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Article

Decision-making model in ancestral knowledge management: The case of the Raicilla in Mexico

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Abstract: Ancestral knowledge is essential in the construction of learning to preserve the sense of relevance, transmit and share knowledge according to its cultural context, and maintain a harmonious relationship with nature and sustainability. The objective of this research is to study and analyze the management of ancestral knowledge in the production of the Raicilla to provide elements to rural communities, producers, and facilitators in decision-making to be able to innovate and be more productive, competitive, sustainable, and improve people's quality of life. The methodological strategy was carried out through Bayesian networks and Fuzzy Logic. To this end, a model was developed to identify and quantify the critical factors that impact optimally managed technology to generate value that translates into innovation and competitive advantages. The evidence shows that the optimal and non-optimal management of knowledge, technology, and innovation management and its factors, through the causality of the variables, permits us to capture the interrelationship more adequately and manage them. The results show that the most relevant factors for adequate management of ancestral knowledge in the Raicilla sector are facilitators, denomination of origin, extraction and fermentation, and government. The proposed model will support these small producers and help them preserve their identity, culture, and customs, contributing greatly to environmental sustainability.

Keywords: ancestral knowledge; knowledge management; Raicilla; Bayesian networks; fuzzy logic; Mexico; low-tech

1. Introduction

Knowledge and knowledge management are terms that, since the mid-1990s, have achieved increasing relevance in the literature focused on the analysis of the competitive advantages of organizations (Easterby, 2008; Manfredi, 2019). This has been influenced by the need at the individual and organizational level to manage the growing flows of information efficiently, the awareness of the importance of knowledge for the prosperity and survival of the organization, as well as the greater availability of information technologies to store it, distribute and manage it (CIDEC, 2000). Even though academic works usually address them simultaneously, these concepts are not always defined, nor do they explain their fundamental distinctions (Easterby, 2008).

In the case of ancestral knowledge, there is a threat to the transmission of this knowledge due to the changes caused by modernization, globalization, and migration. These transformations in the socioeconomic and cultural sphere directly impact the historical and cultural wealth associated with an agave distillate. In this sense, it is relevant to analyze the central processes necessary in the management of ancestral knowledge in the production of the Raicilla through a model to identify the variables with positive relevance that allow an understanding of the importance of preserving the fundamental elements to ensure sustainability and authenticity in Raicilla's production.

Raicilla is an artisanal drink like mezcal and tequila, which is produced from the distillation of agave. However, unlike the other two sectors, despite also having a designation of origin, this root sector is the smallest and presents the most problems. First, most producers enter the market vertically, and many sell their products in short-cycle channels. They need help with problems such as a shortage of raw materials, limited technical training, and lack of innovation in beverage processing. The value chain is poorly articulated, lacks internal cohesion, and individualism prevails. It is necessary to link all the actors involved to innovate commercial strategies and improve the value chain's performance to strengthen the distillate's presence in national and international markets (Moreno-Cardenas et al., 2024).

The management of ancestral knowledge is not just a practice but a value generator. Its oral traditions serve as the cultural backbone, ensuring the sustainability and development of indigenous cultures and regions (Moreno-Cardenas et al., 2024). Therefore, it is necessary to create an environment that favors the recognition and dissemination of ancestral knowledge and its management among companies, communities, producers, and other organizations such as universities and research centers to use knowledge as a resource—strategic combined with scientific knowledge (Mooreno-López et al., 2020).

Derived from the previous problem, the questions that guide this research are: What are the critical factors for adequate decision-making in the Raicilla Industry in Mexico for optimal management of ancestral knowledge? How can the Raicilla sector make better decisions that benefit all producers and rural communities?

The primary objective of this work is to provide crucial knowledge to decision-makers, guiding the development of public policies that support rural communities and small producers. Simultaneously, it contributes to the field by presenting an ancestral knowledge management model in a low-tech sector like Raicilla, potentially revolutionizing the industry's practices.

This work is organized into four sections. The first section addresses the theoretical framework with the main concepts of knowledge management, specifically ancestral knowledge. It also provides a very brief characterization of the Raicilla sector in Mexico. The second section presents the materials and methods for modeling construction based on Bayesian Networks (BNs) and fuzzy logic using TOPSIS. The third section exposes the results obtained by the Bayes Network and Fuzzy TOPSIS modeling. Finally, the fourth section presents the discussion and conclusions.

2. Theoretical framework

2.1. Knowledge and innovation management

According to Soualhia and Mejbri (2014), knowledge is a polysemic term whose meaning fluctuates depending on the context and the specific situation. Although interpretations are only sometimes clear-cut, oscillating between describing it as a justified true belief (Nonaka, 1995) or as an amalgamation of experiences, values, and contextual information (Davenport, 1998), there is some consensus in the literature about its importance as a crucial resource for organizations. The need to differentiate it from the notion of information is highlighted to understand its meaning better.

Knowledge is positioned as the most vital strategic resource for organizations regarding relevance. Therefore, their productive activities' effectiveness and competitiveness focus on efficiently integrating, coordinating, and increasing existing knowledge (Conner, 1996; Nonaka, 1995; Nonaka, 2000; Prévot, 2010).

Although in the field of knowledge management, there is a tendency to consider information and knowledge as synonyms, it is essential to recognize their differences (Sveiby, 2000). Information refers to data processed and presented through spoken language, graphical representations, or numerical tables. At the same time, knowledge implies significant links that people establish in their minds between the information and its application in action in a specific context (Dixon, 2001).

The knowledge creation approach emphasizes the need not to measure and mechanically manage existing knowledge but to focus on creating, retaining, and continuously applying new knowledge (Bayad and Simen, 2003; SFP, 2018). Inspired by Nonaka and collaborators, this approach highlights the existence of implicit and explicit knowledge, the interaction of which is essential to progress toward new knowledge.

The model of dynamic creation of organizational knowledge (SECI Model) is adopted to manage knowledge. This model involves social and collaborative processes as well as individual cognitive processes. Four types of operations stand out: socialization, externalization, combination, and internalization.

Socialization facilitates interaction between bearers of tacit knowledge, allowing the sharing of experiences and knowledge. Externalization identifies and formalizes tacit knowledge through dialogue and collective reflection. A combination brings together explicit knowledge associated with a specific objective. At the same time, internalization involves the employees appropriating this combined knowledge.

In this context, it is emphasized that the effectiveness of these operations requires promoting the organization and creating a context conducive to accumulating knowledge at the individual and collective levels. Top management plays a crucial role in conceptualizing the vision and defining the type of knowledge the organization aspires to, promoting the creation of new knowledge among all staff. Thus, effective knowledge management involves promoting specific operations and creating a favorable environment that favors the accumulation of knowledge at the individual and organizational levels.

2.2. Linking scientific knowledge and ancestral knowledge

According to Reyes-García et al. (2009), ancestral knowledge is all that knowledge possessed by Indigenous peoples and communities, transmitted mainly orally from generation to generation, from parents to children (vertical transmission), or through older or wise people (oblique transmission), within the framework of the dynamics of community coexistence that characterizes these Indigenous peoples.

The knowledge that these communities have preserved from generation to generation "corresponds with the worldview of the communities and has allowed the subsistence of their families" (Reyes-García et al., 2009) since they have generated in the communities, themselves from the "observation, systematic and coexistence with nature and are transmitted by oral tradition" (Gómez et al., 2020). The richness of ancestral knowledge lies in its diversity and deep connection with nature and the culture of the original communities. This knowledge ranges from traditional medicine and gastronomy to construction, forestry, agriculture, and environmental conservation techniques. According to Schaefer (2023), this knowledge allows ancestors' traditions to be remembered and honored and offers practical and sustainable solutions to contemporary challenges.

