www.editada.org

International Journal of Combinatorial Optimization Problems and Informatics, 17(1), Jan-April 2026, 411-417. ISSN: 2007-1558.
https://doi.org/10.61467/2007.1558.2026.v17i1.1182

Toward innovative smart agroalimentary solutions: A pilot optimization algorithm for selecting Oaxaca cheese with nutritional constraints.

Cristina Salas-Vargas [1,2,3], *Randy Alexis Jiménez-Jiménez* [2], *Mauricio Miguel-Estrada* [2,*], *Valentín Efrén Espinosa-Ortiz* [2]

[1]Universidad Politécnica de Atlacomulco. Carretera Atlacomulco San José Toxi Km. 5 Santo Domingo Shomejé, Atlacomulco de Fabela, 50465, Estado de México, México.

[2] Facultad de Medicina Veterinaria y Zootecnia, Universidad Nacional Autónoma de México (UNAM). Ciudad Universitaria, Av. Universidad #3000, Colonia, C.U., Coyoacán, 04510 Ciudad de México

[3]Tecnológico de Estudios Superiores de San Felipe del Progreso (TESSFP). Avenida Instituto Tecnológico S/N, Ejido, Tecnológico, 50640 San Felipe del Progreso, Méx.

E-mails: [*]Corresponding: mauriciome@fmvz.unam.mx
cristina.salas@upatlacomul co.edu.mx, randy-alexis@fmvz.unam.mx, veoee1@hotmail.com.

Abstract. This work presents a combined analysis of the physicochemical characterisation of traditional and commercial Oaxaca cheeses, together with a pilot combinatorial optimisation study using a multi-objective optimisation algorithm. Cheeses that best meet nutritional content standards and regulatory restrictions were selected. Six samples were analysed for nutritional composition, including moisture, protein, and fat, using methods established by the Association of Official Analytical Chemists (AOAC). The field data were used to formulate a linear programming model with constraints derived from current regulations (COFOCALEC 733-2013), which concurrently maximises protein and fat content while minimising moisture. The results indicate that traditional cheeses contain average protein and fat contents of 21.7% and 25.4%, respectively, exceeding those of commercial cheeses (17.14% and 21.2%). The proposed algorithm was tested in a real case study, where it selected traditional cheeses on the basis of their higher nutritional value, as defined by the objective function. This optimal cheese selection methodology could be applied to problems involving extensive databases (Big Data) to support the definition of physicochemical characteristics relevant to the quality assessment of Oaxaca cheeses.

Keywords: Combinatorial optimization, Oaxaca cheese, nutritional quality, linear programming, artisanal agroindustry.

Article Info
Received July 13, 2025
Accepted August 12, 2025

1 Introduction

Agricultural activities face challenges in decision-making for responsible resource management due to factors such as market price fluctuations, the variability of raw materials resulting from climate change issues, which can generate uncertainty in the production process. (Mayorga Castañeda et al. 2012). Quality and management standards for primary products are presented as tools to address these challenges and promote more informed and effective decision-making; however, for traditional or small-scale products, this aspect remains unclear, and alternative methods are being explored to add value to these products. (Aguilar Criado, Sacco dos Anjos, and Velleda Caldas 2011).

Standards-based quality management systems have been promoted as a fundamental way to ensure the sustainability and long-term success of companies (Rabinowicz 2018). Standards such as ISO 9001, ISO 14001, ISO 45001, ISO 50001 support the continuous improvement of systems, and their purpose is to meet global standards and the satisfaction of the demands and expectations of certain types of costumers, which in turn drives competitiveness and operational efficiency and serve as tools to face complex challenges in decision-making. (Reyes Chacón, Cadena López, and Rivera González 2021)

To understand agricultural production systems in this era of global markets, it is essential to look back to the 1990s, when Mexico promoted the mass production and consumption of food, based on ultra-processed food schemes. (Elizabeth et al. 2020; Ibarra Lidia Susana 2016; Rendón-Rendón et al. 2019). One of the main consequences has been that the regulations have focused on regulating food without adequately considering the naturalness of the materials, prioritizing the use of preservatives, additives, and substitutes (Miguel et al. 2015; Villegas de Gante and Huerta Benítez 2015).

This phenomenon is supported by the dairy industry and its products, which have seen an increase in the production of imitation cheeses. These products replace milk, in whole or in part, with processed ingredients that lack animal proteins and fats. (Jiménez-Jiménez, Rendón-Rendón, and Miguel-Estrada 2024).

