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Integrated assessment and prioritization framework for the sustainability of food security among women of reproductive age in Masindray, Madagascar

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Abstract

National responses to food insecurity require comparable diagnostic tools, yet classifications vary across indicators and comparisons under shock conditions remain difficult. This study addresses the need for an evaluation and intervention framework to support the sustainability of food security among women of reproductive age. It examines two research questions: which score can operationalize the sustainability of food security among women of reproductive age, and which sets of leverage points can structure a multisectoral framework for food security intervention? In the rural commune of Masindray, Madagascar, a cross-sectional survey was used to construct a continuous composite score structured around five dimensions and then classified into four levels, S1 to S4. Internal validation relied on Principal Component Analysis and Spearman correlation with the F1 axis, while external validation used Body Mass Index and Mid-Upper Arm Circumference. The strategic rectangle identified a core set of priority modalities. The score ranged from 0.05 to 0.97, with a mean of 0.58. S1 accounted for 4% of the sample, whereas S2 to S4 each represented nearly one third. Internal consistency was high, and external association reached 0.18 with Body Mass Index and 0.28 with Mid-Upper Arm Circumference. The core set highlighted domestic constraints, intra-household decision-making, and access security. These findings support the use of a continuous reading complemented by component-based analysis and multisectoral prioritization. Future work should include multi-season validation, territorial replication, and causal assessment of intervention portfolios.

Keywords: Capabilities; Heterogeneity; Vulnerability; Gender; Public Policy

1. Introduction

National nutrition action and responses to food insecurity require comparable diagnostic tools to guide targeting and service continuity within monitoring and crisis-management frameworks that depend on stable benchmarks for comparing situations and setting support priorities [1, 2]. Their effectiveness, however, depends on actual rights and on access to services and resources across territories.

In this study, the sustainability of food security refers to the extent to which adequate food access can be maintained over time despite structural constraints, seasonal pressures, and shocks. This perspective extends beyond a static assessment by incorporating stability, adjustment capacity, and women's ability to secure food under changing conditions. It is shaped by access to productive resources, markets, and services, as well as by intra-household trade-offs [3]. Access to land and security of access influence investment, production, and exposure to price increases [4], while income variability and market conditions affect dietary diversity and adjustment strategies. At household level,

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women's decision-making power, time constraints, and access to water, hygiene, sanitation, and domestic energy influence meal preparation and exposure to disease [5]. These constraints shift over time with seasonality, lean periods, and shocks [6]. Because these pressures vary from month to month, comparing situations and defining priorities remains difficult. Although measurement frameworks and tools are widely used, classifications still differ across indicator families, and comparison under shock conditions remains problematic. A common benchmark is therefore needed to rank levels of sustainability and connect them to prioritized leverage points [7].

This issue is especially important in the rural commune of Masindray, Madagascar, where women of reproductive age face intersecting constraints related to access, domestic organization, and service conditions. The study therefore seeks to develop an evaluation and intervention framework able to capture the sustainability of food security in all its complexity by integrating access, quality, stability, responses to hardship, and agency, in line with Sen's capability approach [8]. To address this issue, the study proposes a continuous composite score, complemented by a classification into categories for more operational use. It asks the following main question: what evaluation and intervention framework can support the sustainability of food security among women of reproductive age? Two sub-questions structure the analysis: which score operationalizes this sustainability, and which sets of leverage points structure a multisectoral framework for food security intervention? Two hypotheses guide the study: first, that the standardized aggregation of indicators produces a sustainability score with good discriminative capacity; and second, that the hierarchical ordering of modalities reveals a core set of sustainability leverage points useful for structuring intervention prioritization.

2. Material and methods

2.1. Study area and sample

The empirical investigation was carried out in Masindray, a rural commune in Antananarivo Avaradrano District, Analamanga Region, Madagascar (18° 58′ 13.06″ S; 47° 37′ 41.24″ E). The commune was selected because it combines marked spatial differences in access to markets, basic services, and mobility conditions, which are relevant for examining the sustainability of women's food security.

