scores (Table 1) represents the scale used to evaluate each criterion. These values show the range of possible scores for each criterion. Example: A criterion with a range of 60 could have a range of 0 to 60, which means that the performance of this criterion can be measured between 0 and 60. In contrast, a criterion with a range of 10 (such as stem height) has a smaller range, indicating that the

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differences between the seeds will be evaluated on a scale of 0 to 10.

Table 1. *Basic ELECTRE I parameters*

Criteria	Cycle (j)	Potential yield(t)	Ear recovery	Hauteur des plantes(cm)	Weight of 100 graines (g)
Scores Bounds	[-25 ; +25]	[-30 ; +30]	[-10 ; +10]	[-5 ; +5]]	[-15 ; +15]
Amplitude	50	60	20	10	30
Weights	4	8	4	1	3

N.B: the basic concordance and discordance thresholds are c = 0.55 and d = 0.30 respectively.

Robustness: The robustness analysis consists of evaluating how variations in the agreement and disagreement thresholds, as well as in the weights of the criteria, affect the results of the decision. This makes it possible to test the stability of the conclusions drawn from the multi-criteria analysis [26]. In summary, robustness analysis in ELECTRE methods is essential to ensure that the decisions made are robust and reliable, regardless of potential variations in the input parameters. This enhances decision-makers' confidence in the results obtained and helps navigate the uncertainties inherent in multi-criteria analyses.

2.5.2. ELECTRE IS (S for thresholds)

Developed by Roy and SKALKA in 1985, this is an adaptation of the ELECTRE I method to fuzzy logic, incorporating additional elements such as veto thresholds and importance coefficients for the criteria. It allows for a more nuanced evaluation by taking into account the variability of criteria and the preferences of decision-makers [21]. It makes a systematic comparison between seeds on each criterion (pseudo-criteria) and overall. Four thresholds are used by this method in order to conclude the hypothesis of an out classification:

a. Veto threshold: is a value used to define a limit that must not be exceeded for a given criterion. The principle of a veto threshold is to give a criterion the power to oppose outranking on its own, regardless of the weight given to it [23];
b. Threshold of preference: is a value which makes it possible to define a limit above which an alternative is regarded as preferable to another for a given criterion;
c. Indifference threshold: is a value used to define a limit above which alternatives are considered equivalent for a given criterion [23];
d. Concordance threshold c: plays the same role as that used in the Electre I method.

The local concordance index:

a. if $q_j < g_j(s_k) - g_j(s_i) \leq p_j$, the seed s_k is slightly preferred to seed s_i.
b. if p_jj $< g_j(s_k) - g_j(s_i)$, the seed s_k is strictly preferred to seed s_i.
c. if $g_j(s_k) - g_j(s_i) \leq q_j$ then the seeds s_i and s_k are indifferent on the criterion j.

Global concordance index (C_{ik}) is the weighted average of the local concordance indices by the weights of the criteria. $C_{ik} = \frac{\sum_{j=1}^{m} P_j . C_{(s_i,s_k)}}{\sum_{j=1}^{m} P_j}$ where the P are the weights and $C(s_i, s_k)$ the global concordance index. The local mismatch index (d_j)

$$d_j(s_i, s_k) = \begin{cases} 0 \; if \;, \; g_j(s_k) - g_j(s_i) < \gamma \\ \quad\quad 1 \text{ otherwise} \end{cases}$$

where $\gamma = v_j(s_i, s_k) - q_j(s_i, s_k) \frac{1 - C(s_i,s_k)}{1 - c}$

$C(s_i, s_k)$ c, v_j and q_j are respectively global concordance index, concordance threshold, veto threshold and indifference threshold.

The global mismatch index D_{ik} is also binary (0 and 1), with 1 expressing mismatch between two seeds on the five criteria and 0 otherwise. Thus, if $d_j(s_i, s_k) = 0 \;\; \forall j = 1, \ldots, n$, D_{ik} takes 0, and 1 otherwise. The outclassing relationship S is also binary: the hypothesis that the seed S_i outclasses the seed S_k, $(s_i S s_k)$ is accepted if $C(s_i, s_k) \geq$ c and D_{ik}) = 0 takes the value 1 and 0 otherwise.