However, this knowledge, which is closely linked to the experience of practice itself, has been devalued by scientific institutions due to the difficulty in assessing its importance in terms of economic prosperity from a perspective focused on scientific and technological innovation and, consequently, in the high value of explicit knowledge (codified, formalized and quantified) (Sarauz Guadalupe, 2021). However, it is necessary to highlight that the intergenerational transfer of knowledge is a highly relevant strategy since these are considered technical knowledge (know-how, reasons for doing practices) and cognitive (intuitive, personalized), which are transmitted in a latent, diffuse, and informal way, as a way of reproducing and capitalizing on centuries-old and even millennia-old knowledge (Gómez and Gómez, 2006).

2.2.1. Importance of ancestral knowledge and its management

The ancestral knowledge of the communities above and its management, as stated by Ayala (2016), have greater relevance in economies such as Mexico due to the actual and imminent risks of the rupture and intergenerational disconnection of the chain of transmission of tacit knowledge, such as consequence mainly of two structural factors that increase these risks: on the one hand, a demographic transition (decrease in birth rates and aging of the population) that translates into a gradual decline in the experienced population that takes with it its know-how. The operational experience accumulated over time in the renewal of labor, with a considerable accumulation of tacit knowledge and practical knowledge by young people without a professional background, is based on explicit and codified knowledge supported by conventional information systems and by research and development (Ayala, 2016; Maluleka and Ngoepe, 2018).

Ancestral knowledge management involves recognizing and protecting this intangible heritage, ensuring its intergenerational transmission and integration into current practices. According to Greenwood and Lindsay (2019), Indigenous knowledge is fundamentally relational, linked to land, language, and ceremonies, which underlines the importance of keeping this cultural heritage alive through education and community practice (Carranza et al., 2021).

Regarding innovation, Carranza et al. (2021) stress that cultural diversity, nurtured by ancestral knowledge, is an inexhaustible source of creativity and progress. Recognizing and promoting this knowledge fosters social inclusion and participation and opens up new avenues for sustainable development. Cultural diversity broadens choice and contributes to economic growth and communities' intellectual and spiritual well-being.

Moreover, the history of knowledge is shaped by its geo-historical contexts, reinforcing the idea that each ancestral knowledge has an intrinsic value and place of origin that must be respected and preserved. Therefore, the management of ancestral knowledge is not only a matter of conservation but also of adaptation and innovation, using this knowledge as a basis for dealing with climate change and other global challenges (Sarauz Guadalupe, 2021).

2.2.2. Transfer of ancestral knowledge

Older adults mainly transfer knowledge to other generations, so increasing responsiveness among the population is indispensable to preserving this knowledge for future generations (Sarauz Guadalupe, 2021).

Ancestral knowledge is linked to the experience acquired with the exercise of a productive activity linked to daily practice, closely related to "know-how," to the context of those who generate and transmit knowledge, and to a collective construction composed of subjectivities formed by beliefs, myths, rites, intuitions, mental models and technical skills, which in sum represent the creative rationality of the collective. This implies that knowledge is transferred through its language, symbols, movements, times, and actions (Ayala, 2016; Sanipatin, 2023).

In this sense, the transmission of this knowledge does not follow a structured form according to objectives, times, or content. Still, it flows in an improvised and spontaneous way through the actions of daily activities and the accompaniment of older people, where knowledge is accumulated (Ayala, 2016). With the involvement of the new generations who, to a large extent, have had access to formal education (at least elemental) and the increasing use of information and communication technologies, there has been access to explicit knowledge integrating it into some phases of the production process. However, transmission occurs basically through the process of socialization and externalization.

Therefore, integrating ancestral knowledge in knowledge management and innovation is crucial for building a more inclusive and sustainable future. Protecting and promoting this knowledge is a shared responsibility that benefits all of humanity, enriching intercultural dialogue and strengthening practices that guarantee the sustainability of our societies (Martínez et al., 2022; Rodríguez et al., 2022).

2.3. Characterization of the Raicilla Sector in Mexico

The agave distillate industry in Mexico has experienced notable growth in recent years. In the case of Raicilla, exports increased by 307% from January to August 2022 compared to the previous year, reaching 261,637 dollars (IIEG, 2022).

Raicilla, an agave distillate native to the Costa-Sierra Occidental region of Jalisco and Nayarit, is produced using wild endemic agave plants in mountainous areas. According to the Official Gazette of the Federation (CMPR, 2022), it is a liquid with a unique aroma and flavor, influenced by the species of maguey used and the production process. Various qualities arise from soil type, topography, climate, water, producer (master raicillero), alcohol content, and yeasts.

In 2000, the Mexican Raicilla Promoter Council (CMPR) was established to make the drink visible and promote it nationally and internationally. The Council has

XX members, including raw material growers, beverage producers, and marketers. One of the most notable achievements of the Council is obtaining the General Declaration of Protection of the Denomination of Origin (DO) by the Ministry of Economy, achieved on 28 June 2019 (CMPR, 2022; DOF, 2019).

The DO classifies the Raicilla into two categories, considering the geographical differences and the types of agaves used: the Raicilla de la Costa and the Raicilla de la Sierra (see **Table 1**). The production of agave and Raicilla is restricted to 16 specific municipalities in two states of the Republic: Jalisco and Nayarit (DOF, 2019).

Mascota, according to IIEG data (IIEG, 2022), is the municipality with the most significant activity both in the cultivation of raw materials (40.4%) and in the production of the drink (31.3%). Mixtlán and Talpa de Allende follow. According to the same study, most Racially-producing units began activities after 2001 (31.3%), with a significant increase after 2016 (53.1%), linked to the creation of the Raicilla Promotion Council and the publication of the DO.

There are 28 Raicilla labels, among which Balam, El Real, and La Venenosa stand out. Innovative proposals have been introduced, such as Arre Corazón, a collaboration between Don Fernando and Memo Wulff (El Universal, 2022).

The Raicilla is valued locally for its flavor, low propensity to cause discomfort the next day, and beneficial health properties, such as healing wounds and preventing disease. Furthermore, the Raicilla is crucial in preserving biocultural memory and reinforcing local practices, identity, traditional trades, and the regional agave landscape (Toledo and Barrera, 2008).

3. Materials and methods

This research is exploratory, qualitative (descriptive), and quantitative, conducted through questionnaires, interviews, and a focus group. Fifteen questionnaires were collected, and seven interviews were conducted with experts, camerapersons, and producers using a semi-structured script. The questionnaire was applied to producers. Based on the opinions of experts and producers, a model was built to find the main processes required in the management of ancestral knowledge.

3.1. Analysis unit: Raicilla producers

The unit of analysis is the Raicilla producers, especially those associated with the Mexican Raicilla Promotion Council, which had 85 members at the time of the interviews in November 2022; a non-probabilistic convenience sampling was carried out that included 17% of the cases that is, 15 raicilleros. These were deliberately selected, considering the following inclusion criteria: having at least five years of experience in the activity, being willing to dialogue, and possessing knowledge about rootstock production.

Semi-structured interviews were conducted with raicilla producers individually, either in their production locations or, due to geographical dispersion, mainly before the beginning or at the end of one of the Mexican Raicilla Promoter Council sessions. Of the 15 producers interviewed, all are men: 14 are married with children, and one is single without children. Regarding academic degrees, four did not finish primary school, two studied secondary school, three completed high school, five have a bachelor's degree, and one has a postgraduate degree.

The ages range from five producers between 30 and 40 years, three between 41 and 50, four between 51 and 60, and three 61 or older.