The quality of cheese can be determined by its composition and the physicochemical properties of its proteins and fat. (Fox and Cogan 2004). In Mexico, the official standard NOM-243-SSA-2010 (*Secretaría de Salud* 2012) defines cheese as, the product obtained from the curdling of standardized and pasteurized milk from cows or other animal species, with or without the addition of cream and ripening enzymes, melting salts and optional edible ingredients and, depending on its process: fresh, ripened or processed. The Codex Alimentarius and voluntary standards acknowledge that a cheese is worthy of consideration, even if starches are added to stabilize cheese production; however, no differentiation is made to support the quality of natural cheeses (Adolph 2018; Comisión del codex alimentarius 2007). Therefore, the aim is to restore food in Mexico to an incentive for small-scale production, which represents a future for food sovereignty and self-sufficiency. (Sheinbaum 2024).

In agri-food products, quality is usually evaluated subjectively or under partial criteria (Singham, Birwal, and Yadav 2015). At the same time, advances in data analysis, artificial intelligence, and optimization algorithms have provided new tools for decision-making in the agri-food sector. At the same time, optimization models are applied in the design of feed mixtures, raw material selection, and product classification, all of which involve multiple constraints and objectives.

The use of optimization techniques allows for the establishment of systematized decisions supported by objective data, simultaneously considering multiple physicochemical and regulatory attributes, which is strategic for valuing traditional products compared to industrialized ones or among small-scale productions. This computational approach allows a systematic definition of combinations of parameters or batches that are most desirable, for example, maximizing protein and fat while minimizing moisture, all in compliance with regulations such as the NMX-F-733-COFOCALEC-2013 standard.

Combinatorial optimization is a branch of operations research that allows the identification of multiple possible combinations, the one that maximizes or minimizes an objective function, while simultaneously meeting defined constraints. This tool has been successfully employed in logistics, manufacturing, and, more recently, in agri-food chains to improve selection and quality processes (Karimi-Mamaghan et al. 2022).

In the current context, it is important to identify opportunities to improve the competitiveness of traditional agri-food products. Small-scale, traditional, or artisanal cheese production is often considered, from an economic perspective, to be of inferior quality, which limits its market presence due to a lack of scientific evidence. The objective of this study is to present the results of the nutritional analysis of various traditional natural cheeses and compare them with those of ultra-processed or imitation cheeses. The aim is to generate scientific evidence that highlights the nutritional quality of artisanal cheeses produced in family-owned cheese factories, providing key information for informed food sovereignty. This work also aims to lay the foundation for a combinatorial optimization model that quantitatively demonstrates the nutritional superiority of traditional cheeses and supports agri-food revaluation strategies.

This work integrates experimental and computational methods to compare the objective quality of traditional Oaxaca cheeses versus their commercial counterparts. A physicochemical analysis of six samples (traditional and commercial) is performed, and a multi-objective linear optimization model is applied to select, using quantifiable criteria, the cheeses that best meet regulatory nutritional requirements. This combination of approaches not only highlights compositional differences between products but also establishes a replicable methodology for decision-making in artisanal production contexts with extensive data, contributing to Smart Farming and sustainable rural development strategies.

2 Combinatorial Optimization Methodology

The model's objective is to identify the combination of cheese samples that jointly maximize nutritional quality under specific constraints derived from the quality standard (NMX-F-733-COFOCALEC-2013). The optimization is based on measurable attributes: protein content (P), fat content (F), and moisture (M), which are linearly combined into a quality index cost function to be maximized.

Let Q denote the set of cheese samples indexed by $q = 1,2,\dots,n$. Let's define the following parameters and variables.

2.1 Parameters

P_q: Protein percentage of cheese sample q

F_q: Fat percentage of cheese sample q

M_q: Moisture percentage of cheese sample q

Consider $W_p, W_F, W_M \in \mathbb{R}+$: priority weights for protein, fat, and moisture in the quality index.

$k \in N$: maximum number of cheese samples to be selected (e.g. due to cost, availability, or logistics)

2.2 Decision variables

Let $x_q \in \{0,1\}$: a discrete binary variable that takes the value $x_q = 1$ if cheese i is selected, and $x_q = 0$ otherwise.

2.3 Binary optimization problem

This is a 0–1 integer linear programming (ILP) problem, solvable using exact methods (e.g., branch and bound, cutting planes) or heuristic/metaheuristic algorithms (e.g., genetic algorithms, simulated annealing) for larger datasets. To operationalize the proposed combinatorial optimization model, a computational procedure was designed to select the optimal subset of cheese samples that maximizes the nutritional quality index under regulatory constraints. Thus, the mathematical formulation can be stated as follows.

