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Elaboration of an index of regional development strategies for indigenous communities

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Introduction: This study addressed the need to design development strategies that leverage the endogenous resources of indigenous communities. The municipality of Filomeno Mata, Veracruz, Mexico, was selected as a case of study to validate the proposed methodology. The main objective was to develop an effective approach to regional development through the construction of two key indices: the Strategy Suitability Index for Regional Development (IIDR-GM) and the Strategy Adoption Index (IADR).

Methods: A mixed-methods and multidisciplinary framework was employed, combining statistical analyses with qualitative tools. The methods included the Kruskal–Wallis test, goodness-of-fit tests, and the sign test for two paired simples with normal approximation. In parallel, a Participatory Rural Appraisal (PRA) was conducted.

Results: The IIDR-GM and IADR proved to be effective tools for evaluating development strategies. These indices captured the level of acceptance of sustainable interventions tailored to local needs, based on endogenous natural resources and ancestral knowledge. The results demonstrated the feasibility of this model for promoting inclusive and sustainable regional development.

Discussion: However, certain limitations were identified, such as the heterogeneity of micro-regions, which may hinder comparisons across municipalities. These constraints highlight the need for further research to refine and expand this type of analysis. Thus, the present study represents a starting point for the design of regional development strategies that respect cultural diversity and foster sustainability.

KEYWORDS

regional development, regional strategies, Totonacs, strategy adoption index, strategy suitability index

1 Introduction

Regional development in indigenous communities has become an increasingly relevant field of study (Jordan et al., 2020; Mishra et al., 2021). Their inclusion is essential for achieving the Sustainable Development Goals (Leach et al., 2020). These approaches seek not only to improve socioeconomic indicators, but also to preserve the rich cultural and natural heritage of indigenous peoples (Nocca, 2017). It is critical that indigenous communities actively participate in regional development to ensure their wellbeing and the sustainability of their environments (Jordan et al., 2020).

Indigenous peoples, with their vast ancestral knowledge and sustainable practices, offer a unique model of balanced interaction between humans and nature (Mazzocchi, 2020). However, in the era of globalization and trade liberalization, these communities have become increasingly vulnerable to displacement, land alienation, cultural erosion, and social exclusion (Mishra et al., 2021).

In the context, various development strategies have been proposed and implemented in indigenous regions (López-Santiago et al., 2022), including government programs, community development projects, and environmental conservation efforts. Nevertheless, the implementation of such strategies often presents both theoretical and practical complexities (Castro-Arce and Vanclay, 2020). Many initiatives fail to adequately integrate traditional knowledge and cultural practices, which limits their long-term effectiveness and sustainability (Fernández-Llamazares et al., 2021). A pluralistic understanding is required to promote inclusive, equitable, and sustainable actions at both local and global levels (Lam et al., 2020).

Therefore, in this study, the concept of regional development strategy is defined as a set of community-driven, culturally embedded actions designed to improve collective wellbeing through the sustainable use of indigenous resources. This concept aligns with the definition proposed by the FAO (Organización de las Naciones Unidas para la Alimentacion y la Agricultura) (2021), which describes regional development strategies as models built from within communities, focusing on the protection of territories, natural assets, and traditional knowledge related to the sustainable use of biocultural diversity. Lee and Eversole (2019), as well as OECD (Organization for Economic Co-operation and Development) (2020), emphasize that Indigenous peoples are key actors in shaping regional futures and its strategies.

The concept also aligns with the assumption that regional transformation must take place within the territories, through changes in governance systems and the active participation of all stakeholders (Castro-Arce and Vanclay, 2020). In such a setting, the co-production of scientific and indigenous knowledge has proven useful in developing adaptive pathways (Hill et al., 2020). While, community participation strengthens social agency grounded in cultural use and territorial occupation, enabling communities to have a greater presence in decision-making processes (Nina et al., 2019).

The present research was conducted in the municipality of Filomeno Mata, Veracruz, which represents a clear example of the challenges and opportunities faced by indigenous regions in Mexico. Despite a strong cultural identity and deep knowledge of sustainable resource management, this community faces critical issues such as food insecurity, low-income levels, ineffective government transfers, and vulnerable extended family structures (García-Vázquez et al., 2020).

This work seeks to address a critical gap in the design of development strategies for indigenous territories: the absence of context-sensitive evaluation tools that effectively integrate community knowledge with statistically robust frameworks. While existing regional planning models often emphasize top-down interventions or externally defined indicators, they rarely incorporate endogenous cultural logic, food systems and local resource management practices.

For that reason, the main objective was to develop a methodology aimed at promoting regional development in indigenous communities. This approach is grounded in the development of two key indices: the Strategy Suitability Index for Regional Development (IIDR-GM) and the Strategy Adoption Index (IADR). The acronyms IIDR-GM and IADR correspond to their names in Spanish and will be used throughout the document. In the case of IIDR-GM, the suffix "GM" refers to the initials of the index creators.

The proposed indices seek to address this methodological gap by providing a hybrid methodology that assesses both the statistical suitability and the cultural adoption of strategies. This effort contributes to the development of more robust, adaptable, and inclusive frameworks for regional development planning with indigenous contexts.

2 Materials and methods

2.1 Study area and socioeconomic context

The proposed methodology was validated in the municipality of Filomeno Mata, located in the state of Veracruz, Mexico. This region is distinguished by its strong Indigenous identity and the presence of Totonac culture. The Indigenous population of the municipality comprises 16,384 individuals, of whom 7,895 are men and 8,489 are women (SEFIPLAN (Secretaria de Finanzas y Planeación), 2023).

The predominant language spoken in the municipality is Totonac. According to SEFIPLAN (Secretaria de Finanzas y Planeación) (2023), 92.03% of the population over the age of three speaks this language. Furthermore, 15.11% of the population does not speak Spanish and communicates exclusively in Totonac (SEFIPLAN (Secretaria de Finanzas y Planeación), 2023). Beyond its strong linguistic identity, the region is characterized by a complex interplay between socioeconomic challenges and cultural resilience (García-Vázquez et al., 2020).

The municipality exhibits high levels of marginalization, as evidenced by subpar human development indicators in areas such as education, healthcare and income (SEFIPLAN (Secretaria de Finanzas y Planeación), 2023). The local economy predominantly operates in the rural sector, with rainfed agriculture constituting the primary employment source. This is complemented by small-scale livestock activities and a limited tertiary sector dedicated to local trade (López-Santiago et al., 2022).