The analysis relies on a cross-sectional household survey conducted from May to July 2025. The statistical unit retained for this article was the woman of reproductive age interviewed in the household. Sampling followed a quota logic across the commune. The number of interviews assigned to each fokontany was determined according to its relative demographic weight, and field teams then moved through households using a predefined itinerary until the required number of eligible respondents had been reached in each locality. Only one woman aged 15–49 years was interviewed per selected household.

The initial sample size was estimated with Cochran's formula:

$$n = \frac{z^2 \, \hat{P} \left(1 - \hat{P} \right)}{e^2}$$

where

- z^2 is the quantile associated with the confidence level (here, 1.96),
- P is the expected proportion (here, 0.5), and
- e is the margin of error (here, 0.05).

After allowing for non-response, 400 interviews were completed. Four questionnaires were excluded because of incomplete information, which yielded a final analytical sample of 396 women. The questionnaire was administered in Malagasy, and the completed survey forms were subsequently entered and translated into French for analysis.

2.2. Construction and validation of the food security sustainability score

2.2.1. Score construction

The food security sustainability score was based on a multidimensional operationalization derived from recent literature, combining access, quality, and stability with responses to hardship and intra-household agency [9,10]. The unit of analysis was the surveyed woman of reproductive age. Data processing was carried out in Microsoft Excel for data preparation, identification of outliers, normalization, and aggregation. Five dimensions were retained: (i) food access, (ii) diet quality, (iii) temporal stability, (iv) responses to hardship (coping), and (v) agency. The indicators were selected as follows: the Household Food Insecurity Access Scale (HFIAS) for access; the Minimum Dietary Diversity for Women (MDD-W) and the Food Consumption Score (FCS) for quality; the lean season for stability; the Coping Strategy Index (CSI) and Livelihood Coping Strategies (LCS) for responses; and five binary variables of intra-household decision-making for agency.

Continuous indicators were winsorized at the 1st and 99th percentiles and then normalized to the [0,1] range. Directional harmonization was applied so that a higher score always indicated higher sustainability, including for indicators that originally reflected deterioration. Dimensional sub-scores were based on simple means, and the overall score was constructed through weighted additive aggregation, with a threefold higher weight assigned to stability. Four classes, S1 to S4, were defined using score intervals (0.25, 0.50, 0.75), and a threshold of 0.75 was used to qualify a situation as sustainable. The results present the descriptive statistics associated with the continuous score and the distribution across classes.

The algorithm presented below corresponds to the procedure proposed by the author and tested in this study (Figure 1).

