INQUIDE

Chemical Engineering and Development

ISSN: 1390–9428
e–ISSN: 3028–8533
ISSN-L: 3028–8533

Vol. 8 / No. 2
July – December 2025

INQUIDE – Chemical Engineering and Development

INQUIDE – Chemical Engineering and Development * Volume 8 * Number 2 * July / December 2026.
Journal of Science and Technology, edited by the Faculty of Chemical Engineering of the University of Guayaquil (Guayaquil – Ecuador)
Applied research in engineering, industrial processes, sustainable development and technology management is disseminated, with Multidisciplinary approach in the field of engineering.

INQUIDE

Chemical Engineering & Development

Volume 8 – Issue 2

July – December 2026

ISSN: 1390-9428 / e-ISSN: 3028-8533 7 / ISSN-L: 3028-8533

The administration of INQUIDE – Chemical Engineering and Development is carried out through the following parameters:

The journal uses the academic anti-plagiarism turnitin system:

The items have an identification code (Digital Object Identifier)

The editorial process is managed through the Open Journal System

The articles in this issue can be consulted at

https://revistas.ug.edu.ec/index.php/iqd/index

Faculty of Chemical Engineering

University of Guayaquil

INQUIDE – Chemical Engineering and Development is indexed in the following

Databases and information systems:

Selective Database

latindex catálogo 2.0

Crossref

MIAR Matriz de Información para el Análisis de Revistas

BASE

Selective Directories.

RERCIE

AmeliCA

Open Access Scientific Literature Search.

Google Scholar

ROAD

Journal Evaluation Platforms

MIAR Matriz de Información para el Análisis de Revistas

Selective Newspaper Archives

Dialnet

Web Metrics Tool

Google Analytics

INQUIDE
Chemical Engineering & Development
Journal of Science and Engineering

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

Presentation. -

Volume 8, Number 2 – INQUIDE: Chemical Engineering and Development

Dear scientific community, authors and readers of **INQUIDE,**

As Director-Editor of this publishing house, it is a true honor and privilege to present Volume 8, Number 2 of our magazine. In the contemporary scientific ecosystem, the boundaries between the disciplines of science and engineering are becoming increasingly dynamic and porous. Maintaining our rigorous Q1 high-impact classification, this issue of *INQUIDE* consolidates itself as a multidisciplinary cutting-edge space, bringing together research that addresses everything from the optimization of industrial processes to public health management, digital transformation and the development of human talent.

The central purpose of this edition is to build bridges between theoretical mathematical modeling, applied engineering and the biological or management sciences, offering quantifiable and transferable solutions to latent problems in the global and regional environment.

Below, I present an analytical tour of the seven manuscripts of high methodological rigor that make up this volume:

Section I: Frontiers in Chemical and Thermal Engineering

Thermohydraulic optimization and technical feasibility occupy a central role in the first two articles of this installment, demonstrating how simulation and design models define the frontier of energy efficiency.

- **Thermal-hydraulic design of a forced-draft air cooler with finned tubes for methanol cooling** This work presents a meticulous design for the large-scale processing of liquid methanol (28 000 kg/h), achieving temperature mitigation from 90 ºC to 45 ºC. With a fin efficiency of 0.853 and an overall heat transfer coefficient of 280.95 W/m². K, the research validates the feasibility of forced draft under extremely safe pressure drop conditions (559.73 Pa), optimizing the energy consumption of the motor to an efficient value of 7.21 kW.
- **Thermo-hydraulic design of a fin-free double-tube heat exchanger for tomato juice cooling. Part 1 - Finnless Heat Exchanger** In constructive contrast to the previous manuscript, this article stands out for its scientific transparency and value in negative design (technical refutation). When evaluating the cooling of tomato juice (thermal load of 951.77 kW), the authors mathematically demonstrate that the finless configuration is unfeasible due to a drastic frictional pressure drop (16.56 atm), exceeding the operating limits allowed by the process (0.296 atm). The study also provides a valuable capital cost analysis estimated at $165,500, laying the mandatory foundation for Part 2 of the extended surface redesign.

Section II: Health Sciences, Food Safety and Biosecurity

The preservation of public health demands precise analytical tools to monitor emerging chemical and biological risks in mass consumption products in high-density urban areas.

- **Sanitary Risk Management in Bottled Water: Integration of Physicochemical and Microbiological Indicators and Cyanobacteria Risks in Guayas** This study addresses a critical biosecurity problem in Guayaquil, showing that strict compliance with standard physicochemical parameters is not an absolute shield for safety. Using membrane filtration and enzymatic assays, the authors detected E. *coli* contamination events and nutrient conditions conducive to the latent proliferation of cyanobacteria (microcystins), urging a paradigm shift towards comprehensive epidemiological risk management models.
- **Evaluation of the content of tartrazine (E-102) in orange-flavored soft drinks marketed in Guayaquil by UV-Visible spectrophotometry** Using a rigorously validated spectrophotometric analytical methodology, this research quantifies the synthetic additive E-102 in the local market. The statistical findings, validated by the Shapiro-Wilk test, expose a worrying variability and reveal that certain commercial brands exceed the permitted international limit of 100 mg/L (reaching averages of 134.85 mg/L), which represents an urgent call for attention for technical-sanitary control agencies.
- **Effectiveness of purple cabbage-based slimming diets in people with obesity from the Cleotilde Guerrero O Foundation.** From the trenches of applied nutrition sciences and metabolic health, this quasi-experimental design evaluates the clinical impact of purple cabbage phytochemicals and antioxidants. The data collected showed significant reductions in Body Mass Index (BMI) and waist circumference of the patients evaluated, providing key empirical evidence on the functionality of endemic foods in cardiovascular and metabolic support therapies.

Section III: Technological Innovation and Organizational Competitiveness

Finally, the volume closes with two analytical approaches in the field of commercial, productive and talent management development in emerging markets.

- **Use of artificial intelligence in commercial microenterprises in the City of Guayaquil** The digital transformation is evaluated here from a quantitative empirical perspective in the commercial sector of the

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

Pedro Carbo Concepción parish. Through dimensional analysis and reliability scales (Cronbach's Alpha), the research demonstrates that benefit perception and operational optimization mitigate traditional barriers to AI adoption, identifying targeted training as the ultimate catalyst for microenterprise competitiveness.

- **Assessment of Behavioral Competencies in the Ecuadorian Aquaculture Industry: Correlational Analysis of Soft Skills in Guayaquil's Administrative Staff** With aquaculture being a macroeconomic pillar for Ecuador, this article analyzes the human component behind export records. With outstanding statistical robustness (global Cronbach's alpha of 0.944), the analysis evaluates 88 executive profiles across five behavioral dimensions. The results not only reveal a high positive correlation between leadership, communication and problem solving, but also demonstrate gender equity in competency performance, informing the design of cutting-edge corporate professional development policies.

Final Thoughts

The articles collected in this issue reflect the very essence of INQUIDE: science with rigor that has a direct impact on the social, technological and industrial fabric. We are deeply grateful to the authors for entrusting their best scientific productions to our pages, and to the body of peer reviewers for their invaluable and exhaustive blind work that sustains the excellence of our editorial imprint.

The Editorial Board invites the academic, professional and student community to read this issue in detail, whose articles provide scientific evidence, technical analysis and methodological approaches that enrich knowledge in engineering and applied sciences. The set of published works offers relevant inputs for research, professional practice and decision-making in productive and public policy contexts.

Likewise, INQUIDE – Chemical Engineering and Development extends a permanent invitation to national and international researchers to submit original manuscripts for future editions. The journal maintains a firm commitment to editorial quality, the rigor of the blind peer review process and the open dissemination of knowledge, highlighting that no charge is made for the review or publication processes of articles, and reaffirming its international projection as an academic space for the dissemination of high-impact research in chemical engineering and development.

Sincerely,

Francisco Javier Duque-Aldaz.
Director - Editor
INQUIRE.
Chemical Engineering & Development
Science and Engineering for Multidisciplinary Progress

INQUIDE
Chemical Engineering and Development
Journal of Science and Engineering

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

TABLE OF CONTENTS

Research Articles.

INQUIDE
Chemical Engineering and Development
Journal of Science and Engineering

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

INQUIDE
Chemical Engineering and Development
Journal of Science and Engineering

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

Thermo-hydraulic design of a finned tube forced-draft air cooler for methanol cooling.

Diseño térmico-hidráulico de un enfriador por aire de tiro forzado con tubos aleteados para el enfriamiento de metanol.

Amaury Pérez Sánchez [1]* ; Arlette de la Caridad González Abad [2]; Heily Victoria González [3] María Isabel La Rosa Veliz [4]; Zamira María Sarduy Rodríguez [5]; Lizthalía Jiménez Guerra [6]

Received: 02/03/2026 – Accepted: 19/06/2026 – Published: 12/07/2026

Research Articles [X] Review Articles [ ] Essay Articles [ ]

* Corresponding author.

Abstract.
Air-cooled heat exchangers are one of the most efficient and widely used equipment for heat exchange. The present paper deals with the thermo-hydraulic design of a finned tube, forced-draft air-cooled heat exchanger in order to cool down 28,000 kg/h of a liquid methanol stream from 90 ºC to 45 ºC using a well-known design methodology. Several important design parameters were determined such as the air flowrate (55.44 kg/s), the required number of tubes (277), the heat exchanger width (2.78 m) and the overall heat transfer coefficient (280.95 W/m2.K). The calculated pressure drop of the methanol stream (559.73 Pa) was below the maximum allowable value established by the process, while the fin efficiency had a value of 0.853, which can be considered adequate. The driver power for the fan had a value of 7.21 kW, and the designed air cooler could be satisfactorily used for the requested heat exchange service since the value of the parameter ratio between the projected area of the fan and the face area is higher than the value established by the design methodology.

Keywords.
Air cooler, fan driver power, fin efficiency, pressure drop, thermo-hydraulic design.

Resumen.
Los intercambiadores de calor enfriados por aire son uno de los equipos más eficientes y ampliamente usados para el intercambio de calor. El presente artículo trata acerca del diseño térmico-hidráulico de un intercambiador de calor enfriado por aire de tiro forzado con tubos aleteados con el fin de enfriar 28 000 kg/h de una corriente de metanol líquido desde 90 ºC hasta 45 ºC usando una metodología de diseño bien conocida. Varios parámetros importantes de diseño fueron determinados tales como el caudal de aire (55,44 kg/s), el número requerido de tubos (277), el ancho del intercambiador de calor (2.78 m) y el coeficiente global de transferencia de calor (280.95 W/m^2.K). La caída de presión calculada de la corriente de metanol (559,73 Pa) estuvo por debajo del valor máximo permisible establecido por el proceso, mientras que la eficiencia de la aleta tuvo un valor de 0,853, el cual puede considerarse adecuado. La potencia del motor del ventilador tuvo un valor de 7,21 kW, y el enfriador por aire diseñado puede ser usado satisfactoriamente para el servicio de intercambio de calor requerido debido a que el parámetro relación entre el área proyectada del ventilador y el área frontal es superior que el valor establecido por la metodología de diseño.

Palabras clave.
Enfriador por aire, potencia del motor del ventilador, eficiencia de la aleta, caída de presión, diseño térmico-hidráulico.

1. Introduction

One of the most prevalent solutions in the heat exchanger industry is the use of an air-cooled heat exchanger (ACHE) involving air-cooling operation at environment temperature. ACHEs (also known as air coolers) are used in the cooling system and use ambient air for the cooling medium. Air is a resource that can be obtained without cost consideration in the surrounding environment [1].

Air coolers are heat exchangers composed of one or more banks of finned tubes that are utilized to transfer heat from a hot stream to atmospheric air, usually using fans to promote the air flow. Taking into account environmental concerns such as probable water shortage difficulties and regions where the available water needs expensive treatments, air coolers can be a significant choice in relation to conventional water coolers [2].

The operating principle of an ACHE is the following: hot process fluid enters one end of the ACHE and flows through tubes, while ambient air flows over and between the tubes, which typically have externally finned surfaces. The heat is transferred to the air, which cools the process fluid, and the heated air is discharged into the atmosphere. While this is a fundamentally simple concept, maintaining optimum ACHE performance takes persistence on the part of the end user [3].

Among the numerous important benefits that presents the air cooler are that there is no need of using a second working fluid to achieve the heat exchange (that is, it is not required

[1] University of Camagüey; Faculty of Applied Sciences; amaury.perez84@gmail.com ; https://orcid.org/0000-0002-0819-6760, Camagüey, Cuba.
[2] University of Camagüey; Faculty of Applied Sciences; arlette.delacaridad@reduc.edu.cu; https://orcid.org/0000-0002-3193-0660, Camagüey; Cuba.
[3] University of Camagüey; Faculty of Applied Sciences; heily.victoria@reduc.edu.cu; https://orcid.org/0009-0007-9319-6506, Camagüey, Cuba.
[4] University of Camagüey; Faculty of Applied Sciences; maria.rosa@reduc.edu.cu; https://orcid.org/0000-0002-9517-6118, Camagüey; Cuba.
[5] University of Camagüey; Faculty of Applied Sciences; zamira.sarduy@reduc.edu.cu; https://orcid.org/0000-0003-1428-3809, Camagüey; Cuba.
[6] University of Camagüey; Faculty of Applied Sciences; lizthalia.jimenez@reduc.edu.cu; https://orcid.org/0000-0002-2471-7263 Camagüey; Cuba.

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

to have a cooling medium due to using air); allows to save energy costs and to make a heat exchanger less in dimensions; no fouling o corrosion in the tube outside surface [4], no contamination and lower maintenance cost [1].

Environmental concerns such as shortage of water, blow-down disposal and thermal pollution tend to favor the ACHE. Although the capital cost of ACHE is generally high, the operating cost is usually considerably lower than that required by a water-cooled heat exchanger [5].

The main disadvantages associated with the use of ACHE are their low temperature performance due to the low air-side heat transfer coefficient, while its performance is affected by the ambient air temperature, particularly on summer season [1].

To meet these disadvantages, a widespread suggested solution for these heat exchangers is the use of extended surfaces or fins in the air cooler tube bundles, such as wavy fins, slit fins, louvered fins and fins with vortex generators [1] flat fins and serrated fins [6]. The use of fins has enhanced the air-side heat transfer coefficient with relative success.

Air coolers are widely used in power, air conditioning, refrigeration [6] chemical and petrochemical processes [1]. There are thousands of these exchangers in use today, performing the cooling and/or condensing of fluids ranging from engine jacket water to process steam to highly viscous tar [3].

The ACHEs are classified mainly as *forced draft* or *induced draft* [5]. The forced draft ACHE (Fig. 1) is the most economical and most common style air cooler where axial fans used to force air across the fin tube bundle are mounted below the bundle and therefore the mechanical sections are not exposed to the hot exhaust air flow. Also, another advantage of this arrangement is the fact that provides direct access to bundle for replacement. The induced draft ACHE involves axial fans to pull air across the fin tube bundle and it is the second most economical arrangement. Contrary to the previous arrangement, the fans are situated above the bundle thus offering greater control of the process fluid and bundle protection due to the additional structure. Fans used in ACHEs are of the axial-flow type [7].

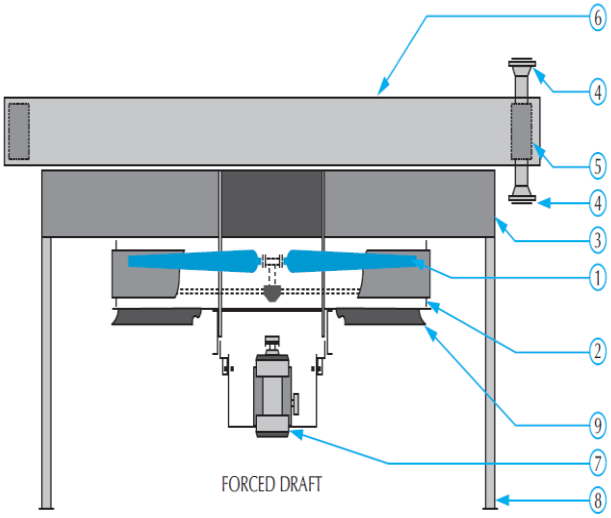


Fig 1. Forced draft air cooler configuration.
Source: Adapted from [8]

The main advantages of forced draft air coolers are [8]:

1. Probably lower horsepower requirements if the effluent air is very hot. (Horsepower varies inversely with the absolute temperature).
2. Better accessibility of fans and upper bearings for maintenance.
3. Better accessibility of bundles for replacement.
4. Accommodates higher process inlet temperatures.

While their main disadvantages are:

1. Less uniform distribution of air over the bundle.
2. Increased probability of hot air recirculation, resulting from low discharge velocity from the bundles, high intake velocity to the fan ring, and no stack.
3. Low natural draft capability of fan failure.
4. Complete exposure of the finned tubes to sun, rain, and hail, which results in poor process control and stability.

The construction of one or more tube bundles, served by one or more fans, complete with a plenum, structure, and auxiliary devices, is called a *bay*. When large flow rates are handled, it is common for the unit to be divided in several bays to facilitate transport and construction. Fig. 2 shows some air cooler configurations. Generally, the design basis consists in using two fan bays [5].

INQUIDE
Chemical Engineering and Development
Journal of Science and Engineering
Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

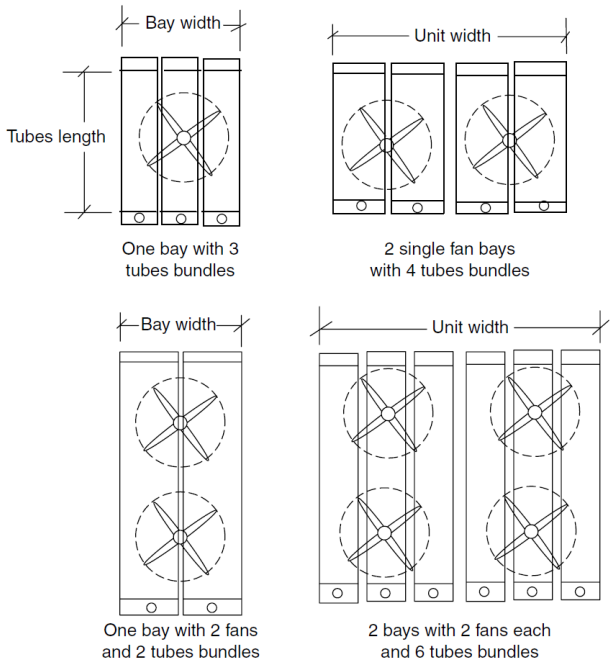


Fig 2. Air cooler configurations.
Source: Adapted from [7]

The heart of the ACHE is the tube bundle. A tube bundle is an assembly of tubes, headers, side frames, and tube supports. Usually, the airside tube surface has extended surface in the form of helical fins to compensate for the low heat-transfer rate of air at atmospheric conditions and low velocities. Because tube-side process pressures normally exceed 1 atm, the optimal tube is usually round and can be of any metal suitable for the process fluid given its corrosivity, pressure, and temperature [3].

The published papers that addressed the design and optimization of air coolers are based on two main approaches: meta-heuristic methods and mathematical programming [2].