Filomeno Mata, a representative community of the mountainous region of the Totonacapan, is renowned for its extensive empirical knowledge related to the utilization and management of natural resources (López, 2019). Neverless, factors such as population growth, unplanned urbanization, and both national and international migration have contributed to a gradual erosion of the intergenerational transmission of traditional knowledge (López, 2019). Despite these limitations, the community has preserved a strong cultural identity rooted in Totonac traditions, including systems of knowledge related to food production, the daily preparation of traditional foods and collective forms of community organization (García-Vázquez et al., 2022).

2.2 Analytical framework and variable selection

To identify the key variables within Totonac households, the database compiled by García (2018) was used. This dataset encompassed the entire population of households in the municipal seat. Sampling was conducted using a finite population approach, resulting in a sample size of 328 households. This sample was proportionally distributed across eight sectors (neighborhoods), reflecting the spatial organization of the municipality (García, 2018). A total of 18 variables were analyzed and grouped into three main factors: economic factor, social factor (food security) and environmental factor (sustainability).

Since the data did not follow a normal distribution, the non-parametric Kruskal–Wallis test was applied, as it is suitable for comparing multiple independent groups (Díaz, 2013). The analysis revealed statistically significant differences among sectors, leading to the selection of the 10 variables with the highest statistical relevance for the study (Table 1).

2.3 Strategy identification and classification

Based on the analysis of García (2018) database, 11 reproduction strategies proposed by Totonac households for community adoption were identified. These strategies were associated with the use of native food resources, representing local practices that reflect traditional and adaptive forms of productive organization, food access, and exchange systems.

Considering their functional similarity and with the aim of structuring these strategies for subsequent analysis, they were grouped into four thematic categories: (1) government and organizational support, (2) local economic development, (3) education and community participation, and (4) alternative exchanges and economies. Table 2 presents the corresponding classification. A detailed description of each strategic group, including its objectives, initiatives, benefits and cultural grounding, is presented in Table 3.

Following the application of the Kruskal–Wallis analysis, a set of variables showing statistically significant differences across municipal sectors was identified. This allowed the selection of the most relevant factors in the reproduction dynamics of Totonac households. These variables were subsequently linked to the reproduction strategy groups proposed by the families themselves through a relative weighting methodology, supported by a percentage-based scale constructed using two complementary statistical approaches: mean comparison and the binomial test.

In accordance with the methodological guidelines proposed by Montgomery (2017), a rank-based mean comparison test was employed to detect statistically significant differences in the average values of each variable across the four strategy groups (Groups 1–4). This test enabled the estimation of the relative weight of each variable in the differentiation between strategies, providing empirical support for the assignment process.

To validate the reliability of the assigned weights, a binomial test was conducted, as described by Ramírez and Polak (2020). This test compared the observed frequencies of each characteristic's presence against a theoretical reference proportion (0.50), evaluating whether the empirical distribution deviated significantly from what would be expected under the null hypothesis. This complementary approach reinforced the statistical validity of the weighting system by confirming the consistency of the observed associations.

In parallel, a comprehensive documentary and contextual analysis was conducted to establish qualitative decision rules pertaining to the behavior of each variable within the strategic groups. These rules were grounded in empirical evidence and field observations, resulting in strategic allocation assumptions based on prevailing social, economic, and food-related patterns.

For instance, it was observed that household income levels directly influence the suitability of specific strategies. Families with higher income levels tended to benefit more from government and institutional support (Strategy Group 1); whereas, in low-income contexts, such support mechanisms are often insufficient or ineffective, rendering strategies focused on local economic development (Strategy Group 2) more appropriate. Similar interpretive associations were identified for the remaining variables, enabling their qualitative linkage to other strategic groups.

Based on the integration of both quantitative and qualitative approaches, a four-level weighting system was constructed. This system was defined by the statistical position of each variable within the strategy groups. Variables associated with the highest mean values were assigned a weight of 100%, indicating their strong discriminative capacity. Variables exhibiting intermediate-high or intermediate-low values, located between the highest and lowest means, received weights of 75% or 50%, respectively, based on their relative proximity

TABLE 1 Kruskal–Wallis test statistics using "Sectors" as the grouping variable.

Factors	Variables	H[11]	*p*[12]	df[13]
Economic factor	X^1 = Household income	42.044	<0.0001	7
	X^2 = Head of household's occupation	15.537	0.0297	
	X^3 = Household composition	18.475	0.001	
	X^4 = Government transfers	25.142	0.0007	
Social factor (Food security)	X^5 = Food security level	46.056	<0.0001	7
	X^6 = Dietary diversity in the household	48.160	<0.0001	
	X^7 = Origin of consumed food	38.382	<0.0001	
Environmental factor (Sustainability)	X^8 = Importance of native resources in the community	46.851	<0.0001	7
	X^9 = Sustainable practices in the local food economy	15.191	0.0336	
	X^{10} = Food self-sufficiency scenarios	19.205	0.0076	

[11]H: test statistic for the Kruskal–Wallis test.
[12]*p*: probability measuring the evidence against the null hypothesis.
[13]df: Degrees of freedom.

TABLE 2 Categorization of strategies.

Category	Strategy	Description
1) Government and organizational support	Strategy 1	Government support programs
	Strategy 2	Preferential consumption of local products
	Strategy 3	Awareness of economic benefits for household units
2) Local economic development	Strategy 4	Creation of a market for regional products
	Strategy 5	Harvesting of wild fruits and products
	Strategy 6	Household gardens
	Strategy 7	Accessibility and increased availability of local products
3) Education and community participation	Strategy 8	Learning to prepare new dishes using local food resources
	Strategy 9	Nutrition workshops
4) Alternative exchanges and economies	Strategy 10	Use of kinship networks for purchasing products
	Strategy 11	Bartering

TABLE 3 Description and cultural grounding of strategy groups.

