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Artícle

Alternative model to measure the adoption of innovations: application in the Puebla beekeeping system

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Abstract:

This work aimed to adapt a methodological tool capable of improving the way to obtain the Innovation Adoption Index in the Puebla beekeeping system. A questionnaire was designed and applied to a sample of 62 beekeepers, from which information was obtained on the use of management, genetics, food, and health innovations, from which 32 original variables and seven innovation categories were defined. The Innovation Adoption Index (InAI) was redesigned and adapted using the analytic hierarchy process (AHP), which made it easier to identify social aspects of beekeepers and innovations that contribute to improving honey productivity. The results show that the innovations that contribute the most to production are those contained in the categories of apiary location and health. On the other hand, the $InAI_{alt}$ evaluation proved to be a pertinent alternative for the explanation of the behavior of the yield per hive in addition to showing the specific contribution percentages on the innovations assessed, which can be used to calculate estimates that are more precise and consistent with the expected yields of the region.

Keywords: Beekeeping, Analytic Hierarchy Process, Agricultural innovation, Adoption of innovations.

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Introduction

The current economic environment has placed unprecedented demands for competitiveness on all companies, underlining the importance of innovation, research, and development activities. Innovation, being a dynamic process, not only drives business growth and economic development but also becomes a strategy for social and cultural change within the organization. In addition, it promotes the creation of new technologies that replace old ones[(1)], thus driving continuous evolution.

It is true that not all innovations have the same impact or value; innovation processes vary significantly from one sector to another, influenced by their conditions and adoption rates[(2,3)]. In addition, what may be considered new for one person in one region may not be new for others within the same geographical area; even some innovations, once they are no longer novel, become common practices, forming part of a technological set regularly applied by some, while for others who are learning and using them, they are still considered innovations, if not good production practices[(4)].

Currently, there is a consensus on a number of ideas to characterize innovation in agriculture. It is recognized that innovation requires knowledge from various sources, including the users of those innovations. In addition, different sources of expertise interact, sharing and combining ideas in processes usually specific to a given context. Each context has its own orders, reflecting its historical origins determined by cultural, political, and social factors[(5)]. Therefore, having methodologies that allow measuring innovations is a fundamental link for understanding them.

A methodology is defined as a set of principles, procedures, and practices aimed at achieving a specific goal[6]. These methodologies are relevant in product development, as they not only ensure that the final product is suitable and adaptable to the user's needs but also contribute to structuring and improving the development process itself. In this sense, understanding the characteristics of innovation and having appropriate methodologies is essential to promote development and continuous improvement in the agricultural sector[7].

The first methodology used to measure agricultural innovation was developed by Fliegel[8], who proposed an indicator of adoption of agricultural practices based on the percentage of practices that producers adopt compared to the total practices available. Later, Muñoz *et al*[9] proposed an innovation adoption index (hereinafter referred to as InAI) to assess a producer's innovative capacity. This index is similar to the one proposed by Fliegel; however, the second authors categorize innovations according to technological packages and calculate a specific InAI for each category, dividing the number of innovations made by the producer by the total number of innovations recorded in that category. Then, they average the InAIs of each category to get the overall InAI of each producer.

Nonetheless, in both methodological proposals, a clear differentiation is not established between the innovations assessed, which means that all innovations have the same weight. On the other hand, Pérez *et al*[10] argue that in order to measure a producer's innovation level, it is necessary to consider both the quantity and the type of innovations implemented. They propose implementing an alternative model that combines elements of traditional approaches with new perspectives with the aim of striking a balance between complexity and dynamism in measurement. To do this, it is necessary to determine the strength of the interrelations between the elements of a hierarchy.

One method used to hierarchize and weight criteria is the Analytic Hierarchy Process (AHP), proposed by Thomas Saaty[11] in the 80s. This multicriteria tool is based on pairwise comparisons of criteria or alternatives using a defined scale, allowing one to prioritize solving various complex multicriteria problems. The process involves obtaining subjective opinions and evaluations. In the AHP, items are compared to each other using a square matrix defined by a set of criteria, which involves weighting the number of rows and columns and assigning each item a relative importance based on expert judgment.