Table 2. *Basic ELECTRE Is parameters*

Parameters	Cycle	Potential yield	Ear coverage	Pant height	Weight of 100 seeds
q_j	3	0,25	0,5	15	2
p_1	80	4	4	170	22
v_1	120	12	8	200	34
P_j	6	8	2	1	3

The basic parameters (Table 2) of the ELECTRE IS method are used to compare different options based on several criteria. $q_j = 3, 0.25, 0.5, 15, 2$ means that for each criterion, differences between options can be ignored if

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they are less than the respective values. For example, for a criterion with a qj of 3, two seeds with a difference of less than 3 on that criterion will be considered equivalent. This allows us to disregard small differences that aren't significant from the perspective of farmers or agricultural objectives. $p_j = 60, 1, 1, 100, 10$ means that for each criterion, the minimum difference to exceed for one seed to be preferred over another is given by the respective values. For example, for potential yield with a pj = 1, a seed must have a performance difference of at least 1 to be preferred over another on that criterion. If the difference is greater than the preference threshold, farmers will choose that seed because it's clearly better than the others. $v_j = 120, 12, 8, 200, 34$ means that for each criterion, if the difference is greater than these values, a seed will be rejected. For example, for the life cycle, a seed will be rejected if it's more than 120 less than another seed on that criterion. This ensures that seeds with major flaws on an important criterion will never be selected, even if they are better on other criteria. Basic concordance threshold is $c = 0.87$.

2.6. Flowchart of both methods combined

This flowchart summarizes the steps of both MCDA methods

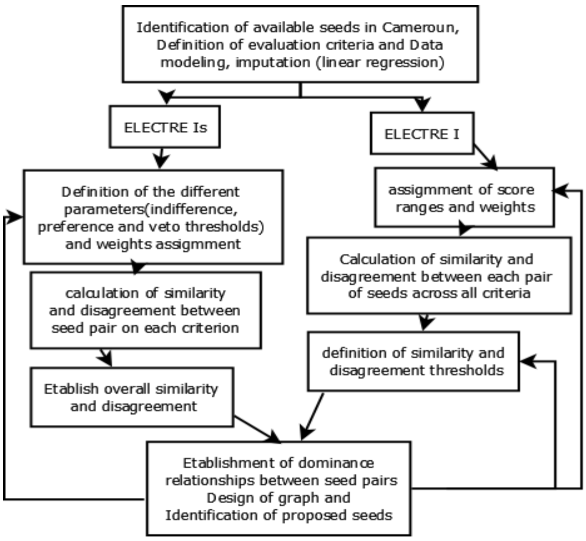

Figure 1. *Flowchart* for both methods

3. RESULTS AND DISCUSSION

3.1. ELECTRE I

In this section, we present the results of these methods ELECTRE I.