Category	Objective	Key initiatives	Benefits	Cultural and contextual foundations
Government and organizational support	Promote sustainable regional development through local product consumption and support programs.	Economic development programs, infrastructure projects, training initiatives, conservation and inclusion programs.	Empowerment, improved food and economic security, institutional trust, coordinated implementation.	Community members increasingly value transparent and inclusive processes; trust is built through participation and technical accompaniment.
Local economic development	Foster economic self-sufficiency through market creation, wild product commercialization, and diversified agriculture.	Regional product markets, green fairs, food calendars, integrated agriculture models, active committees.	Income generation, environmental sustainability, food security, organizational strengthening.	Local knowledge of seasonality and food systems guides production and exchange; strong emphasis on family-based agriculture and mutual support.
Education and community participation	Encourage healthy eating through workshops on traditional and novel dishes with local ingredients.	Nutritional education, recipe development, practical learning materials, food handling models.	Improved health, local knowledge transmission, social cohesion, food sovereignty.	Food preparation is a key vehicle for cultural transmission; education fosters interaction, empowerment, and daily-life application.
Alternative exchanges and economies	Promote solidarity and community self-sufficiency through product exchanges and non-monetary trade.	Barter networks, use of kinship ties, diversified patios for trade and consumption.	Reduced dependency on cash, expanded access to goods, economic stimulation, strengthened relationships.	Reciprocity, trust, and social networks are central to community economic life; informal systems are culturally resilient and adaptive.

to either extreme. Finally, variables linked to the lowest means were assigned a weight of 25%, indicating limited influence on the assignment process (Table 4).

2.4 Proposal of the IIDR-GM

The IIDR-GM was developed to evaluate the pertinence of adopting the reproduction strategy groups proposed by the families in the studied community. This index allowed the estimation of the degree of agreement between the strategies selected by the households and those considered optimal based on the previously identified significant variables.

The development of the IIDR-GM followed four key methodological stages:

Stage 1: Assignment of relative importance using the percentage scale. Based on the previously described statistical analyses (Kruskal–Wallis, mean comparison and binomial test), a percentage scale ranging from 25 to 100% was constructed to assign a relative weight to each significant variable.

Stage 2: Determination of the optimal strategy by sector. To identify the most appropriate strategy group for each sector of the community, the following procedure was carried out: (a) The strategies selected by each family were evaluated based on their performance in the relevant variables; (b) Each family was assigned to the strategy group with the highest cumulative score (calculated from the relative weights of the variables); (c) At the sectoral level, the mode of the strategy groups assigned to families within each sector was computed, thereby identifying the group considered most appropriate by the model for that sector.

Stage 3: Goodness-of-fit test. To assess the agreement between the strategies selected by families and those considered optimal by the model, a chi-square-based goodness-of-fit test was applied.

TABLE 4 Relative weights (%) of variables by reproduction strategy group.

Variables	X^1	X^2	X^3	X^4	X^5	X^6	X^7	X^8	X^9	X^{10}
Strategy group 1	25	75	50	25	100	100	100	100	25	25
Strategy group 2	100	25	25	100	25	25	50	50	75	100
Strategy group 3	75	100	75	75	75	50	75	75	50	50
Strategy group 4	50	50	100	50	50	75	25	25	100	75

Flores and Flores (2023) define this test using the following equation:

$$X^2 = \sum_k \frac{(O_k - E_k)^2}{E_k}$$

Where:

- O_k = observed values (number of families that selected a specific strategy group).
- E_k = expected values (number of families assigned to that group by the model).
- k = total number of data categories (strategy groups).

The tested hypotheses were: Null hypothesis (H_0): *No.same = No.different*. There are no significant differences between observed and expected frequencies. Alternative hypothesis (H_1): *No.same ≠ No.different*. There are significant differences between the selected strategies and those assigned by the model.

Stage 4: Index normalization. To facilitate interpretation and comparison of the IIDR-GM across sectors, the results were transformed to a standardized scale from 0 to 1:

$$IIDR-GM = \frac{Number\ of\ matches\left(observed = expected\right)}{Total\ number\ of\ observations\ per\ sector}$$

A value of 0 indicated no suitability (complete mismatch), while a value of 1 indicated maximum suitability (perfect match). A suitability threshold of 60% (IIDR-GM > 0.60) was established as the minimum criterion to consider the model-suggested strategy group sufficient for planning and developing effective intervention strategies. The analysis revealed significant discrepancies between the strategy groups selected by families and those identified as optimal by the model. This led to the next step in the research process.

2.5 Participatory rural appraisal (PRA) as a central methodological component

PRA is a methodological tool that incorporates the perceptions, knowledge, and experiences of community members into the identification and prioritization of local issues, as well as the formulation of appropriate solutions (Martínez-Jiménez et al., 2023). PRA was not a complementary tool, but a fundamental pillar of the methodology. Its role was to contrast, validate and adapt the outcomes of the statistical model through community input, facilitating a dialogue between quantitative suitability and lived experience.

The PRA process carried out in this study was structured into five key stages:

Stage 1: Identification of household units. The database developed by García (2018) was used to identify the families that participated in the previous study, ensuring continuity by working with the same households.

Stage 2: Informative sectoral workshops. Using participant observation techniques and group dynamics, workshops were organized in each of the community's sectors. During these sessions, clear and accessible information was provided to families regarding the potential benefits of adopting each of the previously identified strategy groups. This exercise facilitated a collective and contextualized understanding.

Stage 3: Semi-structured household interviews. Subsequently, home visits were conducted with families who had participated in the initial survey to deepen the understanding of their perceptions. During these interviews, the benefits of each strategy group were reiterated.

Stage 4: Assessment of adoption level using a Likert scale. A Likert-type form was used to assess families' perceived importance and level of adoption for each strategy group. The scale included the following categories: (1) very important, (2) important, (3) moderately important, and (4) of low importance. These ordinal responses allowed for differentiation between favorable and unfavorable perceptions (Astudillo and Chevez, 2021).

Stage 5: Sign test for paired samples. The resulting information was used to conduct a second evaluation of the IIDR-GM and to construct the second index (IADR), which was validated using a sign test for two paired samples with normal approximation. According to Conover (1999), this test is appropriate to assess whether there was a significant change in the perception and adoption of strategies. The difference for each household was defined as:

$$D_i = X_i - Y_i$$

Where:

X_i and Y_i, represent the observations before and after the treatment, respectively.

The tested hypotheses were: H_0 = The median of the differences is zero (no significant change); H_1 = The median of the differences is not zero (there is a significant change).

To summarize and clearly present the study's methodological approach, Figure 1 illustrates the sequence of steps, from contextualizing the study area to statistical modeling and participatory validation of proposed development strategies.

