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Article

A Simplified Integrative Approach to Assessing Productive Sustainability and Livelihoods in the "Amazonian Chakra" in Ecuador

Bolier Torres [1,2], Marcelo Luna [3], Cristhian Tipán-Torres [2,4], Patricia Ramírez [5], Julio C. Muñoz [3] and Antón García [6,*]

[1] Facultad de Ciencias de la Vida, Universidad Estatal Amazónica (UEA), Pastaza 160101, Ecuador
[2] Ochroma Consulting & Services, Tena 150150, Ecuador
[3] Facultad de Ciencias de la Tierra, Universidad Estatal Amazónica (UEA), Pastaza 160101, Ecuador
[4] Instituto Superior Tecnológico Ciudad de Valencia, Puebloviejo 120201, Ecuador
[5] Facultad de Ciencias Jurídicas, Sociales y de la Educación, Universidad Técnica de Babahoyo, Extensión Quevedo (UTB), Km 3 1/2 Vía a Valencia, Los Ríos 120550, Ecuador
[6] Animal Science Department, University of Cordoba, Rabanales University Campus, 14071 Cordoba, Spain
* Correspondence: pa1gamaa@uco.es

Abstract: This study combines two methodologies—key indicators from the Sustainable Livelihoods Framework (SLF) and the Sustainability Assessment of Food and Agriculture Systems (SAFA) approach—to evaluate sustainability among 330 producers from three associations working within the recently recognized *Amazonian Chakra* system, designated as a Globally Important Agricultural Heritage System (GIAHS). The SAFA framework's four dimensions—Good Governance, Environmental Integrity, Economic Resilience, and Social Well-being—were used to assess sustainability, while the SLF considered key capitals such as financial, natural, and human capitals as critical for understanding livelihood outcomes. The discriminant analysis revealed significant differences across the associations, with Kallari and Wiñak performing better in financial management, environmental practices, and governance compared to Tsatsayaku, which exhibited weaker outcomes in these domains. Key indicators such as chakra income, price determination, and civic responsibility were the most effective in distinguishing the groups. The income analysis further highlights that Tsatsayaku reported the highest total income but relies heavily on non-Chakra sources, while Kallari and Wiñak showed stronger reliance on Chakra income, which aligns with their more sustainable agricultural practices. *Per-capita* income was higher for Tsatsayaku, but extreme poverty levels remained similar across all associations, underscoring the need for targeted financial interventions. Policy recommendations include promoting access to financial resources and strengthening participatory governance models to enhance sustainability outcomes across associations. For future research, combining the SAFA and SLF provides a comprehensive and robust methodology for assessing sustainability in agricultural systems, enabling a deeper understanding of the interactions between social, economic, and environmental factors in diverse contexts.

Keywords: SAFA; livelihoods; discriminant analysis; income; Amazonian Chakra

1. Introduction

The sustainability of small-scale agriculture plays a crucial role in long-term food production, and its success depends not only on the availability of natural resources but also on how these resources are managed by the farmers and communities involved [1,2]. To enhance our understanding of this complex dynamic, the integration of the Sustainable Livelihoods Framework (SLF) is essential [3–5]. This framework emphasizes the role of multiple livelihood capitals—human, social, natural, physical, and financial—that influence agricultural practices and outcomes. By incorporating this holistic perspective, we can better grasp the socio-economic, organizational, and external factors that shape decision-making processes and impact sustainability in small-scale farming systems [6,7].

The concern for sustainability in agriculture emerged in response to environmental issues that began gaining attention in the 1950s and 1960s [8,9]. However, concepts and practices related to sustainability can be traced back to ancient texts from China, India, Greece, and Rome [10,11]. Today, sustainability is a central concept, particularly when evaluating agroforestry systems, which combine trees and crops in the same space. These systems offer numerous benefits, including biodiversity conservation, climate change mitigation, and soil quality improvement [12–15], as well as contributing to the diversification of rural incomes [16,17].

A comprehensive evaluation framework is essential for managing sustainability across agricultural, forestry, and livestock systems, whether collectively or individually. This framework should be cyclical, adaptable, and participatory, fostering interdisciplinary collaboration and feedback to identify intersections between environmental, social, and economic processes crucial to sustainability [18,19]. Sustainability assessments play a key role, using models to project the impacts of planned changes [20]. However, a one-size-fits-all approach is impractical, as evaluations must be tailored to specific contexts [21]. Nonetheless, these assessments provide a vital foundation for discussions, reflections, and adaptive decision-making, supporting more informed and resilient sustainability strategies [22].

The SAFA tool, developed by FAO, is used to assess sustainability in food and agricultural systems through four dimensions: Good Governance, Environmental Integrity, Economic Resilience, and Social Well-being. These dimensions encompass 21 themes, 58 sub-themes, and a total of 116 indicators, scored on a scale of 1 to 5 [23]. Additionally, SAFA aligns with the Bellagio sustainability assessment principles (STAMP), established in 1996 [24], and has been applied across various countries and contexts [25]. However, based on findings from previous research [25,26], we have observed that not all SAFA indicators are well-suited to the context of Amazonian producers. While SAFA is a robust tool, it is necessary to carefully adapt and select variables that better reflect the socio-economic and ecological specificities of EAR. In addition, incorporating SLF [3,5,27] into this process allows for a deeper understanding of how different capitals interact with sustainability goals. This integration creates a more nuanced and context-specific approach to sustainability, which is crucial for smallholder systems such as the Amazonian Chakra.

In this context, the present study aims to propose a simplified integrative approach to assessing productive sustainability and livelihoods in the "Amazonian Chakra" in Ecuador, for which the following partial objectives were developed: a) select and apply the key indicators from the SAFA methodology that are applicable to the Amazonian Chakra system to evaluate its productive sustainability, as well as the main variables representing the capitals of sustainable livelihoods (human, social, natural, physical, and financial) and income; b) assess sustainability through the application of these indicators to producers from three associations in the Ecuadorian Amazon, who predominantly utilize the Globally Important Agricultural Heritage System (GIAHS) known as the Amazonian Chakra; and c) identify those indicators with the greatest discriminating power among the three producer associations in the Amazon.

The article was structured as follows: After this introduction, where Theoretical framework of the Amazonian Chakra, based on the Sustainable Livelihoods Framework (SLF), the Sustainability Assessment of Food and Agriculture Systems (SAFA), and the context of the Amazonian Chakra were reviewed. In Materials and Methods, the design of research was proposed, in addition, the sources of information, the sample, and the statistical analysis were described. In the Results and Discussion, the descriptive date and the fit of the discriminant model were shown. Finally, the conclusions were presented.