It is required to find the total samples of cheese according to the maximization of the cost function

$$\max_{x_q} J(x) = max \sum_{i=1}^{n} \{W_p \times P_q(x_q) + W_F \times F_q(x_q) - W_M \times M_q(x_q)$$

Subject to:

$$P_q > P_{min} \ \forall q \text{ such that } x_q = 1$$
$$F_q > F_{min} \ \forall q \text{ such that } x_q = 1$$
$$M_q > M_{max} \ \forall q \text{ such that } x_q = 1$$
$$Total\ Selected\ Set: Q(x) = \sum_{q=1}^{n} x_q = k \leq n \quad , \quad x_q \in \{0,1\}$$

$P_{min} = 21\%$, $F_{min} = 20\%$, $M_{max} = 51\%$ are minimum/maximum limits defined by the standard NMX-F-733.

The weights W_p, W_F, W_M can be tuned based on nutritional priority rates (e.g., $W_p = 1.0$, $W_F = 0.8$, $W_M = 0.5$).

2.4 Pseudo-code algorithm of the proposed optimization problem

The proposed combinatorial optimization model requires a computational procedure that was designed to select the optimal subset of cheese samples that maximizes the nutritional quality index under regulatory constraints. The following pseudocode outlines a deterministic algorithmic implementation of the 0–1 integer linear program previously formulated. It systematically evaluates feasible subsets of cheese candidates, verifies constraint satisfaction (protein, fat, and moisture thresholds), and identifies the combination that yields the highest value of the composite quality index J. This approach is particularly effective for small datasets and serves as a foundation for scalable implementations using exact or heuristic methods in larger-scale scenarios.

Algorithm 1 Optimal Cheese Selection of a Combinatorial Optimization Problem

Inputs: Set of cheeses Q with attributes: moisture, protein, fat, ash, sodium, calcium.
Parameters:

- Moisture limit: 51%
- Minimum protein: 21%
- Minimum fat: 20%

Decision variables:
$x_q \in \{0, 1\}$ for each cheese $q \in Q$, where $x_q = 1$ if cheese q is selected.

Objective function: Maximize

$$Z = \sum_{q \in Q} \left(W_1 \cdot \text{protein}_q + W_2 \cdot \text{fat}_q - W_3 \cdot \text{moisture}_q \right) \cdot x_q$$

Propose priority weights W_1, W_2, W_3, where $W_i \in \mathbb{R}$ for $i = [1, 3]$

Constraints:
for all $q \in Q$ **do**
    $\text{moisture}_q \cdot x_q \leq 51 \cdot x_q$
    $\text{protein}_q \cdot x_q \geq 21 \cdot x_q$
    $\text{fat}_q \cdot x_q \geq 20 \cdot x_q$
end for
▷ (Optional) Additional constraints if needed:
Propose constraints according to chosen standard: R_1, R_2, R_3, where:
$\sum_{q \in Q} x_q \leq n$
$\sum_{q \in Q} \text{ash}_q \cdot x_q \leq R_1 \cdot \sum_{q \in Q} x_q$
$\sum_{q \in Q} \text{sodium}_q \cdot x_q \leq R_2 \cdot \sum_{q \in Q} x_q$
$\sum_{q \in Q} \text{calcium}_q \cdot x_q \leq R_3 \cdot \sum_{q \in Q} x_q$

Solving: Solve the binary integer programming model.

Output:
Display solution status.
Display selected cheeses and their classification (Traditional or Analog).
Display optimal value of the objective function.

Fig 1. Pseudocode of proposed combinatorial optimization method

3 Case Study: Experimental Selection

An experimental study was carried out in October 2023 in the municipality of Aculco, State of Mexico. Six samples of Oaxaca cheese were selected: three traditional cheeses (made only with cow's milk) from cheese producers who are members of the Research and Incidence Collective-PRONACE and three commercial cheeses (with additives and extenders), acquired in the same study region. Each sample consisted of 500 g; once collected, they were refrigerated at 4 °C and taken that same day to the Animal Nutrition and Biochemistry Laboratory of the FMVZ – UNAM. There, following the guidelines established by the AOAC (AOAC 1990), the corresponding analyses were carried out to determine the percentages of moisture, protein, and crude fat.

4 Results

Laboratory analyses were obtained from six types of cheese, and the results are shown in Table 1.

Table 1. Physicochemical Characteristics of Cheese Oaxaca.