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
S1	-	0.85	0.40	0.60	0.40	0.15	0.80	0.40	0.85	0.75	0.85	0.75	0.75	0.75	0.40
S2	0.95	-	0.40	0.60	0.40	0.35	0.75	0.35	0.95	0.75	0.85	0.75	0.75	0.75	0.35
S3	0.80	0.80	-	0.85	0.60	0.75	0.75	0.75	0.80	0.75	0.85	0.75	0.75	0.75	0.75
S4	0.80	0.80	0.80	-	0.40	0.75	0.75	0.75	0.80	0.75	0.85	0.75	0.75	0.75	0.75
S5	0.80	0.80	0.80	0.80	-	0.60	0.75	0.60	0.80	0.75	0.85	0.75	0.75	0.75	0.60
S6	0.65	0.65	0.25	0.25	0.40	-	0.60	0.60	0.65	0.80	0.65	0.75	0.75	0.75	0.60
S7	0.45	0.45	0.45	0.45	0.45	0.40	-	0.45	0.45	0.60	0.45	0.20	0.60	0.20	0.45
S8	0.60	0.65	0.65	0.65	0.40	0.75	0.55	-	0.60	0.75	0.65	0.75	0.75	0.75	1.00
S9	0.80	0.65	0.40	0.40	0.40	0.35	0.80	0.40		0.75	0.85	0.75	0.75	0.75	0.40
S10	0.25	0.25	0.25	0.25	0.25	0.25	0.40	0.45	0.25	-	0.25	0.55	0.75	0.55	0.45
S11	0.75	0.75	0.35	0.35	0.35	0.35	0.75	0.35	0.75	0.75	-	0.75	0.75	0.75	0.35
S12	0.25	0.25	0.25	0.25	0.25	0.25	0.80	0.45	0.25	0.65	0.25	-	0.75	1.00	0.45
S13	0.25	0.25	0.25	0.25	0.25	0.25	0.40	0.45	0.25	0.45	0.25	0.60	-	0.60	0.45
S14	0.25	0.25	0.25	0.25	0.25	0.25	0.80	0.45	0.25	0.65	0.25	1.00	0.75	-	0.45
S15	0.60	0.65	0.65	0.65	0.40	0.75	0.55	1.00	0.60	0.75	0.65	0.75	0.75	0.75	-

Figure 2. *Discordance matrix*

Concordance matrix: the concordance matrix (Figure 2) provides an assessment of the relative performance of 15 seeds (S_1 to S_{15}) according to 5 criteria that we had defined. Each value in the matrix represents a concordance index between two seeds S_i and S_k. Values close to 1, such as 0.95 or 0.85, indicate that the corresponding seed significantly outperforms the other seed. For example, S_2 outclasses S_1 with an index of 0.95, which means that S_2 is greatly preferred to S_1 on most criteria. A concordance threshold is therefore set according to these values to validate the assertion that the $S_i$seed is preferred to the $S_k$seed.

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
S1	-	0.04	0.20	0.26	0.20	0.13	0.60	0.35	0.01	0.29	0.20	0.38	0.58	0.38	0.35
S2	0.17	-	0.20	0.26	0.20	0.21	0.23	0.13	0.17	0.29	0.16	0.56	0.75	0.56	0.13
S3	0.23	0.06	-	0.22	0.26	0.27	0.23	0.15	0.23	0.27	0.55	0.62	0.81	0.62	0.15
S4	0.23	0.06	0.20	-	0.20	0.27	0.23	0.15	0.23	0.29	0.34	0.62	0.81	0.62	0.15
S5	0.31	0.13	0.08	0.08	-	0.35	0.31	0.23	0.31	0.35	0.68	0.69	0.88	0.69	0.23
S6	0.46	0.50	0.11	0.32	0.39	-	0.25	0.13	0.47	0.40	0.66	0.35	0.54	0.35	0.13
S7	0.80	0.84	0.45	0.66	0.32	0.05	-	0.34	0.81	0.06	1.00	0.38	0.58	0.38	0.34
S8	0.08	0.50	0.11	0.32	0.26	0.12	0.10	-	0.08	0.15	0.66	0.46	0.65	0.46	0.00
S9	0.01	0.01	0.21	0.04	0.21	0.14	0.61	0.36	-	0.29	0.19	0.38	0.58	0.38	0.36
S10	0.53	0.57	0.25	0.40	0.35	0.20	0.13	0.25	0.54	-	0.73	0.35	0.54	0.35	0.25
S11	0.42	0.25	0.19	0.19	0.15	0.46	0.42	0.35	0.42	0.46	-	0.81	1.00	0.81	0.35
S12	0.55	0.59	0.20	0.41	0.26	0.10	1.00	0.16	0.56	0.10	0.75	-	0.19	0.00	0.16
S13	0.55	0.59	0.30	0.41	0.41	0.25	0.26	0.30	0.56	0.05	0.75	0.35	-	0.35	0.30
S14	0.55	0.59	0.20	0.41	0.26	0.10	1.00	0.16	0.56	0.10	0.75	0.00	0.19	-	0.16
S15	0.08	0.50	0.11	0.32	0.26	0.12	0.10	0.00	0.08	0.15	0.66	0.46	0.65	0.46	-