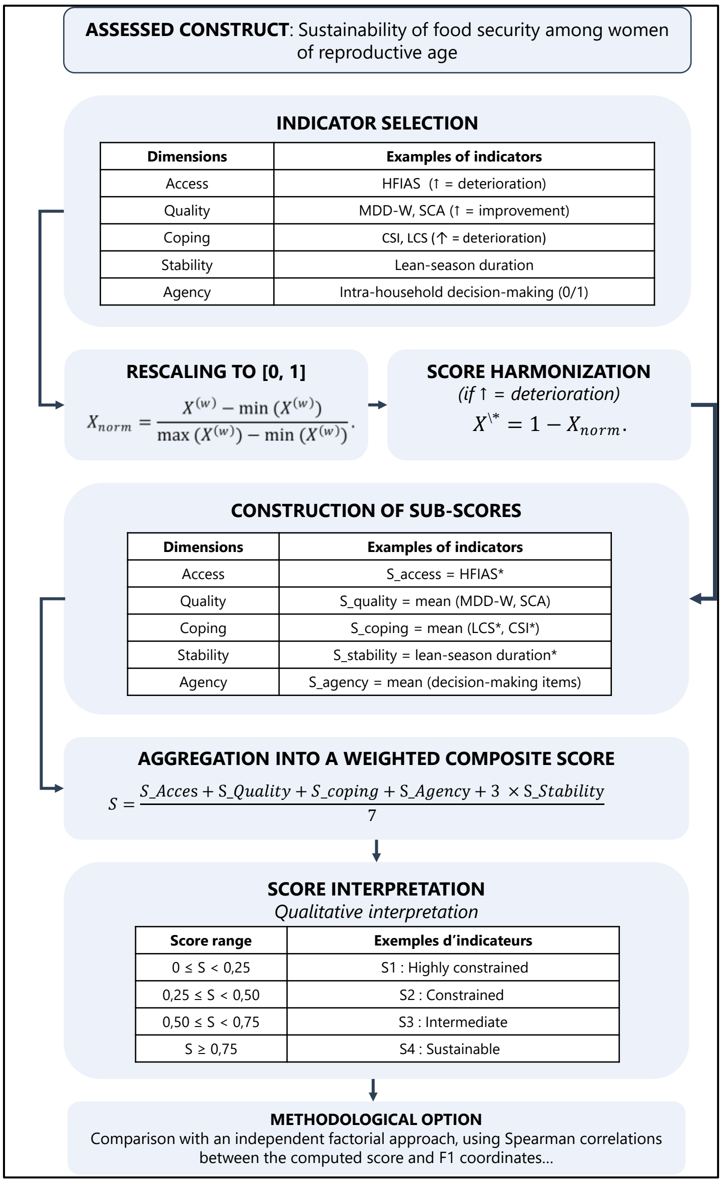

Figure 1 Framework for constructing the sustainability score of food security among women of reproductive age

2.2.2. Validation tests

To assess internal robustness, Principal Component Analysis (PCA) was applied to the indicators retained for the operationalization of food security. The first factorial axis (F1) was extracted as a summary of the common variance. The sustainability score was then compared with F1 using Spearman correlation in order to assess the consistency of ranking between the aggregated score and the factorial summary.

External validation was then conducted using two criteria not included in score construction: Body Mass Index (BMI) and Mid-Upper Arm Circumference (MUAC). Associations between the sustainability score and these criteria were estimated using Spearman correlations.

2.3. Strategic rectangle of food security sustainability leverage points

The strategic rectangle was based on the discriminating modalities of profiles S1 to S4, previously identified through discriminant factor analysis. The modalities retained for this analysis were as follows. The repeated variable names linked to different category codes, such as income_use_decision and land_access_mode, were retained intentionally, as they represent different modalities of the same variable.

Table 1 Discriminating qualitative modalities used in the strategic rectangle

Variable coding	Category coding	Label
respondent_age	A1	Respondent aged 15 to 19 years
animal_product_consumption	N	No consumption of animal products
charcoal_cooking	N	No use of charcoal for cooking
firewood_cooking	N	No use of firewood for cooking
fruit_cultivation	O	Fruit cultivation practiced
food_purchase_decision	DP	Food purchases decided jointly by the respondent and her spouse
food_preparation_decision	H	Food preparation decided by the father or the spouse alone
child_health_decision	DP	Decisions related to children's health made jointly by the respondent and her spouse
income_use_decision	EN	Use of income decided by the respondent together with her spouse
income_use_decision	FS	Use of income decided by the respondent alone or by her mother
health_center_access_time	C3	Distant access to the health center, with a travel time of at least 80 minutes
market_access_time	C2	Nearby market access, with a travel time of 50 to 60 minutes
food_storage_duration	C3	Long food preservation duration, greater than 6 months
agriculture_nutrition_training	N	No training in agriculture or nutrition
handwashing_with_soap	O	Handwashing performed with soap
utensil_cleaning	N	No cleaning of utensils
land_access_mode	DF	Access to land through formal rights, with land title or certificate
land_access_mode	NA	No agricultural activity
livestock_food_share	F	Low share of food derived from livestock, less than 50%
perceived_land_tenure_security	PS	Perceived land tenure security considered low
drinking_water_source	PN	Drinking water supplied from an unprotected well
drinking_water_source	PP	Drinking water supplied from a protected well
cooking_time	C2	Average time spent on cooking between 120 and 180 minutes

crop_type	MA	Cultivation of market garden crops
crop_type	VI	Cultivation of staple food crops

The qualitative modalities were coded as 0/1, after which a correlation matrix was produced in XLSTAT, with p-values calculated for each pair of modalities. The significance of an absolute correlation |ρ| was assessed at the α = 0.05 threshold using the following rule:

$$|\rho| = \frac{t_{\propto}}{\sqrt{n-2+\ t_{\propto}^{2}}}$$

where :

- n is the number of observations, and
- t_α is the quantile of the Student's t distribution with n − 2 degrees of freedom.