In this context, this research aimed to adapt a methodology to obtain an Alternative Innovation Adoption Index ($InAI_{alt}$) through the AHP in order to obtain an indicator that more accurately reflects the measurement of the innovation adoption process and that, in turn, allows understanding this process of vital importance for the agri-food sector, with a particular emphasis on the beekeeping sector, which plays a fundamental role in the pollination of crops and the production of various products that contribute significantly to food security, biodiversity, and the development of rural communities.

Material and methods

The research was exploratory, descriptive, and cross-sectional, supported by primary and secondary sources with technicians, suppliers of inputs in the beekeeping sector, and honey producers. To ensure the integrity of the sample, the credibility of the sources was verified by reviewing their field experience, their reputation in the beekeeping community, and the consistency of their data with the existing literature. The surveys were carried out from July 2021 to March 2022 in the municipalities of Acatlán de Osorio, Guadalupe, San Pablo Anicano, and San Pedro Yeloixtlahuaca in the Mixteca region of the state of Puebla. From a list provided by technicians and suppliers in the region, 48 beekeepers were interviewed, and those who were not registered (14) were identified using the linear snowball technique during the same period. This research stands out for the relevance it acquires by focusing on the state of Puebla, which ranks eighth in honey production in Mexico[12]. This information underlines the significant presence of beekeeping in the region, which deserves a detailed analysis of its impact on the local and national economy. Specifically, the Mixteca region of Puebla emerges as an area conducive to developing beekeeping and producing high-quality honey. This phenomenon is attributed to a combination of factors, among which the following stand out: favorable climatic conditions, the richness of the local flora, the deep-rooted beekeeping tradition, as well as the economic and social impact generated by this activity in the region.

Variables and their analysis

A total of 32 items were analyzed, which were grouped into seven categories (Table 1) based on the manual of good livestock practices in primary honey production of the Secretariat of Agriculture, Livestock, Rural Development, Fisheries and Food (SAGARPA, for its acronym in Spanish) as a basis for analysis.

Table 1: Good honey production practice items

Category	Technological innovation in honey production
Health	**TI01.** Inspection frequency; **TI02.** Logging; **TI03.** Hive tool flaming; **TI04.** Varroosis control; **TI05.** Thymol removal 15 days before harvest; **TI06.** Change of the queen every year; **TI07.** Change of brood chamber frames 2/year.
Artificial feeding	**TI08.** Input for support or maintenance feeding; **TI09.** Input for stimulus feeding; **TI10.** Input for supplementary feeding. **TI 11.** Feeding is suspended at the beginning of flowering.
Location	**TI12.** Distance to the nearest source of water; **TI13.** Location of the apiary human settlements; **TI14.** Distance to the flowering area; **TI15.** Apiary clean of weeds; **TI16.** Hives on a base at 20 cm; **TI17.** Distance to inhabited areas; **TI18.** Knowledge of chemical application; **TI19.** Distance between hives.
Material of protection for the hive	**TI20.** Current condition of the hive equipment; **TI21.** Correct material for coating the hive (resins, waxes); **TI22.** Use of smoker with plant-based combustible material.
Harvest	**TI23.** Correct percentage of capping; **TI24.** Material used to dislodge bees during harvest.
Staff	**TI25.** Staff knows GHPP; **TI26.** There is a hygiene log; **TI27.** Clean clothing; **TI28.** Clothing for exclusive use.
Cleaning and hygiene	**TI29.** Program of procedures for hygiene and personal cleanliness; **TI30.** Procedures for hygiene and cleaning of protective equipment; **TI31.** Procedures for cleaning utensils and containers; **TI32.** Attendance at training workshops.

TI= Technological innovation.

Source: Prepared by the authors based on what was proposed by SAGARPA[13]

The calculation of the InAI or good production practices is carried out for each beekeeping production unit, which allows the evaluation of the degree of innovation. The InAI is a measure that varies between zero and one, where zero indicates a zero level of innovation, and one represents the maximum level of innovation a producer achieves. This index reflects the average percentage of practices implemented by the producer. To calculate the InAI of each producer, the values of the innovation adoption index in each category are averaged using Equation 1[9].

$$InAI_i = \frac{\sum_{j=1}^{n} IAIC_k}{K} \text{ (Equation 1)}$$

Where $InAI_i$= innovation adoption index of the i-th producer; IAICik = adoption index of the i-th producer in the k-th category; K= total number of categories.

