



Application of the Weighted Product Method for Determining Superior Cocoa Clones of the Sari Merta Cocoa Farmers Group

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Abstract. This study applies the Weighted Product method to objectively determine superior cocoa clones based on seven agronomic and economic criteria: productivity, pest resistance, bean quality, selling price, age at first harvest, maintenance cost, and fertilizer requirement. Criterion weights were obtained through a five-point Likert-scale questionnaire completed by 5 purposively selected respondents from the Sari Merta Cocoa Farmers Group, comprising the chairperson, the secretary, and 3 members, and were subsequently normalized according to the WP procedure. Twelve cocoa clone alternatives were evaluated by calculating the S vector, preference values (V), and final rankings. The results indicate that MCC 02 (Masamba Cocoa Clone 02) achieved the highest preference value (0.0936), followed by Padang Tanah (0.0905), RTNJ (0.0881), and BB01 (0.0864), while the Local clone obtained the lowest preference value (0.0707). A sensitivity analysis across 20,000 randomly generated weighting scenarios confirmed that MCC 02 retained the top rank in the large majority of cases (91.1%), and a comparative validation using the Simple Additive Weighting (SAW) method produced an identical ranking order (Spearman's $\rho = 1.00$), supporting the robustness of the recommendation. Beyond its methodological application, the study highlights the practical value of the ranking for cocoa cultivation management and its potential to support the reliable, high-quality cocoa supply that underpins the Sari Merta Cocoa Farmers Group's participation in Bali's developing sustainable agritourism sector. The proposed approach therefore provides an objective, systematic, and reliable decision-support model for selecting superior cocoa clones within the Sari Merta Cocoa Farmers Group.

Keywords: Cocoa Clone Selection, Decision Support System, Multi-Attribute Decision Making, Sari Merta Cocoa Farmers Group, Weighted Product Method

1 Introduction

The rapid advancement of information technology has significantly transformed the agricultural sector by enabling data-driven decision-making and improving farming efficiency. Decision Support Systems (DSS) combined with Multi-Attribute Decision Making (MADM) techniques have been widely adopted to improve decision quality in

agricultural management, including crop selection, resource allocation, and production planning (Gupta & Sharma, 2023; Kumar & Singh, 2023; Li & Zhao, 2023), while the adoption of Green Information Technology has further strengthened sustainable agricultural practices through digital farm management (Zhang et al., 2022).

The Sari Merta Cocoa Farmers Group, located in Jembrana Regency, Bali, cultivates various cocoa clones with different agronomic and economic characteristics. Previous research by Priyana et al. (2025) implemented Green Information Technology to support cocoa cultivation management within the group, but the existing system functions only as an information platform and has not yet incorporated a decision-support mechanism for selecting superior cocoa clones. Each clone exhibits distinct levels of productivity, bean quality, selling price, pest resistance, age at first harvest, maintenance cost, and fertilizer requirement, so selecting the most suitable clone is a strategic decision directly influencing cultivation performance and farmers' income. Based on interviews with the group's management, the current selection process still relies on farmers' experience and subjective judgment rather than a structured multi-criteria evaluation.

Beyond its agronomic and economic significance, cocoa cultivation in Jembrana Regency is increasingly positioned within Bali's broader agenda of sustainable and green tourism development. A consistent supply of high-quality cocoa beans supports farm-based tourism activities such as plantation visits and chocolate-making demonstrations, while strengthening the regional branding of Bali cocoa as a sustainable, farmer-traceable product. Selecting superior cocoa clones is therefore also a contribution to the product quality and supply-chain reliability that underpin such sustainable green-tourism initiatives, situating this study within the wider Sustainable Green Tourism Applied Science context emphasized by ICoSTAS 2026.

Among the various MADM methods applied in agricultural product selection and recommendation (Rahman et al., 2023; Mahendra & Utama, 2025; Hartono & Widodo, 2024), the Weighted Product (WP) method is widely recognized for ranking alternatives by simultaneously considering benefit and cost criteria through multiplicative weighting (Hidayat et al., 2022; Kurniawan & Utomo, 2023; Santoso & Prasetyo, 2022; Putra & Santosa, 2024). Despite its widespread use elsewhere, WP's application to selecting superior cocoa clones remains scarcely documented in community-based farming organizations such as Sari Merta. Rather than proposing a new method, this study's primary contribution lies in the contextual, practical application of the established WP procedure to a real-world cultivation problem, together with empirical validation of the resulting ranking through sensitivity analysis and comparison with an alternative MADM method, using seven evaluation criteria: productivity, pest resistance, bean quality, selling price, age at first harvest, maintenance cost, and fertilizer requirement.