A matrix containing the absolute value of significant relationships, with absence of relationship coded as 0, was then established after excluding the diagonal and neutralizing symmetry to avoid double counting. For each modality, two types of relationships were calculated from the significant inter-variable correlations: L, corresponding to the sum of significant correlations by rows, and P, corresponding to the sum of significant correlations by columns. From these two volumes, two indicators were retained: X, plotted on the horizontal axis and defined as the ratio of L to P; and Y, plotted on the vertical axis and defined as the product of L and P. The partitioning of the strategic rectangle was based on the observed means, namely $\bar{X}$ = 1.52 and $\bar{Y}$ = 15.08, which made it possible to classify the modalities into three groups: dominant-influential, influential, and peripheral. This reading was used to isolate modalities with driving potential and then to constitute a common operational subset for the next stage.

3. Results

3.1. Conceptual evaluation framework

3.1.1. Score distribution and S1-S4 classification

Descriptive statistics for the overall sustainability score were established to characterize the range and dispersion of the observed values within the sample. The score values ranged from 0.0511 to 0.9714. The mean was 0.5807, with a standard deviation of 0.2170, indicating dispersion around the central value. The median was 0.6022.

Table 2 Descriptive statistics of the empirical sustainability score

Minimum	Maximum	Median	Mean	Variance	Standard deviation
0.0511	0.9714	0.6022	0.5807	0.0471	0.2170

The distribution of women of reproductive age across the four sustainability levels defined by the weighted score is presented to describe the sample's class structure. The distribution shows a concentration of observations in classes S2, S3, and S4, each accounting for approximately one-third of the sample, whereas class S1 represents a smaller proportion (Table 3).

Table 3 Distribution of women across sustainability classes

Sustainability class	Score interval	Share (%)
S1 : Highly constrained	0 ≤ S < 0.25	3.81
S2 : Constrained	0.25 ≤ S < 0.50	32.99
S3 : Intermediate	0.50 ≤ S < 0.75	32.49
S4 : Sustainable	S ≥ 0.75	30.71

3.1.2. Validation tests

Internal robustness

The results of the Principal Component Analysis (PCA), applied to the selected indicators, document the factorial summary derived from the correlation matrix. Consistency between the sustainability score and the resulting factorial summary was assessed using Spearman correlation between the aggregated score and the F1 axis. The Spearman correlation between the sustainability score and the F1 axis was ρ = 0.8449, with a p-value below 0.0001 (Table 4).

Table 4 Spearman correlation between the sustainability score and the F1 axis

Compared variables	Spearman's ρ	p-value
Score–F1	0.8449	< 0.0001

External robustness

Associations between the sustainability score, anthropometric criteria, and the indicators considered separately were examined in order to describe the correlation magnitudes obtained using Spearman's method. Correlation magnitudes between the sustainability score and MUAC were higher than those observed with BMI (0.28 versus 0.18). The highest correlation was observed between BMI and MUAC (0.57). Among the indicators considered separately, the HFIAS showed the highest correlation magnitude with the score (0.62), followed by the rCSI (0.53) and the FCS (0.43). Correlation magnitudes for LCS reached 0.28, whereas those observed for MDD-W remained low (0.04). Correlation magnitudes were consistently higher for MUAC than for BMI for the sustainability score, FCS, CSI, and HFIAS. The lowest magnitudes were observed for MDD-W with both anthropometric criteria. The magnitudes associated with LCS occupied an intermediate position relative to the other indicators (Table 5).