To be able to compare the $InAI_i$ *vs* the $InAI_{alt}$, judgments had to be made about the importance of innovation in honey production per hive. To exemplify an application of the AHP, the

$InAI_{alt}$ was created. The hierarchical model established in this factor is illustrated in Figure 1, where it is observed that the $InAI_{alt}$ is explained by seven criteria (health, artificial feeding, location, protective material for the hive, harvest, staff, and cleaning and hygiene) and, in turn, each of them is the result of the variables that constitute the subcriteria and their alternatives.

To determine the relative importance of each innovation, an evaluation process was carried out by a group of five experts in the field of beekeeping and innovation in this sector. These experts were selected due to their experience and practical knowledge in beekeeping, as well as their technical mastery of innovations and good production practices in the sector. The profile sought was one that encompassed several aspects fundamental to the study, including a solid understanding of the needs and challenges faced by the beekeeping production units. During the evaluation, the experts assigned a weight to each innovation, considering two main criteria: first, they weighted the contribution or importance of each innovation within the corresponding categories, and second, they used a scale of 1 to 9 to indicate the relative priority of an alternative over the options compared. On this scale, the value 1 indicates that both options are equally important for the object of study; in contrast, the value 9 indicates the higher priority of an alternative over the options compared. The details of the numerical criterion are specified in Table 2.

Table 2: Preference comparison scale

Value	Definition	Explanation
1	Equally important	Innovations contribute equally to productivity
3	Moderately important	Innovation contributes moderately to productivity
5	Strongly important	Innovation makes a strong contribution to productivity
7	Very strongly important	Innovation is more favored than the other; its predominance was demonstrated in productivity
9	Extremely important	Evidence unquestionably favors innovation over the other
2, 4, 6, 8	Intermediate values	They are used when an intermediate value cannot be defined between adjacent innovations

Source: Prepared by the authors, adapted from Saaty[11].

Once the comparison matrices were filled, a consistency analysis of the judgments issued by the experts was carried out following the procedure described by Zamudio Sánchez and Núñez Vera[14]; the matrices that were not consistent were reevaluated until consistency was achieved with a level of sample significance less than 0.05. Once the consistency of the assignment of values in the matrices was tested, the weights of each attribute or alternative were calculated considering the eigenvalue associated with the maximum eigenvalue of each comparison matrix following the procedure described by Saaty[11].

The two previous tasks were automated using the SAS® V9 tool to program the matrix calculations in dynamic and interactive conditions with the IML (Interactive Matrix Language) procedure, where auxiliary routines were programmed to generate the outputs that included the specific weights of each innovation or category.

In order to assess the congruence of the values obtained with the $InAI_{alt}$ with respect to variables of productive importance, a multiple linear regression model (Equation 2) was used to explain the yield recorded per hive as a function of the $InAI_{alt}$ in interaction with the size of the apiary. The number of hives that each interviewed beekeeper has was used for the grouping into clusters, dividing them into three groups (Cluster 1, 1-10 hives; Cluster 2, 11-20 hives; and Cluster 3, 21-32 hives). This exercise was contrasted with the one used by $InAI_i$. It is essential to mention that the decision to use the number of hives as a grouping criterion was based on its relevance within the regional beekeeping context, as well as its ease of measurement and management in the study. This choice allowed for a balanced and representative distribution of beekeeping production units, thus facilitating analytical comparison between different productivity levels and the adoption of innovations.

$E(Y_i/X = x_i) = \beta_1\chi_{1i} * Z_{1i} + \beta_2\chi_{1i} * Z_{2i} + \beta_3\chi_{1i} * Z_{3i}$ (Equation 2)

Where Yi: Yield per hive of the i-th producer; X1= $InAI_i$ or $InAI_{alt}$ of the i-th producer; Zji= 1 if the ith-producer belongs to the cluster j=1,2,3, and 0 otherwise.

The purpose of the regression model was fundamental for the evaluation of both the predictive and explanatory accuracy of the relationships between the variables, considering the $InAI_{alt}$ as an additional technique to more effectively capture the complexity of the data and the interactions between the variables. In addition, the $InAI_i$ values were graphically represented against the $InAI_{alt}$ values obtained in each category in order to show the differences between these indices.