Figure 3. *Discordance matrix 2*

Discordance matrix: the values in the matrix (Figure 3) represent the discordance indices between each pair of varieties, varying from 0 to 1. High values (close to 1) indicate strong discordance between two varieties on at least one criterion. For example, the variety S_7 has values of 1 with S_{11}, showing that it is very different from these varieties. The low values (close to 0) mean that there is no strong discordance between the varieties. So, a discordance threshold is set according to these values to mark the assertion according to which S_i seed is not preferred to S_k seed.

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	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
S1	-	1	0	1	0	0	0	0	1	1	1	0	0	0	0
S2	1	-	0	1	0	0	1	0	1	1	1	0	0	0	0
S3	1	1	-	1	1	1	1	1	1	1	0	0	0	0	1
S4	1	1	1	-	0	1	1	1	1	1	0	0	0	0	1
S5	0	1	1	1	-	0	0	1	0	0	0	0	0	0	1
S6	0	0	0	0	0	-	1	1	0	0	0	0	0	0	1
S7	0	0	0	0	0	0	-	0	0	1	0	0	0	0	0
S8	1	0	1	0	0	1	1	-	1	1	0	0	0	0	1
S9	1	1	0	0	0	0	0	0	-	1	1	0	0	0	0
S10	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0
S11	0	1	0	0	0	0	0	0	0	0	-	0	0	0	0
S12	0	0	0	0	0	0	0	0	0	1	0	-	1	1	0
S13	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0
S14	0	0	0	0	0	0	0	0	0	1	0	1	1	-	0
S15	1	0	1	0	0	1	1	1	1	1	0	0	0	0	-

Figure 4. *Outranking matrix*

Outranking matrix: The outranking matrix (Figure 4) is a key tool in multi-criteria analysis. A value of 1 in a box indicates that one variety outclasses the other on at least one of the 5 criteria, while 0 means that it does not outclass it. The matrix is not symmetrical, which means that if S1 outperforms S2, S2 does not necessarily outperform S1. The presence of 1 means that there is an outranking relationship and 0 for the absence of an outranking relationship. Columns whose entire value is 0 mean that they are not outclassed by any seed. They are therefore part of the seeds forming the core of the outranking graph, which is the solution. Rows whose values are all zero mean that they are not outclassed by any seed.

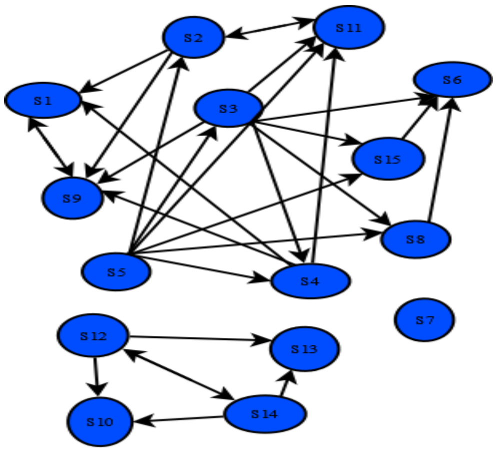

Figure 5. *Outclassing graph*

Outclassing graph: The graph (Figure 5) is used to identify dominant varieties that outclass several other varieties and it is obtained from Table 5. kernel graph constitutes the solution set sought. Varieties that are not outclassed, such as S_6 and S_7, are of interest because they are not inferior to any other on all the criteria. The graphs in this article are oriented by the one-way or two-way arrow indicating the nature of the outclassing relationship between the seeds represented by the different vertices. $s_i \to s_k)$ means that S_i outclass S_k and $s_i \leftrightarrow s_k$ means that S_i outclass S_k and $S_k$outclass S_i (S_i and S_k outclass each other). The core of the graph is defined as all the vertices that are not outclassed by any other vertex. Thus, the core of the graph (Figure 5) is made up of vertices S_5 and S_7. To diversify agronomic traits, we can choose a mixture of varieties with contras$S_i$ting profiles, such as S_3, S_{12} and S_{14}. For a more homogeneous performance, we can select several varieties that outperform each other, such as S_2, S_4 and S_{11}. We consider only the kernel of the graph as a solution; hence the basic solution set is $S_B = \{S_5, S_7\}$.