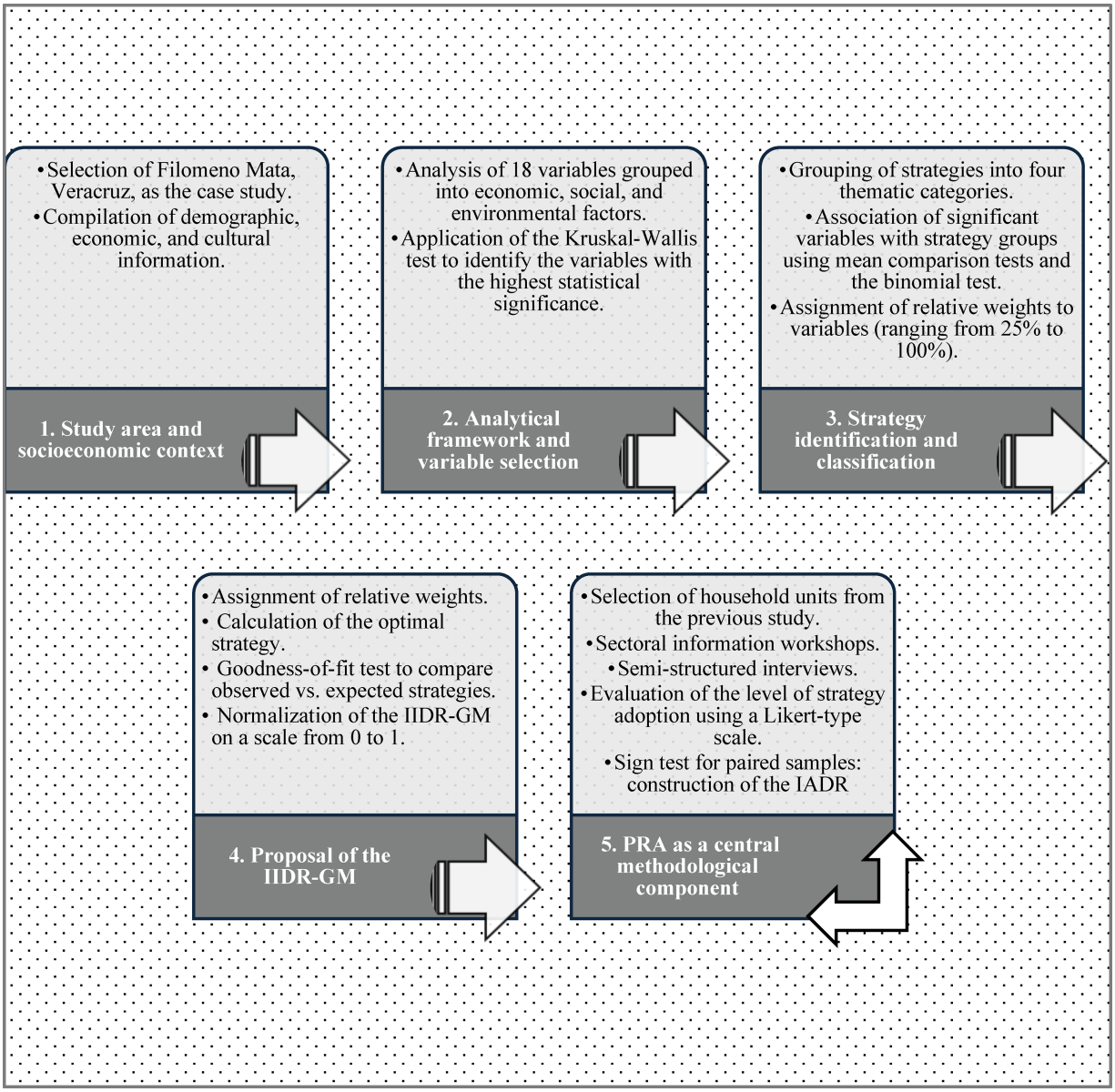

FIGURE 1
Methodological steps followed in the design, validation and evaluation of regional development strategies.

3 Results

3.1 Classification of reproduction strategies for regional development

The initial analysis confirmed that the municipality's primary needs are concentrated in three fundamental areas: food security, economic development, and sustainability. These dimensions were identified as critical pillars for promoting regional development. Using the percentage-based scale, a distribution of strategies was generated according to the significant variables (Table 5).

In contrast, the strategies selected by the families (Table 6) reflected particular interests and criteria, which in many cases differed from the strategies assigned by the model. Overall, the comparative analysis between the assigned and selected strategy groups revealed significant differences.

3.2 Suitability analysis of selected vs. assigned strategy groups

The results of the goodness-of-fit test are presented in Table 7. The comparison between observed and expected values revealed discrepancies, showing that the strategies selected by the families did not match those assigned by the model. As a result, the null hypothesis (H_0) was rejected, indicating that the number of matches was significantly different from the expected values. In other words, there was a significant difference between the strategies selected by the families and those assigned.

TABLE 5 Strategies assigned according to significant variables.

Sector	Group 1	Group 2	Group 3	Group 4	Assigned strategy group (Mode)
1	10	8	0	23	4
2	7	10	1	23	4
3	10	15	3	13	2
4	6	7	2	26	4
5	12	9	4	16	4
6	12	14	8	7	2
7	16	11	5	9	1
8	10	6	3	22	4

TABLE 6 Strategy groups selected by Totonac families.

Sector	Group 1	Group 2	Group 3	Group 4	Strategy group (Mode)
1	16	11	8	6	1
2	5	21	7	8	2
3	10	13	18	0	3
4	20	9	4	8	1
5	14	8	15	4	3
6	9	16	13	3	2
7	8	10	17	6	3
8	4	21	7	9	2

TABLE 7 Goodness-of-fit test for strategy groups.

Sector	Observed matches	Expected values[1]	Chi-square[2]
1	10	41	23.439
2	7	41	28.195
3	7	41	28.195
4	11	41	21.951
5	6	41	29.878
6	10	41	23.439
7	7	41	28.195
8	5	41	31.609
Total	63	328	214.902

[1]Total observations: 328; n = expected mean per sector = 41.
[2]Observed chi-square = 214.902; critical chi-square = 14.067; significance level = 0.05.

To deepen the analysis, the IIDR-GM was calculated to measure the degree of correspondence between selected and assigned strategies for each sector (Figure 2).