Results and discussion

The average age of beekeepers was 39 yr; more than 20 % were under 26 yr of age, and the rest were under 55 yr of age, which allows to assume that beekeeping activity is in the hands of adults; although it is true that the average age coincides with what has been reported in other studies in Mexico[15-18], beekeeping in the study region shows a generational change where young people begin to resume this activity as an alternative source of income.

As for the average years of schooling, these were 8.8, a higher figure than that reported by Güemes *et al*[19] and Magaña *et al*[20] for other states of the Mexican Republic, who indicated an incomplete level of primary education.
The region has an average of 8 yr engaged in beekeeping. Nevertheless, other studies[21,22,23] reported an average of 16, 21, and 22 yr of beekeeping, respectively, higher than what was found in this region, which indicates that the activity is relatively young compared to the states of Jalisco, Yucatán, and Veracruz.

As for the weekly time spent on the activity, the average was 1.65 h, but the range varies from 1 to 3.5 h, depending on the number of hives the beekeeper has. This flexibility in working hours is because beekeeping does not require long work hours to obtain good results, making it an excellent complementary activity according to the beekeepers' perception.

Beekeeping in the region is closely linked to staple crops and wild vegetation areas. A total of 62 apiaries were identified, which together housed 757 hives. The municipalities that stand out for having the highest number of apiaries are Guadalupe and Acatlán de Osorio, with 21 and 16 apiaries, respectively, followed by San Pablo Anicano with 15 and San Pedro Yeloixtlahuaca with 10 apiaries.

Regarding the size of the beekeeping production units, it is observed that the average is 12.21 hives; however, there are variations, from a minimum of three to a maximum of 32. This range of sizes reflects the diversity in the scale of beekeeping production in the region, which may be influenced by factors such as resource availability, beekeepers' experience, and local market demand.

The primary source of income for beekeepers comes from agricultural activities, representing 57.17 % of the total, according to data that coincide with those reported in other works[19,22]. This data suggests a strong economic dependence on agriculture in the study region. In second place are remittances from the United States, a phenomenon that has also been documented[24], where it is mentioned that 80 % of the remittances that arrive in the state of Puebla benefit the inhabitants of the Mixteca region. Beekeeping ranks third as a source of income, being considered a complementary activity due to the seasonal nature of its production process. This characteristic can limit its economic contribution compared to agricultural activities and remittances. Nonetheless, some producers, such as technical advisors and veterinarians, find beekeeping a second source of income.

According to the World Bank[25], the diversification of income sources not only reduces vulnerability to possible fluctuations in a single source of income but also strengthens the capacity for financial resilience in the face of unexpected events, proving to be a key factor in promoting local economic development.

Table 3 shows the specific weights by category according to the type of InAI; as mentioned above, in the traditional $InAI_i$, both the value of each innovation and that of each category will always be the same. The overall $InAI_i$ was 54.14 %; that is, beekeepers are applying 17 of 32 technological innovations assessed for honey production, which means that few innovations have been adopted, leaving a margin to continue advancing in this regard. According to this methodology, the harvest category is the one that contributes the most to honey production (13.71 %).

Table 3: Specific weights and number of innovations (INOV) by category

Category	INOV (n)	%					
		$InAI_i$	Weight	$InAI_i$ weighted	$InAI_{alt}$	Weight	$InAI_{alt}$ weighted
Location	8	65.52	14.29	9.36	81.82	31.74	25.97
Health	7	36.87	14.29	5.27	52.57	29.15	15.32
Feeding	4	47.98	14.29	6.85	31.12	19.21	5.98
Materials	3	91.94	14.29	13.13	79.98	7.78	6.22
Harvest	2	95.97	14.29	13.71	76.86	6.87	5.28
Staff	4	27.42	14.29	3.92	51.55	2.77	1.43
Cleaning and hygiene	4	13.31	14.29	1.90	17.96	2.48	0.45
Total	32		100.00	54.14		100.00	60.65

$InAI_i$= Innovation Adoption Index; $InAI_{alt}$= Alternative Innovation Adoption Index.

On the other hand, according to the weights obtained through the AHP, the categories of location and health of the apiary contribute almost 61 % of the innovations for honey production. The relevance of these categories in beekeeping production entails several important implications. Firstly, it points out that the correct selection of the location of the apiary must consider variables such as the availability of flower sources, climatic conditions, and the presence of pesticide agents, as these can considerably influence honey production volumes. In addition, adopting health management innovations, including disease control and pest prevention, is crucial to safeguard the health and well-being of beekeeping colonies.