Regarding place of origin, 11 are from the municipalities of the Denomination of Origin, three from Guadalajara, and one more from the municipality of Cocula.

Regarding the volume of annual Raicilla production, three produce less than 1000 L, three from 1000 to 2000 L, five from 2 thousand to 5 thousand, and four more than 5 thousand liters. With a minimum of 400 L per year and a maximum of 15 thousand liters per year.

The number of questionnaires collected and the number of samples analyzed to model a Bayes Network and subsequently perform the fuzzy logic analysis is part of the problem of access to experts on specialized topics. Experts' knowledge is not easily accessible for several reasons, including its scarcity and general inaccessibility. Additionally, only some sources of information exist about the topic under study.

The Bayesian Networks allow us to create a probability model by combining observed and recorded evidence based on common sense and real-world knowledge to establish the probability of instances using seemingly unlinked attributes.

We leverage the combined power of Bayesian networks and fuzzy logic to create true-to-life models based on Bayesian networks. These models are a solid basis for making informed decisions, even when information about Raicilla's production and marketing environment is unavailable.

Once the variables under study were defined, the Bayes Network was modeled. This model is based on the Bayesian Network development; it was constructed from four parent nodes called fathers and 16 child nodes (**Figure 1** and **Table 1**).

Table 1. Definition of the variables and nodes.

	Variable	Concept	Dimension
1	Government	The government's role is critical for small producers and rural and indigenous communities to link up with universities and research centers to improve production processes and ensure everyone has a better quality of life. The government must provide effective responses that guarantee their rights and strengthen their collective cultures and identities.	Optimum Regular Deficient
2	Ancestral knowledge	Techniques applied to the production of Raicilla based on ancient knowledge	Optimum Regular Deficient
3	Manufacture of Raicilla	Process production	Optimum Regular Deficient
4	Raicilla	Agave piña	Optimum Regular Deficient
5	Jima	Obtaining agave pineapples by cutting the roots and leaves of the agave	Optimum Regular Deficient
6	Cooking and grinding.	Heating the agave piñas in an earthen hole and crushing the cooked piñas with the help of a horse and a stone	Optimum Regular Deficient
7	Extraction and fermentation	Extraction of agave juice from fermentation	Optimum Regular Deficient
8	Distillation and refining	Heating of the agave juice for the condensation of the unrefined	Optimum Regular Deficient
9	Maturation and Packaging	Raicilla packaging	Optimum Regular Deficient
10	Product Management/process	It is the management model of all the company's value chain processes.	Optimum Regular Deficient
11	Universities and Research Centers Linkage/collaboration	The university-business link objective is to transfer knowledge and technology.	Yes/No
12	Facilitators: Government and universities	The universities and the State are the primary facilitators of the model's implementation and coordination among all the actors.	Optimum Regular Deficient
13	Business Structural Model	Design process to create a new business model in the market, with a value proposition that ensures a sustainable competitive advantage.	Optimum Regular Deficient
14	Business Strategy Model	It is the plan that presents the strategy and the value proposal.	Optimum Regular Deficient
15	Small producers	Producers of Raicilla from rural and Indigenous communities	Yes/No
16	Denomination of origin	The name of a geographical region of the country that designates a product originating from it and whose quality or characteristics are solely due to the geographical location (Martínez-Velasco and Terán-Bustamante, 2022).	Yes/No
17	Protection of Intellectual property	The legal safeguard of an organization's technological heritage.	Yes/No
18	Quality and Risk Management	A set of techniques to support decisions, considering uncertainty, the possibility of future events, and the effects on the agreed objectives.	Optimum Deficient
19	National and International markets	Potential buyers nationally and internationally	Optimum Regular Deficient
20	Knowledge Management	A systematic process of generating, documenting, disseminating, sharing, using, and improving the benefits of individual and organizational knowledge (Martínez-Velasco and Terán-Bustamante, 2023).	Optimum Regular Deficient

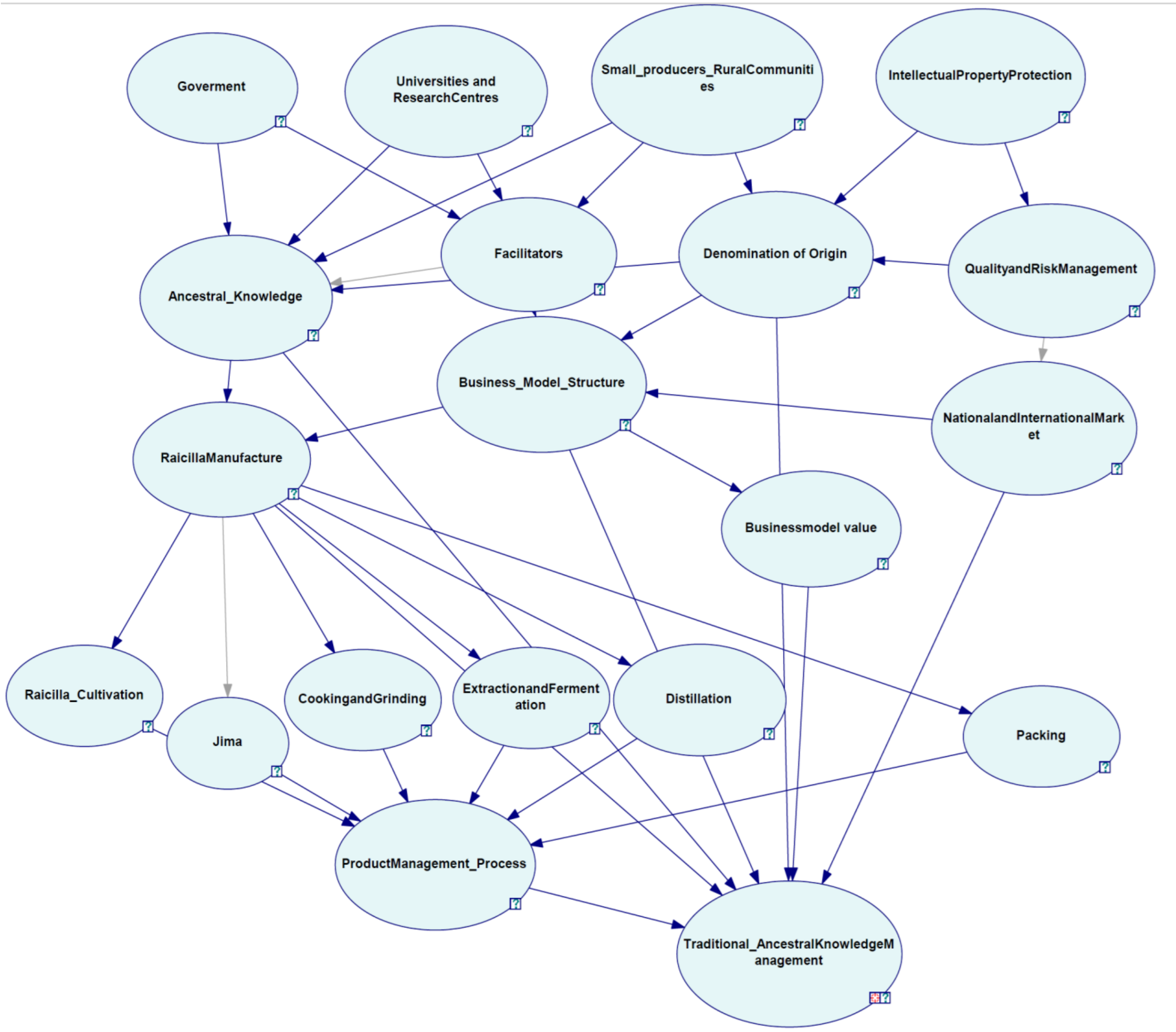

Figure 1. Raicilla Bayes Network Model.