Suitability values ranged from 0.12 to 0.27, indicating a low level of correspondence between selected and assigned strategy groups. The total suitability value was 0.19, suggesting that only 19% of the strategies chosen by families were considered the most suitable according to the model. Conversely, discrepancies between selected and assigned strategies ranged from 0.73 to 0.88, with a total municipal value of 0.81, implying that 81% of the strategies chosen by families did not align with the model's recommendations.

While the IIDR-GM provides a structured estimation of statistically appropriate strategies derived from variable associations, it is important to recognize that these results do not inherently define culturally optimal solutions for the community. The observed discrepancies between the IIDR-GM output and the actual households choices suggest that optimization should be understood as a negotiated process rather than a purely technical outcome. Integrating community perspectives from the outset could reduce these mismatches and establish a more participatory foundation for the selection of effective and contextually appropriate strategies. Consequently, a reassessment of the strategies became necessary in the following step.

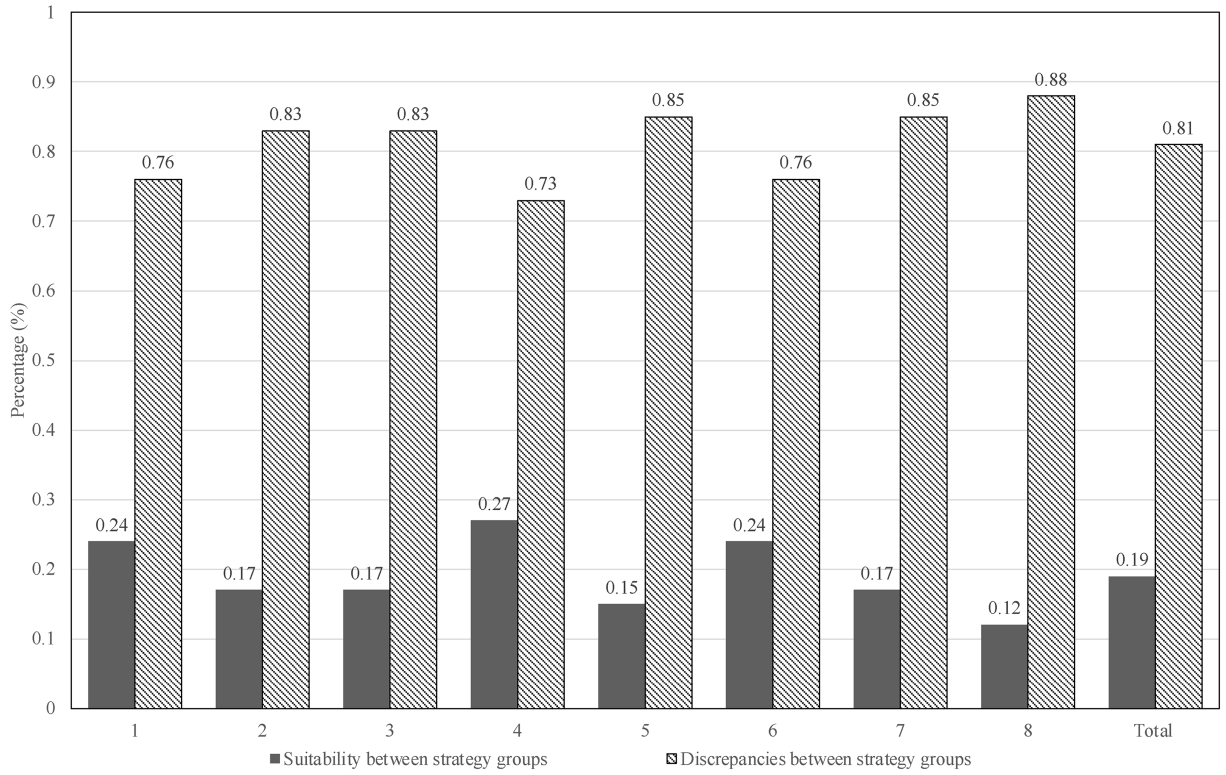

FIGURE 2
IIDR-GM by sector and municipal level.

3.3 Evaluation of strategy acceptance after the PRA

Although direct testimonies were not formally recorded, the qualitative data collected through participant observation and informal conversations revealed key factors underpinning families' preferences. These factors included the continued prevalence of barter practices, short marketing circuits based on trust, proximity, and the availability of diverse local products sourced from both agricultural plots and home gardens. Families demonstrated empirical knowledge of the seasonality, nutritional value, and culinary applications of wild and native foods, which influenced their decision-making process. Local products were also perceived as more affordable and reliable sources of income. Collectively, these factors underscored a distinct cultural logic, thereby highlighting the imperative of integrating local knowledge into the design of sustainable development strategies.

In this context, families reported changes in their levels of acceptance and adoption after being informed about the objectives, key initiatives, benefits, cultural and contextual foundations of each strategy group (Table 3). Once again, a goodness-of-fit test was conducted to compare the strategy groups selected and assigned after the community received this information. The updated IIDR-GM was then calculated (Figure 3).

The results showed that although families still chose suboptimal strategies in some cases, the error rate decreased significantly—from 81% in the previous experiment to 29%. The suitability of selected strategies exceeded 0.60 in all sectors, indicating a notable improvement. Furthermore, when considering both the first and second choices of strategy groups, the null hypothesis (H_0) was accepted, demonstrating that families did not make significant errors in choosing the most appropriate strategies (Figure 4). The results reflected a general improvement in the suitability of choices, with a total value of 0.95.

Subsequently, a sign test for two paired samples with normal approximation was applied (Table 8). This confirmed that, after the community was informed about the strategy groups, participants significantly improved their decisions regarding the adoption of more appropriate strategies.

Based on the resulting data, the IADR index was generated (Figure 5). In each sector and at the municipal level, informing the community about the benefits of the strategies significantly improved their ability to choose the most beneficial strategy group. In this case study, sector 7 was the most prone to suboptimal decisions.

These findings are relevant not only for the studied community but also for potential application in other municipalities. The applied methodology may serve as a model for other regions seeking to implement regional development strategies based on traditional practices and local resources. Nonetheless, methodological refinements remain necessary.