The conventional design procedure of ACHEs is similar to that used for shell and tube heat exchangers. By following design guidelines, the first step of the methodology consists of finding a preliminary design for the unit using an approximate overall heat transfer coefficient. Then, by using a trial-error the initial design is iteratively modified in order to obtain an satisfactory design that satisfy specific tolerance criteria. Even though this method can be proficiently used to rate existing units or to obtain new designs via simulation, it is not well suited for optimization especially when many optimization variables should be considered.

Certainly, the application of this design methodology for a rigorous optimization of ACHEs may be laborious and time consuming if discrete decisions (type of the flow regime, type of the finned tube, number of tube rows, number of tube per row, number of passes, fins per unit length and the mean fin thickness) and operating conditions (velocities, pressure drops, overall transfer coefficient) are measured as optimization parameters [5].

More parameters are taken into account in the thermal design of ACHEs compared to shell and tube exchangers. ACHEs are susceptible to a wide diversity of constantly changing climatic conditions which cause problems of control not encountered with shell and tube exchangers. Designers must achieve an economic balance between the cost of electrical power for the fans and the initial capital expenditure for the equipment. A decision must be made as to what ambient air temperature should be used for design. Air flowrate and exhaust temperature is initially unknown and can be varied in the design stage by varying the number of tube rows and thus modifying the face area [8].

There are several studies where an air cooled heat exchanger is designed or evaluated. In this sense, [4] analyzed the efficiency of different fin types and the use of tube inserts, as well as changes in the heat transfer coefficients of air and natural gas, depending on the changes in the types of fins and tube inserts, and their geometry, for a force draught air-cooled heat exchanger. For that, the application software Xchanger Suite was used.

Also, [9] proposed a modeling approach for air coolers in Concentrated Solar Power plants, and also an optimization-based algorithm to define the optimal operation of the units under fouling and their optimal cleaning scheduling.

Likewise, [10] investigated the use of global sensitivity analysis (GSA) and harmony search (HS) algorithm for design optimization of air cooled heat exchangers from the economic perspective. In this study, GSA was performed to study the influence of the design parameters and to identify the non-influential parameters, in order to reduce the size of the optimization problem. Then the HS is applied to optimize the influential parameters.

Other authors [11] established a three-dimensional simplified model to be used to simulate a temperature flow field of a dry air cooler-finned tube based on Fluent software, while the cooling effect of the equipment on high-temperature and high-pressure natural gas at compressor outlet was also studied. In this study, by comparing and analyzing the relationships among natural gas mass flow, inlet air temperature, inlet natural gas temperature, and outlet natural gas temperature for an air cooler, the formula of temperature drop of dry air cooler to natural gas is fitted, and the fitting formula is verified by field operation data.

Similarly, [6] proposed a strategy by multi-objective genetic algorithm combined with Kriging response surface for optimum design of wavy fin tube in an air cooler, while minimum pressure loss factor, maximum heat transfer factor and overall performance factor were the three objective functions considered.

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

Carvalho et al. [2] presented the optimization of air coolers considering the fan performance, where the selection of the fan is a design variable and the corresponding air flow rate is the result of a mechanical energy balance. This approach permitted an accurate solution, represented by the air cooler tube bundle and bays as well as fans, without the need of any rounding up procedure to identify a suitable fan to be applied after the optimization, as it is used implicitly in all previous approaches.

In [12] a design procedure for a carbon dioxide (CO_2) finned-tube gas cooler was developed and validated experimentally. With focus on the heat transfer characteristics of the air side, the developed model was corroborated with an experimental setup using water as working fluid. Investigations of the effects of fan frequency, water inlet temperature, and water mass flow on the overall heat transfer coefficient were conducted, while deviations between the model and the test results were extracted according to the fan frequency.

In [13] the mathematical modeling of a finned-tube air-cooled CO_2 gas cooler by means of distributed method was described, where the updated correlations of heat transfer coefficients and pressure drops for both refrigerant and air sides were utilized. An efficient solving method was also proposed in the simulation. The model was validated with the test results from published literature, and was then utilized to explore the potential for improved designs of gas coolers to achieve the minimum approach temperature and maximum system operating efficiency.

Manassaldi et al. [5] presented a disjunctive mathematical model for the optimal design of air cooled heat exchangers. The model involved seven discrete decisions which were related to the selection of the type of the finned tube, number of tube rows, number of tube per row, number of passes, fins per unit length, mean fin thickness and the type of the flow regime. Each discrete decision was modeled using disjunctions, Boolean variables and logical propositions, while the main continuous decisions are: fan diameter, bundle width, tube length, pressure drops and velocities in both sides of the ACHE, heat transfer area and fan power consumption.

Hu et al. [14] selected and validated a simulation model using experiment data, and then investigated the heat transfer performance and factors influencing CO_2 air coolers.

In a recent study, [1] suggested the optimal amount of water sprayed of the system to solve the low cooling performance of ACHEs and the equipment's corrosion problem simultaneously. The optimal amount of water sprayed was derived with the developed experimental results and CFD model, where the CFD model calculated the cooling effect and water evaporation ratio according to the ambient air temperature, and the amount of water sprayed. As a result, the optimal amount of water sprayed that can solve cooling performance problems and corrosion problems at the same time was presented, and water mist system was applied to commercial processes.

In [15] a numerical analysis of localized solidification within an air-cooled heat exchanger utilizing molten salt, employing a three-dimensional, pressure-based Newtonian solver coupled with a realizable k-ε turbulence model and an enthalpy-porosity approach was presented. In this study, the operational limits of the working fluid (air) that trigger solidification within the molten salt air-cooled heat exchanger tube bundle were established. A two-step method, involving steady-state and transient analyses, was employed to evaluate the effect of air inlet temperature, pressure, air velocity, and initial molten salt temperatures on the air outlet temperature, overall heat transfer coefficient, and effectiveness.

In [16] a theoretical study on the performance of air cooler to guide the optimal design of air cooler was conducted. The distributed parameter model of the air cooler was first established along with some sub-models calculating the structural parameters, the physical properties of the wet air, the heat transfer coefficient and the flow resistance on the refrigerant side and the air side. Then, the proposed models were integrated to calculate the performance of the air cooler under the effect of different structural parameters, such as fin spacing, fin thickness, tube spacing, outer tube diameter and finned tube materials.

Finally, in [17] a new approach for the globally optimal design of air coolers was presented. First, by coupling the air cooler geometric options with commercially available fans, the traditional mismatch emerging from designing the air cooler first and selecting a commercial fan later was removed. Second, the method departed from the traditional LMTD and ε-NTU methods, adopting a model composed of a differential–algebraic system of equations (DAE system) for the air cooler simulation, which was discretized to consider properties variable with temperature. The resultant optimization problem was solved using Set Trimming and Smart Enumeration, which can identify the global optimum through the simulation of only a small fraction of the search space.

The book written by [18] outlined the advantages and disadvantages of ACHEs, explained and illustrated what ACHEs are, discussed the thermal design of ACHEs as well as the optimization of the thermal design, and examined several special applications of this equipment.

In a certain chemical processing plant it's desired to cool down a liquid methanol stream from 90 ºC to 45 ºC, and for that a forced draft air cooler is proposed due to the scarcity of water supply and the availability of space. In this context, the present work deals with the thermo-hydraulic design of a finned tube forced-draft air-cooled heat exchanger, using a well-known calculation methodology, where several important design parameters are determined such as the

INQUIDE
Chemical Engineering and Development
Journal of Science and Engineering
Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

ratio between the projected area of the fan and the face area of the bay, the overall heat transfer coefficient, the air flowrate, the pressure drop of both streams, and the fan driver power, among others.

2. Materials and methods.

2.1. Definition of the design problem.

It's desired to design a forced draft air cooler to cool down 28,000 kg/h of a methanol stream from 90 ºC to 45 ºC, using air at an inlet temperature of 25 ºC and pressure of 1 atm. The internal and external diameters of the tubes are 20.5 mm and 25.4 mm, respectively, while they will be provided with aluminum fins 15 mm in height, 0.380 mm in thickness, and will have 394 fins per meter. The maximum admissible tube length is 6 m. The arrangement of the tubes will be of triangular pattern with 60.32 mm of pitch. The maximum allowable pressure drop for methanol is 800 Pa, and an internal fouling resistance of 0.0003 K.m^2/W must be used for this fluid. Finally, the value of the parameter S_F is 52.23 mm (Fig. 3), while two fans will be used with 1.8 m diameter. According to the design calculation methodology [7], the ratio between the projected area of the fan and the face area of the bay (that is, the parameter ϕ) should be at a minimum 40 % to have a uniform distribution, and that will be the constraint selected in this study to design the forced draft air cooler.

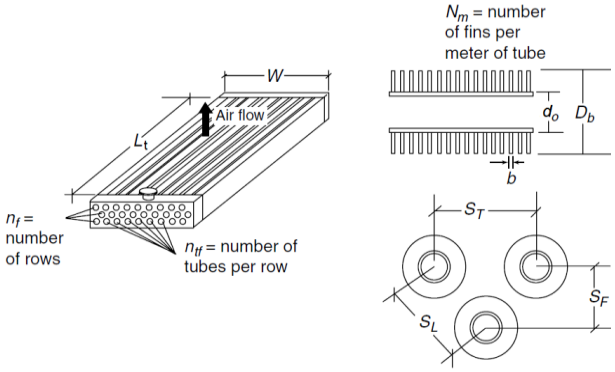


Fig 3. Air cooler nomenclature.
Source: Adapted from [7].

2.2. Design methodology.

To design the forced draft air cooler several correlations, tables and data primarily published in [7,8,19] were used, where firstly the preliminary design is carried out, then the detailed design is realized in order to determine the ratio between the projected area of the fan and the face area of the bay, which must be higher than 40%. Likewise, several important parameters are determined such as the heat transferred, the required air mass flowrate, the fin efficiency, the overall heat transfer coefficient, and the pressure drop for both fluids, among others. Finally, the fan driver power is calculated.

2.3. Preliminary design

Step 1. Definition of the initial data available:

- Methanol mass flowrate (m_h).
- Inlet temperature of methanol (T_1).
- Outlet temperature of methanol (T_2).
- Inlet temperature of air (t_1).
- Pressure of air (P_a).
- Internal diameter of tubes (d_i).
- External diameter of tubes (d_0).
- Fin thickness (b).
- Fin height (H_f).
- Tube pitch (S_L).
- Parameter S_F
- Number of fins per meter of tube (N_m).
- Tube length (L_t).
- Maximum allowable pressure drop for methanol [$\Delta p_{(m)h}$].
- Fouling resistance for methanol (R_h).
- Thermal conductivity of aluminum (k_f).
- Number of fans (n_F).
- Diameter of a fan (D_F).

Step 2. Average temperature of methanol ($\bar{T}$):

$$\bar{T} = \frac{T_1 + T_2}{2} \quad (1)$$

Step 3. Definition of the physical properties for methanol (at the average temperature determined in the previous step) and air (at the inlet temperature):

Table 1 presents the physical properties that must be defined for both the methanol and air streams. The physical properties of methanol are defined at the average temperature determined in the previous step ($\bar{T}$), while for air they are defined at the inlet temperature (25 ºC).

Table 1. Physical properties to be defined for both streams.

Property	Methanol	Air	Units
Density[1]	ρ_h	-	kg/m^3
Viscosity	μ_h	μ_c	Pa.s
Thermal conductivity	k_h	k_c	W/m.K
Heat capacity	Cp_h	Cp_c	J/Kg.K

[1]The density of air will be calculated in a posterior step.
Source: Own elaboration.

Step 4. Heat transferred (Q):
Using data of the hot stream (methanol):

$$Q = \frac{m_h}{3{,}600} \cdot Cp_h \cdot (T_1 - T_2) \quad (2)$$

Step 5. Assumption of the overall heat transfer coefficient (U^a):
A value for the overall heat transfer coefficient must be assumed, taking into account values suggested by [7] depending on the heat exchange application.

Step 6. Parameter Z:

$$Z = \frac{(T_1 - T_2)}{(T_1 - t_1)} \quad (3)$$

INQUIDE
Chemical Engineering and Development
Journal of Science and Engineering
Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

Step 7. Selection of the number of tube rows (n_f) and face velocity (v_f):
The tube rows and face velocity must be selected depending on the calculated value of the parameter Z, by employing the values of Table 2.

Table 2. Design recommendations as a function of Z parameter.

Parameter Z	Number of tube rows (n_f)	Face velocity (v_f) [m/s]
0.4	4	3.3
0.5	5	3
0.6	6	2.8
0.8-1	8-10	2-2.4

Source: Adapted from [8].

Step 8. Assumption of the air outlet temperature (t_2).

Step 9. Preliminary air mass flowrate (m_c):

$$m_c = \frac{Q}{Cp_c \cdot (t_2 - t_1)} \quad (4)$$

Step 10. Air inlet density (ρ_c):

$$\rho_c = \frac{M_c \cdot P_a}{R \cdot t_1} \quad (5)$$

Where M_c = 29 kg/kmol; P_a = 1 atm; R = 0.082 atm.m^3/kmol.K; and t_1 = 298 K.

Step 11. Face area to get the value of the face velocity (a_v):

$$a_v = \frac{m_c}{v_f \cdot \rho_c} \quad (6)$$

Step 12. Heat exchanger width (W^a):

$$W^a = \frac{v}{L_t} \quad (7)$$

Step 13. Log mean temperature difference ($LMTD$):

$$LMTD = \frac{(T_1 - t_2) - (T_2 - t_1)}{ln\frac{(T_1 - t_2)}{(T_2 - t_1)}} \quad (8)$$

Step 14. Heat transfer area (A):

$$A = \frac{Q}{U^a \cdot LMTD} \quad (9)$$

Step 15. Required number of tubes (N):

$$N = \frac{A}{\pi \cdot d_0 \cdot L_t} \quad (10)$$

Where d_0 is given in meters.

Step 16. Number of tubes per row (n_{tf}):

$$n_{tf} = \frac{N}{n_f} \quad (11)$$

Step 17. Parameter S_T.

Step 18. Calculated heat exchanger width (W^c):

$$W^c = S_T \cdot n_{tf} \quad (12)$$

Step 19. Verification of the value of W^a calculated in step 12 with the value of W^c determined in the previous step.
If the value of the calculated heat exchanger width (W^c) differs from the value of W^a, the value of W^c will be maintained, and the parameters air flowrate, air outlet temperature, and $LMTD$ will be corrected considering the result of W^c through the following equations:

Air flowrate (m_c):

$$m_c = v_f \cdot \rho_c \cdot W^c \cdot L_t \quad (13)$$

Air outlet temperature (t_2):

$$t_2 = t_1 + \frac{Q}{m_c \cdot CP_c} \quad (14)$$

Corrected log mean temperature difference ($LMTD$):

$$LMTD = \frac{(T_1 - t_2) - (T_2 - t_1)}{ln\frac{(T_1 - t_2)}{(T_2 - t_1)}} \quad (8)$$

Step 20. Compilation and definition of the design parameters determined in the preliminary design.

The following design parameters must be compiled and defined for the heat exchange process:

- Required number of tubes (N).
- Number of tubes per row (n_{tf}).
- Number of tube rows (n_f)
- Calculated heat exchanger width (W^c).
- Air flowrate (m_c).
- Outlet temperature of air (t_2).
- Log mean temperature difference ($LMTD$).

2.4. Detailed design

Step 21. Adoption of the number of passes for the hot fluid (n).

Step 22. Parameters R and S:

$$R = \frac{(T_1 - T_2)}{(t_2 - t_1)} \quad (15)$$

$$S = \frac{(t_2 - t_1)}{(T_1 - t_1)} \quad (16)$$

Step 23. Parameter P_X:

$$P_X = \frac{1 - \left(\frac{R \cdot S - 1}{S - 1}\right)^{1/Ns}}{R - \left(\frac{R \cdot S - 1}{S - 1}\right)^{1/Ns}} \quad (17)$$

INQUIDE
Chemical Engineering and Development
Journal of Science and Engineering
Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

Where N_S is the number of shell passes, and is equal to 1 for this design approach.

Step 24. $LMTD$ correction factor (F_t):

$$F_t = \frac{\sqrt{R^2+1}}{R-1} \cdot \frac{ln\left[\frac{(1-P_X)}{(1-R\cdot P_X)}\right]}{ln\left[\frac{\left(\frac{2}{P_X}\right)-1-R+\sqrt{R^2+1}}{\left(\frac{2}{P_X}\right)-1-R-\sqrt{R^2+1}}\right]} \quad (18)$$

If R = 1 the following equations must be employed:

$$P_X = \frac{S}{(N_S - N_S\cdot S + S)} \quad (18a)$$

Then:

$$F_t = \frac{\frac{P_X\cdot\sqrt{R^2+1}}{1-P_X}}{ln\left[\frac{\left(\frac{2}{P_X}\right)-1-R+\sqrt{R^2+1}}{\left(\frac{2}{P_X}\right)-1-R-\sqrt{R^2+1}}\right]} \quad (18b)$$

Step 25. Effective mean temperature difference (ΔT):

$$\Delta T = LMTD \cdot F_t \quad (19)$$

Step 26. Flow area for the tube-side fluid (a_t):

$$a_t = \frac{N\cdot\left(\frac{\pi\cdot d_i^2}{4}\right)}{n} \quad 20)$$

Step 27. Velocity of methanol in the tubes (v_t):

$$v_t = \frac{\frac{m_h}{3{,}600}}{\rho_h\cdot a_t} \quad (21)$$

Where m_h is given in kg/h.

Step 28. Reynolds number of methanol (Re_h):

$$Re_h = \frac{d_i\cdot v_t\cdot\rho_h}{\mu_h} \quad (22)$$

Step 29. Prandtl number of methanol (Pr_h):

$$Pr_h = \frac{Cp_h\cdot\mu_h}{k_h} \quad (23)$$

Step 30. Internal film coefficient for methanol (h_i):

- For laminar regime (Re_h < 2,100):

$$h_i = 1.86\cdot\left(\frac{k_h}{d_i}\right)\cdot\left[Re_h\cdot Pr_h\cdot\left(\frac{d_i}{L_t}\right)\right]^{0.33} \quad (24)$$

- For transition regime (2,100 ≤ Re_h ≤ 10,000):

$$h_i = 0.116\cdot Cp_h\cdot\rho_h\cdot v_t\cdot\left(\frac{Re_h^{0.66}-125}{Re_h}\right)\cdot\left[1+\left(\frac{d_i}{L_t}\right)^{0.66}\right]\cdot Pr_h^{-0.66} \quad (25)$$

- For turbulent regime (Re_h > 10,000):

$$h_i = 0.023\cdot\left(\frac{k_h}{d_i}\right)\cdot Re_h^{0.8}\cdot Pr_h^{0.33} \quad (26)$$

Step 31. Internal film coefficient referred to the external area (h_{i0}):

$$h_{i0} = h_i\cdot\frac{d_i}{d_0} \quad (27)$$

Step 32. Plain tube area per meter of tube (A_0):

$$A_0 = \pi\cdot d_0 \quad (28)$$

Where d_0 is given in meters.

Step 33. Bare tube surface per meter of tube (A_D):

$$A_D = A_0\cdot(1-b\cdot N_m) \quad (29)$$

Where b is given in meters.