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2. Theoretical Framework and Context of the Amazonian Chakra

2.1. Sustainable Livelihoods Framework

This study employs the Sustainable Livelihoods Framework (SLF), promoted by the Department for International Development (DFID), a United Kingdom government department, in the late 1990s [3], which highlights the role of various forms of capital in rural development and well-being [3,5]. The SLF provides a comprehensive approach to understanding rural dynamics, addressing basic needs, human rights, and a more qualitative view of poverty [28–30] and insecurity [5]. It suggests that livelihoods are shaped by five key assets: human, social, natural, physical, and financial capital. These assets interact with vulnerability factors, such as crises, trends, and seasonality, as well as with institutional and cultural structures that influence livelihoods [31,32].

Additionally, the framework considers the livelihood strategies that individuals or households adopt, which are influenced by the combination of assets available to them and the broader institutional context [3]. These strategies aim to achieve livelihood outcomes, including improved well-being, reduced vulnerability, and sustainable use of natural resources [27,33,34]. This dynamic interaction highlights how individuals constantly adapt to changing conditions by reconfiguring their asset base and strategies.

Similarly, Masud et al. [35] argue that livelihoods extend beyond employment to include social relationships, property rights, and access to essential public services such as water, education, and healthcare. This aligns with Ellis [33], who emphasizes that livelihoods result from the combination of available assets, mediated by institutions and social relations, that enable individuals or households to sustain themselves. In resource dependent communities, access to these capitals plays a crucial role in determining resilience and the capacity to adapt to environmental and socio-economic changes [36].

The SLF also recognizes the feedback loops between different forms of capital; for instance, an increase in natural capital (such as improved access to land or water) can enhance financial capital, while a decline in one type of capital (such as social or natural capital) can erode the sustainability of livelihood outcomes [3]. The SLF is dynamic [37] and adaptable [38] , allowing it to be combined with other approaches, such as those used to measure productive sustainability. By integrating elements like good governance and the pillars of sustainability (economic, social, and environmental). This adaptability helps design more effective and locally adapted policies and sustainable strategies, addressing the specific needs of rural communities and promoting long-term resilience.

2.2. Sustainability Assessment of Food and Agriculture Systems (SAFA)

Sustainability Assessment of Food and Agriculture Systems (SAFA), developed by the Food and Agriculture Organization (FAO) in 2013, provides a comprehensive framework to evaluate the sustainability of food and agricultural systems through three key tools. These include detailed guidelines outlining sustainability principles, a set of 116 indicators covering 58 sub-themes, 21 themes, and four sustainability dimensions [23], and software that analyzes and visualizes results [39]. The assessment uses a polygonal representation to classify systems across five sustainability levels, from "unacceptable sustainability" (red) to "optimal sustainability" (dark green). This integrated approach enables a rigorous evaluation of strengths, weaknesses, and opportunities for improving sustainability in food production systems, supporting the development of more resilient and sustainable alternatives.

Sustainability assessments benefit from a combination of methods and models to effectively capture the impacts of past or proposed changes within systems [40]. No single framework can fully address the diverse objectives of sustainability evaluation [41]. In this context, the SAFA methodology complements other approaches by providing a structured evaluation of sustainability that can be shaped into specific study areas. When combined with key qualitative and quantitative indicators, such as those from the SLF approach, SAFA enhances contextualization and offers a more holistic understanding of sustainability. These integrations allow researchers to perform more robust multivariate analyses. To explore and compare cases more effectively, identifying key patterns and insights across different contexts. This comprehensive approach strengthens the ability to generate evidence-based policy recommendations aimed at promoting sustainable development.

2.3. Context of the Amazonian Chakra system

In February 2023, the Amazonian Chakra was recognized by FAO as a Globally Important Agricultural Heritage System (GIAHS), defined as *"a sustainable land-use model where productive spaces within farms are managed by families using organic and biodiverse approaches, valuing ancestral knowledge. The Amazonian Chakra, with its biological and cultural diversity, offers multiple services to populations, ranging from food security, ecosystem services, and the preservation of cultural values, to social cohesion and the maintenance of a megadiverse landscape"* [42]. In the Napo province, several producer associations currently manage the Amazonian Chakra system (Figure 1) within various agricultural markets. This study focuses on three key associations: a) *Kallari Association,* considered large in our study, with 980 producers, 95% of whom are Kichwa Amazonian. The association specializes in the processing and commercialization of products such as cacao (*Theobroma cacao* L.), vanilla (*Vanilla* spp.), guayusa (*Ilex guayusa* Loes.), and chocolate bars. These products are primarily exported to international markets, including the Czech Republic, Germany, France, the UK, and the USA; b) *Wiñak Association*, categorized as medium-sized in our study, with 355 Kichwa Amazonian producers. Wiñak focuses on the commercialization of cacao (*Theobroma cacao* L.), guayusa (*Ilex guayusa* Loes.), banana (*Musa paradisiaca* L.), cassava (*Manihot esculenta* Crantz), chocolate bars, and ground guayusa. Cacao, guayusa, and banana are the most relevant products, and their markets extend locally and internationally, including Italy, Japan, Mexico, and Spain; and c) *Tsatsayaku Association*, classified as small, with 58 mestizo and Kichwa producers. Tsatsayaku primarily markets cacao paste (*Theobroma cacao* L.), chocolate, and chocolate nibs, with the first two products being the most prominent. Their commercialization is focused on the national market [25].

Figure 1. Photos: a) Cedar tree (*Cedrela odorata*), b) cocoa pods, and c) typical landscape of the Amazonian Chakra, Napo province, Ecuador.

3. Materials and Methods

3.1. Study Area

The study area is located in the Napo province (Figure 2), within the Upper Amazon region, an area of great biodiversity significance that forms part of the Sumaco Biosphere Reserve (SBR), recognized by UNESCO in 2000 under the Man and the Biosphere (MAB) Programme. This region has been ancestrally inhabited by Kichwa Amazonian indigenous communities, with human presence dating back approximately 400 years. The territory is considered a biodiversity and endemism hotspot [43,44].