Table 5 Spearman correlations between the sustainability score, BMI, MUAC, and the indicators

Variables	Score		BMI		MUAC	
	Spearman's ρ	p-value	Spearman's ρ	p-value	Spearman's ρ	p-value
Score	1	0	0.18	0.0002	0.28	< 0.0001
BMI	0.18	0.0002	1	0	0.57	< 0.0001
MUAC	0.28	< 0.0001	0.57	< 0.0001	1	0
CSI	0.53	< 0.0001	0.07	0.18	0.18	0.0003
HFIAS	0.62	< 0.0001	0.12	0.0205	0.22	< 0.0001
LCS	0.28	< 0.0001	0.16	0.0013	0.11	0.0266
MDD-W	0.04	0.4415	0.06	0.2635	0.01	0.7684
FCS	0.43	< 0.0001	0.11	0.0346	0.26	< 0.0001

3.2. Hierarchization of modalities and identification of a core set of sustainability leverage points

The strategic rectangle identified 25 modalities distributed across two operational sets according to the observed mean thresholds $\bar{X}$ = 1.51 and $\bar{Y}$ = 15.09 (Table 6).

The dominant-influential group comprised 11 modalities, characterized by high levels of both relative influence and connectivity. These were average cooking time of 120 to 180 minutes (cooking_time-C2), handwashing with soap (handwashing_with_soap-O), absence of utensil cleaning (utensil_cleaning-N), no use of charcoal for cooking (charcoal_cooking-N), income use decided jointly by the respondent and her spouse (income_use_decision-EN), child health decisions made jointly (child_health_decision-DP), drinking water supplied from an unprotected well (drinking_water_source-PN), food purchases decided jointly by the respondent and her spouse (food_purchase_decision-DP), no consumption of animal products (animal_product_consumption-N), no use of firewood for cooking (firewood_cooking-N), and a low share of food derived from livestock, below 50% (livestock_food_share-F).

The influential group comprised 14 modalities, marked by above-average relative influence but connectivity below the mean threshold. It included access to land through formal rights (land_access_mode-DF), perception of land tenure security as low (perceived_land_tenure_security-PS), no agricultural activity (land_access_mode-NA), distant access to the health center of at least 80 minutes (health_center_access_time-C3), market access of 50 to 60 minutes (market_access_time-C2), fruit cultivation (fruit_cultivation-O), staple crop cultivation (crop_type-VI), market gardening (crop_type-MA), drinking water supplied from a protected well (drinking_water_source-PP), food preservation duration longer than six months (food_storage_duration-C3), no training in agriculture or nutrition (agriculture_nutrition_training-N), food preparation decided by the father or the spouse alone (food_preparation_decision-H), income use decided by the respondent alone or by her mother (income_use_decision-FS), and respondent age between 15 and 19 years (respondent_age-A1).

Table 6 Strategic-rectangle coordinates of the 25 core sustainability modalities

Variables	X = L/P	Y = LP
cooking_time-C2	5.41	30.85
handwashing_with_soap-O	3.37	28.36
utensil_cleaning-N	2.80	17.02
charcoal_cooking-N	2.66	35.57
income_use_decision-EN	2.51	16.83
child_health_decision-DP	2.44	18.39
drinking_water_source-PN	2.22	27.09
food_purchase_decision-DP	2.08	18.11
animal_product_consumption-N	2.05	23.10
firewood_cooking-N	1.89	32.64
livestock_food_share-F	1.60	39.86
land_access_mode-DF	7.93	7.93
perceived_land_tenure_security-PS	5.75	7.93
land_access_mode-NA	4.96	8.41
health_center_access_time-C3	3.74	3.74
market_access_time-C2	3.66	10.26
fruit_cultivation-O	3.58	4.52
crop_type-VI	3.58	5.36
crop_type-MA	3.35	12.04
drinking_water_source-PP	2.18	5.86
food_storage_duration-C3	1.94	3.23
agriculture_nutrition_training-N	1.81	2.77
food_preparation_decision-H	1.62	3.13
income_use_decision-FS	1.58	13.23
respondent_age-A1	1.54	8.71