This study addresses three research questions: (1) how can the WP method be applied to determine superior cocoa clones of the Sari Merta Cocoa Farmers Group; (2) what ranking results does it generate; and (3) how robust is the resulting ranking to variation in criterion weighting, and how does it compare with an alternative MADM method?

2 Methodology

This study employed a quantitative approach applying the Weighted Product (WP) method, a Multi-Attribute Decision Making (MADM) technique, to determine the superior cocoa clone of the Sari Merta Cocoa Farmers Group (Hidayat et al., 2022; Kurniawan & Utomo, 2023; Gupta & Sharma, 2023). The research was conducted over a six-month period at the group's location in Melaya Village, Jembrana Regency, Bali. Data were collected through observations and interviews (to identify the existing selection process and establish evaluation criteria), a five-point Likert-scale questionnaire (to weight the criteria), documentation (performance values of the clone alternatives), and a literature review (theoretical foundation; Rahman et al., 2023; Kumar & Singh, 2023; Mahendra & Utama, 2025). Having found that the existing selection process relied on subjective judgment without a structured multi-criteria evaluation, the WP method was applied by determining the evaluation criteria and weights, normalizing the weights, constructing the decision matrix, calculating the S vector, computing the preference values (V), ranking the alternatives, and validating the ranking's robustness through sensitivity analysis and comparison with an alternative MADM method.

2.1 Determination of Criteria and Weights

The evaluation criteria were determined through field observations, interviews with the group's management, and a literature review (Gupta & Sharma, 2023; Kumar & Singh, 2023), resulting in seven criteria. Their relative importance was assessed using a five-point Likert scale (1 = Not Important, 5 = Very Important) completed by 5 respondents - the chairperson, the secretary, and 3 members - selected through purposive sampling of members who were active managers or farmers with direct cocoa-cultivation experience and knowledge of productivity, quality, price, maintenance cost, fertilizer requirement, and pest-resistance aspects. The individual responses for each criterion were aggregated by taking their arithmetic mean, which was used as the initial criterion weight reported in Table 1 and Table 2 (Hidayat et al., 2022).

2.2 Data Source and Reliability of the Decision Matrix

The performance values of the twelve cocoa clone alternatives (Section 3.1.d) were obtained through direct field observation of farmers' plantations combined with interviews with the farmers and a representative of the Jembrana Regency Department of Agriculture and Food (Dinas Pertanian dan Pangan), covering the harvest period from early 2025 to June 2026, allowing readers to assess the validity and reproducibility of the resulting ranking.

2.3 Weight Normalization

The criterion weights were normalized so their total equaled one before ranking, following the standard WP procedure (Kurniawan & Utomo, 2023).

$$w_j = \frac{W_j}{\sum W_j} \quad (1)$$

2.4 Decision Matrix Construction

The performance values of all cocoa clone alternatives were organized into a decision matrix, the primary input for the WP calculation (Putra & Santosa, 2024).

2.5 Calculation of the S Vector

The S vector for each alternative was calculated by multiplying its performance values across all criteria, each raised to its normalized weight, with benefit criteria assigned positive exponents and cost criteria negative exponents (Santoso & Prasetyo, 2022).

$$S_i = \prod_{j=1}^n x_{ij}^{w_j} \quad (2)$$

2.6 Preference Value Calculation

The preference value (V) of each alternative was obtained by dividing its S vector by the total S vector of all alternatives, providing the basis for the final ranking (Hidayat et al., 2022; Putra & Santosa, 2024).

$$V_i = \frac{S_i}{\sum_{i=1}^m S_i} \quad (3)$$

2.7 Ranking Results

The alternatives were ranked in descending order of preference value (V); the highest-value alternative was identified as the most recommended superior cocoa clone (Hartono & Widodo, 2024; Mahendra & Utama, 2025).