3.2. Robustness Test of Parameters in ELECTRE I

Robustness: The robustness analysis focused on the way in which the results of a decision can vary in the event of error or estimation of the basic parameters [26]. It has therefore focused essentially on the thresholds of agreement and disagreement and the weights of the criteria.

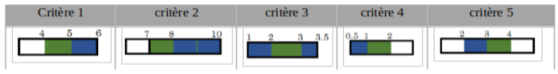

Figure 6. *Tested weights*

Table 3. *Threshold testes*

BN	C & D	Results
Cycle:	$c = 0.55$ & $d = 0.40$	$\{S_5\}$;
$[-25; +25]$	$c = 0.55$ & $d = 0.30$	$\{S_B,\}$
yield:	$c = 0.55$ & $d = 0.20$	$\{S_B\}$;
$[-30; +30]$	$c = 0.55$ & $d = 0.15$	$\{S_B, S_6, S_{10}\}$
Ear coverage:		
$[-10; +10]$	$c = 0.75$ & $d = 0.40$	$\{S_5\}$;
Pant-height:	$c = 0.75$ & $d = 0.30$	$\{S_B,\}$
$[-5; +5]$	$c = 0.75$ & $d = 0.20$	$\{S_B,\}$;
Weight of 100:	$c = 0.75$ & $c = 0.15$	$\{S_B, S_6, S_{10}\}$
$[-15; +15]$		

(Table 3 and Figure 6) show the impact of variations in the concordance thresholds, discordance thresholds, and weights on the results. BN indicates the criteria and their ranges. Figure 2 represents the tested weights, with colored areas showing the base solution and deviations. For Criterion 2, values below 7 move away from the base solution, while values between 7 and 8 indicate stability. For example, with concordance (0.55) and discordance (0.40) thresholds, S5 is selected for Criterion 1. Stricter thresholds include more seeds (S10, S13), while wider thresholds exclude some. S5 remains robust, while S7 is more sensitive to variations.

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3.3. ELECTRE IS

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
S1	-	1.00	0.79	0.81	0.57	0.86	0.89	0.76	1.00	0.87	0.99	0.87	0.84	0.87	0.76
S2	1.00	-	0.79	0.81	0.57	0.86	0.89	0.76	1.00	0.86	0.99	0.87	0.83	0.87	0.76
S3	0.96	0.96	-	0.98	0.81	0.98	0.93	0.98	0.96	0.90	0.94	0.90	0.87	0.90	0.98
S4	0.99	0.99	0.97	-	0.79	0.94	0.89	0.94	0.99	0.86	0.97	0.86	0.83	0.86	0.94
S5	0.94	0.94	1.00	0.97	-	0.97	0.93	0.98	0.94	0.89	0.92	0.90	0.86	0.90	0.98
S6	0.95	0.94	0.92	0.88	0.70	-	0.96	0.92	0.94	0.93	0.92	0.94	0.91	0.94	0.92
S7	0.74	0.73	0.58	0.55	0.57	0.70	-	0.59	0.74	0.96	0.71	0.91	0.93	0.91	0.59
S8	0.94	0.93	0.99	0.95	0.80	1.00	0.95	-	0.93	0.93	0.91	0.94	0.90	0.94	1.00
S9	1.00	1.00	0.78	0.81	0.57	0.86	0.89	0.75	-	0.86	0.99	0.87	0.83	0.87	0.75
S10	0.66	0.65	0.57	0.54	0.59	0.63	0.91	0.60	0.66	-	0.63	0.83	0.98	0.83	0.60
S11	0.96	0.97	0.74	0.78	0.53	0.81	0.84	0.71	0.96	0.81	-	0.82	0.78	0.82	0.71
S12	0.84	0.84	0.68	0.65	0.59	0.81	0.99	0.71	0.84	0.99	0.81	-	0.98	1.00	0.71
S13	0.55	0.54	0.57	0.54	0.59	0.60	0.80	0.60	0.55	0.92	0.52	0.73	-	0.73	0.60
S14	0.84	0.84	0.68	0.65	0.59	0.81	0.99	0.71	0.84	0.99	0.81	1.00	0.98	-	0.71
S15	0.94	0.93	0.99	0.95	0.80	1.00	0.95	1.00	0.93	0.93	0.91	0.94	0.90	0.94	-