In this sense, several authors state that the productivity of honey is the result of a combination of several factors, including the density and quality of flowering, the natural physical environment, and health(26,27). Thanks to the richness of the natural resources available in the study region, the practice of artificially feeding (mainly sugar syrup) hives in times of scarcity is low (2.71 times/year). Nonetheless, Tucuch-Haas *et al*(28) mention that supplementary feeding increases the number of bees and the number of cells with capped brood, nectar-honey, and pollen.

Table 4 exemplifies the construction of the categories and how each innovation contributes a percentage to each of them. As stated, the location of the apiary is a category that accounts for 27.21 % of honey production, but within this category, distances of less than 1 km to the water source and the flowering area contribute 68 % to this category, which is why they are priority activities for the installation or management of an apiary; similar data were reported by other researchers[29].

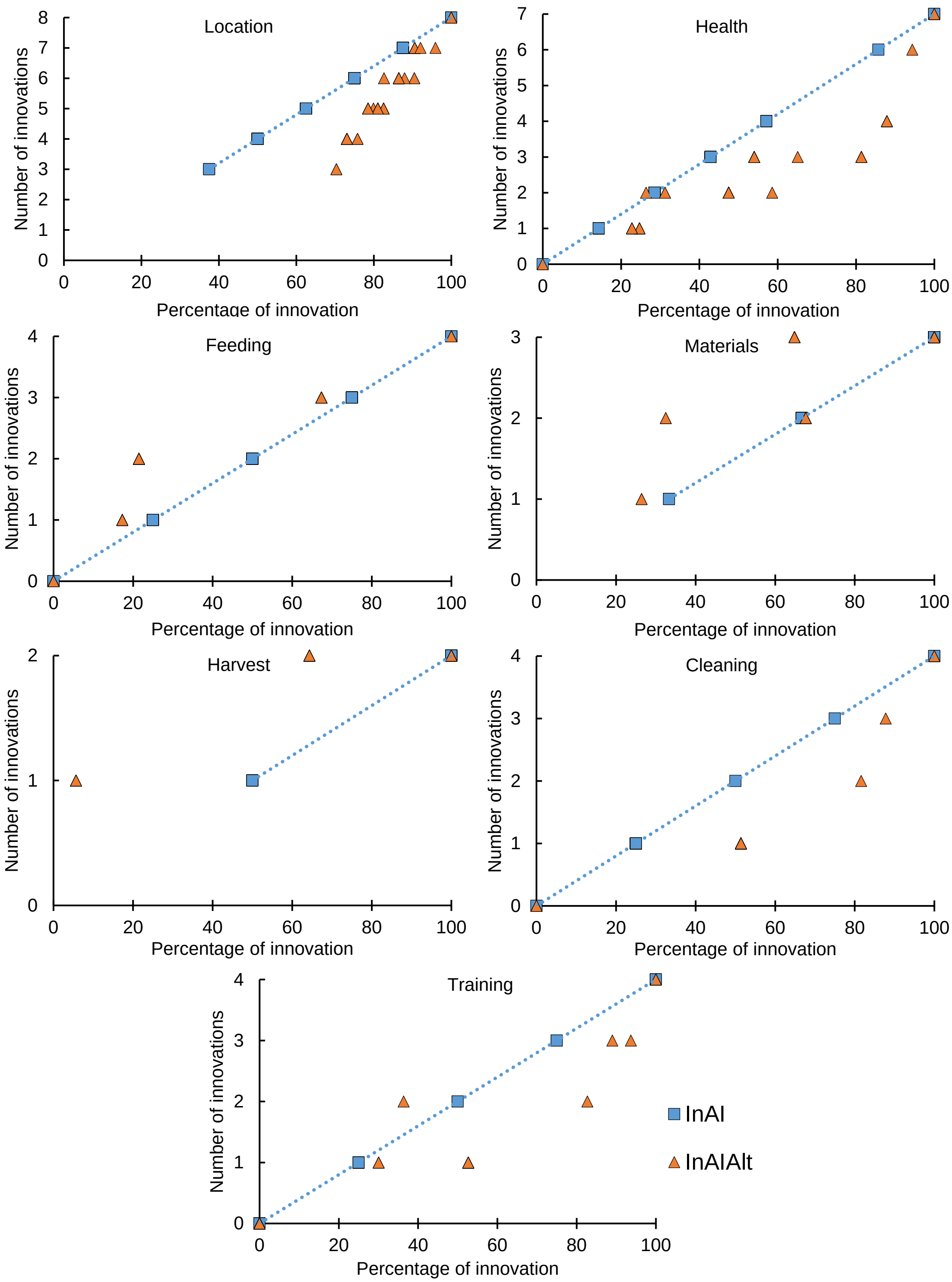
Table 4: Weight of the main innovations in honey production