Legends: cooking_time-C2: average cooking time (120-180 minutes); handwashing_with_soap-O: handwashing with soap; utensil_cleaning-N: no utensil cleaning; charcoal_cooking-N: no use of charcoal for cooking; income_use_decision-EN: income use decided jointly by the respondent and her spouse; child_health_decision-DP: decisions related to children's health made jointly by the respondent and her spouse; drinking_water_source-PN: drinking water supplied from an unprotected well; food_purchase_decision-DP: food purchases decided jointly by the respondent and her spouse; animal_product_consumption-N: no consumption of animal products; firewood_cooking-N: no use of firewood for cooking; livestock_food_share-F: low share of food derived from livestock (less than 50%); land_access_mode-DF: access to land through formal rights (land title or certificate); perceived_land_tenure_security-PS: perceived land tenure security considered low; land_access_mode-NA: no agricultural activity; health_center_access_time-C3: distant access to the health center (≥80 minutes); market_access_time-C2: nearby market access (50-60 minutes); fruit_cultivation-O: fruit cultivation practiced; crop_type-VI: cultivation of staple food crops; crop_type-MA: cultivation of market garden crops; drinking_water_source-PP: drinking water supplied from a protected well; food_storage_duration-C3: long food preservation duration (>6 months); agriculture_nutrition_training-N: no training in agriculture or nutrition; food_preparation_decision-H: food preparation decided by the father or the spouse alone; income_use_decision-FS: income use decided by the respondent alone or by her mother; respondent_age-A1: respondent aged 15-19 years. In the table, X = horizontal axis, defined as the ratio of L to P; Y = vertical axis, defined as the product of L and P; L = sum of significant inter-variable correlations by rows; P = sum of significant inter-variable correlations by columns.

4. Discussion

4.1. Conceptual evaluation framework

4.1.1. Score range and heterogeneity

The descriptive statistics of the overall score indicate marked dispersion, with a central value close to 0.6. The standard deviation confirms heterogeneity across situations. This variability reflects a continuum of sustainability rather than concentration around a single level. It is consistent with a multidimensional reading in which different combinations of constraints and resources generate contrasting vulnerabilities and capacities for adjustment [10].

From a conceptual perspective, such dispersion meets a classic expectation of composite indicators: an aggregated score is intended to condense several dimensions into a single benchmark while retaining the capacity to distinguish between situations that appear similar on one isolated indicator but differ across other components [11]. A highly concentrated score would have suggested either strong homogeneity in the study area or a weakly discriminative instrument. By contrast, the observed range suggests that the tool captures real differences and can support a graduated reading of profiles, which is necessary when the objective concerns sustainability, and therefore trajectories and margins for improvement, rather than a binary snapshot of "food secure/food insecure" status alone [12].

This heterogeneity is consistent with a study conducted in Ethiopia, which emphasizes the plurality of pathways leading to food insecurity: shocks, coping strategies, unequal access to resources, and intra-household trade-offs can produce very different levels of food well-being even within a restricted geographical area [13]. In addition, both the median and the mean lie above the midpoint of the scale, suggesting a distribution that is generally oriented toward intermediate or relatively high score levels, with a minority of very low observations. This structure is common in composite indices when some dimensions deteriorate sharply for a fraction of households, whereas other dimensions remain partly protected for the majority [14].

The overall score nevertheless remains a constructed benchmark on a bounded scale, and its dispersion therefore depends on the dimensions selected, the way they are combined, and the empirical context of the study area. Direct comparison of score levels with other zones or other studies requires harmonization of both the components and the aggregation rules. By contrast, the within-sample reading remains robust: the observed range shows that the score has sufficient discriminative capacity to discuss differences in sustainability and, subsequently, to structure reasoning in terms of priorities and targeting [15].

4.1.2. Distribution across score classes

The distribution of women across sustainability classes shows a strongly asymmetrical structure between the extreme lower end of the score and the rest of the sample. Class S1 remains a minority (3.81%, n = 15), whereas S2, S3, and S4 each include nearly one third of the sample. This structure points to a limited group in highly constrained situations and a majority distributed across intermediate or sustainable levels, leaving room for graduated improvement.