Step 34. Fin diameter (D_b):

$$D_b = d_0 + 2\cdot H_f \quad (30)$$

Where H_f and d_0 are given in meters

Step 35. Fin surface (A_f):

$$A_f = \frac{\pi\cdot 2\cdot N_m\cdot(D_b^2-d_0^2)}{4} \quad (31)$$

Where all the diameters are given in meters.

Step 36. Projected perimeter (P_p):

$$P_p = 2\cdot(D_b-d_0)\cdot N_m + 2\cdot(1-b\cdot N_m) \quad (32)$$

Where all the diameters and b are given in meters.

Step 37. Equivalent diameter (D_{eq}):

$$D_{eq} = \frac{2\cdot(A_f+A_D)}{\pi\cdot P_p} \quad (33)$$

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

Step 38. Airflow area (a_S):

$$a_S = W^c \cdot L_t - n_{tf} \cdot L_t \cdot [d_0 + N_m \cdot (D_b - d_0) \cdot b] \quad (34)$$

Where all the diameters and b are given in meters.

Step 39. Reynolds number for air (Re_c):

$$Re_c = \frac{D_{eq} \cdot m_c}{a_s \cdot \mu_c} \quad (35)$$

Step 40. Parameter j:

$$j = 0.0959 \cdot (Re_c)^{0.718} \quad (36)$$

Step 41. Prandtl number for air (Pr_c):

$$Pr_c = \frac{Cp_c \cdot \mu_c}{k_c} \quad (37)$$

Step 42. Convection film coefficient for tube and fins (h_f):
Since a fouling factor on the air side is not considered:

$$h_f = j \cdot \left(\frac{k_c}{D_{eq}}\right) \cdot Pr_c^{0.33} \quad (38)$$

Step 43. Parameter m:

$$m = \sqrt{\frac{2 \cdot h_f}{k_f \cdot b}} \quad (39)$$

Where b is given in meters.

Step 44. Parameter H:

$$H = \frac{D_b - d_0}{2} \quad (40)$$

Where d_0 is given in meters.

Step 45. Parameter Y:

$$Y = \left(H + \frac{b}{2}\right) \cdot \left(1 + 0.35 \cdot ln\frac{D_b}{d_0}\right) \quad (41)$$

Where b and d_0 are given in meters.

Step 46. Fin efficiency (Ω):

$$\Omega = \frac{\tanh m \cdot Y}{m \cdot Y} \quad (42)$$

Step 47. Film coefficient corrected for fin efficiency, and considering as reference area the external surface of the plain tube (h_{fo}):

$$h_{fo} = \left(\Omega \cdot A_f + A_D\right) \cdot \frac{h_f}{A_0} \quad (43)$$

Step 48. Fouling resistance of tube-side fluid corrected for the internal/external diameters ratio (R_{hi}):

$$R_{hi} = R_h \cdot \frac{d_0}{d_i} \quad (44)$$

Step 49. Overall heat transfer coefficient (U):

$$U = \frac{1}{\frac{1}{h_{fo}} + \frac{1}{h_{io}} + R_{hi}} \quad (45)$$

Step 50. Projected area of the fans (a_F):

$$a_F = n_F \cdot \frac{\pi \cdot D_F^2}{4} \quad (46)$$

Step 51. Ratio between the projected area of the fan and the face area (ϕ):

$$\phi = \frac{a_F}{a_v} \cdot 100 \quad (47)$$

2.5. Pressure drop

Step 52. Friction factor for the tube side fluid (f_t):

- Laminar regime (Re_h< 2,100):

$$f_t = \frac{16}{Re_h} \quad (48)$$

- Turbulent regime (Re_h≥ 2,100):

$$f_t = 0.0035 + \frac{0.264}{Re_h^{0.42}} \quad (49)$$

Step 53. Pressure drop 1 (Δp_1):

$$\Delta p_1 = 4 \cdot f_t \cdot n \cdot \left(\frac{L_t}{d_i}\right) \cdot \frac{\rho_h \cdot v_t^2}{2} \quad (50)$$

Step 54. Pressure drop 2 (Δp_2):

$$\Delta p_2 = 4 \cdot n \cdot \frac{\rho_h \cdot v_t^2}{2} \quad (51)$$

Step 55. Total pressure drop for the tube side fluid (Δp_t):

$$\Delta p_t = \Delta p_1 + \Delta p_2 \quad (52)$$

Step 56. Net free volume (N_{FV}):

(53)

INQUIDE
Chemical Engineering and Development
Journal of Science and Engineering
Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

$$N_{FV} = W^c \cdot L_t \cdot S_F - n_{tf} \cdot \pi \cdot L_t \cdot \frac{d_o^2}{4} - N_m \cdot n_{tf} \cdot \pi \cdot L_t \cdot b \cdot \left(\frac{D_b^2 - d_o^2}{4}\right)$$

Where S_F, d_o, b and D_b are given in meters.

Step 57. Equivalent diameter for friction (D'_{eq}):

$$D'_{eq} = \frac{4 \cdot N_{FV}}{L_t \cdot n_{tf} \cdot (A_f + A_D)} \quad (54)$$

Step 58. Reynolds number of air for pressure drop calculations (Re'_c):

$$Re'_c = \frac{D'_{eq} \cdot m_c}{a_s \cdot \mu_c} \quad (55)$$

Step 59. Friction factor for air (f_a):

$$f_a = 1.276 \cdot Re'^{-0.14}_c \quad (56)$$

Step 60. Average temperature of air through the air cooler ($\bar{t}$):

$$\bar{t} = \frac{t_1 + t_2}{2} \quad (57)$$

Step 61. Average air density in the tube bundle at $\bar{t}$ ($\bar{\rho_c}$):

$$\bar{\rho_c} = \frac{M_c \cdot P_a}{R \cdot (\bar{t} + 273)} \quad (58)$$

Step 62. Pressure drop of air through the bundle (Δp_a):

$$\Delta p_a = \frac{f_a \cdot \left(\frac{m_c}{a_s}\right)^2 \cdot n_f \cdot S_F}{2 \cdot \rho_c \cdot D'_{eq}} \cdot \left(\frac{D'_{eq}}{S_T}\right)^{0.4} \cdot \left(\frac{S_L}{S_T}\right)^{0.6} \quad (59)$$

Where ρ_c is the air inlet density calculated in Step 10.

2.6. Fan driver power

Step 63. Air velocity at the fan (v_F):

$$v_F = \frac{m_c}{2 \cdot \bar{\rho_c} \cdot \frac{\pi \cdot D_F^2}{4}} \quad (60)$$

Step 64. Pressure developed by the fan (P_F):

$$P_F = \Delta p_a + \frac{\bar{\rho_c} \cdot v_F^2}{2} \quad (61)$$

Step 65. Volumetric flowrate in the fans (q_F):

$$q_F = \frac{m_c}{2 \cdot \bar{\rho_c}} \quad (62)$$

Step 66 . Fan driver power (P_D):

$$P_D = \frac{q_F \cdot P_F}{\eta_F \cdot \eta_d} \quad (63)$$

Where η_F is 0.75 and η_d is 0.95, according to [7].

3. Results.

3.1. Preliminary design

Step 1. Definition of the initial data available:

- Methanol mass flowrate (m_h): 28,000 kg/h.
- Inlet temperature of methanol (T_1): 90 ºC.
- Outlet temperature of methanol (T_2): 45 ºC.
- Inlet temperature of air (t_1): 25 ºC.
- Pressure of air (P_a): 1 atm.
- Internal diameter of tubes (d_i): 20.5 mm = 0.0205 m.
- External diameter of tubes (d_0): 25.4 mm = 0.0254 m.
- Fin thickness (b): 0.380 mm = 0.00038 m.
- Fin height (H_f): 15 mm = 0.015 m.
- Tube pitch (S_L): 60.32 mm = 0.06032 m.
- Parameter S_F: 52.23 mm = 0.05223 m.
- Number of fins per meter of tube (N_m): 394.
- Tube length (L_t): 6 m
- Maximum allowable pressure drop for methanol [$\Delta p_{(m)h}$]: 800 Pa.
- Fouling resistance for methanol (R_h): 0.0003 K.m^2/W.
- Thermal conductivity of aluminum (k_f): 200 W/m.K [7].
- Number of fans (n_F): 2.
- Diameter of a fan (D_F): 1.8 m.

Step 2. Average temperature of methanol ($\bar{T}$):

$$\bar{T} = \frac{T_1 + T_2}{2} = \frac{90 + 45}{2} = 67.5\ ºC \quad (1)$$

Step 3. Definition of the physical properties for methanol and air:

Table 3 presents the values of the physical properties to be defined for both streams, according to data reported by [20]. The physical properties for methanol are established at 67.5 ºC; while for air they are defined at 25 ºC.

Table 3. Physical properties to be defined for both streams.

Property	Methanol	Air	Units
Density	746.73	-	kg/m^3
Viscosity	0.000336	0.000018	Pa.s
Thermal conductivity	0.1880	0.0260	W/m.K
Heat capacity	2,835.79	1,011	J/Kg.K

Source: Own elaboration.

Step 4. Heat transferred (Q):

Using data of the hot stream (methanol):

$$Q = \frac{m_h}{3{,}600} \cdot Cp_h \cdot (T_1 - T_2) = 992{,}526.5\ W \quad (2)$$

Step 5. Assumption of the overall heat transfer coefficient (U^a):

INQUIDE
Chemical Engineering and Development
Journal of Science and Engineering
Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

As suggested by [7], a value for the overall heat transfer coefficient of 260 W/m^2.K was assumed for this type of heat exchange application.

Step 6. Parameter Z:

$$Z = \frac{(T_1 - T_2)}{(T_1 - t_1)} = \frac{(90 - 45)}{(90 - 25)} = 0.692 \quad (3)$$

Step 7. Selection of the number of tube rows (n_f) and face velocity (v_f):
According to Table 1 [8] for a value for the parameter Z of 0.692, the parameters number of tube rows and face velocity will have values of 6 and 2.8 m/s, respectively.

Step 8. Assumption of the air outlet temperature (t_2):
A value for the air outlet temperature of 50 ºC will be assumed.
Table 4 displays the results of the parameters determined in steps 9-18.

Table 4. Parameters determined in steps 9-18.

Step	Parameter	Symbol	Value	Units
9	Preliminary air flowrate	m_c	39.27	kg/s
10	Air inlet density	ρ_c	1.187	kg/m^3
11	Face area	a_v	12.02	m^2
12	Heat exchanger width	W^a	2.00	m
13	Log mean temperature difference	$LMTD$	28.85	ºC
14	Heat transfer area	A	132.32	m^2
15	Required number of tubes	N	277	-
16	Number of tubes per row	n_{tf}	46.17	-
17	Parameter S_T[1]	S_T	0.06032	m
18	Calculated heat exchanger width	W^c	2.78	m

[1]As suggested by [7], the value of the parameter S_T is equal to the tube pitch (S_L) = 0.06032 m, for the proposed geometry.
Source: Own elaboration.

Step 19. Verification of the value of W^a calculated in step 12 with the value of W^c determined in the previous step.
The value of the calculated heat exchanger width (W^c = 2.78 m) slightly differs from the value of W^a determined in step 12 (2.00 m) for a face velocity of 2.8 m/s. In this case, we will keep this geometry and correct the air flowrate, the air outlet temperature and $LMTD$. Consequently:

Air flowrate:

$$m_c = v_f \cdot \rho_c \cdot W^c \cdot L_t \quad (13)$$
$$m_c = 2.8 \cdot 1.187 \cdot 2.78 \cdot 6 = 55.44\ kg/s$$

Air outlet temperature:

$$t_2 = t_1 + \frac{Q}{m_c \cdot CP_c} = 25 + \frac{992{,}526.5}{55.44 \cdot 1{,}011} \quad (14)$$
$$t_2 = 42.71\ ºC$$

Corrected log mean temperature difference ($LMTD$):

$$LMTD = \frac{(T_1 - t_2) - (T_2 - t_1)}{ln\frac{(T_1 - t_2)}{(T_2 - t_1)}} \quad (8)$$
$$LMTD = \frac{(90 - 42.71) - (45 - 25)}{ln\frac{(90 - 42.71)}{(45 - 25)}} = 31.71\ ºC$$

Step 20. Compilation and definition of the design parameters determined in the preliminary design.
The proposed air cooler will present the following preliminary design parameters:

- Required number of tubes (N) = 277.
- Number of tubes per row (n_{tf}) = 46.17.
- Number of tube rows (n_f) = 6.
- Calculated heat exchanger width (W^c) = 2.78 m.
- Air flowrate (m_c) = 55.44 kg/s.
- Outlet temperature of air (t_2) = 42.71 ºC.
- Log mean temperature difference ($LMTD$) = 31.71 ºC.

3.2. Detailed design:

Step 21. Assumption of the number of passes for the hot fluid (n).
We shall assume two passes for the hot fluid.

Table 5 presents the values of the parameters determined in steps 22-29.

Table 5. Parameters determined in steps 22-29.

Step	Parameter	Symbol	Value	Units
22	Parameter R	R	2.541	-
	Parameter S	S	0.272	-
23	Parameter P_X[1]	P_X	0.272	-
24	LMTD correction factor[2]	F_t	0.843	-
25	Effective mean temperature difference	ΔT	26.73	ºC
26	Flow area for the tube-side fluid	a_t	0.0457	m^2
27	Velocity of methanol in the tubes	v_t	0.228	m/s
28	Reynolds number of methanol[3]	Re_h	10,388	-
29	Prandtl number of methanol	Pr_h	5.068	-

[1] Since $R \neq 1$, equation (17) will be used to determine P_X.
[2] Since $R \neq 1$, equation (18) will be used to determine F_t.

[3] The methanol flows under turbulent regime since $Re_h > 10{,}000$.
Source: Own elaboration.

Step 30. Internal film coefficient for methanol (h_i):
Since the methanol flows under turbulent regime, equation (26) will be used to determine the internal film coefficient. Thus:

$$h_i = 0.023 \cdot \left(\frac{k_h}{d_i}\right) \cdot Re_h^{0.8} \cdot Pr_h^{0.33} \quad (26)$$

$$h_i = 0.023 \cdot \left(\frac{0.1880}{0.0205}\right) \cdot 10{,}388^{0.8} \cdot 5.068^{0.33}$$

$$h_i = 588.59\ W/m^2.K$$

Table 6 exhibits the results of the parameters determined in steps 31-51.

Table 6. Parameters determined in steps 31-51.

Step	Parameter	Symbol	Value	Units
31	Internal film coefficient referred to the external area	h_{i0}	475.04	W/m^2.K
32	Plain tube area per meter of tube	A_0	0.0797	m^2/m
33	Bare tube surface per meter of tube	A_D	0.0677	m^2/m
34	Fin diameter	D_b	0.0554	m
35	Fin surface	A_f	1.503	m^2/m
36	Projected perimeter	P_p	25.34	m
37	Equivalent diameter	D_{eq}	0.0394	m
38	Airflow area	a_S	8.399	m^2
39	Reynolds number for air	Re_c	14,448	-
40	Parameter j	j	93.02	-
41	Prandtl number for air	Pr_c	0.700	-
42	Convection film coefficient for tube and fins	h_f	54.56	W/m^2.K
43	Parameter m	m	37.89	-
44	Parameter H	H	0.0150	-
45	Parameter Y	Y	0.0193	-
46	Fin efficiency	Ω	0.853	-
47	Film coefficient corrected for fin efficiency	h_{fo}	924	W/m^2.K
48	Fouling resistance of tube-side fluid corrected for the internal/external diameters ratio	R_{hi}	0.000372	K.m^2/W
49	Overall heat transfer coefficient	U	280.95	W/m^2.K
50	Projected area of the fans	a_F	5.087	m^2
51	Ratio of the projected area of the fan/face area	ϕ	42.32	%

Source: Own elaboration.

3.3. Pressure drop

Table 7 exposes the results of the parameters determined in steps 52-62.

Table 7. Results of the parameters determined in steps 52-62.

Step	Parameter	Symbol	Value	Units
52	Friction factor for methanol[1]	f_t	0.0089	-
53	Pressure drop 1	Δp_1	404.46	Pa
54	Pressure drop 2	Δp_2	155.27	Pa
55	Total pressure drop for methanol	Δp_t	559.73	Pa
56	Net free volume	N_{FV}	0.6518	m^3
57	Equivalent diameter for friction	D'_{eq}	0.0060	m
58	Reynolds number of air for pressure drop calculations	Re'_c	2,200	-
59	Friction factor for air	f_a	0.4327	-
60	Average temperature of air through the air cooler	$\bar{t}$	33.85	ºC
61	Average air density in the tube bundle at $\bar{t}$	$\bar{\rho_c}$	1.153	kg/m^3
62	Pressure drop of air through the bundle	Δp_a	164.79	Pa

[1] Equation (49) was employed to determine the friction factor for methanol since $Re_h \geq 2{,}100$.
Source: Own elaboration.

3.4. Fan driver power

Table 8 shows the results of the parameters included in steps 63-66.

Table 8. Results of the parameters included in steps 63-66.

Step	Parameter	Symbol	Value	Units
63	Air velocity at the fan	v_F	9.45	m/s
64	Pressure developed by the fan	P_F	216.27	Pa

65	Volumetric flowrate in the fans	q_F	24.04	m^3/s
66	Fan driver power	P_D	7,297.03 ~ 7.3	W kW

Source: Own elaboration.

4. Discussion.

The preliminary designed air cooler will have 277 tubes, a number of tube rows of 6 and a number of tubes per row of 46.17 (five rows with 46 tubes and one row with 47 tubes). The width has a value of 2.78 m, which can be considered adequate to contain the two fans with a diameter of 1.8 m. It will be necessary an air flowrate of 55.44 kg/s, while the outlet temperature of air will be 42.71 ºC and the LMTD is 31.71 ºC.

In [7] an ACHE was designed to cool down 180,000 kg of heavy-gas oil from 76 ºC to 66 ºC. The preliminary design of this air cooler yielded the following results: number of tubes: 262; four tube rows; a face velocity of 3.3 m/s; a number of tubes per row of 65.5 (two rows with 65 tubes and two rows with 66 tubes); an air flowrate of 105.5 kg/s; an LMTD of 35.2 ºC; an air outlet temperature of 41.5 ºC and a width of 3.94 m to contain two fans with a diameter of 2.5 m.

According to Table 5, the effective mean temperature difference has a value of 26.73 ºC, while the tube-side fluid (methanol) will flow under turbulent regime since its Reynolds number is higher than 10,000, thus the equation (26) is used to determine the internal film coefficient, which has a value 588.59 W/m^2.K. The Reynolds number for air (14,448) is 1.39 times higher than the Reynolds number of methanol (10,388), which is due primarily to the higher value of the mass flowrate (55.44 kg/s) and the lower value of the viscosity (0.000018 Pa.s) of air as compared with the values of these parameters for methanol (mass flowrate of 7.78 kg/s and viscosity of 0.000336 Pa.s). Then, the internal film coefficient referred to the external area has a value of 475.04 W/m^2.K (Table 6).