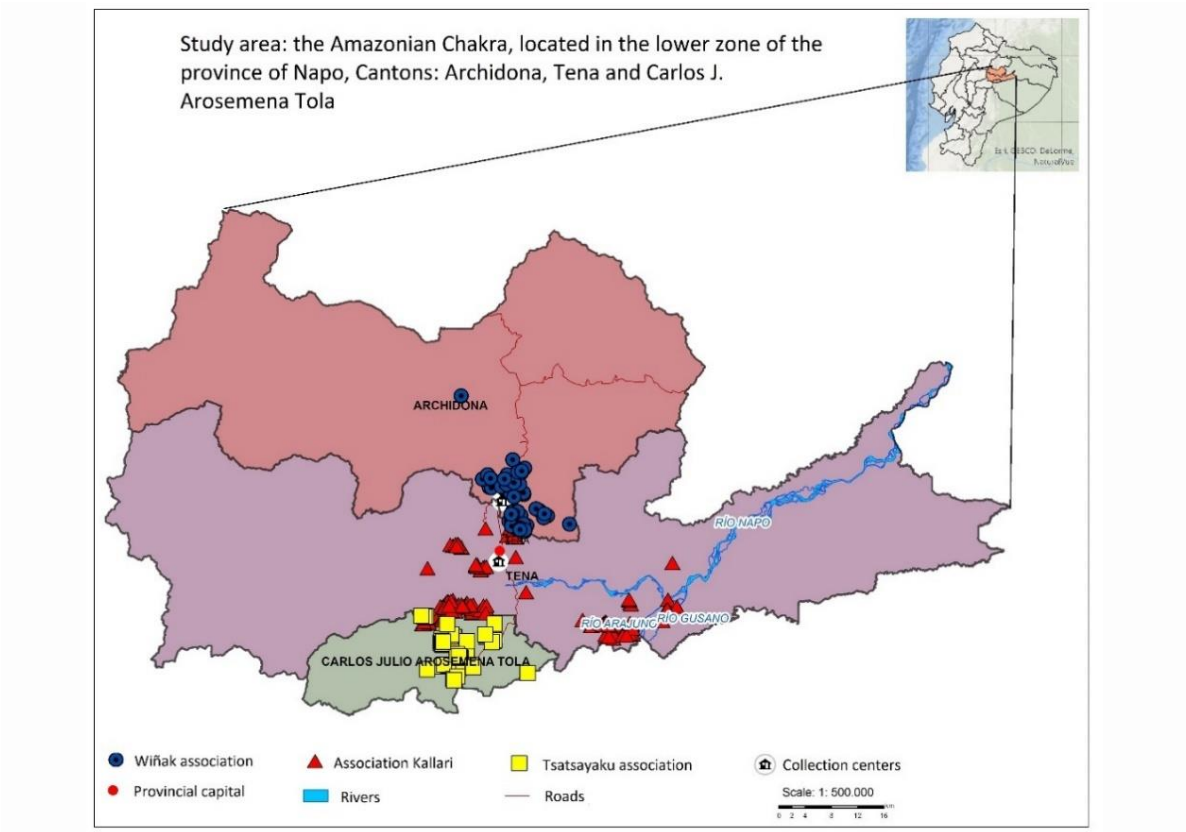

Figure 2. Study area, locations of households producing cocoa in *Amazonian Chakra* system. The blue circle shows the households producers of the Tsatsayaku Association (Arosemena Tola). The red triangles represent households' producers of the Wiñak Association (Archidona) and the yellow squares household's producers of the Kallari Association (Tena), Napo, Ecuador.

3.2. Sampling and Data Collection

The data were collected as part of the FAO-Ecuador project "Climate Intelligent Agriculture in Cacao Produced in Agroforestry Systems," conducted between October and November 2020. Knowing the number of farmers in each of the three associations (small – Tsatsayaku; medium – Wiñak; large – Kallari), probabilistic sampling was employed to determine the sample size. The finite population formula was applied, considering a 95% confidence level and a 5% margin of error. Within each association, random sampling was used to select the rural households to be surveyed, based on a list provided by the president of each association. Initially, a total of 343 households were surveyed: 168 from Kallari, 130 from Wiñak, and 45 from Tsatsayaku [25]. After data cleaning, 13 incomplete records were removed, resulting in a final sample of 330 households distributed as follows: Kallari (156), Wiñak (129), and Tsatsayaku 45 households.

3.3. Determination of Per Capita Income and Poverty Index

Per capita income and the extreme poverty level were calculated following the methodology proposed by [30], who determined the proportion of the population in extreme poverty using the Foster-Greer-Thorbecke (FGT) poverty index [45]. The formula used is *Po* = Np/N, where *Po* represents the proportion of the sample classified as extremely poor, *Np* is the number of households in extreme poverty, and *N* is the total number of households in each producer association. A household is classified as income-poor if it earns, on average, less than USD 2.96 per day, based on Ecuador's national poverty line reported for 2022. A household with a total income below USD 1.67 per day is classified as extremely poor [46].

3.4. Research Design

To achieve the proposed objectives, a two-stage qualitative and quantitative mixed methodology was used (Figure 3). **On the one hand**, the relevant index in the Amazonian Chakra system were selected. This stage was started with 116 indicators of the SAFA methodology, 15 livelihood indicators and 5 income indicators of the chakra *(Supplemtary Material Tables S1 and 2)*. The indicators were evaluated and grouped into dimensions based on the bibliography and by Delphi method with a panel of experts (n=15). Subsequently, indicators were grouped into dimensions to deepen the knowledge of their relationships and the incidence on obtained variability.

Key livelihood variables and sustainability indicators for the Amazonian Chakra system were identified through a workshop involving 15 expert researchers and stakeholders engaged in sustainable development projects. During the workshop, both questionnaires were adapted to the Amazonian Chakra context, and the relevance of each question to the local setting was assessed. As a result, 100 indicators were selected, consisting of 80 from the SAFA questionnaire and 20 from the livelihoods and income survey. The experts evaluated each question using a Likert scale from 1 to 5 [47]. In the first round of evaluation, questions that received the highest score (five) from at least nine experts were retained, while those receiving the lowest score (one) from nine experts were discarded.

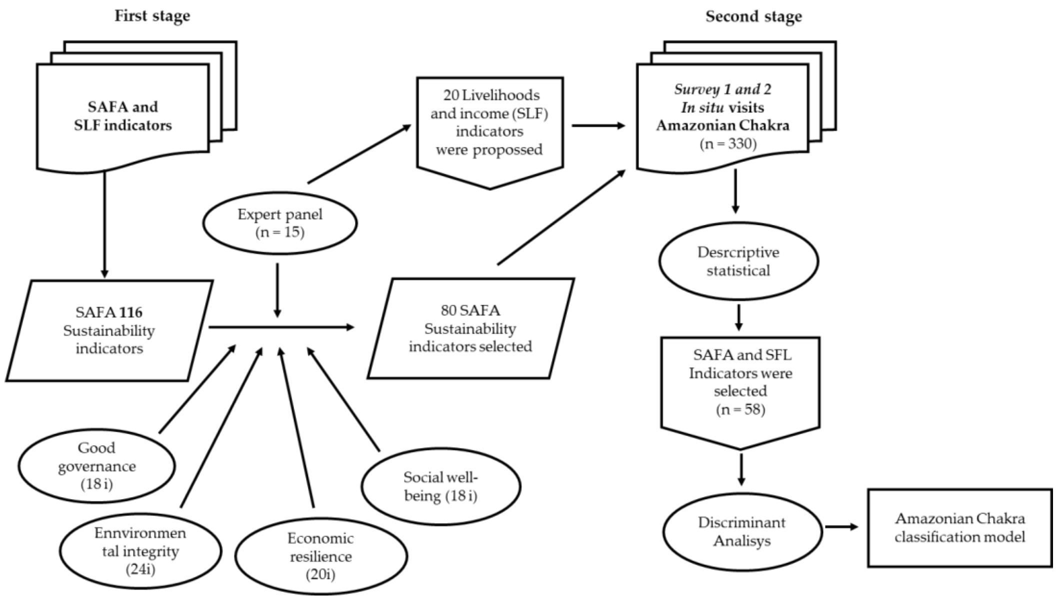

Figure 3. Research stages.