3.2. Data analysis

The data analysis was done in two phases, a Bayes Network (BN) model and a Fuzzy Model based on the dataset generated by the predecessor BN model. First, based on the experts' knowledge, the problem was modeled using a Bayes Network (BN).

3.2.1. Bayes Network

Bayes Networks represent systems as a network of relations between variables from primary cause to final outcome; where the cause-effect assumptions are explicit, they are suitable for utilizing data and knowledge from different sources and handling missing data. BNs readily incorporate and explicitly represent uncertain information, and this uncertainty is propagated through to and expressed in the model outputs (Chen and Polino, 2012). The data extracted from the questionnaires applied to experts on the topic discussed are suitable for modeling using Bayes Networks. The aim is to identify the causality of the variables on the ancestral knowledge variable.

3.2.2. Fuzzy Model

As the second step, a Fuzzy Model was built considering the most relevant variables for the classification. Once the fuzzy logic model to be applied was established, the characteristics of the TOPSIS method were included. TOPSIS technique has been frequently used to solve decision-making problems, comparing all the alternatives included in the problem (Herrera et al., 2020). This method works based on the premise that the selected alternative should have the minimum distance to the Positive Ideal Solution (PIS) (this alternative minimizes the cost and maximizes the benefit) and the longest distance to the Negative Ideal Solution (NIS) (Nazim et al., 2022).

4. Results

The BN modeled in this work has four parent nodes, sixteen child nodes, and 38 arcs (**Figure 1**). Based on the patterns generated by the Bayes Network Model, a dataset composed of 1000 instances was generated, and the Ancestral Knowledge variable was selected as the target to classify the dataset and determine the variables´ relevance.

	Traditional_AncestralKnowledgeManagement	ProductManagement_Process	Packing	Distillation	ExtractionandFermentation	Jima	CookingandGrinding	Businessmodel value	Raicilla_Cultivation	RaicillaManufacture	Business_Model_Structure	NationalandInternationalMarket	Ancestral_Knowledge	Denomination of Origin	QualityandRiskManagement	Facilitators	IntellectualPropertyProtection	Small_producers_RuralCommunities	Universities and ResearchCentres	Goverment
Traditional_AncestralKnowledgeManagement																				
ProductManagement_Process	X																			
Packing		X																		
Distillation		X																		
ExtractionandFermentation		X																		
Jima		X																		
CookingandGrinding		X																		
Businessmodel value	X																			
Raicilla_Cultivation		X																		
RaicillaManufacture	X		X	X	X	X	X		X											
Business_Model_Structure	X							X		X										
NationalandInternationalMarket	X										X									
Ancestral_Knowledge	X									X										
Denomination of Origin	X										X		X							
QualityandRiskManagement												X		X						
Facilitators											X		X							
IntellectualPropertyProtection														X	X					
Small_producers_RuralCommunities													X	X		X				
Universities and ResearchCentres													X			X				
Goverment													X			X				

Figure 2. Adjacency Matrix for Raicilla Bayes Network Model.

The resulting adjacency matrix (**Figure 2**) for the Raicilla Bayes Network Model indicates the relationships established between the variables through the corresponding nodes and arcs. It is observed that the variable Raicilla Manufacture is related to seven variables. This variable has the most relationships between nodes, indicating that six child nodes, Raicilla Cultivation, Jima, Cooking, Extraction, Distillation, and Packing, are part of the manufacturing process and directly influence the Product Management Process. The last node, corresponding to the variable target, Traditional Ancestral Knowledge Management, is directly related to Raicilla Manufacture.

The Phases of the Fuzzy TOPSIS Method:

Phase 1: Decision matrix building.

This study has five criteria, generating five alternatives based on the fuzzy TOPSIS method. The following table shows each criterion and the weight assigned. (**Table 2**).

Table 2. Criteria attributes.

	Variable	Type	Weight
1	Ancestral Knowledge	+	(0.200, 0.450, 1.000)
2	Facilitators	+	(0.200, 0.400, 0.800)
3	Denomination of Origin	+	(0.200, 0.380, 0.760)
4	Extraction and Fermentation	−	(0.100, 0.200, 0.400)
5	Government	−	(0.100, 0.200, 0.340)

The fuzzy scale used in the model has three levels (**Table 3**). It was modeled considering the weights for each variable, where *L* means the Low value, *M* is the medium value, and *U* represents the Upper value.

Table 3. Criteria attributes.

Code	Linguistic terms	*L*	*M*	*U*
1	Optimum	1	2	3
2	Regular	0.6	0.8	2
3	Deficient	0.4	0.6	1

The alternatives were then evaluated using the criteria of five human experts. The experts' opinions were considered for each stage of this work. They are displayed through the evaluated alternatives presented in a decision matrix (**Table 4**). Several experts participated in this case, so the following matrix represents the experts' arithmetic mean.

Table 4. Decision matrix.

	Ancestral Knowledge	Facilitators	Denomination of Origin	Extraction and Fermentation	Government
Alternative 1	(1.000, 2.000, 3.000)	(0.600, 0.800, 2.000)	(1.000, 2.000, 3.000)	(1.000, 2.000, 3.000)	(0.400, 0.600, 1.000)
Alternative 2	(1.000, 2.000, 3.000)	(0.400, 0.600, 1.000)	(1.000, 2.000, 3.000)	(0.400, 0.600, 1.000)	(0.600, 0.800, 2.000)
Alternative 3	(0.600, 0.800, 2.000)	(1.000, 2.000, 3.000)	(0.600, 0.800, 2.000)	(0.400, 0.600, 1.000)	(0.400, 0.600, 1.000)
Alternative 4	(1.000, 2.000, 3.000)	(0.600, 0.800, 2.000)	(1.000, 2.000, 3.000)	(0.600, 0.800, 2.000)	(0.400, 0.600, 1.000)
Alternative 5	(1.000, 2.000, 3.000)	(0.600, 0.800, 2.000)	(0.600, 0.800, 2.000)	(0.400, 0.600, 1.000)	(0.600, 0.800, 2.000)

The next step implies creating the normalized decision matrix, which considers the positive and negative ideal solutions.

Phase 2: Create the normalized decision matrix

Founded on the positive and negative ideal solutions, the following relation can calculate a normalized decision matrix:

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right);\ c_j^* = \max_i c_{ij};\ \text{Positive ideal solution.}$$

$$\tilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right);\ a_j^- = \min_i a_{ij};\ \text{Negative ideal solution.}$$

The normalized decision matrix is shown in **Table 5**.

Table 5. Normalized decision matrix.

	Ancestral Knowledge	**Facilitators**	**Denomination of Origin**	**Extraction and Fermentation**	**Government**
Alternative 1	(0.333, 0.667, 1.000)	(0.200, 0.267, 0.667)	(0.333, 0.667, 1.000)	(0.133, 0.200, 0.400)	(0.400, 0.667, 1.000)
Alternative 2	(0.333, 0.667, 1.000)	(0.133, 0.200, 0.333)	(0.333, 0.667, 1.000)	(0.400, 0.667, 1.000)	(0.200, 0.500, 0.667)
Alternative 3	(0.200, 0.267, 0.667)	(0.333, 0.667, 1.000)	(0.200, 0.267, 0.667)	(0.400, 0.667, 1.000)	(0.400, 0.667, 1.000)
Alternative 4	(0.333, 0.667, 1.000)	(0.200, 0.267, 0.667)	(0.333, 0.667, 1.000)	(0.200, 0.500, 0.667)	(0.400, 0.667, 1.000)
Alternative 5	(0.333, 0.667, 1.000)	(0.200, 0.267, 0.667)	(0.200, 0.267, 0.667)	(0.400, 0.667, 1.000)	(0.200, 0.500, 0.667)

Phase 3: Weighted normalized decision matrix creation

Taking into account the weights of each criterion, the weighted normalized decision matrix is computed by multiplying the weight of the criteria in the normalized fuzzy decision matrix through the equation:

$$\tilde{v}_{ij} = \tilde{r}_{ij}.\tilde{w}_{ij}$$

where $\tilde{w}_{ij}$ represents the weight of the criterion c_j.