3.4 Methodological framework for regional development

The proposed methodological approach seeks to be innovative, realistic and replicable. It is based on a methodological reconfiguration informed by the strengths and lessons learned during the diagnostic

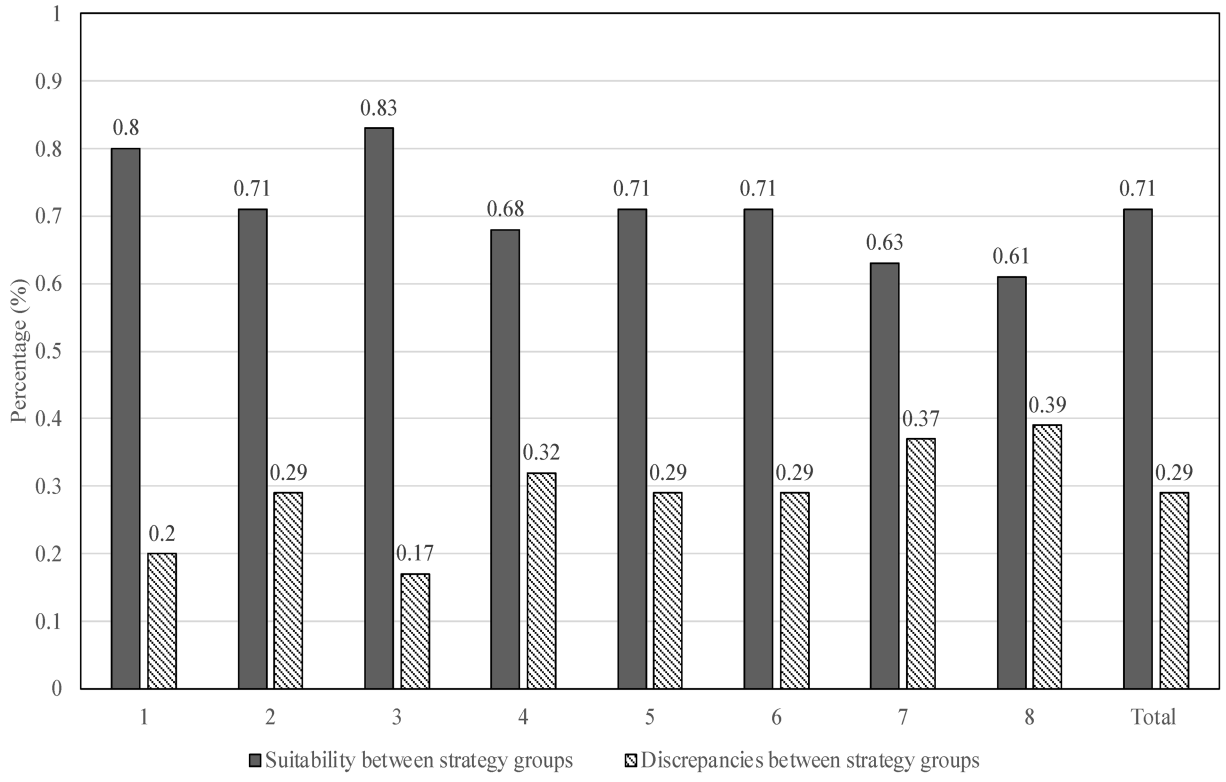

FIGURE 3
IIDR-GM after PRA.

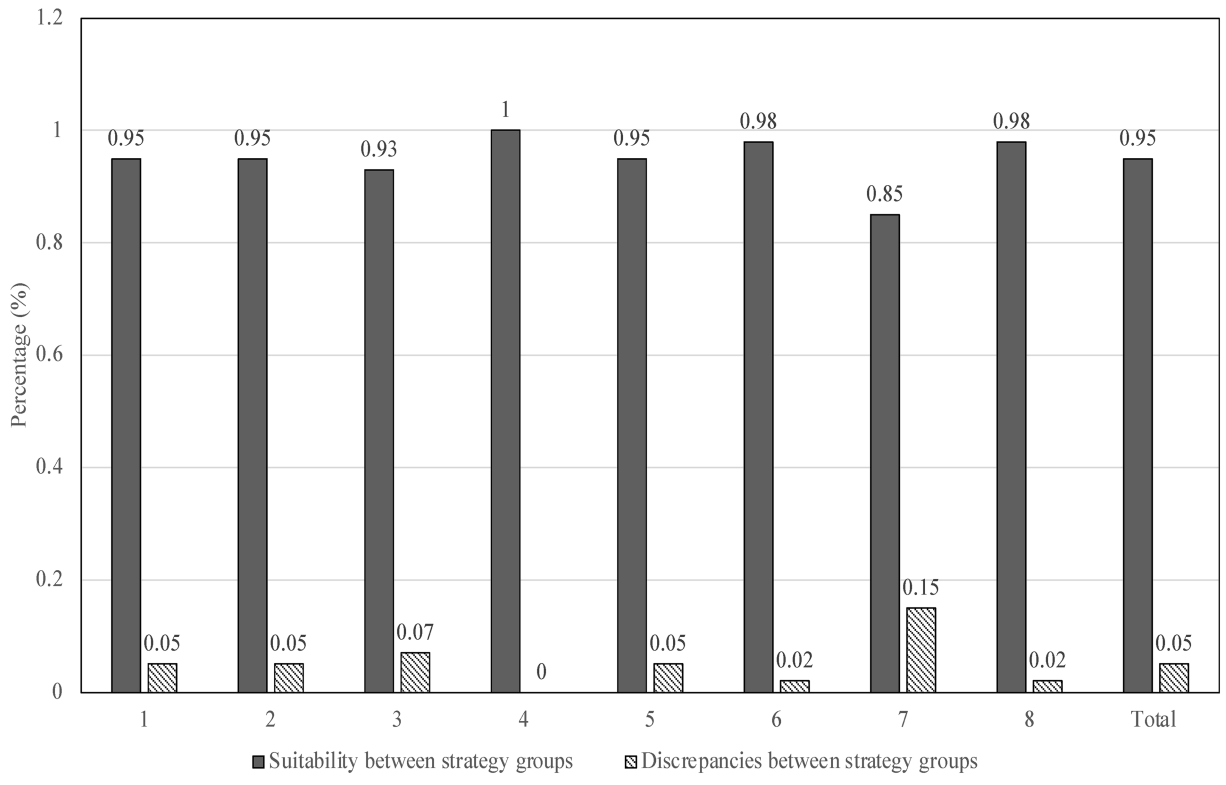

FIGURE 4
IIDR-GM considering the first and second choice of Totonac households.

TABLE 8 Sign test for two paired samples with approximation to normal distribution.