2.8 Sensitivity Analysis

Robustness to variation in criterion weighting was examined through two procedures: (1) a one-at-a-time (OAT) analysis varying each criterion weight individually by $\pm 10\%$, $\pm 20\%$, and $\pm 30\%$ while keeping the relative proportion of the remaining weights unchanged, and re-computing the ranking for each scenario; and (2) a Monte Carlo simulation independently drawing all seven weights from a uniform distribution over the Likert range (1–5) and recalculating the ranking across 20,000 scenarios, recording how often each alternative attained the first rank and a top-three position.

2.9 Comparative Validation Using the Simple Additive Weighting (SAW) Method

As a further validation, the ranking was compared with one produced by the Simple Additive Weighting (SAW) method, another widely used MADM technique. In SAW, each benefit-criterion value is normalized by the column maximum and each cost-

criterion value by the column minimum divided by each entry; the normalized values are multiplied by the same normalized weights used in WP and summed into a preference score. The WP and SAW rankings were compared using Spearman's rank correlation coefficient.

3 Result and Discussion

3.1 Result

The selection of superior cocoa clones at Sari Merta Cocoa Farmers Group currently relies on farmers' experience and subjective judgment rather than a structured multi-criteria evaluation. As each clone differs in productivity, pest resistance, bean quality, selling price, age at first harvest, maintenance cost, and fertilizer requirement, this study applies the Weighted Product (WP) method to objectively evaluate and rank the alternatives through the following stages.

Determination of Criteria and Weights. Seven evaluation criteria were identified through field observations, interviews, and a literature review, and their relative importance was assessed using a five-point Likert scale (1 = Not Important, 5 = Very Important) by the 5 respondents described in Section 2.1. The criteria and resulting weights are shown in Table 1 and Table 2.

Table 1. Criteria and Weighting Table

Code	Criteria	Type	Unit
C1	Productivity	Benefit	kg/tree/year
C2	Pest Resistance	Benefit	Score (1–5)
C3	Seed Quality	Benefit	Score (1–5)
C4	Selling Price	Benefit	Rp/kg
C5	Fruiting Age	Cost	Month
C6	Maintenance Costs	Cost	Rp/tree/year
C7	Fertilizer Requirements	Cost	kg/tree/year

Table 2. Resulting Criteria Weighting Table

Code	Criteria	Weight	Importance	Type
C1	Productivity	5	Very Important	Benefit
C2	Pest Resistance	3	Moderately Important	Benefit
C3	Seed Quality	4	Important	Benefit
C4	Selling Price	5	Very Important	Benefit
C5	Fruiting Age	4	Important	Cost
C6	Maintenance Costs	3	Moderately Important	Cost
C7	Fertilizer Requirements	3	Moderately Important	Cost

Productivity and selling price received the highest weight (5), followed by bean quality and age at first harvest (4), while pest resistance, maintenance cost, and fertilizer requirement received a weight of 3. The total initial weight is $\sum W = 5+3+4+5+4+3+3 = 27$, used for normalization.

Data Source and Reliability of the Decision Matrix. The performance values in Table 4 were collected through direct field observation of farmers' plantations, combined with interviews with the farmers and a representative of the Jembrana Regency Department of Agriculture and Food, covering the harvest period from early 2025 to June 2026.

Weight Normalization. Benefit criteria were assigned positive normalized weights and cost criteria negative weights, as shown in Table 3.

Table 3. Normalization Results Table

Code	Criteria	Weight	Normalized Weight
C1	Productivity	5	0.1852
C2	Pest Resistance	3	0.1111
C3	Seed Quality	4	0.1481
C4	Selling Price	5	0.1852
C5	Fruiting Age	4	-0.1481
C6	Maintenance Costs	3	-0.1111
C7	Fertilizer Requirements	3	-0.1111

Decision Matrix Construction. The performance values of each cocoa clone across all criteria, obtained as described in Section 3.1.b, were organized into the decision matrix in Table 4.