Sample type	Humidity (%)	PC (%)	Crude Fat (%)
T1	43.32	19.83	30.76
T2	47.77	23.31	19.49
T3	45.55	21.97	25.95
C1	48.98	17.72	22.58
C2	44.85	19.39	26.92
C3	54.55	14.3	14.11
Standard 733 -COFOCALEC-2013	51 max	21 min	20 min

T=Traditional, C=Commercial

The algorithm evaluated all possible cheese combinations, verifying that they fulfill with the COFOCALEC standard constraints, and selected the best combination that maximizes the index value of J. As a result, the algorithm identified that sample T3 is the optimal cheese of the optimization process, as shown in Figure 2.

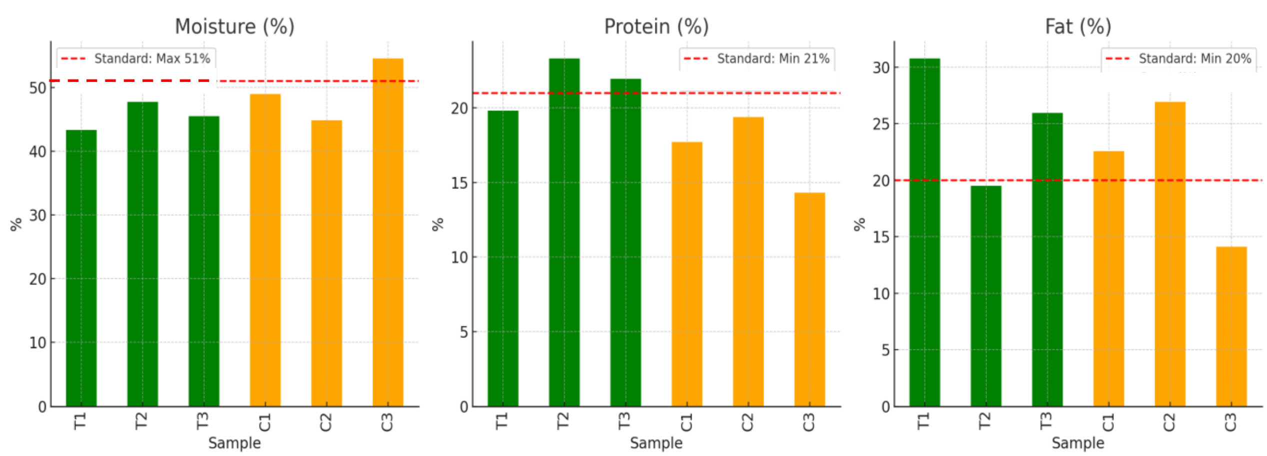

Fig 2. Comparison between traditional and commercial cheese samples subject to nutritional constraints

The model confirms that traditional cheeses have better nutritional performance, being richer in protein and fat, and lower in moisture. The optimization validated that traditional cheeses are preferable based on regulatory constraints and the nutritional objective function.

5 Discussion

The ability to revalue a traditional artisanal product under industrial standards in the agricultural sector is far from harmonious, so adapting regulations is the next step in adding value. Quality issues in the food chains of traditional products are demanding for the Mexican countryside, while industrialized products manage to enter the market without questioning their nutritional value. This study integrates physicochemical analysis of Oaxaca cheeses with a combinatorial optimization tool, which represents a relevant methodological and instrumental contribution to the evaluation of traditional artisanal foods versus industrial ones. In this regard (Taşkıner and Bilgen 2021), I list a series of contributions to the management of production processes, concluding that obtaining a quality record requires the development of specific optimization models. And for these models, it's important to include the variety and heterogeneity of products to observe complexity, as was done in our study. Qualitative or mixed studies that address how rural communities sustain artisanal production in the face of food industrialization are approaches that can aid optimization.

6 Conclusions

The obtained results show that traditional Oaxaca cheeses made from cow's milk not only meet national regulatory standards but also exhibit superior nutritional quality compared to commercial alternatives, with significantly higher protein and fat content and lower moisture levels.

The combinatorial optimization model provided a quantitative validation of this nutritional advantage by selecting traditional cheeses as the optimal choice under multiple regulatory and nutritional constraints.

This study presents robust scientific evidence to support the revalorization of artisanal dairy products, positioning them as strategic assets in promoting food sovereignty, rural innovation, and the development of smart agrifood systems. The integration of computational decision-making tools, such as the proposed optimization model, lays the groundwork for scalable, data-driven applications in Smart Farming, helping small-scale producers align traditional practices with modern standards of quality and traceability.