Sector	No.$^{+}$	No.$^{=}$	No.$^{-}$	Sig. α = 0.05
1	23	18	0	*
2	22	18	1	*
3	27	14	0	*
4	17	24	0	*
5	23	16	2	*
6	19	21	1	*
7	19	14	8	*
8	20	21	0	*
Total	170	146	12	*

$^{+}$Number of times families improved their choice of strategy group (better adoption).
$^{=}$Families made the same choice as before.
$^{-}$Families made a less favorable choice.
t-test statistic per sector = 14.225; t-test statistic at the municipal level = 146.251.

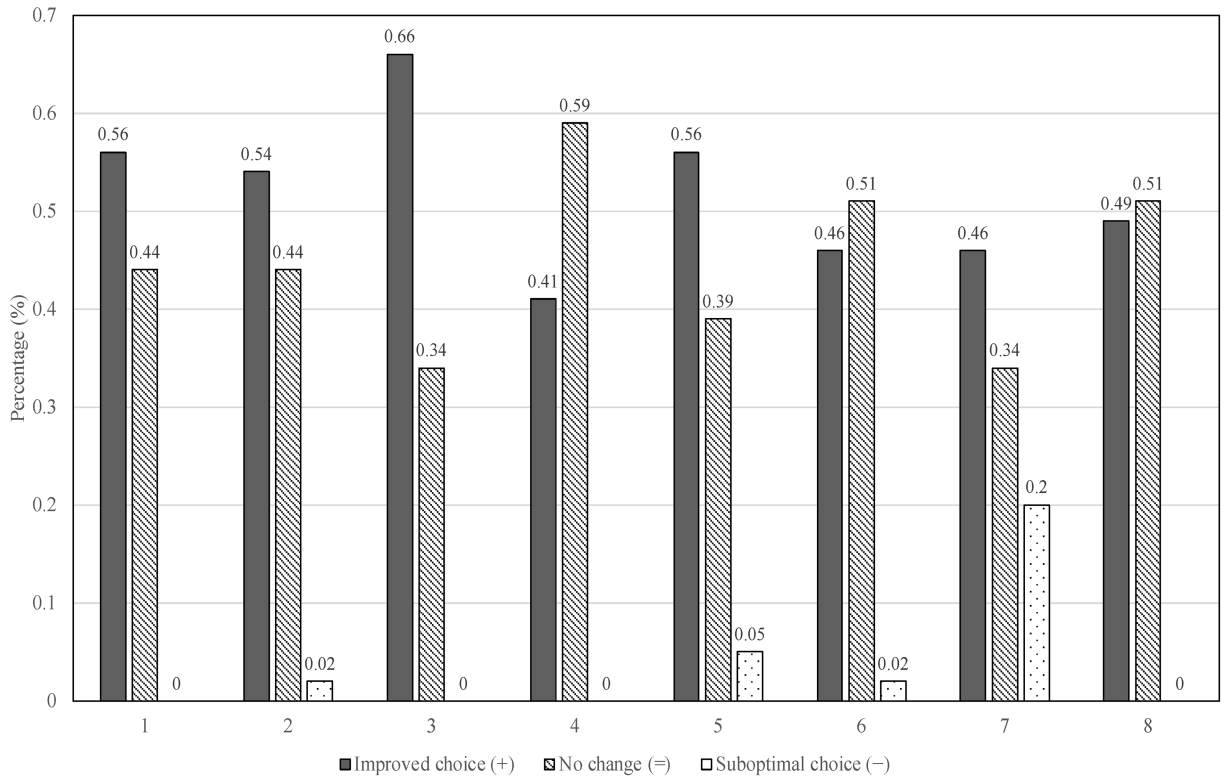

FIGURE 5
IADR in the Totonac community.

process conducted in the Totonac community. The following steps are recommended to guide regional development in microregions:

Step 1: Selection of the territorial study area. Microregions should be selected based on the Municipal Development Index (MDI), which evaluates four key dimensions: economic, social, environmental, and institutional. Microregions with low scores should be prioritized for intervention.

Step 2: Initial diagnosis. A thorough documentary review is required, complemented by interviews with key regional stakeholders. Based on this analysis, a SWOT (Strengths, Weaknesses, Opportunities, and Threats) diagnosis should be developed.

Step 3: Identification of natural resources. A detailed assessment of the available natural resources in the microregion is essential. This process can be carried out using the Cultural Significance Index (CSI) and the classification of Ecosystem Services (ES), which together provide a comprehensive view of natural resources and their sustainability in the local context.

Step 4: Strategy planning and formulation. The community should be actively involved in designing the strategies through participatory diagnostic workshops. The strategies will be structured around four thematic areas: (1) government and organizational support, (2) local economic development, (3)

education and community participation, and (4) alternative exchanges and economies.

Step 5: Semi-structured interviews. Household-level interviews should be implemented to obtain quantitative variables related to the economic, social (food security), and environmental factors. To facilitate the identification of significant variables across municipalities (sectors were used in this study as an example) and to enable more robust statistical analysis through rank mean comparisons and binomial tests, it is recommended to use only dichotomous variables. This approach helps reduce bias in the assignment of relative weights to strategy groups, improving the accuracy and consistency of the analysis.

Step 6: Strategy evaluation. To assess the suitability of the proposed strategies, the IIDR-GM index will be used. Strategies will be considered effective if their results exceed a threshold of 0.60. If not, additional visits and complementary evaluations will be conducted to adjust the strategies, followed by a second evaluation using the IIDR-GM and the IADR.

Step 7: Implementation. Educational and training programs should be developed to guide communities through the steps necessary for adopting the strategy groups. In addition, regular evaluations must be conducted to measure the effectiveness of interventions and make adjustments based on the results obtained. Community participation will be key to ensuring the relevance and sustainability of the implemented strategies.

In the case studied, notable discrepancies were observed between the results from the initial surveys and the follow-up evaluations. To address this issue, participatory workshops should be implemented starting from step 2 (initial diagnosis).

4 Discussion

Indigenous peoples face increasingly precarious conditions that threaten their cultural identity and traditional livelihoods (Palma and Díaz-Puente, 2024). In Mexico, rural communities are immersed in a complex socio-environmental context characterized by environmental degradation, climate change, and chronic poverty (Galicia et al., 2020). Considering this scenario, effective regional development strategies must address an integrated approach that simultaneously addresses economic, social, and environmental dimensions, recognizing their deep interrelation and the inefficacy of isolated interventions (Hariram et al., 2023; Lu, 2024).