Table 6 illustrates the weighted normalized decision matrix.

Table 6. The weighted normalized decision matrix.

	Ancestral Knowledge	**Facilitators**	**Denomination of Origin**	**Extraction and Fermentation**	**Government**
Alternative 1	(0.067, 0.300, 1.000)	(0.040, 0.107, 0.533)	(0.067, 0.253, 0.760)	(0.013, 0.040, 0.160)	(0.040, 0.133, 0.340)
Alternative 2	(0.067, 0.300, 1.000)	(0.027, 0.080, 0.267)	(0.067, 0.253, 0.760)	(0.040, 0.133, 0.400)	(0.020, 0.100, 0.227)
Alternative 3	(0.040, 0.120, 0.667)	(0.067, 0.267, 0.800)	(0.040, 0.101, 0.507)	(0.040, 0.133, 0.400)	(0.040, 0.133, 0.340)
Alternative 4	(0.067, 0.300, 1.000)	(0.040, 0.107, 0.533)	(0.067, 0.253, 0.760)	(0.020, 0.100, 0.267)	(0.040, 0.133, 0.340)
Alternative 5	(0.067, 0.300, 1.000)	(0.040, 0.107, 0.533)	(0.040, 0.101, 0.507)	(0.040, 0.133, 0.400)	(0.020, 0.100, 0.227)

Below are the calculations performed to obtain the optimal conditions to obtain the best result for the target variable.

Phase 4: The fuzzy positive ideal solution (FPIS, A^*) and the fuzzy negative ideal solution (FNIS, A^-) determination

The FPIS and FNIS of the alternatives are stated as follows:

$$A^* = \{\tilde{v}_1^*, \tilde{v}_2^*, \dots, \tilde{v}_n^*\} = \{(|i \in B), (|i \in C)\}$$

$$A^- = \{\tilde{v}_1^-, \tilde{v}_2^-, \dots, \tilde{v}_n^-\} = \{(|i \in B\ ), (|i \in C)\}$$

where $\tilde{v}_i^*$ is the max value of i for all the alternatives, and $\tilde{v}_1^-$ is the min value of i for all the alternatives. The B and C are the positive and negative ideal solutions, respectively.

Table 7 displays the positive and negative ideal solutions.

Table 7. The positive and negative ideal solutions.

	Positive ideal	Negative ideal
Ancestral Knowledge	(0.067, 0.300, 1.000)	(0.040, 0.120, 0.667)
Facilitators	(0.067, 0.267, 0.800)	(0.027, 0.080, 0.267)
Denomination of Origin	(0.067, 0.253, 0.760)	(0.040, 0.101, 0.507)
Extraction and Fermentation	(0.013, 0.040, 0.160)	(0.040, 0.133, 0.400)
Government	(0.020, 0.100, 0.227)	(0.040, 0.133, 0.340)

The distance between each alternative indicates the ranking for the proposed solutions computed in the next phase.

Phase 5: Computing of the distance between each alternative and the fuzzy positive ideal solution A^* and the distance between each alternative and the fuzzy negative ideal solution A^-.

The length separating each alternative and the FPIS and the distance between each of them and the FNIS are obtained as follows:

$$S_i^* = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^*),\ i = 1, 2, \ldots, m$$

$$S_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-),\ i = 1, 2, \ldots, m$$

The distance (d) between two triangular fuzzy numbers (a_1, b_1, c_1) and (a_2, b_2, c_2), is calculated as follows:

$$d_v(\widetilde{M}_1, \widetilde{M}_2) = \sqrt{\frac{1}{3}[(a_1 - a_2)^2 + (b_1 - b_2)^2 + (c_1 - c_2)^2]}$$

Note that $d(\tilde{v}_{ij}, \tilde{v}_j^*)$ and $d(\tilde{v}_{ij}, \tilde{v}_j^-)$ are crisp numbers.

Table 8 indicates the distance between positive and negative ideal solutions.

Table 8. Distance from positive and negative ideal solutions.

	Distance from the positive ideal	Distance from the negative ideal
Alternative 1	0.249	0.695
Alternative 2	0.477	0.46
Alternative 3	0.609	0.327
Alternative 4	0.32	0.626
Alternative 5	0.501	0.443

The ranking indicated in **Table 9** shows the results signaling their degree of ideality for the solutions.

Phase 6: Computation of the closeness coefficient and ranking of alternatives.

The closeness coefficient of each alternative is computed as follows:

$$CC_i = \frac{S_i^-}{S_i^+ + S_i^-}$$

The most suitable alternative is closest to the FPIS and farthest from the FNIS. The table below depicts each alternative's closeness coefficient and its ranking.

Table 9. Closeness coefficient.

	C_i	Rank
Alternative 1	0.736	1
Alternative 2	0.491	3
Alternative 3	0.349	5
Alternative 4	0.661	2
Alternative 5	0.47	4

Figure 3 portrays the closeness coefficient of each alternative, meaning that alternative 1 provides the best solution. All other options regard the same variables: ancestral knowledge, facilitators, designation of origin, extraction and fertilization, and government. The most suitable combination of variables to acquire the optimal result of the target variable is found in alternative 1, where the highest values correspond to ancestral knowledge, denomination of origin, and extraction and fermentation.

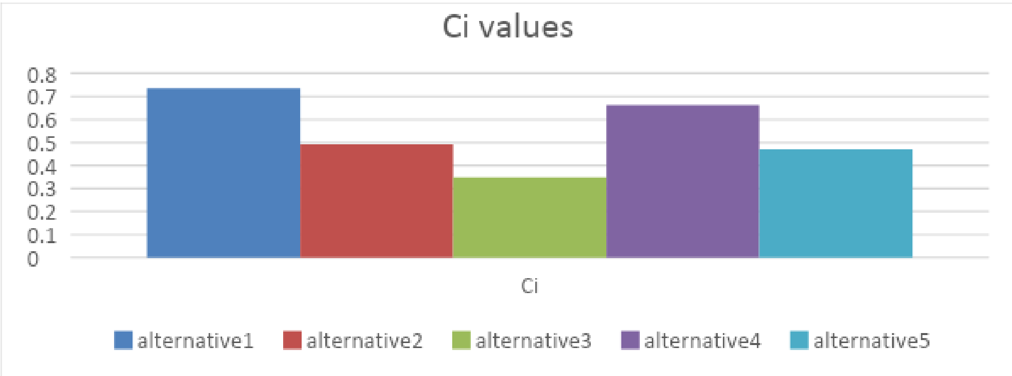

Figure 3. Closeness coefficient graph.

Figure 4 presents each variable's values in various combinations as an explicit representation of previously explained alternatives. Ten possible combinations of variables are shown. The best combination is indicated with a red box corresponding to the previous alternative.

Next, the relationship between pairs of variables is analyzed in pairs, where the influence that each of them has on the horizontal axes to reach the target variable, shown on the vertical axis, can be seen. This analysis is about alternative 1, which indicates the best combination of variables; if the ancestral knowledge variable takes values in the range [0.5, 0.9], the values of the Facilitators variable do not have a substantial influence on the target variable Traditional Ancestral Knowledge Management (TF_KM) reaches the highest values. This indicates that the most influential variable is ancestral knowledge (**Figure 5**).