Table 4. Table Decision Matrix

Alternative	C1	C2	C3	C4	C5	C6	C7
MCC 01	4	3	4	25000	18	80000	2
MCC 02	6	4	5	25000	18	85000	2.5
Panther	5	4	4	25000	18	100000	3
Sulawesi 1	4	3	4	25000	18	75000	2
Sulawesi 2	5	3	4	25000	18	80000	2.5
Padang Tanah	6	3	4	25000	18	80000	2
Malaysia/Panchor	3	3	3	25000	24	75000	2
Skavina	3	3	4	25000	24	75000	2
RTNJ	5	4	4	25000	18	80000	2.5
Lokal	3.5	3	3	18000	30	60000	2
BB01	4.5	3	4	25000	18	75000	2
ICCRI 09	4	3	4	25000	18	80000	2.5

S Vector Calculation. The S vector for each alternative, computed by raising each criterion value to its normalized weight (positive exponents for benefit criteria, negative for cost criteria) and multiplying across criteria, is shown below. A2 (MCC 02) achieved the highest S value (2.2443), followed by A6 (Padang Tanah, 2.1704), A9 (RTNJ, 2.1135), and A11 (BB01, 2.0726), while A10 (Lokal) was lowest (1.6954); the total across all alternatives was 23.9770 (see Table 5).

Table 5. S Vector Calculation

Alternative	C1	C2	C3	C4	C5	C6	C7	S
A1	1.293	1.130	1.228	6.523	0.652	0.285	0.926	2.0134
A2	1.393	1.167	1.269	6.523	0.652	0.283	0.903	2.2443
A3	1.347	1.167	1.228	6.523	0.652	0.278	0.885	2.0203
A4	1.293	1.130	1.228	6.523	0.652	0.287	0.926	2.0279
A5	1.347	1.130	1.228	6.523	0.652	0.285	0.903	2.0470
A6	1.393	1.130	1.228	6.523	0.652	0.285	0.926	2.1704
A7	1.226	1.130	1.177	6.523	0.624	0.287	0.926	1.7656
A8	1.226	1.130	1.228	6.523	0.624	0.287	0.926	1.8425
A9	1.347	1.167	1.228	6.523	0.652	0.285	0.903	2.1135
A10	1.261	1.130	1.177	6.138	0.604	0.295	0.926	1.6954
A11	1.321	1.130	1.228	6.523	0.652	0.287	0.926	2.0726
A12	1.293	1.130	1.228	6.523	0.652	0.285	0.903	1.9641
Addition Result								23.9770

Preference Value Calculation. Preference values (V), obtained by normalizing each S vector against the total, followed the same ordering: A2 (0.0936) > A6 (0.0905) > A9 (0.0881) > A11 (0.0864), with A10 lowest (0.0707) (see Table 6).

Table 6. Preference Value Calculation

Alternative	S	V
A1	2.0134	0.0840
A2	2.2443	0.0936
A3	2.0203	0.0843
A4	2.0279	0.0846
A5	2.0470	0.0854
A6	2.1704	0.0905
A7	1.7656	0.0736
A8	1.8425	0.0768
A9	2.1135	0.0881
A10	1.6954	0.0707
A11	2.0726	0.0864
A12	1.9641	0.0819
Addition Result	23.9770	1

Ranking Results. Sorting the preference values in descending order yields the final ranking below, with MCC 02 as the most recommended superior clone (see Table 7).

Table 7. Ranging Result

Alternative	S	Rangking
A2	0.0936	1
A6	0.0905	2
A9	0.0881	3
A11	0.0864	4
A5	0.0854	5
A4	0.0846	6
A3	0.0843	7
A1	0.0840	8
A12	0.0819	9
A8	0.0768	10
A7	0.0736	11
A10	0.0707	12

Sensitivity Analysis Results. The one-at-a-time (OAT) analysis, varying each criterion weight by up to $\pm 30\%$, showed MCC 02 remaining top-ranked under every tested perturbation for all seven criteria. The Monte Carlo simulation (20,000 randomized scenarios) showed MCC 02 obtaining the highest preference value in 91.1% of scenarios, with Padang Tanah as the only alternative able to overtake it (8.9%); no other alternative ever attained the first rank. MCC 02 and Padang Tanah appeared in the top three in 99.6% and 99.3% of scenarios respectively, followed by RTNJ (74.8%) and BB01 (25.4%), summarized in Table 8.

Table 8. Monte Carlo Sensitivity Analysis (20,000 Randomized Weighting Scenarios)

Alternative	Top-1 Frequency	Top-3 Frequency
MCC 02	91.1%	99.6%
Padang Tanah	8.9%	99.3%
RTNJ	0.0%	74.8%
BB01	0.0%	25.4%
Panther	0.0%	0.5%
Sulawesi 1	0.0%	0.4%
Other alternatives	0.0%	< 0.1%

Comparative Validation Results (SAW Method). The Simple Additive Weighting (SAW) method, applied to the same decision matrix and weights as a cross-method validation, produced a ranking identical to WP for all twelve alternatives (Spearman's $\rho = 1.00$), shown in Table 9.