This study proposed a multidimensional and participatory framework for development planning in indigenous territories. This framework aims to transcend conventional technical prescriptions, advocating for culturally rooted strategies. It integrates economic, food security, and environmental, dimensions, which are recognized as fundamental pillars of human wellbeing (Wang et al., 2018), thereby responding to the urgent need to reconcile sustainability with cultural identity.

A key finding was the observed discrepancy between statistically optimal strategies (IIDR-GM) and the actual choices made by households. This divergence highlights a critical insight: optimality must not be understood solely as a technical outcome but rather as a negotiated process that reflects local values, expectations, and lived experiences. Sometimes, the strategies proposed by the model did not align with community realities or culturally significant decision-making processes. Consequently, an integrated perspective became essential for a more accurate interpretation of territorial dynamics (Borowski and Patuk, 2021).

Although certain strategies identified through the analysis of significant variables appeared potentially effective, they were not initially attractive to specific households. This phenomenon may be attributed to factors such as prior inefficiencies or the presence of institutional barriers. Therefore, it is essential to ensure robust community participation throughout all stages of strategy formulation and adoption. According to Lucky (2016) and Chawan and Mohammad (2022), community participation directly influences development by creating new opportunities to improve life quality and strengthen local socioeconomic activities.

This tension underscored the role of PRA as a central methodological element rather than a supplementary tool. It functioned as a dynamic space for collective learning and validation, where households collectively reflected on the appropriateness of strategies and refined their preferences through dialogue and mutual support. The subsequent increase in adoption scores following PRA implementation suggests that participation and reflection fostered a deeper understanding and internalization of strategic options. PRA proved to be a key tool in moving beyond unidirectional or purely technical approaches (Bermejo et al., 2004), which is consistent with studies highlighting the importance of community participation in the success of sustainable development initiatives and projects (Ćurčić et al., 2021; del Arco et al., 2021; Laurent and Ernest, 2021).

In addition, the contextual analysis revealed that food security extends beyond mere agricultural productivity, encompassing community resilience, environmental management, and culturally rooted food practices (McDaniel et al., 2021; Yusriadi and Cahaya, 2022). Therefore, it is essential to integrate food security as a cross-cutting axis in development strategies, considering its environmental, social, and economic implications within regional policies, plans, and programs (Rohr et al., 2021). In this regard, the implementation of rational and diverse strategies focused on the use of natural resources emerged as a key pathway to enhance sustainability and food security in vulnerable communities (García-Vázquez et al., 2020).

Recent studies have confirmed that up to 63% of adaptation strategies implemented by rural communities are linked on natural resources reliance. These strategies encompass changes in crop composition, adoption of conservation techniques, and strengthening of community social networks (Schlingmann et al., 2021). These new functional and normative forms represent a recomposition process that allows peasant communities to cope with external pressures and sustain social reproduction, despite facing significant challenges (Galicia et al., 2020).

In these contexts, the need to integrate local knowledge systems is significantly reinforced, particularly in territories where empirical data is limited and vertical planning approaches tend to overlook sociocultural dimensions (Palma and Díaz-Puente, 2024). Consequently, the extensive knowledge possessed by indigenous cultures regarding flora utilization acquires strategic value, not solely for its economic utility but also for its potential to bolster sustainable resource management (López et al., 2019; Brondízio et al., 2021).

This research also highlights broader implications: the proposed indices (IIDR-GM and IADR) should be conceptualized as adaptive frameworks rather than rigid or prescriptive tools. Their structure allows the incorporation of new variables, adjusted weights, and participatory mechanisms tailored to specific socio-territorial contexts. Consequently, their application to other indigenous or rural communities is feasible, contingent upon ensuring robust processes of community engagement, empirical validation, and cultural

contextualization. In this regard, numerous studies have emphasized the importance of generating strategies through self-managed processes supported by participatory research tools (Eaton-González et al., 2021; Rubio et al., 2021; Polanco-Rodríguez et al., 2024).

Ultimately, the long-term success of these strategies will depend on the community's capacity to maintain and institutionalize the implemented changes. In this process, community education and knowledge co-production play a fundamental role. Educational initiatives that empower local actors to reflect, decide, and act collectively are essential to drive sustainable transformations (Ćurčić et al., 2021; del Arco et al., 2021). The active involvement of communities in diagnosing, designing, and monitoring their own development strategies not only promotes local ownership but also enhances the adaptability and relevance of such strategies across diverse contexts.

5 Study limitations

While the proposed methodology is innovative, certain limitations must be acknowledged. The construction of the percentage scale and the assignment of relative weights may introduce bias if the available information is not accurate. The heterogeneity of the selected microregions may complicate comparisons between municipalities due to their socio-economic differences. Therefore, the use of dichotomous scales for significant variables is recommended. This research serves as a starting point that requires further adjustments and refinements through future studies that deepen this type of analysis.

6 Conclusion

The IIDR-GM and IADR provided a comprehensive understanding of the suitability and adoption readiness of regional development strategies in the studied community. The results made it possible to identify effective strategy groups, facilitating the implementation of local development policies aligned with the households needs and capacities.

Emphasizing community participation throughout the process, strengthens both the validity and sustainability of the interventions, while also promotes the empowerment of communities by actively involving them in the diagnosis, planning, and implementation of strategies.

The strategies developed are culturally adapted, respecting and valuing the cultural patterns, natural resources, and organizational structures specific to indigenous peoples. The use of statistical tools and empirical tests to validate the strategies adds scientific rigor to the process, improving the reliability and replicability of the results in future studies. The methodological process is scalable and adaptable to different contexts and regions, allowing for application in a variety of scenarios, provided that the steps outlined in the methodological framework are followed.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical approval was not required for the studies involving humans because the Universidad Autónoma Chapingo does not yet have an ethics committee. However, respondents gave their signed approval after the information was read to them. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

RG-V: Conceptualization, Data curation, Resources, Validation, Writing – review & editing, Methodology, Writing – original draft. ML-S: Writing – review & editing, Formal analysis, Supervision, Writing – original draft, Conceptualization, Resources. CM-B: Validation, Writing – review & editing, Data curation, Resources. BS-T: Writing – review & editing, Formal analysis, Validation, Resources. SM-C: Writing – review & editing, Resources. AL-S: Writing – review & editing, Resources.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Gen AI was used in the creation of this manuscript.

Publisher's note

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