To determine the degree of agreement among the experts, the Ishikawa index was applied, which measures the level of consensus, as described in previous studies [48,49]. This index compares the responses given by each expert to each question in the SAFA questionnaire, thereby assessing the level of agreement. The calculation of the proportion of experts who agreed on each response resulted in a concordance value for each question. Subsequently, questions with a concordance level above 60% and an average score higher than 3.5 were selected. This concordance threshold was chosen to

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ensure that the selected questions reflected a high level of agreement among experts, while the average score served as an additional indicator of the quality of the selected questions.

In a second stage, field work was carried out with two questionnaires and in situ field visits. 330 Amazonian Chakra were visited and two survey model were applied. The first survey characterizes the livelihoods and income of the studied population, using the methodology proposed by the Poverty and Environment Network (PEN) of the Center for International Forestry Research (CIFOR) [50,51]. This methodology employs a prototype survey designed to systematically collect data, allowing the assessment of livelihoods and income across diverse socioeconomic and biophysical contexts [51]. Fifteen variables were selected to represent the five capitals: human, social, natural, physical, and financial. Additionally, five variables derived from income calculations were used to gather detailed household income information, particularly in contexts where significant interactions exist between forests, the Amazonian Chakra, and human activity.

The second survey employed 80 sustainability indicators from the SAFA tool [23], specifically selected for the Amazonian Chakra context by a panel of experts in collaboration with sustainability specialists with local knowledge. Together, these two surveys, comprising a total of 100 indicators/variables, were applied to a random sample of 330 households belonging to three rural associations dedicated to cacao production in the Amazonian Chakra system. This combined approach enables a comprehensive evaluation of the livelihoods and sustainability of these productive systems, identifying opportunities for improvement and promoting sustainable management practices.

Finally, the database was analyzed using descriptive statistics, the Pearson total correlation matrix, and significant differences between associations for each variable. 56 variables were selected for discriminant analysis.

3.5. Statistical Analysis

Safa, livelihood and income variables were standardized according to Gonzalez Martinez et al. [52]. Kolmogorov–Smirnov test and Bartlett test were performed to verify the normality and equality of the data variance (homoscedasticity). The KMO sampling adequacy test showed a value greater or 0.7, while the Bartlett test showed a satisfactory probability value ($p < 0.001$), thus indicating that the sampling was adequate [52,53].

The cuantitative variables were compared using the analysis of variance (ANOVA), establishing the three associations (Kallari, Wiñak and Tsatsayaku) as a fixed effect, with two degree of freedom. Cualitative variabes (original and adjusted) were compared by Kruskal-Wallis test with three associations included as a fixed effect.

Later, a discriminant analysis was performed with all the significat transformed variables, including the classification matrix, as well as the graphic representation of the Mahanalobis distances through clusters and the spatial distribution of farms through canonical Scatterplot, establishing the association type as the grouping variable. A direct method of selection of variables was used at p-value < 0.05. Second, the selection of the most discriminant variables was made applying the F of Snedecor, Wilks' Lambda and the 1-Tolerance. High values of F for each variable indicate that the means of each group are widely separated and these groups are homogeneous. Small Lambda values indicate that the variable discriminates well amongst groups. Finally, variables with a high percentage of tolerance (1-Toler) that reduced the redundant information were searched.

4. Results and Discussion

4.1. Livelihoods in the Amazonian Chakra

The analysis of human capital (L-HC) reveals important demographic differences among the associations. Household size averages around 5.2 members with no significant differences across groups, suggesting similar household structures. These findings align with the 5.6 members per household reported by [54] for timber producers in the lower region of Napo province. However, they are lower than the 6.6 members per household reported by [30] in a study on livelihood

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strategies among Kichwa and mestizo populations in the SBR. Wiñak producers has a significantly higher proportion of female household heads (68.2%) compared to Kallari (57.7%) and Tsatsayaku (51.1%) ($p < 0.05$), likely due to the Chakra system being traditionally managed by women to ensure food security, even though today it also includes marketable products like cacao, coffee, guayusa, etc. In terms of ethnicity, Wiñak (97.7%) and Kallari (94.2%) have a much higher proportion of Kichwa population than Tsatsayaku (73.3%) ($p < 0.001$), underscoring stronger indigenous cultural ties in the first two associations, which reinforces the role of the Amazonian Chakra for these populations. Additionally, Wiñak has a significantly younger average household head age (43.8 years) compared to Kallari (51.8 years) and Tsatsayaku (50.5 years) ($p < 0.001$), which may affect innovation and decision-making. Education levels are similar across all groups, with no significant differences.

The analysis of social capital (L-SC) shows significant differences in access to training on Best Management Practices (BMP) among the associations. Tsatsayaku has the highest percentage of producers who have received BMP training (62.2%), significantly higher than Wiñak (51.2%) and Kallari (43.6%) ($p < 0.05$). In addition to training, social capital also encompasses the associative activities of producers, which play a critical role in fostering sustainable development [31,32]. The higher level of training and involvement reflects a stronger capacity for collective action and resource management, key components for enhancing sustainability through improved agricultural and forestry practices.

The results of natural capital (L-NC) reveal significant differences in land use and management among the associations. Tsatsayaku has the largest Chakra area (2.7 ha), significantly more than Kallari (2.1 ha) and Wiñak (1.9 ha) ($p < 0.001$). Similarly, forest area is substantially greater in Tsatsayaku (11.8 ha), compared to Kallari (4.1 ha) and Wiñak (1.2 ha) ($p < 0.001$), indicating that Tsatsayaku producers manage larger forested lands. In terms of other crops, Tsatsayaku also leads with 1 ha, significantly more than Kallari and Wiñak (both below 0.3 ha) ($p < 0.01$). Overall, total farm area is largest in Tsatsayaku (15.6 ha), while Wiñak and Kallari manage smaller farms (3.5 ha and 6.2 ha, respectively) ($p < 0.001$). In comparison, Kichwa farmers dedicated to agriculture in Pastaza have significantly larger landholdings, averaging 64 hectares per household [55]. There were no significant differences in distance to the city or road access to the community among the associations. These findings highlight the larger landholdings and more extensive use of natural resources in Tsatsayaku, which could have implications for their capacity for sustainable land management.