The classes are based on fixed score thresholds, which justifies a joint reading of class membership and continuous values near class boundaries. The international literature on composite indicators recalls that conclusions often depend on the thresholds selected, especially for cases located near class boundaries, where situations may be very similar despite being assigned to different classes [11].

4.1.3. Concordance with the factorial axis

The high correlation between the score and the F1 axis indicates a very close hierarchy between an aggregation-based summary and a factorial summary, which strengthens the internal coherence of the tool. The score therefore captures a major common gradient in the data. This concordance is not sufficient to cover all dimensions relevant to sustainability, which justifies a component-based reading during interpretation and prioritization [11].

4.1.4. Nutritional robustness of the score

The results also compare the magnitudes of Spearman correlations between anthropometric criteria, the sustainability score, and the associated indicators. Correlations with Mid-Upper Arm Circumference (MUAC) are higher than those with Body Mass Index (BMI) for the sustainability score, the Food Consumption Score (FCS), the Coping Strategy Index (CSI), and the Household Food Insecurity Access Scale (HFIAS). For both anthropometric criteria, Minimum Dietary Diversity for Women (MDD-W) shows the weakest association. Livelihood Coping Strategies (LCS) occupies an intermediate position. This pattern supports the view that, in this sample, MUAC reflects the sustainability gradient captured by the score better than BMI.

In addition, the external correlations show that the synthetic score is more strongly associated with the anthropometric criteria than the indicators considered separately. The score-BMI association reaches ρ = 0.18 and exceeds all BMI-indicator magnitudes, whose maximum remains 0.16 for LCS. The score-MUAC association reaches ρ = 0.28 and also exceeds all MUAC-indicator magnitudes, whose maximum is 0.26 for FCS. The sharpest contrast concerns dietary diversity: the MDD-W-BMI (0.06) and MDD-W-MUAC (0.01) magnitudes remain close to zero, whereas the score retains a positive association with both criteria. Thus, aggregation does not dilute the observed nutritional relationship; rather, it strengthens it in relative terms.

This result may be explained by the cumulative nature of nutritional status, which arises from simultaneous constraints [16]. An isolated indicator captures only one segment of these mechanisms, as emphasized in comparisons of food security tools: each measure covers a specific domain, and use of a single instrument produces incomplete classifications [17]. Studies among women of reproductive age describe heterogeneous links between food insecurity and nutritional status, which further supports the value of a multidimensional synthesis [18]. Seasonal analyses also confirm fluctuations in women's BMI in line with changes in food security [19].

From an operational perspective, this relative gain in correlation magnitude supports the use of the score as a diagnostic synthesis when the aim is to prevent nutritional risk among women. The proximity between the score-MUAC (0.28) and FCS-MUAC (0.26) correlations nevertheless suggests that the score improves the association, but only to a limited extent. The magnitudes remain moderate, which is consistent with instruments that do not capture the same time horizon as anthropometry and with extra-food determinants of maternal malnutrition [20, 21]. In the Malagasy context, recent findings describe limited dietary diversity and weak nutrition knowledge among rural women, which supports the value of an instrument combining several dimensions [22]. Finally, MUAC retains practical relevance for adult screening, with strong MUAC-BMI concordance and recommendations supporting its use in context.

4.1.5. Integrated reading of sustainability

Taken together, the results support an evaluation model of food security sustainability among women of reproductive age built around access, quality, stability, responses to hardship, and agency. It derives from the architecture adopted: the score combines several dimensions, with specific attention to access, quality, stability, responses to hardship, and agency. This structure brings the model closer to contemporary frameworks that define food security as a multidimensional construct and situate sustainability in the capacity to maintain functions over time under constraints and shocks [9, 10]. It also makes visible a principle that is useful for intervention: a global score has operational value only if it retains a component-based reading, so that it is possible to identify what degrades the level of sustainability for an individual or a group, rather than producing an opaque classification [11].

Two implications emerge directly. First, the model provides a basis for prioritization: an intervention does not target the same issue when the dominant constraint relates to stability, responses to hardship, or limited decision-making capacity. Second, the integration of agency places food-related decisions and power relations at the center of the diagnosis, which is consistent with an empirical literature on the links between autonomy, intra-household decision-making, and food security [6].