The value of the convection film coefficient for tube and fins is 54.56 W/m^2.K (Table 6) which can be considered typically low as reported by the literature [19]. The fin efficiency has a value of 0.853, and can be classified as adequate [7], while the film coefficient corrected for fin efficiency is 924 W/m^2.K, which has a high value mainly due to the high value for the fin efficiency and the rather low value of the parameter plain tube area per meter of tube (0.0797 m^2/m). The calculated overall heat transfer coefficient has a value of 280.95 W/m^2.K, and reasonably agrees with the assumed value for this parameter in Step 5 (260 W/m^2.K), indicating the feasibility and viability of the results obtained for the overall heat transfer coefficient through this design methodology. Finally, the ratio of the projected area of the fan with the face area is 42.32%, which is higher than the value established by the process (40%) to have a uniform distribution, thus suggesting that the designed air cooler is feasible to use for this heat exchanger service.

In [7] the tube-side fluid flows under transition regime, since the Reynolds number for this fluid has a value of 4,511, thus the internal film coefficient referred to the external area has a value of 405 W/m^2.K. The Reynolds number for the air has a value of 14,784, the convection film coefficient for tube and fins is 58.1 W/m^2.K, the fin efficiency is 0.83 and the film coefficient corrected for fin efficiency is 1,028 W/m^2.K. Likewise, the calculated overall heat transfer coefficient is 264 W/m^2.K, which is very close to the value assumed of 250 W/m^2.K. Finally, the value of the ratio of the projected area of the fan with the face area is 46%, which is above than the 40% requested, thus indicating that the designer air cooler is viable to employ.

The pressure drop for methanol is 559.73 Pa, which is below the maximum allowable value established by the process for this stream (800 Pa), while the pressure drop of air through the bundle is 164.79 Pa, i.e. the pressure drop of methanol is 3.39 times higher than the pressure drop of air (Table 7).

In [7] the pressure drop for the tube side fluid (heavy-gas oil) has a value of 46,996 Pa, which can be considered high, although is below the value set by the process for this stream (50,000 Pa), while the pressure drop for air is 164.7 Pa.

As shown in Table 8, the air velocity at the fan, which depends on the adopted fan diameter (the smaller this diameter, the higher will be the velocity for the same volumetric flow), is 9.45 m/s, the pressure developed by the fan, which is the sum of the velocity head and the frictional pressure drop through the bundle, is 216.27 Pa, and the volumetric flowrate in the fans is 24.04 m^3/s. Finally, the fan driver power is around 7.3 kW.

In [7] the air velocity at the fan is 9.21 m/s, the pressure developed by the fan is 214.2 Pa, and the volumetric flowrate in the fans is 45.2 m^3/s, thus requiring a fan driver power of 13.6 kW.

5. Conclusions.

A finned tube forced-draft air-cooled heat exchanger was designed using a well-known calculation methodology, in order to cool down a liquid methanol stream. Several parameters were determined such as the heat exchanged (992,526.5 W), the air flowrate (55.44 kg/s), the required number of tubes (277), the heat exchanger width (2.78 m) and the overall heat transfer coefficient (280.95 W/m^2.K). The methanol stream will flow under turbulent regime inside the tubes of the designed ACHE, while the pressure drop of this stream is 559.73 Pa, which is below the maximum allowable value established by the process (800 Pa). The fin efficiency has a value of 0.853, which can be considered acceptable, and the value for the fan driver power is 7.3 kW. The designed forced draft ACHE could be

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

satisfactorily used for the heat exchange application since the value of the parameter ratio between the projected area of the fan and the face area (42.32%) is higher than the value established by the design methodology (40%).

6. Acknowledgements (if applicable)

7.- Author Contributions (Contributor Roles Taxonomy (CRediT))

1. Conceptualization: Amaury Pérez Sánchez, Arlette de la Caridad González Abad.
2. Data curation: Amaury Pérez Sánchez, Heily Victoria González, María Isabel La Rosa Veliz.
3. Formal analysis: Amaury Pérez Sánchez, Arlette de la Caridad González Abad, Zamira María Sarduy Rodríguez.
4. Acquisition of funds: Amaury Pérez Sánchez.
5. Research: Arlette de la Caridad González Abad, Heily Victoria González, Lizthalía Jiménez Guerra.
6. Methodology: Amaury Pérez Sánchez, Arlette de la Caridad González Abad, María Isabel La Rosa Veliz, Zamira María Sarduy Rodríguez.
7. Project management: Amaury Pérez Sánchez, Lizthalía Jiménez Guerra.
8. Resources: Arlette de la Caridad González Abad, Heily Victoria González, María Isabel La Rosa Veliz
9. Software: Amaury Pérez Sánchez, Lizthalía Jiménez Guerra
10. Supervision: Amaury Pérez Sánchez, Arlette de la Caridad González Abad, Heily Victoria González.
11. Validation: María Isabel La Rosa Veliz, Zamira María Sarduy Rodríguez, Lizthalía Jiménez Guerra.
12. Display: Arlette de la Caridad González Abad, Heily Victoria González.
13. Wording - original draft: María Isabel La Rosa Veliz, Zamira María Sarduy Rodríguez, Lizthalía Jiménez Guerra.
14. Writing - revision and editing: Amaury Pérez Sánchez, Arlette de la Caridad González Abad.

8. Appendix.

Nomenclature.

a_F	Projected area of the fans	m^2
a_S	Airflow area	m^2
a_t	Flow area for the tube-side fluid	m^2
a_v	Face area	m^2
A	Heat transfer area	m^2
A_D	Bare tube surface per meter of tube	m^2/m
A_f	Fin surface	m^2/m
A_0	Plain tube area per meter of tube	m^2/m
b	Fin thickness	m
Cp	Heat capacity	J/Kg.K
d_i	Internal diameter of tubes	m
d_0	External diameter of tubes	m
D_b	Fin diameter	m
D_{eq}	Equivalent diameter	m
D'_{eq}	Equivalent diameter for friction	m
D_F	Diameter of a fan	m
f	Friction factor	-
F_t	LMTD correction factor	-
h_f	Convection film coefficient for tube and fins	$W/m^2.K$
h_{fo}	Film coefficient corrected for fin efficiency	$W/m^2.K$
h_i	Internal film coefficient	$W/m^2.K$
h_{i0}	Internal film coefficient referred to the external area	$W/m^2.K$
H	Parameter	-
H_f	Fin height	m
j	Parameter	-
k	Thermal conductivity	W/m.K
k_f	Thermal conductivity of fin material	W/m.K
L_t	Tube length	m
$LMTD$	Log mean temperature difference	ºC
m	Mass flowrate	kg/h
m	Parameter	-
n_f	Number of tube rows	-
n_F	Number of fans	-
n_{tf}	Number of tubes per row	-
N	Required number of tubes	-
N_{FV}	Net free volume	m^3
N_m	Number of fins per meter of tube	-
P_a	Pressure of air	atm
P_D	Fan driver power	kW
P_F	Pressure developed by the fan	Pa
P_p	Projected perimeter	m
P_X	Parameter	-
Pr	Prandtl number	-
Δp_1	Pressure drop 1 for the tube-side fluid	Pa
Δp_2	Pressure drop 2 for the tube-side fluid	Pa
Δp_a	Pressure drop of air through the bundle	Pa
Δp_t	Total pressure drop for the tube-side fluid	Pa
$\Delta p_{(m)h}$	Maximum allowable pressure drop for methanol	Pa
q_F	Volumetric flow in the fans	m^3/s
Q	Heat transferred	W
R	Fouling resistance	$K.m^2/W$
R	Ideal Gas Constant	$atm.m^3/kmol.K$
R	Thermal parameter	-
R_{hi}	Fouling resistance of tube-side fluid corrected for the internal/ external diameters ratio	$K.m^2/W$
Re	Reynolds number	-

Re'_c	Reynolds number of air for pressure drop calculations	-
S	Thermal parameter	-
S_F	Parameter	m
S_L	Tube pitch	m
S_T	Parameter	m
t	Temperature of cold fluid	ºC
$\bar{t}$	Average temperature of cold fluid through the air cooler	ºC
T	Temperature of hot fluid	ºC
$\bar{T}$	Average temperature of hot fluid	ºC
ΔT	Effective mean temperature difference	ºC
U^a	Overall heat transfer coefficient assumed	W/m^2.K
U	Overall heat transfer coefficient	W/m^2.K
v_f	Face velocity	m/s
v_F	Air velocity at the fan	m/s
v_t	Velocity of methanol in the tubes	m/s
W^a	Heat exchanger width (assumed)	m
W^c	Heat exchanger width (calculated)	m
Y	Parameter	-
Z	Parameter	-

Greek symbols

ρ	Density	kg/m^3
$\bar{\rho}$	Average density	
μ	Viscosity	Pa.s
Ω	Fin efficiency	-
ϕ	Ratio of the projected area of the fan/face area	%

Subscripts

1	Inlet
2	Outlet
a	Air
c	Cold fluid
h	Hot fluid
t	Tube-side fluid

7.- References.

[1] H. Park, J. Roh, K. c. Oh, H. Cho, and J. Kim, "Modeling and optimization of water mist system for effective air-cooled heat exchangers," *International Journal of Heat and Mass Transfer*, vol. 184, p. 122297, 2022. https://doi.org/10.1016/j.ijheatmasstransfer.2021.122297

[2] C. B. Carvalho, M. A. S. S. Ravagnani, M. J. Bagajewicz, and A. L. H. Costa, "Globally optimal design of air coolers considering fan performance," *Applied Thermal Engineering*, vol. 161, p. 114188, 2019. https://doi.org/10.1016/j.applthermaleng.2019.114188

[3] Boes, S. (2017). Improve Air-Cooled Heat Exchanger Performance. *Chemical Engineering Progress*, 1-7.

[4] D. Artemyev and A. Zaitsev, "Analysis of increase in efficiency of air-cooled heat exchangers due to intensification of heat exchange," *IOP Conf. Series: Earth and Environmental Science*, vol. 866, p. 012020, 2021. https://doi.org/10.1088/1755-1315/866/1/012020

[5] J. I. Manassaldi, N. J. Scenna, and S. F. Mussati, "Optimization mathematical model for the detailed design of air cooled heat exchangers," *Energy*, vol. 64, pp. 734-746, 2014. http://dx.doi.org/10.1016/j.energy.2013.09.062

[6] L. Zhou *et al.*, "Optimum design for wavy fin tube in an air cooler with genetic algorithm," *Journal of Physics: Conference Series*, vol. 2369, p. 012028, 2022. https://doi.org/10.1088/1742-6596/2369/1/012028

[7] E. Cao, *Heat transfer in process engineering*. New York, USA: The McGraw-Hill Companies, Inc, 2010.

[8] Hudson, "The Basics of Air-Cooled Heat Exchangers," H. P. Corporation, Ed., ed. Texas, USA, 2007.

[9] F. L. Santamaria, J. A. Luceño, M. Martín, and S. Macchietto, "Optimal operation and cleaning scheduling of air coolers in concentrated solar plants," *Computers and Chemical Engineering*, vol. 150, p. 107312, 2021. https://doi.org/10.1016/j.compchemeng.2021.107312

[10] R. Doodman, M. Fesanghary, and R. Hosseini, "A robust stochastic approach for design optimization of air cooled heat exchangers," *Applied Energy*, vol. 86, pp. 1240-1245, 2009. https://doi.org/10.1016/j.apenergy.2008.08.021

[11] E. Liu, B. Guo, L. Lv, W. Qiao, and M. Azimi, "Numerical simulation and simplified calculation method for heat exchange performance of dry air cooler in natural gas pipeline compressor station," *Energy Science & Engineering*, vol. 8, pp. 2256–2270, 2020.

[12] C. Alexopoulos, O. Aljolani, F. Heberle, T. C. Roumpedakis, D. Brüggemann, and S. Karellas, "Design Evaluation for a Finned-Tube CO2 Gas Cooler in Residential Applications," *Energies*, vol. 13, p. 2428, 2020. https://doi.org/10.3390/en13092428

[13] Y. T. Ge and R. T. Cropper, "Simulation and performance evaluation of finned-tube CO2 gas coolers for refrigeration systems," *Applied Thermal Engineering*, vol. 29, pp. 957–965, 2009. https://doi.org/10.1016/j.applthermaleng.2008.05.013

[14] K. Hu *et al.*, "Heat transfer rate prediction and performance optimization of CO2 air cooler in refrigeration system," *Case Studies in Thermal Engineering*, vol. 47, p. 103063, 2023. https://doi.org/https://doi.org/10.1016/j.csite.2023.103063

[15] K. Raj, N. B. Desai, R. Kothari, and F. Haglind, "Transient computational fluid dynamics analysis of solidification in molten salt air-cooled heat exchangers," *Energy Conversion and Management*,

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

vol. 347, p. 120539, 2026. https://doi.org/10.1016/j.enconman.2025.120539

[16] L. Dong and Z. He, "Theoretical Study on the Performance of Air Cooler in Cold Storage," *IOP Conf. Series: Materials Science and Engineering*, vol. 1180, p. 012040, 2021. https://doi.org/10.1088/1757-899X/1180/1/012040

[17] M. T. d. C. Santos, A. R. Secchi, M. J. Bagajewicz, and A. L. H. Costa, "On a new globally optimal method for the design optimization of air coolers coupled with real fans," *Chemical Engineering Science*, vol. 303, p. 120926, 2025. https://doi.org/https://doi.org/10.1016/j.ces.2024.120926

[18] R. Mukherjee, "Effectively Design Air-Cooled Heat Exchangers," *Chemical Engineering Progress*, pp. 26-47, 1997.

[19] R. Mukherjee, *Practical Thermal Design of Air-Cooled Heat Exchangers*. Connecticut, USA: Begell House, Inc, 2007.

[20] D. W. Green and M. Z. Southard, *Perry's Chemical Engineers' Handbook*. New York. USA: McGraw-Hill Education, 2019.

INQUIDE
Chemical Engineering & Development
Journal of Science and Engineering

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

INQUIDE
Ingeniería Química y Desarrollo

Health Risk Management in Bottled Water: Integration of Physicochemical, Microbiological Indicators and Cyanobacterial Risks in Guayas.

Gestión del riesgo sanitario en agua embotellada: integración de indicadores fisicoquímicos, microbiológicos y riesgos por cianobacterias en Guayas.

Fabiola Villa Sánchez [1]; Antonio Escobar Machado;[2] Edisson Lascano Mora [3]Tony Coloma Coloma [4]
Hernan Villa Sánchez [5] Amy Merchán Mendoza [6]

Received: 01/11/2026 – Accepted: 04/27/2026 – Published: 07/12/2026

Research Articles [X] Review Articles [ ] Essay Articles [ ]

* Corresponding author.

Abstract.
Bottled water quality represents a growing public health concern, particularly in contexts exposed to environmental pressures and emerging biological contaminants. This study aimed to evaluate bottled water quality and associated health risks using physicochemical and microbiological indicators, as well as conditions favoring cyanobacterial proliferation. Samples from different commercial brands in Guayaquil were analyzed using spectrophotometric methods, physicochemical measurements, membrane filtration for Escherichia coli, and enzymatic assays for microcystin detection. Results revealed significant inter-brand variability, characterized by low residual chlorine, moderate nutrient presence, and sporadic microbiological contamination events, indicating vulnerability in product sanitary stability. Furthermore, nutrient availability and environmental conditions suggest potential for cyanobacterial growth. Overall, findings demonstrate that compliance with physicochemical standards does not ensure safety, highlighting the need for an integrated risk management approach to improve bottled water quality control.

Keywords:
Bottled Water, Water Quality, Health Risk, Physicochemical Indicators, Escherichia Coli, Microbiological Safety, INEN 2200 Standard..

Resumen.
La calidad del agua embotellada representa un desafío creciente para la salud pública, especialmente en contextos con presión ambiental y riesgos emergentes asociados a contaminantes biológicos. El objetivo del estudio fue evaluar la calidad del agua embotellada y su riesgo sanitario mediante indicadores fisicoquímicos, microbiológicos y la identificación de condiciones favorables para cianobacterias. Se analizaron muestras de distintas marcas comercializadas en Guayaquil mediante espectrofotometría, medición de parámetros fisicoquímicos, filtración por membrana para Escherichia coli y detección de microcistinas mediante ensayo enzimático. Los resultados evidenciaron variabilidad significativa entre marcas, con niveles bajos de cloro residual, presencia moderada de nutrientes y eventos puntuales de contaminación microbiológica, lo que indica vulnerabilidad en la estabilidad sanitaria del producto. Además, la combinación de nutrientes y condiciones ambientales sugiere potencial para proliferación de cianobacterias. En conjunto, los hallazgos evidencian que el cumplimiento fisicoquímico no garantiza la inocuidad, destacando la necesidad de un enfoque integral de gestión del riesgo para fortalecer el control de calidad del agua embotellada.

Palabras clave:
Agua Embotellada, Calidad Del Agua, Riesgo Sanitario, Indicadores Fisicoquímicos, Escherichia Coli, Inocuidad Microbiológica, Norma INEN 2200.

1.- Introduction

Access to safe drinking water is one of the main public health challenges worldwide. The quality of water intended for human consumption must guarantee the absence of physical, chemical and microbiological contaminants that may pose health risks. In this context, the World Health Organization (WHO) establishes that the protection of public health depends on comprehensive risk management based on continuous monitoring of quality parameters and the implementation of water safety plans from source to consumer [1]

Water pollution poses a significant threat to human health and ecosystems. Microbiological contamination is mainly associated with waterborne infectious diseases, while chemical contamination can generate chronic effects such as neurological and reproductive alterations and various types of cancer. Although disinfection processes, particularly chlorination, have significantly reduced the incidence of waterborne infectious diseases, they can also produce chemical by-products that are potentially harmful to health when not properly controlled.[2]

[1] University of Guayaquil; fabiola.villas@ug.edu.ec; https://orcid.org/0000-0002-9260-5810, Guayaquil; Ecuador.
[2] National University of Chimborazo; antonio.escobar@unach.edu.ec; https://orcid.org/0000-0002-9850-0155, Chimborazo; Ecuador.
[3] University of Guayaquil; edisson.lascanomo@ug.edu.ec; Guayaquil; Ecuador.
[4] University of Guayaquil; tony.colomac@ug.edu.ec ; https://orcid.org/0009-0004-1221-1590; Guayaquil; Ecuador.
[5] Independent Researcher; hvvs@hotmail.com; https://orcid.org/0000-0001-9087-055X, Guayaquil; Ecuador.
[6] Independent Researcher; amymerchan05@gmail.com; https://orcid.org/0009-0007-5575-2428; Guayaquil; Ecuador.