Table 1. Mean of the main livelihoods and economic characteristics of livelihoods of producers' associations, RBS, Ecuadorian Amazon.

Livelihood variables	Mean n=330	Kallari n=156	Wiñak n=129	Tsatsayaku n=45	sig.
Human Capital (L-HC)					
Gender/Head of household (female%)	59	57.7 [a]	68.2 [b]	51.1 [a]	*
Ethnicity (% Kichwa)	88.4	94.2 [b]	97.7 [b]	73.3 [a]	***
Household head age (years)	48.7	51.8 [a]	43.8 [b]	50.5 [a]	***
Social Capital (L-SC)					
Training received (BMP) (%)	52.3	43.6 [a]	51.2 [a]	62.2 [b]	*
Natural Capital (L-NC)					
Chakra (ha)	2.2	2.1 [a]	1.9 [a]	2.7 [b]	***
Forest (ha)	5.7	4.1 [a]	1.2 [a]	11.8 [b]	***
Other crops (ha)	0.4	0.0 [a]	0.3 [a]	1 [b]	**
Total farm area (ha)	8.4	6.2 [a]	3.5 [a]	15.6 [b]	***
Finantial Capital (L-FC)					
Access to credit (%)	08	9.6 [a]	4.7 [a]	24.4 [b]	**

Access to government bonus (%)	56	60.9 [b]	62.0 [b]	44.4 [a]	**
Physical Capital (L-PhC)					
engine technology (yes=1)	1.54	64.1 [c]	24.8 [a]	48.9 [b]	***
Cell phone (yes=1)	69	59.6 [a]	62.0 [a]	77.8 [b]	*

p-Value: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; n.s. = no significant among groups. *Source*: Authors computation from survey data. ANOVA for continuous variables and *Chi* square for categorical variables.

The physical capital (L-PhC) reveals significant differences in access to essential agricultural tools and communication devices among the associations. Access engine technologies (use of strimmers, among others) shows the highest disparity, with Wiñak having the largest percentage of producers owning this tool (64.1%), followed by Kallari (48.9%) and Tsatsayaku (24.8%) (p < 0.001). This suggests that Wiñak and Kallari have better access to agricultural equipment necessary for sustainable land management. Cell phone ownership also differs significantly, with Tsatsayaku having the highest percentage of producers owning cell phones (77.8%), compared to Kallari (62.0%) and Wiñak (59.6%) ($p < 0.05$). This reflects better communication capabilities in Tsatsayaku. No significant differences were found in terms of household goods or vehicle ownership, with access to cars or motorcycles being relatively low across all associations.

4.2. Well-Being, Income, and Poverty Index in Households of the Amazonian Chakra

Two indicators were used to assess household well-being: *per capita* income (PCI) and the poverty index (FGT) [45]. Our results show that the average annual PCI was highest among cacao-producing households in the Tsatsayaku association (USD 714.15), largely due to larger landholdings and engagement in additional activities such as livestock farming. The PCI for Wiñak and Kallari producers was relatively similar, at USD 324.07 and USD 361.46, respectively. These figures are comparable to the USD 327 PCI reported by Torres et al. [30] for Amazonian producers who had adopted agriculture-oriented livelihood strategies.

Overall, extreme poverty was reported in 82% of households across the three producer associations (Table 2). However, Tsatsayaku producers had the lowest extreme poverty rate (69%), while Wiñak (89%) and Kallari (87%) exhibited higher rates, exceeding those reported by [30] for the Sumaco Biosphere Reserve (SBR).

Significant differences in income generated from the Amazonian Chakra were observed across the three associations (Table 2). Tsatsayaku reported an average income of USD 490.36, Wiñak USD 487.37, and Kallari led with an average income of USD 673.34. A deeper analysis of total income shows that income from the Chakra represents only 16% of the average total income in Tsatsayaku (USD 3,096.94). However, for Wiñak producers, Chakra-related income accounts for 37% of their total income of USD 1,284.45. For Kallari producers, this income constitutes 44% of their average household income of USD 1,652.73 (Table 2).

Table 2. Income of producers belonging to the Amazonian Chakra of three local associative organizations, RBS, Ecuadorian Amazon.

Variables	**Mean n=330**	**Kallari n=156**	**Wiñak n=129**	**Tsatsayaku n=45**	**sig.**
Income					
Total income (USD)	1652.73	1540.68 [a]	1287.45 [a]	3096.94 [b]	***
Chakra income (USD)	575.69	673.34 [b]	487.38 [a]	490.36 [a]	*
Other income (USD)	565.54	305.12 [a]	299.03 [a]	2232.35 [b]	***
Per-capita income (USD/annual)	394.94	361.46 [a]	324.07 [a]	714.15 [b]	**

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Headcount index (% extremely poor)	82	86.5	89.1	68.9	n.s

p-Value: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; n.s = no significant among groups. *Source*: Authors computation from survey data. ANOVA for continuous variables and *Chi* square for categorical variables.

4.3. Sustainability Dimensions Assessment

Among the four sustainability dimensions analyzed using 80 SAFA indicators, we found that 44 out of the 80 evaluated indicators (55%) showed significant differences across the three producer groups. These results highlight the diverse sustainability practices and outcomes among the associations, emphasizing areas where specific groups excel or need improvement (Table 3).

Table 3. SAFA indicators evaluated in the three producer's associations evaluated in the Sumaco Biosphere Reserve, EAR.