Acknowledgements

This work was supported by CONAHCYT-PRONAII 321289 with the Project "Desarrollo de estrategias participativas para el fortalecimiento de redes de producción y consumo de productos lácteos tradicionales orientadas a la soberanía alimentaria de territorios del centro-occidente de México".

References

Adolph, Ralph. 2018. "Reseña de Las Normas NMX Voluntaruas Del Queso En México y Normas Correspondientes Del Codex." *U.S. Dairy Esport Council*: 1–23.

Aguilar Criado, E., Sacco dos Anjos, F., & Velleda Caldas, N. (2011). Productos locales, mercados globales: Nuevas estrategias de desarrollo en el mundo rural. *Estudios Sociológicos, 29*(85), 189–214.

AOAC International. (1990). *Official methods of analysis* (15th ed.). AOAC International.

Comisión del Codex Alimentarius. (2007). *Alimentos producidos orgánicamente* (3.ª ed.). FAO/OMS. http://www.fao.org/3/a1385s/a1385s00.pdf

Elizabeth, Leonie et al. 2020. "Ultra-Processed Foods and Health Outcomes: A Narrative Review." *Nutrients* 12(7): 1–36.

Fox, P. F., & Cogan, T. M. (2004). Factors that affect the quality of cheese. En P. F. Fox, P. L. H. McSweeney, T. M. Cogan, & T. P. Guinee (Eds.), *Cheese: Chemistry, physics and microbiology* (Vol. 1, pp. 583–608). Elsevier Academic Press.

Ibarra, L. S. (2016). Transition food in Mexico. *Razón y Palabra, 20*, 162–179. http://www.revistarazonypalabra.org/

Jiménez-Jiménez, R. A., Rendón-Rendón, M. C., & Miguel-Estrada, M. (2024, January 20). ¿Qué es eso que comemos? La calidad nutricional de los quesos tradicionales. *La Jornada del Campo*. https://www.jornada.com.mx/2024/01/20/delcampo/index.html

Karimi-Mamaghan, M., Mohammadi, M., Meyer, P., Karimi-Mamaghan, A., & Talbi, E.-G. (2022). Machine learning at the service of meta-heuristics for solving combinatorial optimization problems: A state-of-the-art. *European Journal of Operational Research, 296*(2), 393–422. https://doi.org/10.1016/j.ejor.2021.04.032

Mayorga Castañeda, F. J., et al. (2012). *México: El sector agropecuario ante el desafío del cambio climático*. Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación (SAGARPA). https://www.agricultura.gob.mx/sites/default/files/sagarpa/document/2019/01/28/1608/01022019-cambio-climatico.pdf

Rabinowicz, S. (2018). Sistema de gestión de sostenibilidad (SGS). *Anuario de la Facultad de Ciencias Económicas del Rosario*, (13). https://repositorio.uca.edu.ar/handle/123456789/8665

Rendón-Rendón, M. C., et al. (2019). The social fabric of cheese agroindustry: Cooperation and competition aspects. *Sustainability, 11*(10), 2921. https://www.mdpi.com/2071-1050/11/10/2921

Reyes Chacón, D. A., Cadena López, A., & Rivera González, G. (2021). El sistema de gestión de calidad y su relación con la innovación. *Inter Disciplina, 10*(26).

Secretaría de Salud. (2012). *Norma Oficial Mexicana NOM-243-SSA1-2010, Productos y servicios. Leche, fórmula láctea, producto lácteo combinado y derivados lácteos*. Diario Oficial de la Federación.

Sheinbaum, C. (2024). *Soberanía alimentaria*. Consejo Mexicano para el Desarrollo Rural Sustentable. https://www.cmdrs.gob.mx/sites/default/files/cmdrs/sesion/2024/07/04/6220/generales/2-soberania-alimentaria.pdf

Sheinbaum, C. (2024). *Soberanía alimentaria*. Consejo Mexicano para el Desarrollo Rural Sustentable. https://www.cmdrs.gob.mx/sites/default/files/cmdrs/sesion/2024/07/04/6220/generales/2-soberania-alimentaria.pdf

Taşkıner, T., & Bilgen, B. (2021). Optimization models for harvest and production planning in agri-food supply chain: A systematic review. *Logistics, 5*(3), 1–27.

Villegas de Gante, A., & Huerta Benítez, R. (2015). Naturaleza, evolución, contrastes e implicaciones de las imitaciones de quesos mexicanos genuinos. *Estudios Sociales: Revista de Investigación Científica, 23*(45), 214–236.