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

The relevance of microbiological control of water has been widely documented. reported an outbreak of gastroenteritis caused by *Shigella sonnei* associated with the consumption of contaminated public supply water, showing that failures in disinfection systems can trigger important public health problems. These findings highlight the need to implement continuous monitoring systems that allow for the timely detection of microbiological risks and the prevention of epidemic outbreaks.[3]

In recent decades, the perception of insecurity regarding mains water has driven a sustained growth in bottled water consumption worldwide. The global bottled water market mobilizes billions of dollars annually and continues to expand due to consumers' perception of greater purity and health safety. However, various studies have shown that the quality of bottled water can be affected by factors related to the source of catchment, treatment processes, bottling, storage and distribution conditions, generating variability between brands and production batches.[4]

In Ecuador, bottled water consumption has increased significantly due to limited reliance on some public supply sources. In the city of Guayaquil, 83.8% of consumers report using bottled water on a regular basis, associating this product with attributes of safety, purity and quality. However, research carried out in Quito showed that, although the physicochemical parameters of bottled mineral water generally comply with national and international regulations, some samples showed moderate concentrations of heterotrophic bacteria and microorganisms of the genus *Pseudomonas*, which shows the need to maintain periodic microbiological controls to guarantee the safety of the product [5]

Despite the abundance of water resources in Ecuador, significant challenges related to water quality remain. In particular, microbiological indicators continue to be fundamental tools for determining the health safety of water resources, since they allow the identification of the possible presence of pathogenic microorganisms associated with fecal contamination and other emerging risks. Among the latter, the proliferation of cyanotoxin-producing cyanobacteria stands out, currently considered a growing threat to public health and aquatic ecosystems. Factors such as the increase in nutrients, especially nitrogen and phosphorus, as well as the increase in temperature associated with climate change, favour eutrophication processes and the proliferation of potentially toxic microorganisms.[6]

Cyanobacteria have a secondary metabolism capable of producing toxic compounds such as microcystins, anatoxins and cylindrospermopsins, which have hepatotoxic, neurotoxic and dermatotoxic effects on aquatic organisms and humans. These toxins can be released into the environment during cellular senescence, increasing the risk of exposure through contaminated water consumption, recreational activities, and the food chain.[7]

The province of Guayas represents a scenario of special interest due to the growing anthropogenic pressure on its water resources. Recent studies have identified microbiological contamination in sources intended for human consumption. reported the presence of total coliforms and *Escherichia coli* in samples of bottled water marketed in different cantons of the province, while they detected genes associated with the production of microcystins and cylinspermopsins in samples from the Daule River. These findings show the existence of potential health risks even in the absence of visible cyanobacteria blooms.[8]

In addition, the Guayas basin faces limited availability of information on the factors that trigger harmful algal blooms and toxin production in tropical ecosystems. Recent research indicates that the specific thresholds of the physicochemical and climatic variables that favor these phenomena in the region are still unknown. This situation is particularly worrying considering that climate change could increase the frequency and intensity of toxic blooms, generating greater risks to human and environmental health.[9]

From a public health perspective, water quality management requires a comprehensive approach that considers both traditional microbiological risks and emerging threats associated with biological and chemical contaminants. Under the paradigm of "One Health" (*One Health*), it is essential to recognize the close interrelationship between human health, animal health and the health of aquatic ecosystems. In this context, the evaluation of physicochemical and microbiological parameters of water is a fundamental tool for the early identification of risks, the formulation of mitigation strategies and the protection of the health of the population.[10]

Therefore, the objective of this study is to evaluate water quality through the determination of physicochemical and microbiological indicators, with emphasis on the identification of health risks associated with indicator microorganisms and emerging contaminants, contributing to the strengthening of water quality surveillance and management systems in the province of Guayas.[11]

1.1. Health risk management in water systems for human consumption.

Health risk management in water systems for human consumption is a comprehensive approach aimed at identifying, evaluating and controlling hazards that may compromise the health of the population. Various studies have indicated that the guarantee of safe water does not depend only on compliance with regulatory parameters, but also on the implementation of dynamic strategies that allow anticipating and mitigating risks throughout the supply

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

chain, from the source to the final consumer. In this context, the concept of risk management has evolved from a reactive approach to preventive models, in which the early identification of hazards and the reduction of their probability of occurrence are prioritized. [12]

From a methodological perspective, recent literature suggests that risk management systems in drinking water should be based on tools such as Water Safety Plans, which integrate hazard analysis, vulnerability assessment, and the implementation of control measures at each stage of the process. This approach recognises that health risks can originate from microbiological contaminants as well as chemical compounds and, more recently, from emerging contaminants such as cyanotoxins. Likewise, the need to consider factors such as environmental variability, anthropogenic influence, and the operating conditions of treatment and distribution systems, which can act as critical determinants in the generation and propagation of risk, is emphasized.[13]

In relation to the variables analysed in this study, health risk management acquires particular relevance as it evidences the interaction between physicochemical and microbiological parameters as determinants of water quality. The literature has highlighted that suboptimal levels of disinfectants, such as residual chlorine, can reduce the capacity for microbiological control, while the presence of nutrients such as nitrates and phosphates can favor eutrophication processes and the development of potentially harmful microorganisms. In this sense, the integrated evaluation of these parameters allows not only to diagnose the current state of the water, but also to infer conditions that could increase the probability of health risks over time.[14]

Consequently, the adoption of a risk management approach in the analysis of bottled water is essential to transcend traditional schemes based on compliance with permissible limits and move towards predictive and preventive models. The identification of variability in the evaluated parameters and the detection of specific pollution events show the need to strengthen monitoring and control systems, incorporating indicators that allow anticipating emerging risks. In this way, this study is framed in a comprehensive perspective that seeks to contribute to the development of more robust strategies for the protection of public health in the province of Guayas.[15]

1.2. Physicochemical indicators as tools for assessing water quality.

Physicochemical indicators are fundamental tools for the evaluation of the quality of water intended for human consumption, since they allow characterizing its chemical and physical properties, as well as identifying possible alterations derived from natural processes or anthropogenic activities. Studies have shown that parameters such as pH, electrical conductivity, total dissolved solids, and nutrient concentration provide key information on the condition of water and its suitability for consumption. In this sense, these indicators not only reflect the intrinsic quality of the water resource, but also act as early signals of possible contamination or deterioration processes.[2]

From an analytical perspective, recent literature suggests that the interpretation of physicochemical indicators should be approached in an integrated way, considering the interactions between variables and their influence on the stability of the aquatic system. pH, for example, conditions the solubility of chemical compounds and biological activity, while conductivity and total dissolved solids are associated with the mineralization of water and the presence of dissolved ions. On the other hand, nutrients such as nitrates, nitrites and phosphates play a central role in eutrophication processes, acting as limiting factors for the growth of microorganisms. This systemic approach allows us to understand that water quality does not depend on a single parameter, but on the complex interaction between multiple variables that can amplify or mitigate health risks.[16]

In relation to the variables analysed in this study, physicochemical indicators acquire special relevance as they show patterns of variability that may be associated with both the origin of the water and the treatment and storage processes. Moderate concentrations of nitrates and phosphates, combined with low levels of residual chlorine, suggest potentially favorable conditions for the proliferation of microorganisms, including toxin-producing cyanobacteria. In addition, the observed variability in parameters such as electrical conductivity and total dissolved solids indicates differences in chemical composition between samples, which could influence water stability and the efficiency of disinfection processes. In this way, physicochemical indicators not only allow us to assess the current quality of the water, but also to infer underlying processes that could impact its safety over time.[17]

Consequently, although physicochemical indicators are widely used as control criteria in health regulations, their ability to guarantee water safety is limited when considered in isolation. The literature has highlighted that compliance with permissible values does not necessarily imply the absence of risk, especially in contexts where there are emerging contaminants or conditions that favor biological proliferation. Therefore, the analysis of these indicators must be integrated into a broader risk management approach, in which their interpretation is complemented by microbiological data and the evaluation of environmental and operational factors. In this framework, the present study aims to demonstrate the need for a multidimensional evaluation to improve the surveillance and control of bottled water quality in environments with high anthropogenic pressure.[18]

1.3. Microbiological indicators and risk associated with faecal contamination.

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

Microbiological indicators are one of the fundamental pillars in the evaluation of the sanitary quality of water for human consumption, due to their ability to evidence the possible presence of pathogenic microorganisms associated with fecal contamination. Several studies have indicated that the detection of indicator bacteria, particularly Escherichia coli, allows inferring the existence of recent contamination and, therefore, the potential presence of etiological agents responsible for waterborne diseases. In this sense, microbiological indicators not only fulfill a monitoring function, but also represent a direct criterion of safety, since their presence implies an immediate risk to public health. [19]

From a conceptual perspective, the scientific literature has consolidated the use of E. coli as a universal marker of fecal contamination due to its specificity, abundance in the intestinal tract of warm-blooded animals, and ease of detection by standardized methods. This approach is based on the premise that the introduction of fecal matter into water systems entails the possible presence of pathogens such as bacteria, viruses and protozoa, which may not be directly detected due to their analytical complexity. However, it is also recognized that microbiological indicators have limitations, as they do not always reflect the presence of all pathogens or fully capture the dynamics of emerging contaminants, reinforcing the need to complement their analysis with other parameters.[20]

In the context of the present study, microbiological evaluation is critically important as it reveals the presence of E. coli in certain bottled water samples, which is direct evidence of failures in the disinfection, packaging, or storage processes. The coexistence of contamination-free samples with others with high concentrations of colony-forming units suggests significant variability in sanitary quality between brands and batches. This heterogeneity, in combination with low levels of residual chlorine observed in the physicochemical analysis, indicates conditions conducive to microbial survival and proliferation, increasing the probability of exposure to pathogens. In addition, this scenario shows the vulnerability of the system to post-treatment contamination events, which can occur even when the water initially meets quality standards.[21]

Consequently, the interpretation of microbiological indicators in the framework of health risk management requires an approach that goes beyond the timely verification of regulatory compliance and is oriented towards understanding the dynamics of contamination and exposure. The presence of sporadic but significant fecal contamination events suggests a risk model characterized by low frequency and high severity, which is particularly relevant in terms of public health. Therefore, the integration of microbiological indicators with physicochemical and environmental variables is positioned as a fundamental strategy for the development of more robust surveillance systems, capable of anticipating risks and guaranteeing the safety of bottled water in contexts with high anthropogenic pressure.[22]

1.4. Cyanobacteria and cyanotoxins as emerging contaminants.

Cyanobacteria, also known as blue-green algae, are a group of photosynthetic microorganisms widely distributed in aquatic ecosystems, whose health relevance has increased significantly in recent decades. Various studies have indicated that, under certain environmental conditions, these microalgae can proliferate massively, generating harmful algal blooms that compromise water quality. This phenomenon, known as eutrophication, is mainly associated with the enrichment of nutrients such as nitrogen and phosphorus, as well as climatic factors such as the increase in temperature and the stability of the water column. In this context, cyanobacteria have been recognized as emerging contaminants due to their ability to alter the physicochemical conditions of water and to produce toxic compounds with direct implications for public health.[23]

From a toxicological perspective, the scientific literature has documented that many species of cyanobacteria are capable of synthesizing secondary metabolites known as cyanotoxins, among which microcystins, anatoxins and cylinspermopsins stand out. These compounds have a wide variety of adverse effects, including liver toxicity, neurotoxicity, and dermatological effects, depending on the route of exposure and the dose ingested. At the molecular level, microcystins, for example, act as potent inhibitors of phosphatase enzymes, disrupting critical cellular processes and causing tissue damage. The complexity of these toxins lies in their chemical stability and in their ability to persist in water even after cell death of cyanobacteria, which amplifies the risk of exposure in both raw and treated water.[24]

In relation to the variables analyzed in the present study, the presence of nutrients such as phosphates and nitrates acquires a central role as limiting factors in the proliferation of cyanobacteria. Recent literature suggests that moderate concentrations of these compounds may be sufficient to trigger algal growth processes in aquatic systems, especially in favorable thermal conditions such as those observed in tropical environments. Likewise, the low concentration of residual chlorine identified in some samples could limit the inhibition capacity of these microorganisms in long-term storage systems. Although the initial analysis did not show significant presence of cyanotoxins, the observation of growth under subsequent experimental conditions suggests the existence of a latent proliferation potential, which reinforces the hypothesis of vulnerability of the system to this type of contaminants. [25]

Consequently, the inclusion of cyanobacteria and their toxins in the water quality analysis responds to the need to expand the traditional approach towards an emerging risk perspective. The literature has highlighted that conventional monitoring systems, focused on classic physicochemical

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

and microbiological parameters, may be insufficient to detect these risks early. Therefore, the integration of indicators associated with eutrophication and the specific surveillance of cyanotoxins is positioned as a critical component in health risk management. In this sense, the present study contributes to evidence the importance of considering these emerging contaminants in the evaluation of the quality of bottled water, particularly in regions with environmental conditions that favor their proliferation. [26]

1.5. Bottled water: perception of quality, real risks and control challenges.

Bottled water consumption has experienced sustained growth globally, driven mainly by the perception of greater purity, health safety and organoleptic quality compared to mains water. Various studies have indicated that this preference responds both to factors of institutional trust and to previous experiences related to the quality of public supply. In urban contexts with high pressure on supply systems, as is the case in several cities in Latin America, the choice of bottled water is associated with the search for a reduction in perceived health risk, positioning itself as an apparently safer alternative for human consumption.[27]

However, recent literature suggests that there is a significant gap between the perception of quality and the actual risks associated with bottled water. Despite being subject to specific regulations, its quality can be compromised by multiple factors along the value chain, including the source of capture, treatment processes, bottling conditions, as well as storage and distribution. The absence of an adequate disinfectant residual, together with exposure to variable environmental conditions, can favor the proliferation of microorganisms or the alteration of the physicochemical characteristics of the water. This set of factors shows that bottled water is not an inherently risk-free product, but that its safety depends on systematic and continuous control.[28]

Within the framework of this study, the evaluation of physicochemical and microbiological parameters reveals the existence of variability between brands and batches, which reinforces the hypothesis that quality control systems are not homogeneous in practice. The detection of low levels of residual chlorine, together with the presence of nutrients and specific events of microbiological contamination, suggests that production and management conditions can generate scenarios conducive to the deterioration of water quality. In addition, the possible interaction between these factors and the proliferation of emerging contaminants, such as cyanobacteria, introduces an additional dimension of risk that is not always considered in traditional surveillance systems.

Consequently, the challenges in the control of bottled water quality require the adoption of more comprehensive approaches based on health risk management, which incorporate the simultaneous monitoring of physicochemical, microbiological and emerging variables. The literature has emphasized the need to strengthen traceability systems, improve disinfection protocols, and ensure adequate storage and distribution conditions to minimize the likelihood of contamination. In this context, this study contributes to evidence the importance of rethinking bottled water quality assessment models, promoting a more critical and evidence-based view that effectively protects the health of consumers in environments with high demand and potential exposure.[29]

2.- Materials and methods.

The present study opted for a quantitative methodological design that integrated laboratory analysis with the collection of contextual information on the consumption of bottled water in the province of Guayas.

1. Sample collection

Bottled water samples were taken from various distribution points in the city of Guayaquil, including supermarkets, neighborhood stores, and street vendors. The sample included different brands and production batches, which were determined by a survey applied to consumers using Google Forms as a digital platform to determine the most consumed brands in order to obtain a representative view of the quality of the water that reaches the population. The sample size was defined by means of probability sampling, considering the accessibility and availability of the products in the market.[30]

2. Parameters analyzed

In the laboratory, analyses of physicochemical and microbiological parameters and the proliferation of cyanobacteria were carried out, using the following equipment and supplies:

- Nutrients (phosphates, nitrites and nitrates): They were determined with the Hach DRY 900 spectrophotometer equipment, using specific reagents for each of these parameters.
- Residual free chlorine: This was measured with the Hach DRY 900 spectrophotometer, following the protocols indicated by the manufacturer.
- pH: It was quantified with a digital pH-meter.
- *Eschericha coli* was performed by filtration method and cyanobacteria (Microcystin- RL)

3. Analysis procedure

Each sample was properly processed to ensure the reliability of the results. The values obtained were compared with the maximum permissible limits established by the Ecuadorian Technical Standard NTE INEN 2200:2017 – Bottled Purified Water, as well as with the recommendations of the World Health Organization (WHO, 2017) for water intended for human consumption.

4. Microbiological Methods

The detection of microcystins in the water samples was performed using the MicroCystest® kit (Zeulab, Spain), a method based on the inhibition of the enzyme protein

phosphatase 2A (PP2A), the biological mechanism responsible for the toxicity of microcystins and nodularins. This methodology allows the real potential toxicity of the samples to be determined, detecting different variants of microcystins present in the water.
The procedure consisted of adding 50 µL of sample or standard in each well of a microplate, followed by the incorporation of the phosphatase solution and the chromogenic substrate. The samples were then incubated at 37 °C for 30 minutes. At the end of the incubation period, the stop solution was added and the spectrophotometric reading was performed at a wavelength of 405 nm. The concentration of microcystins was determined by means of a calibration curve elaborated with microcystin-LR standards.

The analytical validation of the method included the determination of the limit of detection (0.09 µg/L) and the limit of quantification (0.23 µg/L), as well as the evaluation of precision and accuracy by means of repeatability, intermediate precision and recovery tests.

For the determination of *Eschericha coli.* It has been performed by 100 mL membrane filtration, the filter is taken and placed in the selective medium for *E. coli* in blue, and the m-TEC agar, used in EPA method 1103.2, which consists of: a) Filtration: A known volume of water sample is filtered through a filtration membrane (usually with a pore size of 0.45 µm), retaining bacteria on the surface; b) Culture: The membrane is placed on a Petri dish with mTEC agar. c) Incubation: It is incubated at a high temperature (usually 44.5 °C for 24 hours) to inhibit unwanted bacteria d) Counting: After incubation, E . *coli* forms yellow-green colonies, which are counted directly as colony-forming units (CFUs) per 100 mL of sample.

3.- Results.

The results obtained are presented in the following tables of the parameters determined by the physical, chemical and microbiological analyses

Table 1. Water analysis using the HACH DRY 900

Sample	March	Free chlorine (mg/L)	Phosphate (mg/L)	nitratos (mg/L)	nitrites (mg/L)
ACB	Pure Water	0,02	1,6	1,2	0,001
ACF	Thessaly	0,03	2,0	2,0	0,007
ACF	Mountain	0,02	1,2	1,5	0,002
ANA	Ok	0,04	1,8	0,3	0,004
ASG	Ok	0,03	0,9	0,9	0,006
ACB	Ok	0,04	1,0	0,7	0,004
SCB	Aqua Premium	0,03	1,0	1,1	0,004
SNA	Omizu	0,02	1,4	4,7	0,004
SCB	Alive	0,01	1,1	1,3	0,002
SSG	Aqua Premium	0,01	1,5	1,2	0,007
SSG	Omizu	0,02	1,1	3,8	0,006
SSD	Thessaly	0,03	2,6	2,3	0,003
SSD	Alive	0,01	0,9	1,0	0,004
SSG	Pure Water	0,02	1,8	1,6	0,001
SSD	Sky	0,04	1,1	0,7	0,005
SSD	All Natural	0,03	1,7	1,3	0,001
SSD	Dasani	0,02	1,3	1,1	0,004
TCF	Mountain	0,02	1,3	1,6	0,001
TNA	Alive	0,02	0,9	1,3	0,002
TNA	Pure Water	0,07	1,5	1,1	0,005
TNA	Sky	0,06	1,0	0,4	0,006
TNA	All Natural	0,03	1,3	1,1	0,002
TNA	Dasani	0,03	1,1	0,9	0,009
TNA	Omizu	0,03	1,3	3,5	0,004
TNA	Thessaly	0,05	2,7	2,8	0,008
TNA	Aqua Premium	0,03	1,4	0,8	0,005
TSG	Mountain	0,02	1,5	1,4	0,021
ACB	All Natural	0,04	1,3	1,1	0,009
ACB	Sky	0,03	0,9	0,6	0,007
ACB	Dasani	0,03	1,4	0,8	0,004

The physicochemical characterization presented in Table 1 shows a relevant inter-brand variability in the main parameters associated with both water quality and the potential development of sanitary risks, which reflects heterogeneity in the collection, treatment and control processes in the bottled water industry in the province of Guayas. In terms of residual free chlorine, values ranged from 0.01 to 0.07 mg/L, consistently below the range recommended by the World Health Organization (0.2–0.5 mg/L) to ensure effective disinfection during storage and distribution. This condition implies a limited persistence of the disinfectant effect, which increases the probability of post-bottling microbiological recontamination, especially under inadequate handling conditions or prolonged environmental exposure. The wide range observed also suggests inconsistencies in chlorination protocols between different brands and batches, which constitutes a factor of uncertainty in health risk management.