SAFA			All	Kallari	Wiñak	Tsatsayaku	Sig.
	– Themes – Indicators		n = 330	n = 156	n = 129	n = 45	
Godd governance (14)	G1.1.1	Mission Explicitness	3.08	3.21 [b]	3.27 [b]	2.09 [a]	***
	G1.1.2	Mission Driven	3.07	3.20 [b]	3.25 [b]	2.13 [a]	***
	G1.2.1	Due Diligence	3.03	3.10 [b]	3.25 [b]	2.18 [a]	***
	G2.1.1	Holistic Audits	3.11	3.14 [b]	3.40 [b]	2.18 [a]	***
	G2.2.1	Responsibility	3.02	3.03 [b]	3.33 [b]	2.11 [a]	***
	G2.3.1	Transparency	3.05	3.08 [b]	3.32 [b]	2.13 [a]	***
	G3.1.1	Stakeholder Identification	3.23	3.28 [b]	3.46 [b]	2.38 [a]	***
	G3.1.2	Stakeholder Engagement	3.25	3.24 [b]	3.48 [b]	2.60 [a]	***
	G3.1.4	Effective Participation	3.05	3.13 [b]	3.13 [b]	2.51 [a]	**
	G3.2.1	Grievance Procedures	3.11	3.27 [b]	3.09 [b]	2.64 [a]	**
	G4.2.1	Remedy, Restoration and Prevention	3.34	3.32 [a, b]	3.52 [b]	2.87 [a]	*
	G4.3.1	Responsibility	3.19	3.03 [a, b]	3.48 [b]	2.91 [a]	***
	G5.1.1	Sustainability Management Plan	3.38	3.50 [b]	3.53 [b]	2.51 [a]	***
	G5.2.1	Full-Cost Accounting	3.18	3.33 [b]	3.22 [b]	2.56 [a]	***
Ennvironmental integrity (15)	E1.1.1	GHG Reduction Target	3.48	3.68 [b]	3.44 [b]	2.91 [a]	***
	E1.1.2	GHG Mitigation Practices	3.58	3.70 [b]	3.57 [a, b]	3.20 [a]	*
	E2.1.2	Water Conservation Practices	3.26	3.10 [a]	3.27 [a, b]	3.78 [b]	*
	E2.2.2	Water Pollution Prevention Practices	4.14	4.31 [b]	4.04 [a, b]	3.87 [a]	*
	E3.2.1	Land Conservation and Rehabilitation Plan	3.68	3.86 [b]	3.66 [b]	3.13 [a]	***
	E3.2.2	Land Conservation and Rehabilitation Practices	3.86	3.92 [b]	4.00 [b]	3.29 [a]	***
	E4.1.4	Ecosystem Connectivity	3.96	4.06 [b]	3.98 [b]	3.53 [a]	**
	E4.1.5	Land-Use and Land-Cover Change	3.78	3.96 [b]	3.76 [b]	3.27	***
	E4.2.2	Species Conservation Practices	3.83	4.01 [b]	3.79 [b]	3.31 [a]	***
	E4.2.3	Diversity and Abundance of Key Species	3.94	4.09 [b]	3.96 [b]	3.33 [a]	**
	E4.2.4	Diversity of Production	4.00	4.14 [b]	4.01 [b]	3.49 [a]	***
	E4.3.1	Wild Genetic Diversity Enhancing Practices	4.06	4.10 [b]	4.19 [b]	3.51 [a]	***
	E4.3.2	Agro-Biodiversity in-situ Conservation	4.07	4.10 [b]	4.14 [b]	3.73 [a]	*
	E5.2.1	Renewable Energy Use Target	2.43	2.62 [b]	2.40 [b]	1.87 [a]	***
	E5.2.2	Energy-Saving Practices	2.39	2.63 [b]	2.32 [b]	1.73 [a]	***

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Economic resilience (11)	C1.2.1	Community Investment	3.47	3.62 [b]	3.39 [a, b]	3.20 [a]	*
	C1.3.1	Long Term Profitability	3.23	3.40 [b]	3.16 [a, b]	2.82 [a]	**
	C1.3.2	Business Plan	3.15	3.42 [c]	3.05 [b]	2.51 [a]	***
	C1.4.1	Net Income	3.19	3.40 [b]	3.06 [a, b]	2.82 [a]	***
	C1.4.2	Cost of Production	3.15	3.36 [b]	3.03 [a, b]	2.80 [a]	***
	C1.4.3	Price Determination	3.26	3.44 [b]	3.12 [a, b]	3.09 [a]	**
	C2.1.2	Product Diversification	3.59	3.67 [b]	3.67 [b]	3.09 [a]	**
	C2.3.1	Stability of Market	3.09	3.22 [b]	3.10 [b]	2.64 [a]	**
	C2.4.1	Net Cash Flow	3.09	3.25 [b]	3.08 [b]	2.60 [a]	***
	C2.4.2	Safety Nets	2.96	3.17 [b]	2.93 [b]	2.31 [a]	***
	C2.5.1	Risk Management	3.31	3.47 [b]	3.22 [a, b]	2.96 [a]	*
Social well-being (4)	S2.1.1	Fair Pricing and Transparent Contracts	3.30	3.45 [b]	3.29 [b]	2.82 [a]	***
	S5.1.1	Safety and Health Training	3.47	3.74 [b]	3.36 [a, b]	2.84 [a]	***
	S5.2.1	Public Health	4.19	4.12 [a]	4.24 [b]	4.29 [b]	***
	S6.1.1	Indigenous Knowledge	4.26	4.44 [b]	4.36 [b]	4.21 [a]	***

[1] *p*-Value: * $p < 0,05$; ** $p < 0,01$; *** $p < 0,001$; n.s. = not significant among groups; different letters indicate significant differences between social groups at 5%.

4.3.1. Good Governance

In the governance dimension, wiñak (3.36) and kallari (3.26) consistently outperformed tsatsayaku (2.59), reflecting stronger governance structures in the former two associations. Tsatsayaku exhibited lower scores in key indicators such as mission explicitness (2.09) and responsibility (2.11), while wiñak and kallari demonstrated significantly higher values for these indicators (between 3.20 and 3.33). The indicators holistic audits and transparency also highlighted this disparity, with tsatsayaku scoring ~2.10, in contrast to ~3.10 in kallari and ~3.40 in wiñak. Additionally, stakeholder engagement and sustainability management plan showed similar trends, with wiñak and kallari scoring significantly higher (~3.48 and ~3.50) compared to tsatsayaku (~2.60 and 2.51).

4.3.2. Environmental Integrity

Regarding the environmental dimension, kallari (3.70) and wiñak (3.64) again outperformed tsatsayaku (3.27) across most indicators. Kallari led in areas such as GHG reduction target (3.68) and species conservation practices (4.01), whereas tsatsayaku scored significantly lower in these categories (2.91 and 3.31, respectively). Similarly, for land conservation and rehabilitation practices, kallari (3.92) and wiñak (4.00) were higher than tsatsayaku (3.29). Significant differences were also observed in agro-biodiversity conservation and wild genetic diversity practices, where wiñak and kallari achieved scores around 4.10, while tsatsayaku lagged (~3.50).

4.3.3. Economic Resilience

With regard to economic resiliency dimension, kallari (3.60) outperformed both wiñak (3.46) and tsatsayaku (3.18). Key indicators such as net income (3.40), cost of production (3.36), and long-term profitability (3.40) were significantly higher for kallari compared to tsatsayaku, which scored notably lower in these areas (2.82–3.02). Wiñak showed intermediate performance across most indicators, though closer to kallari in areas such as product diversification (3.67) and stability of market (3.22). The largest disparities were seen in business plan and safety nets, where kallari demonstrated stronger economic strategies (3.42 and 3.17, respectively), compared to tsatsayaku (2.51 and 2.31).