Table 9. Comparison Between WP and SAW Rankings

Alternative	WP Preference (V)	WP Rank	SAW Score	SAW Rank
MCC 02	0.0936	1	0.9451	1
Padang Tanah	0.0905	2	0.9148	2
RTNJ	0.0881	3	0.8895	3
BB01	0.0864	4	0.8741	4
Sulawesi 2	0.0854	5	0.8617	5
Sulawesi 1	0.0846	6	0.8586	6
Panther	0.0843	7	0.8580	7
MCC 01	0.0840	8	0.8531	8
ICCRI 09	0.0819	9	0.8309	9
Skavina	0.0768	10	0.7907	10
Malaysia/Panchor	0.0736	11	0.7611	11
Lokal	0.0707	12	0.7247	12

3.2 Discussion

The WP method ranked the twelve alternatives with A2 (MCC 02/Masamba Cocoa Clone 02) as the superior clone ($V = 0.0936$), followed by A6 (Padang Tanah, 0.0905), A9 (RTNJ, 0.0881), and A11 (BB01, 0.0864), while A10 (Lokal) ranked lowest (0.0707). This outcome stems from MCC 02 combining the highest productivity (6 kg/tree/year), pest resistance (4), and seed quality (5) among all alternatives - criteria that together carry the largest share of the normalized weight (0.4444 combined) - at only a modestly higher maintenance cost and fertilizer requirement than clones such as Sulawesi 1 or BB01. In practice, MCC 02 offers farmers higher yield, greater pest resilience, and better bean quality for a marginal increase in input cost, a favorable trade-off given that productivity and selling price were rated the most important criteria by the group's management and farmers.

Because the top preference values are close (only 0.0031 between MCC 02 and Padang Tanah), robustness was tested through sensitivity analysis and cross-method validation: MCC 02 remained top-ranked under every single-criterion weight perturbation of up to $\pm 30\%$ and retained the first rank in 91.1% of 20,000 Monte Carlo weighting scenarios, while the Simple Additive Weighting (SAW) method produced an identical overall ranking (Spearman's $\rho = 1.00$) despite its different aggregation logic - together confirming that the recommendation reflects genuine differences among the clones rather than an artifact of a single weighting configuration or method. Accordingly, the study's contribution lies not in methodological novelty, since the WP procedure is well established, but in its contextual, empirically validated application to a community-level decision that can be integrated into the group's Green Information Technology platform (Priyana et al., 2025) and that supports its ongoing agritourism activities, such as hosting KKN university students, through a more reliable, quality-assured cocoa supply.

4 Conclusion

This study applied the Weighted Product (WP) method to determine the superior cocoa clone of the Sari Merta Cocoa Farmers Group by defining seven agronomic and economic criteria, weighting them through a Likert-scale questionnaire completed by 5 purposively selected respondents, normalizing the weights, constructing a decision matrix from field-verified data, and computing the S vector and preference values (V) to rank twelve clone alternatives.

The ranking identified MCC 02 (Masamba Cocoa Clone 02) as the most recommended superior clone, with the highest preference value (0.0936), followed by Padang Tanah (0.0905) and RTNJ (0.0881), while the Local clone ranked lowest (0.0707) - providing the Sari Merta Cocoa Farmers Group an objective, systematic basis for cocoa clone selection in place of prior subjective judgment.

A sensitivity analysis across 20,000 randomly generated weighting scenarios showed MCC 02 retaining the top rank in 91.1% of cases, and a comparative validation using the Simple Additive Weighting (SAW) method produced an identical ranking order (Spearman's $\rho = 1.00$), confirming that the recommendation is robust rather than an artifact of a single weighting configuration or aggregation procedure. Rather than methodological novelty, the study's contribution lies in this practical, empirically validated application, which can be integrated into the group's existing Green Information Technology platform (Priyana et al., 2025) to support both cultivation planning and its ongoing agritourism activities; future work should expand the respondent base and complement it with expert- or FGD-based validation.

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