Regarding dissolved nutrients, phosphates had concentrations between 0.9 and 2.7 mg/L, while nitrates varied between 0.3 and 4.7 mg/L. Although these values are below the maximum permissible limits established by international regulations for human consumption, their presence in relatively high concentrations in certain

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

samples, particularly in brands such as Thessaly and Omizu, suggests contributions of anthropogenic origin associated with agricultural runoff or urban influences. From an ecological and health perspective, these nutrients are a key limiting factor in eutrophication processes, and can promote the proliferation of cyanobacteria in aquatic systems, including in treated water supply chains. In this sense, the coexistence of moderate levels of nitrogen and phosphorus increases the probability of generating trophic conditions favorable for the development of harmful algal blooms and the eventual production of cyanotoxins, which represents an emerging risk that transcends conventional physicochemical controls.

In relation to nitrites, the concentrations recorded were generally low (0.001–0.021 mg/L), however, the presence of high punctual values, as in the sample corresponding to the Montaña brand (0.021 mg/L), can be interpreted as an indicator of recent processes of contamination or incomplete transformation of nitrogen, reflecting possible deficiencies in the quality of the treatment or in the storage conditions. From the point of view of health risk, although the concentrations do not reach acute toxicity levels, the detection of nitrites acquires epidemiological relevance as it is associated with the formation of potentially harmful compounds, such as nitrosamines, and with adverse effects in vulnerable populations.

In an integrated manner, the analysis of Table 1 shows that, although the parameters evaluated are within permissible ranges in most cases, the variability observed and the combination of factors such as low chlorine residual and the presence of nutrients generate a scenario conducive to an increase in health risk. In particular, the convergence of conditions that favor both microbial survival and nutrient availability poses a potential risk of deterioration of water quality during its useful life, evidencing the need to strengthen control systems, implement continuous monitoring strategies and adopt a preventive approach based on comprehensive risk management.

Table 2. Results of the samples analyzed according to descriptive statistics

Numerical variable	# of data	Media	Standard Deviation	Medium	Cropped average (10%)
Cloro_libre (mg/L)	29	0,030	0,0138	0,03	0,0284
pH	30	7,141	0,4249	7,29	7,1958
Phosphates (mg/L)	30	1,387	0,4508	1,3	1,3167
Nitrates (mg/L)	30	1,470	1,0154	1,15	1,2833
Nitrites (mg/L)	30	0,005	0,0038	0,004	0,0044
uS/cm	30	221,667	216,8998	198,5	179,54
T_°C	30	25,047	0,5829	25,1	25,125
ppm	30	110,800	108,5247	99,5	89,750
mV	30	334,367	34,4528	330	333,541

The analysis of the descriptive statistics presented in Table 2 allows us to evaluate the central tendency, dispersion and stability of physicochemical parameters, providing an inferential basis for interpreting water quality and its implication in health risk. In the case of residual free chlorine, a mean of 0.030 mg/L with a standard deviation of 0.0138 is observed, indicating low relative variability but consistently reduced levels in most samples. The coincidence between the mean, median (0.03 mg/L) and trimmed mean (0.0284 mg/L) suggests an approximately symmetrical distribution with no influential extreme values, reinforcing the evidence of a systematic trend towards suboptimal concentrations of residual chlorine. From a health perspective, this homogeneity at low levels implies a generalized scenario of insufficient disinfectant capacity, consistently increasing the probability of survival or reintroduction of microorganisms during the distribution chain.

The pH has a mean of 7.141 with a moderate standard deviation (0.4249), indicating a relatively stable distribution around neutrality. The difference between the mean and the median (7.29) suggests a slight asymmetry towards lower values, although without critical deviations from the recommended range. The proximity between the arithmetic mean and the trimmed mean shows the absence of significant outliers, indicating relatively homogeneous chemical conditions between the samples. Although these values do not represent a direct risk to health, their stability contributes to maintaining favorable physicochemical conditions for biological processes, which becomes relevant in the presence of other factors such as the availability of nutrients.

In relation to phosphates, the mean of 1.387 mg/L and the standard deviation of 0.4508 reflect moderate variability, with a slight difference from the median (1.3 mg/L), indicating a slight positive asymmetry. This characteristic suggests the presence of some samples with relatively high concentrations that increase the average. From an environmental point of view, the persistence of phosphorus levels in this range can favor trophic enrichment processes, particularly when combined with appreciable concentrations of nitrogen, generating conditions conducive to the proliferation of cyanobacteria and increasing the potential risk of cyanotoxin production.

The behavior of nitrates shows a mean of 1.470 mg/L with a high standard deviation (1.0154), which shows a high dispersion of the data. The difference between the mean and the median (1.15 mg/L), as well as the reduction in the cut mean (1.2833 mg/L), suggest the presence of extremely high values that induce a positive asymmetry in the distribution. This pattern implies that, although most of the samples have moderate levels, there are specific cases with significantly higher concentrations that may be associated

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

with specific sources of contamination. From the perspective of risk, this heterogeneity indicates that certain batches or brands are more likely to contribute to eutrophication processes or to show failures in the control of the quality of the source water.

Nitrites have a mean of 0.005 mg/L and a standard deviation of 0.0038, reflecting a relatively high variability compared to their mean value. The median (0.004 mg/L) and the trimmed mean (0.0044 mg/L) indicate a slight asymmetry towards higher values, which can be interpreted as evidence of specific events of recent contamination. Although concentrations remain low in absolute terms, their relative variability suggests instability in nitrogen oxidation processes, which could imply indirect risks associated with the formation of potentially harmful by-products.

The parameters associated with water mineralization, such as electrical conductivity (221.667 µS/cm) and total dissolved solids (110.800 ppm), have high standard deviations (216.8998 and 108.5247 respectively), indicating considerable dispersion and marked heterogeneity between samples. The difference between the mean and the median in both cases suggests the presence of extreme high values that significantly influence the distribution. This behavior is consistent with differences in water origins and treatment processes, which has implications for both sensory quality and chemical stability of the product. From a risk perspective, this variability could affect the interaction between chemical compounds and microorganisms, indirectly influencing the viability of certain pathogens or the persistence of potentially toxic compounds.

Finally, the temperature (mean of 25.047 °C) and the redox potential (334.367 mV) show low variability, which indicates relatively stable conditions during the analysis. However, thermal stability around values close to 25 °C may favor microbial growth in the absence of adequate disinfectant control, while redox potential values reflect a moderately oxidizing environment that, although it contributes to microbiological control, may not be sufficient in combination with low levels of residual chlorine.

Overall, inferential analysis of the descriptive statistics evidences that while parameter means are within acceptable ranges, dispersion and asymmetry of several key variables, particularly nutrients and mineralization parameters, reveal significant heterogeneity in bottled water quality. This variability, added to consistently low levels of residual chlorine, configures a latent health risk scenario, in which apparent chemical stability can mask conditions conducive to microbiological contamination and the proliferation of potentially harmful organisms.

Table 3. Microbiological analysis results

March	Codig	Presentation	Production	Expiration	UFC/100mL
AQUA	TNA	500 ml	26/05/25	26/07/25	0
	SSD	500 ml	26/05/25	26/07/25	0
	ACB	500 ml	26/05/25	26/07/25	0
ALL NATURE	TNA	625 ml	06/06/25	04/10/25	0
	SSD	625 ml	22/05/25	12/09/25	0
	ACB	625 ml	15/05/25	12/09/25	0
TESALI	TNA	625 ml	15/05/25	11/09/25	0
	SSD	625 ml	15/05/25	11/09/25	800
	ACB	625 ml	15/05/25	11/09/25	0
ALIVE	TNA	600 ml	06/05/25	03/10/25	0
	ACB	600 ml	19/05/25	16/10/25	0
	SSD	600 ml	16/04/25	13/09/25	0
PURE	TNA	500 ml	11/05/25	07/11/25	0
	ACB	500 ml	27/05/25	23/11/25	0
	SSD	500 ml	15/03/25	11/09/25	0
SKY	TNA	625 ml	11/05/25	07/11/25	0
	ACB	625 ml	11/05/25	07/11/25	0
	SSD	625 ml	11/05/25	07/11/25	0
OK	TNA	600 ml	23/05/25	20/10/25	0
	ACB	600 ml	23/05/25	20/10/25	0
	SSD	600 ml	23/05/25	20/10/25	0
MANY	TNA	500 ml	19/04/25	20/09/25	350
	ACB	500 ml	19/04/25	20/09/25	200
	SSD	500 ml	19/04/25	20/09/25	650
DASSANI	TNA	600 ml	19/05/25	20/08/25	0
	ACB	600 ml	19/05/25	20/08/25	0
	SSD	600 ml	19/05/25	20/08/25	0
OMIZU	TNA	500 ml	19/02/25	20/05/25	0
	ACB	600 ml	19/05/25	20/08/25	0
	SSD	600 ml	19/05/25	20/08/25	0

The microbiological analysis presented in Table 3 shows a heterogeneous behavior in the sanitary quality of bottled water, with direct implications in the assessment of risk to public health. In general terms, it is observed that most of the samples analyzed (24 out of 30) did not present detectable growth of Escherichia coli, which suggests that, under normal conditions, a significant proportion of the brands comply with the microbiological standards established by current regulations, which require the total absence of this indicator in water intended for human consumption. The consistency of negative results across multiple brands and batches indicates the partial implementation of proper disinfection and sanitary control practices during the treatment and packaging processes.

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

However, the detection of E. coli in four samples introduces a critical element in the evaluation of the system, since its presence constitutes an unequivocal indicator of recent faecal contamination and, therefore, of a failure in the microbiological integrity of the product. The concentrations recorded, which reach values of up to 800 CFU/100 mL in the Tesalia brand (SSD code) and range from 200 to 650 CFU/100 mL in different lots of the Mountain brand, reflect significantly high levels compared to the permissible limit (0 CFU/100 mL). From an inferential perspective, these values do not represent simple marginal deviations, but critical events that show conditions of substantial contamination, with a high microbial load that considerably increases the probability of the presence of enteric pathogens.

The distribution of the positive results also shows a specific pattern associated with certain sample codes, particularly SSD and to a lesser extent other codes in the Mountain brand, which suggests the possible existence of systematic factors related to specific stages of the production process or the distribution chain. This behavior points to the hypothesis of localized failures, either in disinfection systems, in storage conditions or in post-bottling handling. The coincidence of production dates in contaminated batches reinforces the possibility of specific contamination events in the plant or adverse environmental conditions in certain periods, which introduces a temporal dimension in the risk dynamics.

From the health risk management approach, the coexistence of a high percentage of compliant samples with a small but significantly contaminated subset suggests a non-uniform risk scenario, characterized by a low frequency of events but with high severity. This type of distribution is particularly relevant in drinking water systems, since the occurrence of microbiological contamination events, although sporadic, can have disproportionate consequences in terms of public health, including outbreaks of gastrointestinal diseases. The magnitude of the observed values indicates that, in positive cases, the potential exposure far exceeds the safety thresholds, which increases the probability of infection in consumers.

Additionally, the interpretation of these results must be integrated with the previously observed physicochemical conditions, particularly the low levels of residual chlorine, which limit the microbial inhibition capacity during storage. This interaction suggests that the initial absence of contamination does not guarantee the safety of the product over time, as suboptimal disinfection conditions can facilitate bacterial growth in later stages. Consequently, the microbiological evidence presented not only reflects point contamination events, but also the structural vulnerability of the system to failures in quality control.

Overall, the results in Table 3 highlight the need to strengthen microbiological quality assurance systems through the implementation of stricter controls, continuous monitoring and traceability of production batches. They also highlight the importance of adopting a preventive approach based on comprehensive risk management, which is not limited to compliance with physicochemical parameters, but systematically incorporates microbiological surveillance as a central axis to guarantee the safety of bottled water.

Table 4. Results of the samples analyzed according to absolute deviation

Numerical variable	# of data	Absolute Deviation from the Median	Minimum	Maximum	Range
Free chlorine (mg/L)	29	0,015	0,0100	0,07	0,0600
pH	30	0,222	6,2600	7,62	1,3600
Phosphates (mg/L)	30	0,297	0,9000	2,7	1,8000
nitratos_ (mg/L)	30	0,519	0,3000	4,7	4,4000
Nitrites (mg/L)	30	0,003	0,0010	0,021	0,0200
uS/cm	30	203,116	0,0000	792	792,000
T_°C	30	0,593	23,4000	25,8	2,4000
Ppm	30	102,299	0,0000	396	396,000
mV	30	37,065	247,000	398	151,000

The analysis based on the absolute deviation from the median (MAD) and the dispersion statistics presented in Table 4 allows us to delve into the robustness and heterogeneity of the physicochemical parameters, providing relevant inferential evidence for the evaluation of health risk. Unlike the standard deviation, the MAD offers a less sensitive measure to extreme values, so its interpretation is particularly useful to identify the structural stability of the data and detect the presence of outliers with a potential impact on water quality.

In the case of residual free chlorine, the absolute deviation from the median (0.015 mg/L) together with a range of 0.060 mg/L reveals a moderate dispersion around consistently low values, confirming that the low chlorine concentration does not respond to point outliers, but to a systematic condition in most samples. This pattern reinforces the hypothesis of insufficient control of the disinfectant residue throughout the sample, uniformly increasing vulnerability to microbiological recontamination processes and compromising the sanitary stability of the product during storage.

The pH has a MAD of 0.222 and a relatively limited range (1.36 units), indicating considerable chemical stability between the samples. This low dispersion, both in absolute and robust terms, suggests that pH is not a relevant differentiating factor in terms of direct health risk; However, its homogeneous behavior within the neutral to

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

slightly alkaline range may facilitate the persistence of certain microorganisms in the absence of effective disinfectant mechanisms, especially when combined with other limiting factors such as low residual chlorine.

Regarding phosphates, the MAD of 0.297 mg/L and the range of 1.8 mg/L show an intermediate variability with the presence of relatively high values. This behavior suggests that, even though most of the samples have concentrations close to the median, there are significant increases in certain conditions that could favor trophic enrichment processes. In this context, phosphorus continues to position itself as a critical factor in the assessment of ecological risk, since small variations in its concentration can trigger substantial changes in biological dynamics, particularly in systems susceptible to the proliferation of cyanobacteria.

The analysis of nitrates shows a MAD of 0.519 mg/L and a wide range of 4.4 mg/L, which shows a high heterogeneity in the distribution of this nutrient. The combination of a relatively high robust dispersion with a wide range suggests the coexistence of two behaviors: a majority group of moderate values and a fraction of samples with significantly higher concentrations. From the health risk approach, this non-uniform distribution implies that certain batches present more favorable conditions for eutrophication processes or reflect possible influences from external sources of contamination, increasing uncertainty in water quality.

In the case of nitrites, the MAD is low (0.003 mg/L), but its range (0.020 mg/L) indicates the presence of extreme values that, although rare, are relevant due to their health significance. This discrepancy between central stability and range amplitude suggests recent pollution events or failures in complete nitrogen oxidation. From an epidemiological perspective, even small concentrations of nitrites can have implications in vulnerable populations, reinforcing the need to consider not only the magnitude but also the variability of this parameter.

Parameters associated with mineralization, such as electrical conductivity and total dissolved solids, have the highest dispersion values, with MAD of 203.116 µS/cm and 102.299 ppm respectively, and extremely wide ranges (792 µS/cm and 396 ppm). This high variability confirms a marked heterogeneity in the origin of the water and in the treatment processes applied by the different brands. From a health point of view, this compositional diversity can influence the chemical stability of the water and the interaction between microorganisms and the aqueous matrix, indirectly affecting the persistence of contaminants and the efficiency of disinfection processes.

Finally, the temperature and redox potential present relatively low MAD values compared to their ranges, which indicates conditions of operational stability during sampling, although with a certain amplitude that could respond to variations in storage and handling. Temperature around 25 °C, combined with moderate values of redox potential, can contribute to microbial viability in the absence of adequate chemical control, thus reinforcing the interaction between physicochemical and microbiological variables in the construction of the health risk.

Overall, the robust dispersion analysis confirms that the quality of bottled water depends not only on the average values of the parameters, but also on its structural variability and the presence of extreme values. The coexistence of stability in some parameters and high heterogeneity in others configures a complex scenario in which the health risk is not homogeneous, but is unevenly distributed between samples, brands and batches. This behavior highlights the need for monitoring approaches that incorporate robust variability metrics and allow for early identification of critical conditions that may compromise product safety.

Table 5. Results of samples tested for bias

Numerical variable	# of data	Bias	Curtosis	Standard Mean Error
Cloro_libre (mg/L)	29	1,014	1,0780	0,002554
pH	30	-1,093	-0,2706	0,0775693
Fosfatos_(mg/L)	30	1,357	1,5780	0,0823133
nitratos_(mg/L)	30	1,656	2,1482	0,1853949
nitritos_(mg/L)	30	2,376	7,7043	0,000698
uS/cm	30	1,459	1,5211	39,600312
T_°C	30	-1,185	1,1433	0,1064293
Ppm	30	1,457	1,5122	19,813812
mV	30	-0,039	-0,2561	6,290201

The analysis of the coefficients of asymmetry (bias) and kurtosis presented in Table 5 allows us to delve deeper into the shape of the distributions of the physicochemical parameters, providing critical inferential evidence on the presence of extreme values and their implication in the assessment of health risk. In general terms, the predominance of positive biases in several variables indicates asymmetrical distributions to the right, which implies the existence of high values that, although they do not represent the central trend, have a significant impact on the quality of the system and on the interpretation of risk.

In the case of residual free chlorine, positive bias (1.014) and slightly elevated kurtosis (1.078) show an asymmetric distribution with the presence of isolated high values, although most samples are concentrated at low levels. This behavior confirms that higher chlorine values, although they exist, do not represent the dominant condition of the system. From a health perspective, this reinforces the interpretation that microbiological protection is insufficient in most cases, and that events with greater chlorinated residual do not compensate for the generalized disinfection deficit.

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

The pH has a negative bias (-1.093) and a kurtosis close to zero (-0.2706), which indicates a slight concentration of values towards the upper part of the range with a relatively flattened distribution. This pattern suggests a structural stability of the parameter, with low presence of extreme values. Although pH does not represent a direct risk in the observed ranges, its uniform distribution confirms consistent physicochemical conditions that could favor the persistence of microorganisms in the absence of adequate disinfectant barriers.