4.3.4. Social Welfare

The social well-being dimension was relatively similar, with kallari (3.86), wiñak (3.85), and tsatsayaku (3.76) showing comparable overall scores. However, kallari outperformed the others in key areas such as safety and health training (3.74), where tsatsayaku lagged significantly behind (2.84). Similarly, in public health, wiñak (4.24) and kallari (4.12) scored higher than tsatsayaku (3.87). While indicators such as gender equality, non-discrimination, and food sovereignty showed little variation across the associations, tsatsayaku demonstrated slightly lower scores in areas related to support for vulnerable people and access to medical care. overall, kallari and wiñak exhibited stronger outcomes in health and safety-related indicators, while tsatsayaku showed some minor gaps in social well-being.

4.4. Multivariate Discriminant Analysis by Association (SAFA- SLF)

The multivariate discriminant analysis of 58 indicators from the SAFA and SLF revealed that several variables significantly differentiated the associations (Table 4). Wilks' Lambda was used as a key measure, with values closer to 0 indicating stronger discriminating power.

Notably, the technicalization of tasks (use of strimmers, among others) (L-PhC.1) (Wilks' Lambda = 0.39, $p < 0.001$) exhibited the highest discriminatory ability, suggesting that the availability and use of technology marked significant differences among associations, marking it as a critical factor in financial management and productivity. Of the 58 proposed indicators, the discriminant model accepted 33 and excluded 25 variables. Subsequently, according to Wilks' Lambda, p-value, Snedecor's F and tolerance level, a final model was proposed with 19 indicators; 7 of (SLF) and 12 of the SAFA methodologies. Other key indicators, such as total income (L-FC.1) (Wilks' Lambda = 0.98, $p < 0.01$) and chakra income (L-FC.2) (Wilks' Lambda = 0.97, $p < 0.01$), as well as business plan (C1.3.2) (Wilks' Lambda = 0.97, $p < 0.01$) and price determination (C1.4.3) (Wilks' Lambda = 0.97, $p < 0.01$), showed significant variation, pointing to disparities in income generation, bussiness plan and market dynamics across associations. Moreover, L-FC.1 includes both on-farm and off-farm income, such as employment and non-agricultural work, revealing disparities in access to alternative income sources between the associations. This highlights how some groups rely more heavily on diverse income streams beyond agriculture [56,57], which can impact their financial stability and resilience [1,26,36].

Furthermore, human capital and environmental management practices were also significant discriminators. For example, age of the household head (L-HC.1) (Wilks' Lambda = 0.96, $p < 0.001$) and water pollution prevention practices (E2.2.2) (Wilks' Lambda = 0.96, $p < 0.001$) highlighted the importance of demographic factors and environmental stewardship in shaping sustainability outcomes. Additionally, civic responsibility (G4.3.1) (Wilks' Lambda = 0.95, $p < 0.001$) and safety nets (C2.4.2) (Wilks' Lambda = 0.97, $p < 0.01$) were strong governance and economic resilience indicators, respectively, showing significant differences between the associations. These findings underscored the great value of considering livelihoods in sustainability assessment and the need for targeted efforts to improve governance, environmental practices, and economic safety nets, particularly in associations that performed weaker in these areas.

Some indicators, such as farm size (L-NC.1) also emerged as a significant factor (Wilks' Lambda = 0.98, $p < 0.05$), indicating that the size of landholdings is a key determinant of livelihood outcomes. Larger farms enable greater diversification of production, which can promote economic stability and sustainability. In the area of governance, indicators such as civic responsibility (G4.3.1) (Wilks' Lambda = 0.96, $p < 0.001$), full-cost accounting (G5.2.1) (Wilks' Lambda = 0.98, $p < 0.05$), and holistic audits (G2.1.1) highlighted the importance of institutional strength and accountability. Associations with stronger governance frameworks were better able to manage resources sustainably and improve livelihood outcomes. This suggests that while certain governance and natural capital factors may be consistent, this needs to be further strengthened, as other areas, such as income diversification, financial access and market stability, need strategic intervention. By strengthening some elements of natural resource governance, positive impacts on other aspects of sustainability can be achieved. [58].

Focusing on indicators with significant discriminatory power, such as wild genetic diversity enhancing practices (E4.3.1) (Wilks' Lambda = 0.97, $p < 0.01$), water conservation practices (E2.1.2)

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(Wilks' Lambda = 0.94, $p < 0.001$) and public health (S5.2.1) (Wilks' Lambda = 0.97, $p < 0.01$), can guide more personalized sustainability management practices. These results demonstrate that associations focusing on water conservation and biodiversity enhancement are better equipped to maintain ecological balance, which is critical in the Amazonian Chakra system. Furthermore, agro-biodiversity in-situ conservation (E4.3.2) (Wilks' Lambda = 0.98, $p < 0.01$) were also significant, highlighting the importance of environmentally sustainable practices. This approach will allow for better allocation of resources, improving sustainability outcomes in a context-specific manner across the different associations.

Table 4. Discriminant functions of livelihood and sustainability indicators of three producer associations involving the Amazonian Chakra, SBR, Ecuadorian Amazon.

No.	Parameters [1]	Wilks' - Lambda	Partial - Lambda	F-remove	*p*-level [2]	Toler	1-Toler
1	L-PhC.1	0.39	0.88	20.30	***	0.90	0.10
2	L-NC.1	0.35	0.98	2.50	*	0.04	0.96
3	C1.3.2	0.35	0.97	4.23	**	0.52	0.48
4	E2.1.2	0.36	0.94	8.98	***	0.72	0.28
5	L-HC.1	0.36	0.96	5.92	***	0.90	0.10
6	E2.2.2	0.36	0.95	7.25	***	0.54	0.46
7	L-HC.2	0.35	0.97	4.12	***	0.79	0.21
8	C2.4.2	0.35	0.97	4.28	**	0.32	0.68
9	C1.4.3	0.35	0.97	4.91	**	0.54	0.46
10	S5.2.1	0.35	0.97	5.06	**	0.62	0.38
11	S5.1.1	0.35	0.98	3.16	*	0.72	0.28
12	E4.3.1	0.35	0.97	4.91	**	0.19	0.81
13	L-FC.1	0.35	0.98	3.42	**	0.74	0.26
14	E4.3.2	0.35	0.98	3.38	*	0.22	0.78
15	L-FC.2	0.35	0.97	4.06	**	0.79	0.21
16	L-FC.3	0.35	0.98	3.28	*	0.83	0.17
17	G4.3.1	0.36	0.96	6.95	***	0.40	0.60
18	G5.2.1	0.35	0.98	3.01	*	0.73	0.27
19	G2.1.1	0.35	0.98	3.68	**	0.34	0.66