Apiary location		**Health**	
Innovation	**%**	**Innovation**	**%**
Distance < 1,000 m to the nearest source of water	48.35	Inspection frequency ≤ 15 d	33.89
Distance < 1,000 m to the flowering area	19.69	Hive tool flaming before inspecting a hive	24.71
Minimum distance between hives ≥ 2 m	9.44	Mite control (*Varroa destructor*) (thymol)	22.78
Hives on a base ≥ 20 cm	7.95	Change of brood chamber frames 2/year	6.52
Apiary clean of weeds	5.44	Change of the queen every year	5.61
Knowledge of chemical application dates	4.10	Thymol removal 15 d before flowering	3.60
Distance to inhabited areas > 200 m	2.74	Logging	2.90
Distance > 400 m to human settlements	2.30		
Total percentage	100.0		100.00

Health is another fundamental pillar because poor sanitary management increases production costs and the mortality of bee colonies; keeping a hive strong translates into greater productive efficiency. Even though there are seven innovations within health, inspection frequency, hive tool flaming, and varroosis control contribute more than 80 % of this category, making them high-impact activities.

The $InAI_{alt}$ presented variations for different innovations (Figure 2); it can be observed that, for the same number of innovations, a different percentage of innovation can be obtained within each category (higher or lower) according to the weight obtained through the AHP, except for the extreme values that always maintain the same percentage (0 or 100) regardless of the number of innovations or the weight assigned by any methodology. This situation favors both researchers and producers in knowing the current level between one producer and another, even having the same number of innovations, because each one has different objectives and priorities in terms of innovation.

Figure 2: Comparison of the main categories of innovation that contribute to honey production



One of the advantages of using the AHP is that values can be assigned to innovations that, although they do not comply with what is set out in the manual of good practices, could have a value other than zero or be with a higher value without fully complying with what is required, as is traditionally done with the InAI methodology. To exemplify this situation, the graph of materials (Figure 2) shows that, despite meeting all three characteristics, the percentage of innovation is less than 100; this situation could be explained by the fact that, despite having the necessary materials to cover this category, their current condition may not be optimal for proper management in the apiary, but it cannot be completely ruled out because it is better to have this innovation in not so favorable conditions than not to have it.

About the $InAI_{alt}$ evaluation, Table 5 shows the general results. Both regressions (InAI and $InAI_{alt}$) show a significant overall test (<.0001) and the RMSE is around 3.4, meaning that both models are statistically relevant in explaining the behavior of yield per hive. Judging by the R^2 statistic, both models explain 69 % of the variability inherent in yield per hive.

Table 5: Result of the multiple regression model

		InAI				
	Parameter	**Coefficient**	**S.D.**	**t-value**	**Significance**	**VIF**
InAI	Yield/hive*Cluster 1 (1-10 hives) n=30	15.80	1.37	11.55	<.0001	1.75
$InAI_{alt}$		14.33	1.22	11.79	<.0001	2.07
InAI	Yield/hive*Cluster 2	18.69	1.44	12.94	<.0001	1.75
$InAI_{alt}$	(11-20 hives) n=19	16.68	1.25	13.37	<.0001	2.07
InAI	Yield/hive*Cluster 3	26.09	1.39	18.75	<.0001	1.75
$InAI_{alt}$	(21-32 hives) n=13	22.95	1.19	19.24	<.0001	2.07