Phosphates show a positive bias (1.357) and high kurtosis (1.578), indicating a tailed distribution towards high values and a certain concentration of data around the mean with the presence of peaks. This behavior is consistent with the existence of samples with significantly higher concentrations that can act as critical points in the dynamics of the system. From the risk approach, these high values become relevant by enhancing eutrophication processes, increasing the probability of cyanobacteria proliferation and, consequently, of cyanotoxin generation.

The nitrate analysis shows a more pronounced positive bias (1.656) and high kurtosis (2.1482), reflecting a highly asymmetric and leptocurtic distribution. This pattern shows that, although most of the samples are concentrated in moderate values, there are high concentrations that significantly increase the mean. The presence of these extreme values suggests localized sources of contamination that generate heterogeneity in water quality. From a health point of view, this distribution implies that certain batches have a greater potential to contribute to trophic enrichment processes and, therefore, to associated environmental and health risks.

The behavior of nitrites is particularly relevant, with a very high bias (2.376) and extremely high kurtosis (7.7043), indicating a highly concentrated distribution at low values but with the presence of infrequent extreme peaks. This pattern suggests specific events of recent contamination or treatment failures, which, although statistically unrepresentative, have a high health relevance. From a risk perspective, this type of distribution characterizes scenarios where the frequency of events is low but their potential severity is high, which is consistent with systems vulnerable to sporadic failures.

Mineralization parameters, such as conductivity (bias 1.459; kurtosis 1.5211) and total dissolved solids (bias 1.457; kurtosis 1.5122), exhibit similar behaviors, with positive asymmetry and high kurtosis, indicating high heterogeneity in water composition. This pattern confirms the existence of samples with significantly higher levels of mineralization, which can influence the chemical stability of the system and the interaction with microorganisms. From a risk point of view, this variability can affect bacterial survival dynamics and the effectiveness of disinfection processes.

In contrast, the temperature shows a negative bias (-1.185) and a positive kurtosis (1.1433), indicating a slight concentration of values at the upper end with some central accumulation. This behavior, together with the low variability previously observed, suggests relatively stable thermal conditions, but in ranges that may favor microbial growth. On the other hand, the redox potential (mV) has a bias close to zero (-0.039) and a negative kurtosis (-0.2561), which indicates a practically symmetrical and homogeneous distribution, without significant presence of extreme values.

The joint analysis of the bias coefficients, kurtosis and standard error of the mean allows us to infer that, although some parameters have relatively stable distributions, others show marked asymmetries and long tails that show the presence of critical values. This statistical configuration is indicative of a non-homogeneous system, in which water quality can vary significantly between samples and where the presence of extreme events, although rare, has a disproportionate impact on the health risk assessment. In this context, the identification and control of these outliers is essential for the design of monitoring and management strategies, as they constitute the main determinants of emerging risks associated with bottled water quality.

4.- Discussion

4.1. Interpretation of the results

The results obtained show that the quality of the bottled water evaluated cannot be interpreted only under a regulatory compliance approach, but requires a comprehensive analysis based on health risk management. Although most physicochemical parameters remain within permissible ranges, the presence of significant variability between brands and batches suggests the existence of heterogeneity in the processes of capture, treatment and quality control. This behavior confirms that water quality is not a static condition, but the result of complex operational dynamics that can generate scenarios of sanitary vulnerability, even in regulated systems.

A particularly relevant finding is the consistency of suboptimal levels of residual chlorine, which represents a critical factor from the point of view of disinfection. From a technical perspective, residual chlorine acts as a secondary barrier that ensures the microbiological stability of water during storage and distribution. The literature has established that concentrations below the recommended ranges reduce the efficacy of this barrier, increasing the probability of post-treatment contamination. In this context, the results suggest that the analyzed system has a limited microbiological control capacity over time, which could explain the appearance of specific contamination events detected in the microbiological analysis.[31]

In relation to nutrients, the presence of nitrates, nitrites and phosphates in moderate concentrations, although within acceptable limits, acquires relevance when considered from

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

an ecological and emerging risk approach. Recent literature suggests that the simultaneous availability of nitrogen and phosphorus can favor eutrophication processes, even in apparently controlled systems, particularly in tropical conditions characterized by high temperatures. In this sense, the coexistence of nutrients with low levels of disinfectant configures a scenario conducive to the development of microorganisms, including cyanobacteria potentially producing toxins, which transcends traditional quality assessment approaches.

Finally, the detection of microbiological contamination in a small but significant number of samples introduces a critical dimension in the interpretation of the results. From the point of view of risk management, this behavior is consistent with systems characterized by low frequency of events but high severity, where the occurrence of punctual failures can generate disproportionate impacts on public health. Overall, the findings show that apparent physicochemical conformity does not guarantee health safety, which reinforces the need to adopt comprehensive approaches that consider the interaction between chemical, microbiological and environmental variables.

4.2. Comparison with previous studies

The results obtained are relevant in line with previous research that has documented the variability in bottled water quality and the limitations of control systems based exclusively on conventional parameters. Various studies have reported that, although bottled water usually meets established physicochemical criteria, microbiological inconsistencies may occur associated with failures in disinfection processes or inadequate storage conditions. This pattern coincides with observed findings, where most samples meet regulatory requirements, but isolated fecal contamination events persist.[32]

In particular, the microbiological results are consistent with what has been reported in regional studies, such as the one carried out in the province of Guayas, where the presence of Escherichia coli in commercialized bottled water was evidenced. This coincidence reinforces the hypothesis that, in local contexts, quality assurance systems present structural weaknesses that allow the occurrence of pollution events. Likewise, recent research has indicated that the perception of safety associated with bottled water does not always correspond to its actual microbiological quality, which positions these findings within a broader problem of trust and regulation in alternative supply systems.[33]

In relation to physicochemical parameters, the results are consistent with studies that have shown the influence of factors such as the source of uptake and treatment processes on the variability of parameters such as conductivity, dissolved solids and nutrients. However, the present study provides an additional element by integrating these parameters with the health risk approach, showing how the presence of nutrients, even in moderate concentrations, can become relevant in terms of eutrophication processes and biological proliferation. This integration allows us to move beyond the description of quality to a functional interpretation of the system.[34]

Additionally, the findings related to the potential for cyanobacteria proliferation align with recent research that has documented the presence of genes associated with the production of cyanotoxins in bodies of water in the region, such as the Daule River. This convergence of evidence suggests that the area's water systems present favorable conditions for the development of emerging contaminants, and that these risks may extend to treated water systems if adequate controls are not in place. In this sense, the study contributes to expanding existing knowledge by linking bottled water quality to regional environmental dynamics and emerging risks.[35]

4.3. Theoretical and practical implications

From a theoretical point of view, the results of the study provide evidence that reinforces the need to move from traditional quality control approaches to comprehensive models based on health risk management. The literature has indicated that the evaluation of water quality must consider not only compliance with maximum permissible limits, but also the probability of occurrence of adverse events and their possible consequences. In this context, the present study contributes to consolidate a multidimensional approach that integrates physicochemical, microbiological and environmental variables, expanding the conceptual framework for the evaluation of bottled water systems.

The study also provides a relevant perspective by incorporating the analysis of emerging contaminants, such as cyanobacteria and their toxins, within the context of bottled water. This approach allows the discussion to be extended beyond traditional indicators, evidencing the need to include variables associated with eutrophication and ecological dynamics in monitoring systems. In this way, it contributes to the development of more complete conceptual models that consider the interaction between chemical, biological and environmental processes in the generation of health risk.

In practical terms, the results have direct implications for the bottled water industry and for regulatory entities. Evidence of low levels of residual chlorine suggests the need to review and optimize disinfection processes to ensure the microbiological stability of the product during its life cycle. Likewise, the variability observed between brands highlights the importance of strengthening quality control systems, including periodic audits, real-time monitoring and batch traceability, in order to reduce the occurrence of contamination events.

Additionally, from an applied perspective, the findings open the possibility of developing technological innovation strategies aimed at improving treatment and storage systems, such as the use of alternative disinfectants, intelligent sensors for continuous monitoring or predictive models of water quality. Likewise, in the field of

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

environmental management, the results suggest the need to implement integrated policies that address water quality from source to consumption, incorporating the "One Health" approach as a framework for decision-making.

4.4. Limitations and future projections

Despite the relevance of the findings obtained, the study has certain limitations that must be considered in the interpretation of the results. First, the sample size, while representative of the most consumed brands, may not fully capture the variability of the bottled water market in Guayas province, which could limit the generalizability of the results. Likewise, the selection of samples was made based on availability and accessibility, which introduces a possible bias associated with the commercial distribution of the products.

From a methodological point of view, the analysis focused on a specific set of physicochemical and microbiological parameters, implying that other potentially relevant pollutants, such as heavy metals, microplastics or emerging organic compounds, were not considered. This limitation restricts the scope of the study in terms of comprehensive characterization of water quality and suggests the need to broaden the spectrum of analysis in future research.

In relation to cyanotoxins, although a validated detection method was used, the results obtained reflect the apparent absence of these substances under initial conditions, but show their possible development under controlled experimental conditions. However, the study does not incorporate a longitudinal analysis that allows the evaluation of the temporal evolution of these pollutants in real storage conditions, which limits the understanding of their dynamics in consumption scenarios. This restriction highlights the need for more in-depth studies that integrate temporal analyses and variable environmental conditions.

In this context, future research should be oriented towards the development of predictive risk models that integrate physicochemical, microbiological and environmental variables, allowing contamination scenarios to be anticipated. It is also recommended to incorporate advanced analysis techniques, such as molecular tools for the detection of toxigenic genes or real-time sensors for quality monitoring. These lines of research would not only make it possible to overcome the identified limitations, but would also contribute to the development of more robust and adaptive management systems, capable of responding to emerging challenges in the quality of water for human consumption.

5.- Conclusion.

5.1. Synthesis of findings

The present study made it possible to comprehensively evaluate the quality of bottled water marketed in the province of Guayas through the application of physicochemical and microbiological indicators, showing that, although most of the samples comply with the limits established by current regulations, there are significant variations between brands and batches that condition the sanitary stability of the product. In particular, it was identified that the physicochemical parameters present heterogeneous behaviors, characterized by the presence of nutrients in moderate concentrations and consistently low levels of residual chlorine, which limits the ability to control microbiological quality during storage.

Likewise, the microbiological results revealed the presence of specific fecal contamination events, which shows that compliance with physicochemical parameters does not guarantee the safety of the water by itself. This evidence confirms that bottled water quality responds to complex dynamics involving both treatment processes and subsequent handling conditions. In this sense, the objectives of the study were met by evidencing the need to integrate multiple indicators for a more robust assessment of health risk in water systems for human consumption.

5.2. Scientific and technical contributions

From a scientific point of view, the study contributes to strengthening the conceptual framework of health risk management in bottled water systems, by demonstrating that the evaluation based on traditional parameters is insufficient when analyzed in isolation. The integration of physicochemical and microbiological variables, together with the consideration of factors associated with emerging pollutants, allows us to move towards a multidimensional approach that broadens the understanding of the processes that determine water quality.

In the technical field, the work provides relevant empirical evidence on the variability in the quality of bottled water in a tropical context, identifying conditions that can favor the proliferation of microorganisms and the deterioration of quality during the supply chain. Likewise, the incorporation of cyanotoxin analysis, even when they were not initially detected in the samples, represents a methodological advance by considering the potential for the development of emerging risks under specific environmental conditions, thus contributing to closing gaps in the conventional assessment of water quality.

5.3. Theoretical implications and practical applications

The findings of the study have relevant implications for the theoretical development of water quality assessment models, as they demonstrate the need to adopt risk-based approaches that integrate chemical, microbiological and ecological variables. This perspective allows us to move towards more robust conceptual frameworks, in which water quality is understood as a dynamic system influenced by multiple interrelated factors, thus overcoming traditional approaches focused exclusively on regulatory compliance.

From the applied point of view, the results highlight the importance of strengthening quality control systems in the bottled water industry, particularly in relation to the

optimization of disinfection processes, the continuous monitoring of critical parameters and the implementation of traceability systems that allow identifying and correcting failures in the supply chain. Likewise, the need to incorporate emerging contamination indicators and preventive strategies to mitigate risks associated with the proliferation of cyanobacteria, especially in regions with favorable environmental conditions for their development, is evident.

5.4. Projections and lines of future research

Based on the results obtained, several lines of future research are identified aimed at deepening the understanding of the factors that condition the quality of bottled water. Firstly, it is recommended to develop longitudinal studies to evaluate the temporal evolution of physicochemical and microbiological parameters during storage, in order to determine the stability of the product throughout its shelf life. It is also pertinent to incorporate the analysis of other emerging pollutants, such as heavy metals, microplastics and organic compounds, which could influence water quality and the health of consumers.

Additionally, it is suggested to move towards the development of predictive risk models that integrate environmental, operational and water quality variables, allowing anticipating pollution scenarios and optimizing management systems. Finally, the implementation of advanced monitoring techniques, including molecular tools for the detection of toxigenic microorganisms and real-time sensors, represents a promising line to strengthen health surveillance and contribute to the design of safer and more resilient supply systems in contexts of high anthropogenic pressure.

6.- Acknowledgements.

Not applicable.

7.- Contributions of authors (Taxonomy of contributors' roles - CRediT)

1. Conceptualization: Fabiola Villa Sánchez
2. Data Curation: Amy Merchán Mendoza
3. Formal analysis: Fabiola Villa Sánchez
4. Acquisition of funds: Tony Coloma Coloma
5. Research: Antonio Escobar Machado
6. Methodology: Tony Coloma Coloma
7. Project management: Hernan Villa Sánchez
8. Resources: Hernan Villa Sánchez
9. Software: Antonio Escobar Machado
10. Supervision: Edisson Lascano Mora
11. Validation: Tony Coloma Coloma
12. Visualization: Amy Merchán Mendoza
13. Writing - original draft: Edisson Lascano Mora
14. Writing-proofreading and editing: Amy Merchán Mendoza

8.- Appendix.

Not applicable.

9.- References.

[1] World Health Organization (WHO), "Guidelines for drinking-water quality: Fourth edition incorporating the first, second and third addenda," World Health Organization. , 2026. [Online]. Available: https://www.who.int/publications/i/item/9789240121225 . [Accessed 2026].

[2] Villanueva, C. M., Kogevinas, M., & Grimalt, J. O., "Chlorination of drinking water in Spain and bladder cancer.," in *Gaceta Sanitaria*, 2001, pp. 15(1), 48–53.

[3] Godoy, P., Bartolomé, R., Torres, J., Espinet, L., Escobar, A., Nuin, C., & Domínguez, Á., "Rote de gastroenteritis por el consumo de agua de agua de público causa por Shigella sonnei.," Gaceta Sanitaria, 25(5), 363–367, 2011. [Online]. Available: https://doi.org/10.1016/j.gaceta.2011.0. [Accessed 2026].

[4] McLachlan, R. I., & Tuffley, C., "Parametric study of E. coli incidence with reference to the New Zealand freshwater standards and the Manawatū-Whanganui region," arXiv, 2011. [Online]. Available: https://arxiv.org/abs/2110.01808. [Accessed 2026].

[5] C. P. R. J. A. &. L. F. A. Llushca, ". Physicochemical and microbiological quality of bottled spring mineral water marketed in Quito, Ecuador.," *Acta Farmacêutica Portuguesa.* , 2023.

[6] Instituto Ecuatoriano de Normalización (INEN)., "NTE INEN 2200: Bottled water. Requirements.," *NTE INEN 2200: Bottled water. Requirements.* , 2014.

[7] Alejandro Quezada, Daniela del Cisne, "Identification of cyanobacteria associated with risks to human health present in the aquatic biodiversity of the Papallacta Lagoon.," INSTITUTIONAL REPOSITORY CENTRAL UNIVERSITY OF ECUADOR, 2023. [Online]. Available: https://www.dspace.uce.edu.ec/entities/publication/9da979f3-4c27-4bbc-93d4-da9dfae5c09a. [Accessed 2026].

[8] Estupiñán Vera, G. E., Briceño Castillo, J. P., Cazañas Chica, J. D., & Vinces Muñoz, A. A., "Level of acceptance of the types of bottled water in the city of Guayaquil.," RECIMUNDO, 9(2), 596–607, 2025. [Online]. Available: https://doi.org/10.26820/recimundo/9.(2).April.2025.596-607 . [Accessed 2026].

[9] Huisman, J., & Visser, P. M. , "Harmful cyanobacterial blooms: Causes, consequences and control strategies.," *Aquatic Ecology.* , 2018.

[10] Schreiber, A., & Van der Merwe, M., ". One Health and water quality management: Integrating ecosystem, animal and human health.," 2021.

[11] Coloma Gavilanes, Julio Ferdinand; Labanda Lucero, Ricardo Andrés, "Molecular tools for the detection of

potentially toxic cyanobacteria in aquatic ecosystems of the Daule River," DSpace Repository, 2023. [Online]. Available: https://dspace.espol.edu.ec/xmlui/handle/123456789/58379?locale-attribute=en. [Accessed 2026].

[12] R. Rojas, "Guide for the Surveillance and Control of the Quality of Water for Human Consumption," PAHO, 2002.

[13] L. A. Zapata Aspiazu, E. Haymacaña Moreno, F. J. Duque-Aldaz, F. G. Cabezas García and R. A. Sánchez Ancajima, "ARIMA vs. Hybrid Models with Machine Learning for Forecasting Ecuador's GDP.," 2026.

[14] Zepeda Rodríguez, L. F., & Tello Ibarra, J. V., "Bottled Water: Sanitary Contemplations between the Human Right to Health and Private Industry.," Constitutional Issues. Revista Mexicana de Derecho Constitucional, 26(52), e19558. , 2025. [Online]. Available: https://doi.org/10.22201/iij.24484881e.2025.52.19558 . [Accessed 2026].

[15] B. Fournier and R. Mujeriego Sahuquillo, "Gestión del riesgo sanitario en la regeneración del agua," UPC, 2006.

[16] B. M. Guillén Chuncho, "valuation of chemical and microbiological components in bottled water for human consumption, marketed in three cantons of the province of Guayas," UG Repository, 2020. [Online]. Available: https://repositorio.ug.edu.ec/handle/redug/49925. . [Accessed 2026].

[17] E. I. Carrillo Paredes and J. E. Baldeón Cajo, "Control of the quality of water for human consumption through physicochemical and microbiological parameters in the Parish of San Andrés, Chimborazo, for efficient sanitary management," UISEK, 2018.

[18] E. Osorio Caicedo and D. Paredes Cuervo, "Strategic Guidelines Focused on the Reduction of Health Risk Applied in Two Community Supply Systems," UTP, 2022.

[19] B. L. Guzmán, G. Nava and P. Díaz, "The quality of water for human consumption and its association with morbidity and mortality in Colombia, 2008-2012," *Biomédica*, vol. 35, 2015.

[20] J. E. Estiven Pincay Moran, J. F. Ramírez Salcan, A. F. López Vargas, F. J. Duque-Aldaz, W. Villamagua Castillo and R. Sánchez Casanova, "Evaluation and Proposal for an Environmental Management System in a Mango Plantation," *Inquide*, vol. 7, no. 1, 2025.