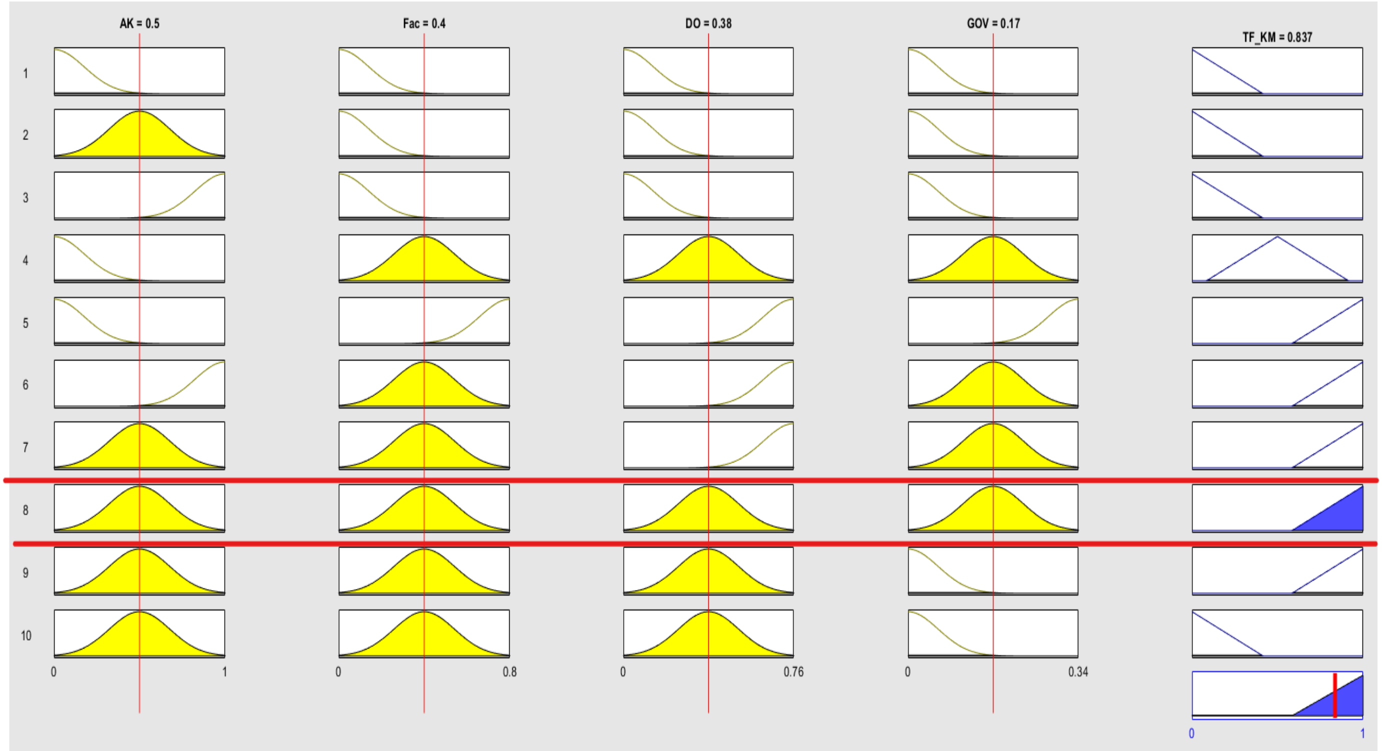

Figure 4. Values for each of the variables to reach the ideal solution.

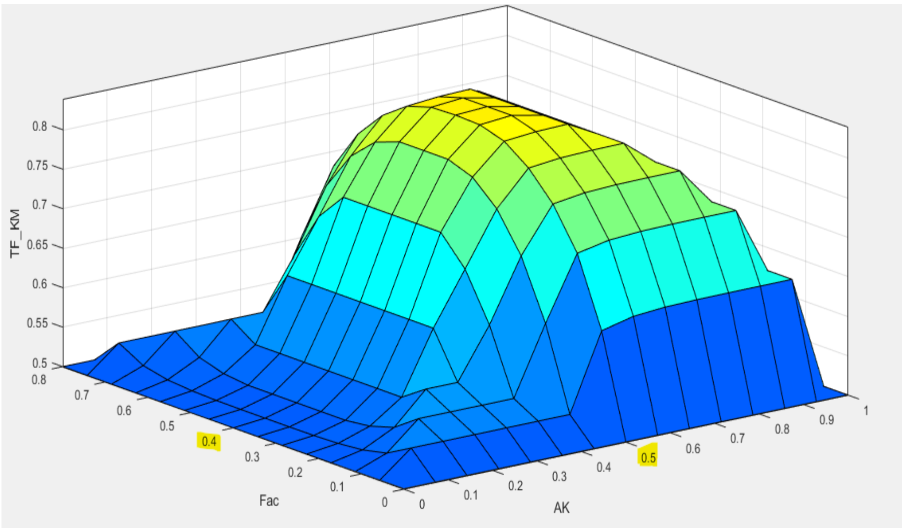

Figure 5. Facilitators vs. ancestral knowledge variables.

According to the results shown in alternative 1, the relationship between the variables denomination of origin (DO) and ancestral knowledge (AK) is directly proportional. It is observed that values in the range [0.3, 1.0] and [0.2, 0.75] for AK and DO, respectively, allow the optimal value for the objective variable (TF_KM) to be reached (**Figure 6**).

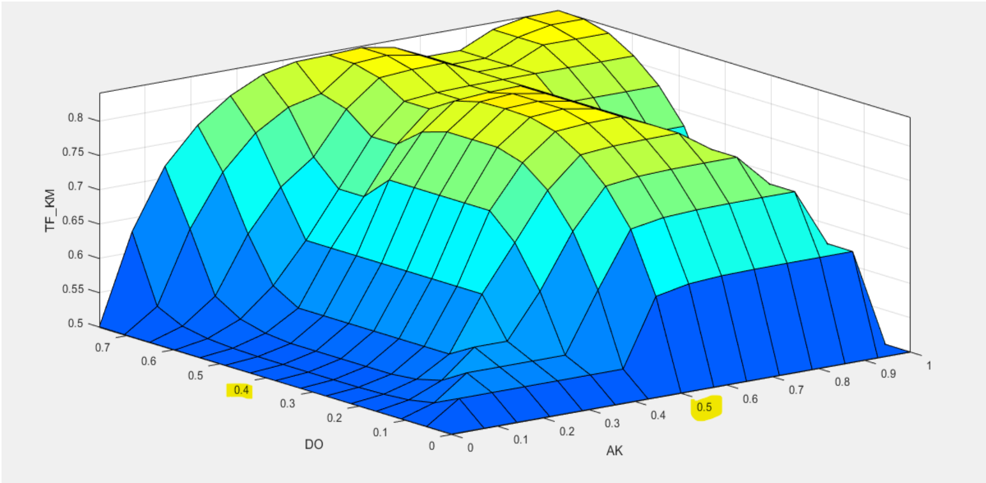

Figure 6. Denomination of origin vs ancestral knowledge variables.

Thus, the relationship between the variables Government (GOV) and Ancestral Knowledge (AK) indicates that AK is the most relevant variable, with values in the range [0.5, 1.0]. This allows the maximum value to be reached for the target variable (TF_KM) even if the GOV variable has values in the range [0.15, 0.25] (**Figure 7**).