Figure 7. *Global concordance matrix*

Global concordance matrix (Figure 7): provides a quantitative assessment of the similarities between these varieties (S_1 to S_{15}) on different criteria. Each value in the matrix represents a concordance coefficient, ranging from 0 to 1, where 1 indicates perfect concordance and 0 no concordance. The boxes on the diagonal (not shown) are empty, as a seed cannot be compared with itself. Coefficients close to 1 (e.g. between S_1 and S_2, S_3 and S_4) indicate that these seeds share similar characteristics. For example, S1 and S_2 have a coefficient of 0.9, suggesting that they are very similar on the criteria assessed. Lower values (such as 0.34 between S_1 and S_5) suggest greater discordance, indicating that these varieties differ significantly on some criteria. We can use this matrix to select varieties that complement or resemble each other, depending on the needs (or purpose) of the crop. In short, this global concordance matrix is a valuable tool for assessing the relationships between different maize varieties, making it easier to make informed decisions when choosing seed based on agronomic objectives or criteria.

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
S1	-	1	1	1	0	0	0	0	0	0	0	0	0	0	0
S2	1	-	1	1	0	0	0	0	0	0	0	0	0	0	0
S3	1	1	-	0	0	0	0	0	0	0	0	0	0	0	0
S4	1	1	1	-	0	0	0	0	0	0	0	0	0	0	0
S5	1	1	1	1	-	0	0	0	0	0	0	0	0	0	0
S6	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0
S7	0	0	0	0	0	0	-	0	0	0	0	0	0	0	0
S8	0	0	0	0	0	0	0	-	0	0	0	0	0	0	0
S9	0	0	0	0	0	0	0	0	-	0	0	0	0	0	0
S10	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0
S11	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0
S12	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0
S13	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0
S14	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0
S15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-

Figure 8. *Global discordance matrix*

Global disagreement matrix (Figure 8) shows the overall disagreement between the 15 seeds. It is symmetrical, with values of 0 or 1 in each box. A value of 1 indicates strong disagreement between two varieties on at least one criterion, while 0 means no strong disagreement. Varieties S_1 to S_5 are strongly discordant with each other, with values of 1 in all boxes except the diagonal. Varieties S_6 to S_{15}, on the other hand, do not disagree with each other or with each other. This suggests that varieties S_1 to S_5 are very different from each other on at least one important criterion, while varieties S_6 to S_{15}, are more similar. In summary, this matrix gives a good overview of the similarities and differences between maize varieties, enabling informed choices to be made according to production objectives.

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
S1	-	1	0	0	0	0	1	0	0	0	0	1	0	1	0
S2	1	-	0	0	0	0	1	0	0	0	1	0	0	0	0
S3	1	1	-	1	0	1	0	1	1	1	1	1	0	1	1
S4	1	1	1	-	0	1	1	1	1	0	1	0	0	0	0
S5	0	1	1	1	-	1	1	1	1	1	1	1	0	1	1
S6	1	1	1	1	0	-	1	1	1	1	1	1	1	1	1
S7	0	0	0	0	0	0	-	0	1	1	1	1	1	0	0
S8	1	1	1	1	0	1	0	-	1	1	0	1	1	1	1
S9	0	0	0	0	0	0	1	0	-	0	1	1	1	1	0
S10	0	0	0	0	0	0	1	0	1	-	0	0	1	0	0
S11	1	1	0	0	0	0	0	0	0	0	-	0	0	0	0
S12	0	0	0	0	0	0	1	0	1	1	0	-	0	1	0
S13	0	0	0	0	0	0	0	0	0	1	0	0	-	0	0
S14	0	0	0	0	0	0	1	0	0	1	0	1	1	-	0
S15	0	0	0	0	0	1	0	1	0	0	0	0	0	0	-