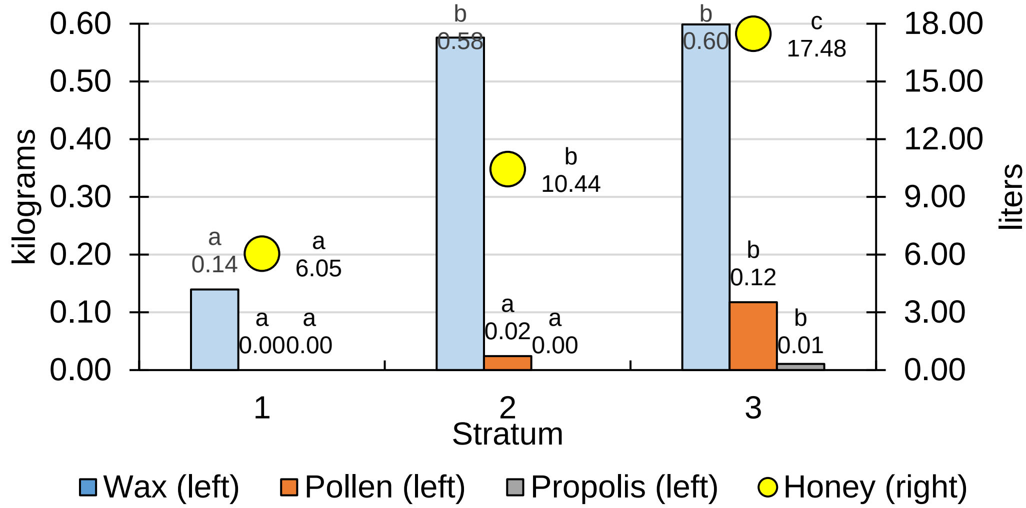
VIF= Variance inflation factor.

InAI general regression rest: F-value 217.48, *P*-value <.0001, R^2 0.652, RMSE 3.544.

$InAI_{alt}$ general regression test: F-value 229.29, *P*-value <.0001, R^2 0.668, RMSE 3.459.

It is also observed that the coefficients associated with InAI and $InAI_{alt}$ in each cluster are statistically significant (<.0001); that is, they are all non-zero; however, the standard errors associated with InAI are greater than $InAI_{alt}$, between 8 and 10 %. The estimated coefficients reveal a significant difference between the proposed and traditional models. This finding suggests that the expected yields in each cluster (small, medium, and large) are overestimated when the traditional method is used; in contrast, the proposed alternative produces estimate that are more adjusted to the analyzed reality. This discrepancy can be attributed to the proposed model minimizing errors, resulting in more accurate estimates (Figure 3). In addition, the new $InAI_{alt}$ could help to understand why stratum 3 producers can obtain more byproducts from the hive.