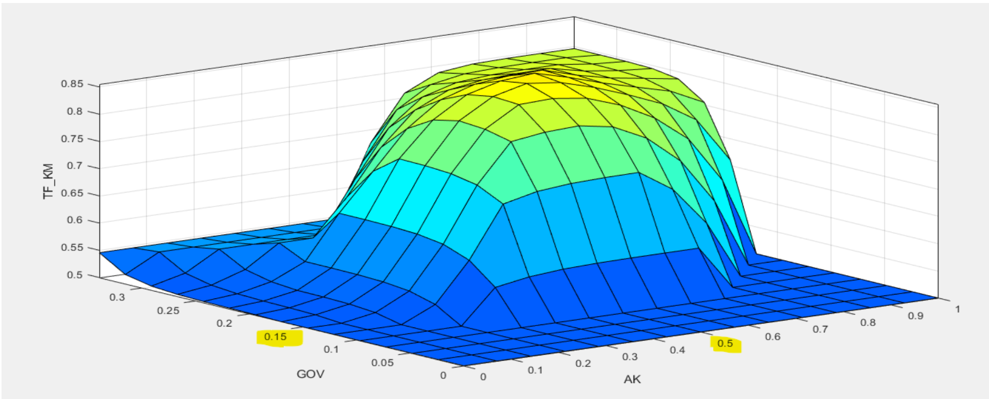

Figure 7. Government vs. ancestral knowledge variables.

The most relevant variables to obtain the best results for the target variable are determined based on the classification process. ReliefF is a classification algorithm that measures the ability of an attribute or variable to distinguish between classes in similar data instances. ReliefF is part of an algorithm family that is efficient at detecting univariate effects and two-way interactions; they scale linearly well with the number of features but quadratically with the training number of the choice. Instance neighbors are critical to the Relief algorithm's family success, setting these methods apart from other feature selection approaches. The individual feature weights generated by the ReliefF algorithm can guide subsequent machine learning methods, such as function weighting (Urbanowicz et al., 2018).

Consequently, the most positively relevant variables (**Table 10**) are Ancestral Knowledge, Facilitators, and Denomination of Origin. Additionally, it is observed that the viable ones with negative influence are Extraction and Fermentation, as well as Government. The most positively and negatively influential variables have been included to consider the pros and cons of achieving the best value for the target variable.

Table 10. Variable's relevance.

#	Variable	ReliefF Value
1	Ancestral Knowledge	0.083
2	Facilitators	0.063
3	Denomination of Origin	0.045
4	Business Model Structure	0.039
5	Jima	0.031
6	Raicilla Manufacture	0.030
7	Universities and Research Centers	0.029
8	Raicilla Cultivation	0.024
9	Distillation	0.023
10	Product Management Process	0.021
11	Intellectual Property Protection	0.018
12	Quality and Risk Management	0.017
13	Business model value	0.016
14	Packing	0.015
15	Cooking and grinding	0.007
16	Small producers Rural Communities	−0.001
17	National and International Market	−0.010
18	Extraction and Fermentation	−0.011
19	Government	−0.023

The combination to achieve the best possible values for the target variable (Traditional Ancestral Knowledge Management) was established from the Raicilla Bayes Network Model. This model indicates that 91% was reached for the state "Optimum" if the variables selected as the most influential have the values of 88% for the Government variable in its state "Optimum," 90% for the Facilitators variable in the state "Optimum," and 95% for Denomination of Origin for "Yes" state (**Figure 8**).

The next step proposed in this work is generating a fuzzy logic model, where the most relevant variables are considered positively and negatively to achieve the best result for the target variable (**Figure 9**). When applying the Mamdani inference method, the following steps are done: defining a set of fuzzy rules, fuzzifying the inputs by using the input membership functions, mixing the fuzzy inputs according to the fuzzy rules to establish a rule strength, finding the consequent rule by combining the rule strength and the output membership function, combining the results to obtain an output distribution, and blurring the sharp output distribution. Mamdani systems have proven helpful in approximating and controlling functions (Martínez-Velasco et al., 2023), offering interesting potential applications in the social sciences. They are a deductive logical inference tool to study, through simulation, the consequences and behavior of a model defined by IF-THEN rules.

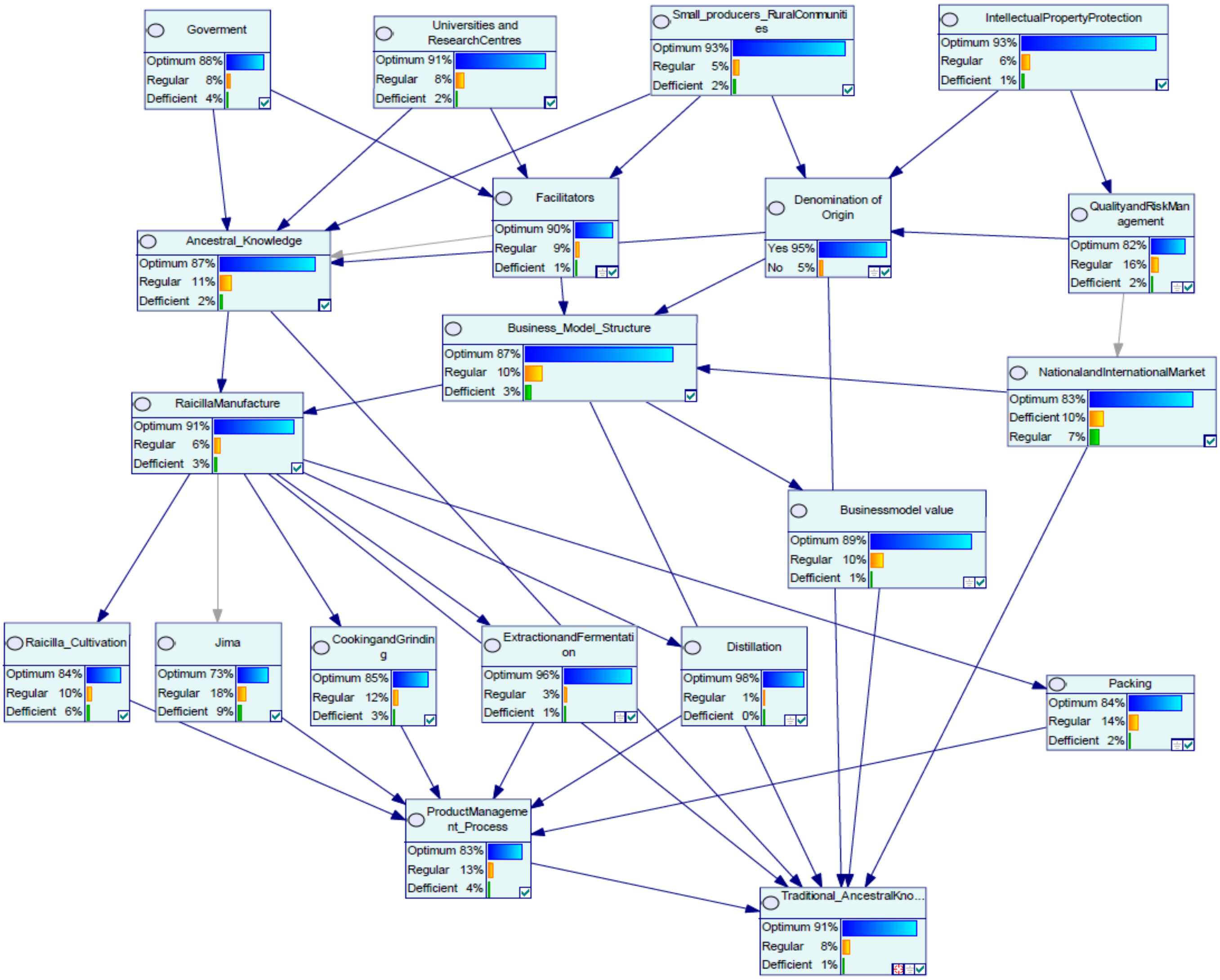

Figure 8. Bayes network probabilities for the best results to the target variable: Traditional ancestral knowledge.