Figure 9. *Upgrading matrix*

Upgrading matrix: The matrix (Figure 9) is square with 15 rows and 15 columns, represents the results of a competition among 15 maize varieties designated from (S_1 to S_{15}). The values in the matrix are either 0 or 1. A value of 1 indicates that one variety outclasses another, while a 0 means it does not. The diagonal is empty because a variety cannot outperform itself. **Dominant varieties**: S_6: with a total of 13 victories, S_6 outclasses almost all other varieties, making it the most dominant variety. S_5: with 12 victories, S5 also shows solid performance by outclassing several other varieties. S_3 and S_8: Each with 11 victories, these varieties stand out for their competitiveness against a good number of other seeds. **Non-Dominant Varieties:** S_7, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, and S_{15}: these varieties have outclassed only a small number of other varieties or none at all in some cases. Therefore, they are considered less dominant in this competition. **Balanced Varieties:** S_1 and S_2:

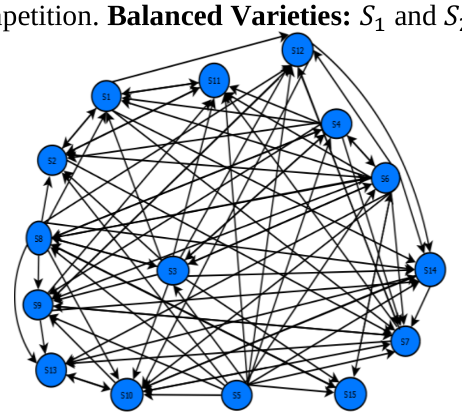

Figure 10. *Outclassing graph*

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Outclassing graph (figure 10): is a visual representation of outclassing relationships between corn varieties. Each variety is represented by a node, and if an outclassing relationship exists between two varieties, an arrow is drawn from the outclassing variety to the outclassed variety. In this graph, we can identify several potential kernels:$\{S_5\}$ this variety forms a kernel because not only does it outclass several varieties, but it is not outclassed by any variety. We can also add variety S_6, which has the highest number of wins followed by seeds s3 and s8. So our basic solution is : $S_B = \{S_5, S_6\}$

Table 4. *Robustness test*

Parameters	solutions		
	C=0.87	C=0.96	C=0.75
$q/p_1/v_1/P$	S_B	$\{S_5, S_6\}$	$\{\emptyset\}$
$q/p_1/v_2/P$	$\{S_5\}$	$\{S_5, S_6\}$	$\{\emptyset\}$
$q/p_2/v_1/P$	$\{S_5, S_6\}$	$\{S_5, S_6, S_{10}\}$	$\{S_5\}$
$q/p_2/v_2/P$	$\{S_5, S_6\}$	$\{S_5, S_6, S_{10}\}$	$\{S_5\}$

Robustness test (Table 4): Three different configurations of these parameters are tested: Base parameters: Reference values used in the initial solution. Modified parameters 1: Alternative values for certain parameters, such as p_1 and v_2; Modified parameters 2: Other alternative values, such as p_2 and v_1. The results show how the solutions adopted vary according to the parameters used: With the basic parameters, the optimal solution is the basic solution noted S_B. With modified parameters 1, the optimal solutions are S5 and S10 for the two configurations tested. With modified parameters 2, we obtain: For the first configuration: S_5, S_{10} and S_{13}. For the second configuration: S_5 only. For the third configuration: No solution is selected.