[1] L-PhC.1 = engine technology; L-NC.1 = farm size; C1.3.2 = business plan; E2.1.2 = water conservation practices; L-HC.1 = age household head; E2.2.2 = water pollution prevention practices; L-HC.2 = ethnicity; C2.4.2 = safety nets; C1.4.3 = price determination; S5.2.1 = public health; S5.1.1 = safety and health training; E4.3.1 = wild genetic diversity enhancing practices; L-FC.1 = total income; E4.3.2 = agro-biodiversity *in-situ* conservation; L-FC.2 = chakra income; L-FC.3 = access state bonus; G4.3.1 = civic responsibility; G5.2.1 = full-cost accounting; G2.1.1 = holistic audits. [2] *p*-Value: $*p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

In Figure 4a, the canonical discriminant function plot shows clear separation among the producers of the three associations. Kallari is distinctly separated along Root 1, suggesting that indicators related to financial management and environmental practices are the most significant in differentiating this group from Wiñak and Tsatsayaku, which cluster more closely. Tsatsayaku shows greater internal variability along Root 2, indicating heterogeneity within the group, while Wiñak and Kallari present more cohesive clusters.

The cluster analysis in Figure 4b confirms these findings, with Wiñak and Kallari forming a closer cluster, reflecting similar sustainability practices, while Tsatsayaku is more distant, highlighting its distinct characteristics. These results suggest that Kallari and Wiñak share stronger governance and financial resilience, while Tsatsayaku may benefit from targeted interventions in these areas to enhance its sustainability performance.

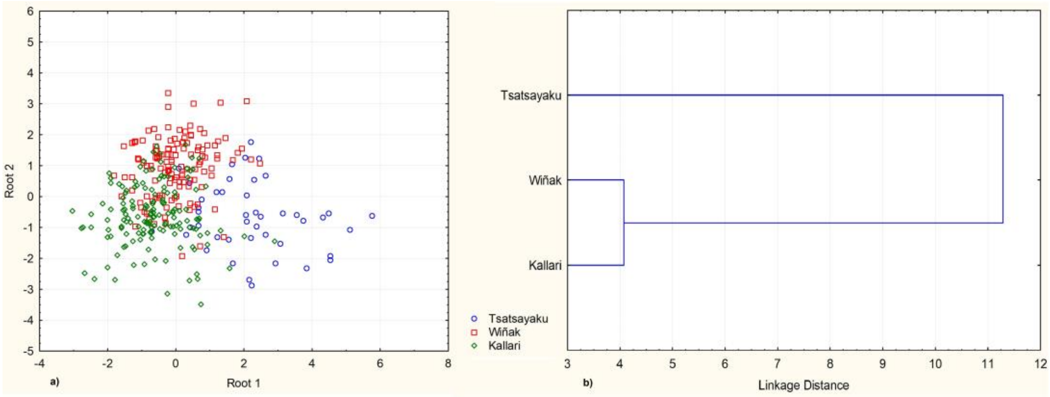

Figure 4. Plot of the discriminant scores of individual observations obtained with the canonical discriminant function (a) and cluster analysis from Mahalanobis distances (b) for the producers of the three associations studied.

The sustainability assessment was carried out using 58 indicators: 44 SAFA, 14 livelihoods and income indicators. Finally, the proposed classification model used 19 indicators: 12 SAFA items and 7 livelihood and income items. The livelihood variables showed high discriminating power between associations. Two variables of great importance were the level of technological development and the size. The size is limited by the surface area of the protected space, which makes increasing it very complex. On the other hand, the technological level is associated with other variables included in the model, such as the age of the owner, ethnicity, access to credit, income, etc. According to Bastanchury et al. and De-Pablos-Heredero et al. [59,60] small farms can be viable through sustainable intensification by locating their production in the area of increasing returns.

Improving the level of technical development requires addressing different aspects. Indigenous people are more vulnerable and showed worse indicators. It is necessary to have the technology and enhance dynamic capacities to develop efficient use [60,61].

At the level of public policies, it would be interesting to facilitate access to credit for indigenous populations [62], promote the succession of Chakras, which is a case of a family business [63] and women's access to ownership of exploration [64]. These policies could promote technological improvement.

Given the importance of governance indicators, policies should also aim to strengthen the participatory and organizational capacity of productive associations [65], especially around internal financial accountability and resource management such as access to soft loans or access to special markets [38,66,67]. In addition, the promotion of sustainable environmental practices, such as water conservation, biodiversity protection [7,68], and carbon sequestration [14,69] will be essential to ensure long-term sustainability. In addition, all these social, environmental and good governance aspects related to the can also be strengthened to attract new sustainable income through community and scientific [70] tourism around the Amazon Chakra system which today is a GIAHS site [42].

Amongst the main limitations of the study, the following ones can be highlighted: this multivariate study is exploratory and should be complemented with other studies that quantify the causal relationship between sustainability and livelihood dimensions with economic results of Amazonian Chakra. The sample is sufficient and broad but should be increased with traditional systems in other countries, which would allow the results to be extended to other contexts.

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4. Conclusions

The discriminant analysis revealed key insights into the sustainability practices of the three associations, highlighting areas for improvement in governance, financial management, and environmental practices. Based on these findings, the following conclusions and policy recommendations are proposed to enhance producer sustainability.

First, regarding financial and environmental sustainability, the discriminant analysis revealed significant differences in key indicators such as chakra income, price determination, and wild genetic diversity. Kallari and Wiñak showed stronger performance in these areas, while Tsatsayaku lagged, especially in financial management and environmental practices. This highlight efforts for financial incentives and credit Access, policies should promote financial support, credit access, and market transparency, addressing their economic vulnerabilities and fostering long-term stability.

Governance and community engagement indicators like civic responsibility and safety nets were critical in distinguishing associations. Wiñak and Kallari exhibited better governance structures and economic resilience compared to Tsatsayaku. Strengthening community participation and transparency is essential for improving governance in associations with lower performance. To improve governance, decision-makers should encourage participatory governance through training programs on transparency and civic responsibility, increasing community engagement.

The analysis indicates the need for interventions focused on financial management and access to resources, including credit and environmental practices. The results provide clear direction for targeted resource allocation and sustainability improvements. Environmental conservation practices policies must incentivize sustainable environmental practices such as biodiversity conservation and water management, especially in associations with weaker environmental performance.

Supplementary Materials: The following supporting information can be downloaded at: Preprints.org.

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