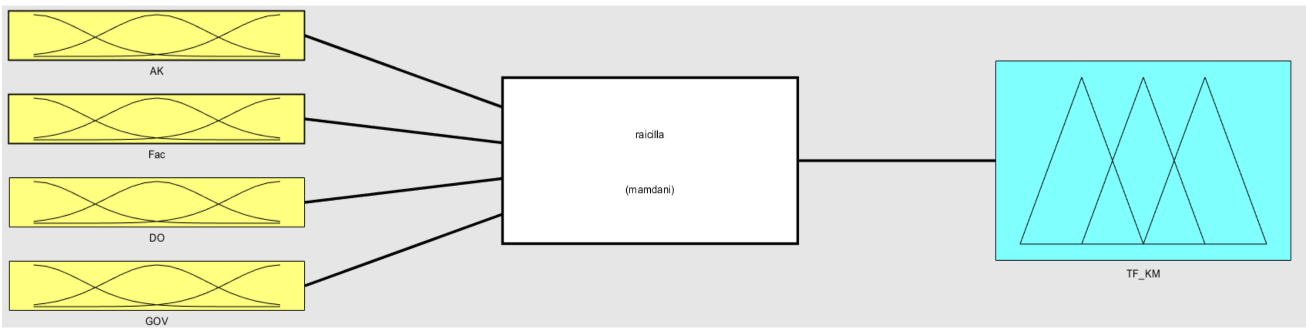

Figure 9. Selected features new dataset to fuzzy logic analysis.

Once the fuzzy logic model to be applied was established, the characteristics of the TOPSIS method were included. TOPSIS is based on the premise that the most outstanding solution has the shortest distance from the positive-ideal solution and the longest from the negative-ideal one. Alternatives are ranked using an overall index calculated based on the distances from the ideal solutions.

In this way, the results support the premises that indicate that ancestral knowledge and the designation of origin are the variables that positively influence the value the target variable achieves. Also, it should be noted that the variables that influence negatively for the same purpose are Facilitators and government.

The results include the characteristics of the Raicilla production process in Mexico, a core component of the model's development.

4.1. Sowing of the raw material: Raicilla as an organic product

According to the geographical region where it is grown and the types of agaves that are obtained, there are two types of Raicilla, these are:

1) The Raicilla de la Costa is made with the agaves Angustifolia How and Rhodacantha.
2) The Raicilla de la Sierra is made with the agaves Maximiliana Baker, Inaequidens Koch, and Valenciana.

4.2. Production: Raicilla production process

The production process of Raicilla is similar to that of other agave distillates, covering at least six stages: agave harvesting, cooking, milling, fermentation, distillation, and bottling. However, for this particular case, according to the Designation of Origin and the draft of the Official Mexican Standard, there are three categories of Raicilla. For each of them, differences are established in the production process. The main differences lie in the tool used, the fuel type, and the material from which the vessels are made.

1) Raicilla: Its elaboration must comply with at least the following five stages and equipment:

   a) Jimado: Cutting the leaves (stalks) to magueys or mature agaves.

   b) Firing: firing heads in well, masonry, or autoclave ovens.

   c) Milling: tahona, Egyptian or Chilean mill, ripper, trapiche, or mill train.

   d) Fermentation: wooden containers, masonry basins, or stainless-steel tanks.

   e) Distillation: stills, continuous, discontinuous distillers, or copper or stainless-steel columns.

2) Artisanal Raicilla: Its elaboration must comply with at least five stages and equipment:

   a) Jimado: Cutting the leaves (stalks) to magueys or Agaves.

   b) Cooking: cooking maguey heads in a pit or elevated masonry ovens heated with gas or wood.

   c) Milling: with a mallet, tahona, Chilean or Egyptian mill, trapiche, or blow ripper.

   d) Fermentation: cavities in stone, soil or trunk, masonry basins, wooden or clay containers, and animal skins, whose process includes the maguey fiber (bagasse).

   e) Distillation: with direct fire in copper boiler stills or clay pot and clay, wood, copper, or stainless steel montera up to 500 L; the process may include the fiber of the maguey bagasse).

3) Raicilla Ancestral Tradition: Its elaboration must comply with at least the following stages and equipment:

   a) Cooking: cooking agave or maguey heads in well or masonry ovens.

   b) Milling: with a mallet on a canoe or wooden basin, tahona, Chilean or Egyptian mill.

c) Fermentation: cavities in stone, soil or trunk, masonry basins, wooden or clay buckets, and skins of various animals, where the process must include the maguey fiber (bagasse).

d) Distillation: Direct fire produced with wood in clay pots and clay or wood montera. The process must include the fiber of the maguey (bagasse) (DOF, 2019).

4.3. Transfer of ancestral knowledge in the Raicilla sector in Mexico

Social, economic, and cultural changes resulting from modernization, globalization, and migration threaten the transmission of ancestral knowledge.

However, an agave distillate's historical and cultural richness must be a socio-ecological interpretation of the agri-food culture that includes material and immaterial aspects (Lucio, 2020).

5. Discussion and conclusions

The context where Raicilla is produced is complex; the viability and permanence of this artisanal distillate can only be maintained if the germplasm reservoirs are conserved, if its producers continue to safeguard the know-how surrounding the traditional distillate beyond official standards and of the denominations of origin and conserving their ancestral knowledge that gives life to their environment. Therefore, the raicilleros will have to rethink the path to follow, which without a doubt should be a combination of the preservation of biocultural memory (Toledo and Barrera, 2008) of which they are carriers, and on the other hand, business culture, official standards, and globalization, since the latter seem to be part of the changes for producers (Nuño and Navarro, 2021; Nava-Cárdenas, 2023).

This analysis shows that the variables with the most significant positive relevance, Ancestral Knowledge and Designation of Origin, have a weight that allows their influence to be much more potent than those with negative influence: extraction, Fermentation, and Government. In this way, the critical factors to consider for the optimal management of ancestral Knowledge of Raicilla production are the variables that have been found most positively relevant to the target variable.

In practice, it would be desirable for all five variables to have a positive influence. However, this combination of variables makes it possible to obtain good results for the target variable (Traditional Ancestral Knowledge Management).

Consequently, it is necessary to consider actions that allow conserving and applying good practices based on ancestral Knowledge and protecting the areas that have given the Raicilla the Designation of Origin.

The fact that the study is based on interviews and surveys conducted at a specific time makes it cross-sectional, which is one of the limitations as it may not fully capture seasonal variations in the process and key phases of the product chain. This temporal limitation may also leave out the collection of some of the traditional knowledge held by the master raisin farmers, and therefore not be able to achieve a broad coverage of this knowledge and the essence of the various phases of transferring and managing it. To overcome these limitations, it is advisable to carry out longer and broader studies that include different moments of the process under a framework that guarantees the protection of ancestral knowledge and respects the cultural practices involved.

The proposed model seeks to support these small producers by promoting appropriate public policies. This will preserve their identity, culture, and customs, which will contribute greatly to environmental sustainability, which is today a great concern in producing distillates in an artisanal way.

In future works, specific interventions proposed by experts could be simulated in the problems that mainly affect the production of artisanal distillates through probabilistic models such as Bayes Networks to carry out experiments that allow the appropriate interventions to be proposed at the right time to improve conditions. in the production of Raicilla.

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