Figure 3: Average yield per hive in the Mixteca region of Puebla, Mexico



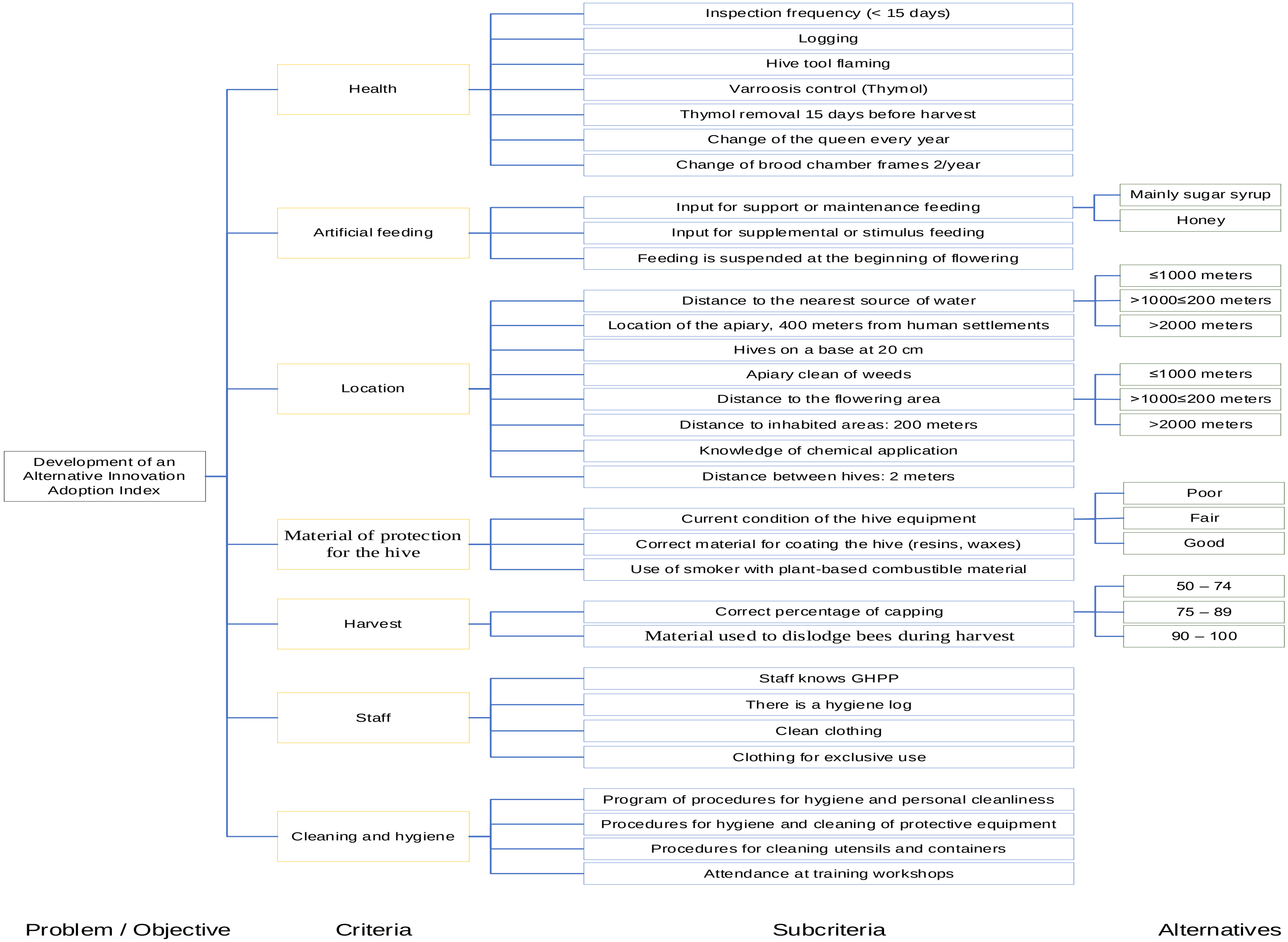
[abc] Means with different letters by column for the respective variable indicate significant differences (P<0.05).

Using $InAI_{alt}$ made it possible to identify the most relevant categories and practices in the field of beekeeping, which suggests a new way of planning and executing training and extension programs in this activity. By defining priority areas, beekeeper training can focus on crucial aspects such as hive health, feed management, and selecting the best site for the apiary. This approach allows beekeepers to concentrate on improving practices that have the greatest impact on bee health and productivity rather than trying to innovate in all aspects simultaneously. This strategy not only optimizes the available resources but also promotes a gradual and successful transition to more efficient and sustainable beekeeping methods.

Conclusions and implications

In the Mixteca region of Puebla, beekeeping is practiced mainly in small-scale units and usually as a complementary activity. Nevertheless, on the other hand, there is a productive potential due to its agroecological conditions, in addition to being a source of income with reduced working hours. The proposed $InAI_{alt}$ made it possible to identify the categories and innovations with the greatest contributions to honey production in the region of study based on the weights granted through the AHP, which allows adapting this methodology to different regions and production systems thanks to its adaptability, which only requires a database with the innovations that are to be evaluated in a production system and a panel of experts from the area to reach a result that is more conclusive with the reality of the region. It has been shown that the measurement of innovation includes not only technical and productive aspects but also environmental aspects; this holistic view allows for a more accurate assessment of the overall impact of innovation and its contribution to beekeeping development. The evaluation of the suitability of the $InAI_{alt}$ carried out through the regression models indicates that the results are consistent with those obtained in the InAI (fit of the models); however, the proposal produces estimates that are more accurate and consistent with the expected yields of the area. Therefore, it is proposed that for future research, regressions be carried out considering each of the byproducts of beekeeping to corroborate the model's scope. Finally, the proposed methodology exhibits sectoral and territorial flexibility, characterized by its versatility and adaptability, distinguishing it as an ideal instrument for implementation in multiple production scenarios. Consequently, its adoption would contribute to generating tangible improvements in terms of efficiency and quality in the operational sphere in order to have a better measurement of the process of adoption of innovations in the agricultural sector.

Figure 1: Hierarchical Model for obtaining the beekeeping InAI with the AHP



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