3.4. Discussion

Agricultural conditions, based on five agronomic criteria The maize varieties CLH103, CMS8501, CMS8602 and CMS9015 have distinct agronomic characteristics suited to Cameroon's agricultural conditions. CLH103 offers a high yield of 9.5 tons per hectare, with a 115-day ripening cycle, good ear coverage and a 100-grain weight of 24.5 grams. CMS8501 has a yield of 6.5 tons per hectare, a 107.5-day cycle, no ear coverage and a 100-grain weight of 24.5 grams. CMS8602 stands out with a yield of 3.75 tons per hectare, a short cycle of 95 days, good ear coverage and a 100-grain weight of 18 grams. Finally, CMS9015 offers a yield of 2.75 tons per hectare, a very short cycle of 87.5 days, no ear coverage and a 100-grain weight of 18 grams. These characteristics directly influence the selection of varieties according to production objectives, local climatic conditions and the specific needs of Cameroonian farmers.

However, several limitations need to be highlighted. Crucial criteria such as disease resistance, drought tolerance and pest resistance have not been taken into account in this analysis. These characteristics are essential to ensure crop sustainability, especially in a context of unpredictable climatic conditions. Incorporating these criteria in future analyses could improve the robustness of the results and make them more representative of the challenges farmers face on a daily basis.

In addition, the ELECTRE IS method, while robust and reliable, presents a certain computational complexity. Calculating outranking relationships and managing exclusion thresholds increases the workload, which could become an obstacle if the number of varieties to be compared or the criteria to be considered were to increase. A potential solution would be to optimize these algorithms to reduce their resource consumption, or to use parallelized approaches to speed up computation, thus widening the scope of application of this method.

Compared with other approaches such as WASPAS, which does not systematically take into account the comparison between seeds for each criterion, or AHP-TOPSIS, which can be more sensitive to variations in weightings, ELECTRE methods offer a more rigorous analysis of trade-offs between criteria. However, the simplicity of interpretation of AHP-TOPSIS remains an advantage, although this method is less robust to biases associated with subjective weightings.

The results of this study provide Cameroonian farmers with valuable information for selecting maize varieties adapted to their specific needs. For example, farmers looking for shorter production cycles might prefer the CMS8602 variety, while those aiming for higher yields might opt for CLH103. However, it is crucial to also consider factors such as disease resistance and drought tolerance, which were not included in this analysis, but which are crucial to crop success in varied environments.

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In conclusion, although the methods used provided relevant results for maize seed selection in Cameroon, there is still room for improvement. The integration of new criteria, particularly those related to climatic conditions and biotic factors, would make selection more robust. In addition, optimization of algorithmic complexity, coupled with artificial intelligence techniques, could make the approach more suitable for larger datasets or a greater number of criteria. To validate these results, it would be relevant to test them under real field conditions, in order to assess their effectiveness in practical situations.

CONCLUSION

The wise selection of maize seeds is crucial for ensuring optimal, sustainable, and profitable agricultural production. Our study highlighted the effectiveness of the ELECTRE I and ELECTRE IS multicriteria analysis methods in assisting Cameroonian farmers with making informed decisions when selecting maize varieties. By evaluating five key agronomic criteria, these methods identified the varieties best suited for the country's various agro-ecological zones. This approach enhances knowledge in multicriteria decision-making and agricultural planning by providing a robust analytical framework to assess and compare different varietal options. It underscores the importance of integrating decision-support tools into agricultural practices to improve yields and crop resilience. To further develop this approach, it would be beneficial to expand the evaluation criteria to include factors such as disease resistance, drought tolerance, and adaptation to climate change. Additionally, simplifying the analysis methods and training farmers on their use could facilitate their widespread adoption. In practice, the application of these methods can significantly improve maize yields in Cameroon by helping farmers select varieties suited to their specific conditions. This study thus contributes to better agricultural decision-making, promoting more productive and sustainable farming. Looking ahead, integrating these tools into agricultural development programs and tailoring them to the needs of local farmers could strengthen food security and resilience to climate challenges. Future research should also explore applying these methods to other crops and agro-ecological contexts to maximize their impact.

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