4.2. Central leverage points in the system

The core set of 25 modalities highlights entry points that reinforce one another rather than a list of isolated determinants. Three groups stand out.

4.2.1. Domestic constraints and the meal preparation environment

The first finding concerns the weight of domestic constraints that structure everyday trade-offs. Time devoted to cooking (cooking_time-C2), cooking conditions (charcoal_cooking-N; firewood_cooking-N), and hygiene practices related to meal preparation (handwashing_with_soap-O; utensil_cleaning-N) appear in the core set. From a sustainability perspective, this means that intervention becomes more effective when time constraints and the domestic environment are treated as second-order determinants, because they condition the adoption and continuity of other food-related practices [10]. Here, the core set suggests formulating actions that reduce domestic transaction costs such as time, drudgery, and access constraints, while also improving the sanitary quality of meals, rather than concentrating effort on isolated nutrition messages.

4.2.2. Agency and intra-household governance

The second finding concerns agency and intra-household governance. The core set retains modalities related to decisions about income use (income_use_decision-EN; income_use_decision-FS), food purchases (food_purchase_decision-DP), and children's health (child_health_decision-DP). For intervention, this result should not be read as a moral injunction, but as a programmatic constraint: sustainability depends on the capacity to transform a resource (income, access) into actual consumption and favorable choices, which requires decision-making room and compatible priority-setting rules [23, 24]. In a systemic framework, increasing a resource without influencing its allocation may produce only a weak or unstable effect, because the system redirects the benefit toward other uses. One operational implication is to combine economic action (income, assets, access) with arrangements that secure decision-making over food and health, for example through intra-family discussion mechanisms, expenditure planning, or direct access to certain goods.

4.2.3. Productive base and access security

The third finding relates to the productive base and access security, particularly access to land (land_access_mode-DF; land_access_mode-NA), perceived land tenure security (perceived_land_tenure_security-PS), and certain markers linked to livestock and animal products (livestock_food_share-F; animal_product_consumption-N). The core set suggests that, for part of the households, sustainability depends on secure access to land and means of production, as well as on the capacity to convert these means into food availability and dietary diversity [25]. This reading is consistent with food systems approaches that emphasize the interdependence between production, access, and use, as well as the existence of bottleneck constraints that govern several dimensions simultaneously [10].

5. Conclusion

This study developed a continuous composite score to assess food security sustainability among women of reproductive age and translated this score into four operational classes, S1-S4. The results show that the tool provides a coherent basis for distinguishing different levels of sustainability, while the validation procedures support its internal consistency and its alignment with nutritional benchmarks. The strategic rectangle further identified a core set of structuring modalities that can help guide the prioritization of intervention levers.

Taken together, these findings support the value of a multidimensional and operational framework for assessing food security sustainability among women of reproductive age. Beyond classification alone, the proposed approach makes it possible to link observed levels of sustainability to a structured set of leverage points, which strengthens its relevance for diagnosis, prioritization, and intervention design.

Several directions for further research could consolidate these contributions. A first priority is temporal validation of the score through multi-season follow-up in order to characterize sustainability trajectories and assess the stability of S1-S4 classifications under seasonality and shocks. A second priority concerns transferability of the framework through replication in other rural areas and in peri-urban settings, in order to distinguish what reflects a common structure of sustainability from what is context-specific. A third direction is the causal evaluation of intervention configurations associated with the classes, using quasi-experimental designs to compare action portfolios and identify combinations whose effects are maintained over time.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that they have no competing interests related to this work.

Statement of ethical approval

This research was based on an interviewer-administered survey conducted among women of reproductive age in the study area. Before field implementation, authorization to conduct the survey was obtained from the relevant local administrative authorities. The study was carried out in accordance with the ethical principles generally applied to non-interventional social research involving human participants.

Statement of informed consent

All participants took part on a voluntary basis. Before each interview, the objectives of the study were explained to the respondent, and informed consent was obtained prior to data collection.

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