[21] F. J. Duque-Aldaz, E. R. Haymacaña Moreno, L. A. Zapata Aspiazu and F. Carrasco Choque, "Prediction of moisture content in the cocoa drying process by simple linear regression.," *Inquide*, vol. 6, no. 2, 2024.

[22] A. Pérez Vidal, P. Torres Lozada and C. H. Cruz Vélez, "Water Security Plans. Fundamentals and perspectives of implementation in Colombia," *Engineering and Research*, vol. 29, no. 3, 2009.

[23] M. Padilla Gómez and F. Ascuntar Ríos, "Analysis of the health and environmental risks identified in the water supply systems for human consumption of the category 4, 5 and 6 municipalities of the Department of Valle del Cauca," Universidad Autónoma de Occidente, 2020.

[24] C. M. Tito Arequipa and V. M. Ortiz Bustamante, "Study of water quality as a sanitary risk factor and water supply management model of the Santo Samana neighborhood of the city of Latacunga in the period 2015.," Technical University of Cotopaxi, 2017.

[25] F. J. Duque-Aldaz, F. R. Rodríguez-Flores and J. Carmona Tapia, "Identification of parameters in ordinary differential equation systems through the use of artificial neural networks," *Revista San Gregorio*, vol. 1, no. 2, 2025.

[26] K. E. Zambrano Acosta and N. Vásquez Sarria, "Study of environmental and health risk factors and their impact on the quality of water for human consumption in some rural areas of Valle del Cauca," Universidad Autónoma de Occidente, 2018.

[27] L. E. Quispe Alegre, "Development and implementation of a control and monitoring prototype to determine the sanitary risk of the water supply system for human consumption in the town of El Triunfo, through electronic sensors and web technology, 2017," UNAMAD, 2019.

[28] R. González Forero and N. F. Ajiaco Ajiaco, "Design of a risk management system based on the ISO 31000 Standard for chlorine disinfection systems in water treatment plants," Universidad de La Salle, 2018.

[29] G. E. Castro Rosales, A. D. Torres Alvarado, L. S. Zalamea Cedeño, F. J. Duque-Aldaz and F. R. Rodríguez-Flores, "Comprehensive Ergonomic Proposal for the Reduction of Musculoskeletal Risks in Soap Production: An Approach Based on Statistical Analysis and Postural Evaluation," *Inquide*, vol. 7, no. 2, 2025.

[30] G. J. Morocho Choca, L. Á. Bucheli Carpio and F. J. Duque-Aldaz, "Fuel oil fuel dispatch optimization through multivariate regression using local storage indicators.," *Inquide*, vol. 6, no. 2, 2024.

[31] E. Haymacaña Moreno, L. A. Zapata Aspiazu, F. J. Duque-Aldaz, G. F. Cabezas García and R. A. Sánchez Ancajima, Time series modeling of secondary school enrollment in Ecuador: a Box–Jenkins analysis (1971–2023), Inquide, 2026.

[32] B. L. Guzmán B., G. Nava T. and P. D. Bevilacqua, "Surveillance of the quality of water for human consumption in Colombia: challenges for

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

environmental health," *Revista Facultad Nacional de Salud Pública*, vol. 34, no. 2, 2016.

[33] L. Alcalde Sanz, M. Folch Sánchez and J. C. Tapias Pantebre, "Evaluation and management of the risk associated with the reuse of wastewater," University of Barcelona., 2012.

[34] J. Ramírez Flórez and J. W. Sanchez Marin, "Support in a sanitary risk project focused on the water line for human consumption and recreational use in the Ministry of Health of the Mayor's Office of Medellín," Tecnológico de Antioquia, 2021.

[35] J. J. Cavero Torres and B. R. Mariño Tenio, "Diagnosis in sanitation systems from disaster risk management: a systematic review," *InveCom Journal*, vol. 5, no. 3, 2025.

INQUIDE
Chemical Engineering and Development
Journal of Science and Engineering

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

Thermo-hydraulic design of an unfinned and finned double pipe heat exchanger for tomato juice cooling. Part 1 - Unfinned heat exchanger

Diseño térmico-hidráulico de un intercambiador de calor de doble tubo sin y con aletas para el enfriamiento de jugo de tomate. Parte 1 – Intercambiador de calor sin aletas

Amaury Pérez Sánchez [1]*; Laura Thalía Álvarez Lores [2]; Laura de la Caridad Arias Águila [3]; Lizthalía Jiménez Guerra [4]; Heily Victoria González [5]; Arlette de la Caridad González Abad [6]

Received: 21/02/2026 – Accepted: 15/05/2026 – Published: 12/07/2026

Research Articles [X] Review Articles [ ] Essay Articles [ ]

* Corresponding author.

Abstract.
The double pipe heat exchanger (DPHE) is commonly used in the food industry due to its simplicity in mechanical design, minimal maintenance, ease of cleaning and also the possibility to operate at high temperatures and pressures. The objective of this paper is to design an unfinned DPHE form the thermo-hydraulic point of view, to determine its feasibility to cool down a stream of hot tomato juice using chilled water as coolant. The main design parameters calculated were the total number of hairpins (32), the cleanliness factor (0.708), the percent over surface (41.29%), and the frictional pressure drop and pumping power for both fluids. Likewise, it will be required a mass flowrate of cooling water of 6.50 kg/s, with a heat load of 951.77 kW. The designed DPHE cannot be successfully applied to the requested heat transfer service because the high values obtained for the total number of hairpins, percent over surface and the frictional pressure drop (16.56 atm) for the annulus fluid (chilled water), which is quite higher than the maximum allowable value set by the process (0.296 atm) for this stream, thus increasing also the pumping power of this fluid to a significant value (13.67 kW). The designed unfinned DPHE will cost around USD $ 165,500 based on Jan, 2026.

Keywords.
Double pipe heat exchanger, design, total number of hairpins, percent over surface, pressure drop, pumping power.

Resumen.
El intercambiador de calor de doble tubo (ICDT) es comúnmente usado en la industria alimenticia debido a su simplicidad en el diseño mecánico, mínimo mantenimiento, facilidad de limpieza y también la posibilidad de operar a elevadas temperaturas y presiones. El objetivo de este artículo es el de diseñar un ICDT desde el punto de vista térmico-hidráulico, para determinar su factibilidad para enfriar una corriente de jugo de tomate caliente usando agua fría como agente de enfriamiento. Los principales parámetros de diseño calculados fueron el número total de horquillas (32), el factor de limpieza (0,708), el porcentaje de sobre superficie (41,29%), y la caída de presión friccional y potencia de bombeo para ambos fluidos. Asimismo, se requerirá un caudal másico de agua fría de 6,50 kg/s, con una carga de calor de 951,77 kW. El ICDT diseñado no puede ser aplicado satisfactoriamente para el servicio de transferencia de calor requerido, debido a los elevados valores obtenidos para el número total de horquillas, porcentaje de sobre superficie y caída de presión friccional (16,56 atm) para el fluido del ánulo (agua fría), el cual es muy superior al valor mínimo permisible fijado por el proceso (0,296 atm) para esta corriente, incrementado por tanto también la potencia de bombeo de este fluido hacia un valor significativo (13,67 kW). El ICDT sin aletas diseñado costará alrededor de USD $ 165 500 basado en Enero del 2026.

Palabras clave.
Intercambiador de calor de doble tubo, diseño, número total de horquillas, porcentaje de sobre superficie, caída de presión, potencia de bombeo.

1. Introduction.

Heat exchanger equipment transfers heat from a hot fluid to a cold fluid, where both fluids are separated by means of a solid wall. Typically, most heat exchangers are two-fluid heat exchangers, although three-fluid heat exchangers are becoming popular. In terms of construction, heat exchangers can be classified as shell and tube, concentric tube and finned tube heat exchangers. The choice of a heat exchanger for a given application is dependent on the application itself, available resources, space, economics, materials selection, and other factors. Whatever may be the choice of a heat exchanger, it is very essential that a heat exchanger be designed such that it delivers the required heat transfer while occupying less space, has pressure drops under the allowable limits set by the process, and yet be cost competitive [1].

Double pipe heat exchanger (DPHE) is regarded as one of the simplest types of tubular heat exchanger. It is made up of concentric pipes that are separated by mechanical closures. Double pipe heat exchangers are relatively cheap to construct and require minimal maintenance. They are used in high temperature and high pressure applications [2].

DPHE (also called hairpin heat exchangers) are a widely used configuration in heating and industrial systems.

[1] Faculty of Applied Sciences; University of Camagüey; amaury.perez84@gmail.com; https://orcid.org/0000-0002-0819-6760, Camagüey; Cuba.
[2] Faculty of Applied Sciences; University of Camagüey; laura.alvarez@reduc.edu.cu; https://orcid.org/0009-0007-2643-018X , Camagüey; Cuba.
[3] Faculty of Applied Sciences; University of Camagüey; aguilaariaslaura@gmail.com; https://orcid.org/0000-0002-6494-9747, Camagüey; Cuba.
[4] Technical Area, Fuel Storage Facility 540; lizthalia.jimenez@reduc.edu.cu; https://orcid.org/0009-0004-4537-2366, Camagüey, Cuba.
[5] Faculty of Applied Sciences; University of Camagüey; heily.victoria@reduc.edu.cu; https://orcid.org/0009-0007-9319-6506, Camagüey, Cuba.
[6] Faculty of Applied Sciences; University of Camagüey; arlette.delacaridad@reduc.edu.cu; https://orcid.org/0000-0002-3193-0660, Camagüey; Cuba.

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

DPHEs can be used in the chemical, food, oil and gas industries, solar and geothermal energy applications, air-conditioning applications, reheating, preheating, and digester heating processes. Moreover, DPHE is still widely used for the research and development of experimental facilities in energy engineering laboratories. One advantage is the low cost of design and maintenance. This type of heat exchanger is simple in structure and easy to install, clean, maintain, and modify, which allows a significant extension of life and service [3].

DPHE consists of one or more pipes placed concentrically inside another pipe of a larger diameter with appropriate fittings to direct the flow from one section to the next. One fluid flows through the inner pipe (tube-side), and the other flows through the annular space (annulus). The inner pipe is connected by U-shaped return bends enclosed in a return-bend housing. DPHE can be arranged in various series and parallel arrangements to meet pressure drop requirements. The major use of the DPHE is the sensible heating or cooling process of fluids where small heat transfer areas (up to 50 m^2) are required. This configuration is also very suitable for one or both of the fluids at high pressure because of the smaller diameter of the pipes. They can be used when one stream is a gas, viscous liquid, or small in volume, and also under severe fouling conditions because of the ease of cleaning and maintenance [4].

According to [5], if the stream contains solids in suspension, DPHE may also be a better alternative, because they can be built with an inner tube with larger diameter to avoid plugging. In addition, double pipe heat exchangers are easily cleaned, and the longitudinal flow avoids the existence of stagnation regions, which in shell and tube exchangers are prone to fouling. DPHEs have also the benefit of flexibility due to its modular structure, which allows an easier adaptation to process modifications.

Tomato (*Lycopersicon esculentum* Mill) is one of the most widely consumed cultivated horticultural crops globally and ranks second in global production among vegetable crops. Tomato undergoes a variety of different treatments aiming to transform it into well-known commercial products such as sauce, ketchup and juice, canned whole tomatoes, and tomato paste/concentrate. For example, for preservation after harvesting, tomatoes are thermally treated with several techniques, such as pasteurization and sterilization, and drying and evaporation at high temperatures, which help to ensure the microbiological safety and stability of the resulting products [6].

The technology for the production of tomato juice drink is basically the same with that used for the production of tomato paste. The process involves selection of ripen and wholesome fruits, followed by washing, chopping, removal of seeds, hot break, pre-heating demineralized water, and then screened over 0.3-0.4 mm meshes to extract finer juice with less suspended solids and to remove free fatty acids and oily matter. The juice obtained may be concentrated by heating under vacuum. Salt, sugar and spices may be added to taste. The finished product is usually stored in compatible packaging materials made of glass or aluminum coated containers [7].

As stated by [8], two methods are used commercially to produce tomato juice: hot break and cold break. “Hot break” typically refers to a chopping temperature of 85 to 90 ºC, which causes inactivation of enzymes important to aroma and viscosity. Pectinmethylesterase and polygalacturonase break down chains of pectin in tomato tissue. By inactivating these enzymes in the hot break process, a more viscous product can be achieved, which is usually desirable. Conversely, lipoxygenase is the initiating enzyme involved in the creation of important fresh aroma compounds through the breakdown of unsaturated fatty acids, and when it is inactivated in the hot break, fewer aroma compounds are present. These authors also mention that “cold break” refers to a temperature below 70 ºC to increase enzyme activity. A characteristic of the cold break process is a decrease in viscosity. Advantages of cold breaking over hot breaking are that the final product is said to have a more natural color and a fresher flavor. The hot break method is used to produce the majority of tomato products to maintain a high viscosity. However, an increase in the use of the cold break method should produce tomato products with a fresher aroma.

In [6] is indicated that conventional heat treatments are currently the most common ones in the food industry, but due to the heat transfer mechanism (conduction and convection), these processes have some drawbacks such as high temperature, loss of nutritional value, and sensory changes. In addition, the combustion of the fuel used to generate heat results in economic energy losses. These disadvantages can be avoided with modern technologies such as ohmic heating, which is a thermal treatment that heats food by passing an alternating electric current through it; as a consequence, this method has a large capacity for rapid and homogeneous heating. In addition, this technique provides safe and high-quality food products while preserving their nutritional value and is characterized by high energy allowing reducing heating time by 90–95%. These authors developed an ohmic-vacuum combination heating system for producing tomato paste at temperatures of 70, 80, and 90 ºC and pressure of 0.3, 0.5, and 0.7 bar and electric field of 1.82, 2.73, and 3.64 V/cm using a central composite design. The effects of heating conditions on the quality and sensory evaluation of tomato paste were also evaluated in this study, while each combination of temperature, pressure, and the electric field was quantified for specific energy consumption, energy efficiency, and productivity.

Few studies are reported related to the thermo-hydraulic design or assessment of heat transfer equipment to process tomato products. In this sense, [9] applied Computational Fluid Dynamics (CFD) to design a shell and tube heat exchanger on an industrial scale and to simulate heat

transfer in order to visualize the pasteurization process of tomato paste with the objective of presenting it to the industry, where the behavior of viscosity in the pasteurization process of tomato paste was explained using the Herschel-Bulkley model. Likewise, [10] aimed to survey possible improvements in thermophysical properties of nanofluids when they are used as heating mediums for time reduction and energy saving in food industries for the first time. Accordingly, three different variables of temperature (70, 80, and 90 °C), alumina nanoparticle concentration (0, 2, and 4 %), and time (30, 60, and 90 s) were selected for thermal processing of tomato juice by a shell and tube heat exchanger. Similarly, [11] evaluated the thermal performance of a triple-tube heat exchanger equipped with staggered fins for tomato concentrate processing. In this study, challenges were encountered due to the high viscosity of non-Newtonian fluids treated in the food industry, which lead to laminar flow and limited thermal penetration. Numerical simulations, implemented within an ANSYS® Fluent environment, were used to solve the equations governing the thermofluid dynamics of a triple-tube heat exchanger with staggered fins in the internal annulus. The rheological behavior of tomato concentrate was modeled by means of a power-law model, coupled with the Arrhenius law to introduce temperature dependency of the consistency index. Experimental validation was adopted to verify simulations accuracy. Despite all the studies mentioned above, to the best of the authors' knowledge, the design of a DPHE for tomato juice cooling has not been reported yet.

Some of the authors of the present study recently published an article [12] where an unfinned DPHE was designed from the thermo-hydraulic point of view, to cool a stream of liquid cow's milk using chilled water as coolant. The design methodology employed in this research was that reported by [13], obtaining as the main result that the designed unfinned DPHE cannot be applied satisfactorily in the requested heat transfer service because the quite high value obtained for the tube-side fluid pressure drop.

In a Cuban food processing facility is desired to cool a stream of tomato juice using chilled water as coolant, and two DPHEs have been proposed for this thermal system, the first one unfinned and the second with longitudinal fins in the inner tube (finned). Therefore, the present paper aims to design the unfinned DPHE from the thermo-hydraulic point of view, in order to know the suitability of this heat exchanger for this heat exchange service. The design methodology employed in the present paper was that reported by [13], where several important design parameters are calculated such as the total number of hairpins, the cleanliness factor, the percent over surface, as well as the pressure drop and pumping power of both liquid streams. Also, the purchase cost of the unfinned DPHE is calculated. In a second paper, a finned DPHE will be designed in order to calculate the same design parameters previously mentioned, while the design results of the present paper will be compared with those of the finned DPHE designed in the second paper, with the purpose of selecting the most appropiate and suitable DPHE from the thermal and hydraulic points of view to perform this heat exchange service.

2. Materials and methods.

2.1. Problem statement.

In a Cuban food processing facility is required to cool down 14,000 kg/h of a stream of tomato juice from 90 ºC to 30 ºC using chilled water as coolant available at 5 ºC, while the outlet temperature of this chilled water must not exceed 40 ºC. The selected construction material of the DPHE is carbon steel, while the pressure drop of the tomato juice and chilled water streams should not be higher than 300,000 Pa. Design a suitable unfinned DPHE from the thermo-hydraulic point of view to satisfy this heat transfer service, using the following inlet data for the tubes:

- Tube length: 4.0 m.
- Annulus internal diameter: 0.07790 m.
- Internal diameter of inner tube: 0.0525 m.
- External diameter of inner tube: 0.0603 m.
- Thermal conductivity of carbon steel: 54 W/m.K [13].

2.2. Design methodology

Total number of hairpins and percent over surface

Step 1. Definition of the initial parameters for the streams: Table 1 presents the initial parameters that must be defined for both fluids.

Table 1. Initial parameters that must be defined for the two fluids.

Parameter	Hot fluid	Cold fluid	Units
Mass flowrate	m_h	m_c	kg/h
Inlet temperature	T_1	t_1	ºC
Outlet temperature	T_2	t_2	ºC
Maximum allowable pressure drop	ΔP_{mh}	ΔP_{mc}	Pa
Fouling factor	R_h	R_c	m^2.K/W

Source: Own elaboration.

Step 2. Definition of the geometric data for the hairpins: Table 2 shows the geometric data that should be defined for the hairpins.

Table 2. Geometric data to be defined for the hairpins.

Parameter	Symbol	Units
Length	L_t	m
Internal diameter annulus	D_i	m
Internal diameter inner tube	d_i	m
External diameter inner tube	d_e	m

Thermal conductivity metallic material of the inner pipe	k_m	W/m.K

Source: Own elaboration.

Step 3. Definition of the flow arrangement inside the double-pipe heat exchanger:

- Counterflow
- Parallel

Step 4. Allocation of fluids inside the double-pipe heat exchanger

Step 5. Consider insulation of the double-pipe heat exchanger against heat losses.

Step 6. Average temperature of both streams:

- Hot fluid (T):

$$\bar{T} = \frac{T_1 + T_2}{2} \quad (1)$$

- Cold fluid ($\bar{t}$):

$$\bar{t} = \frac{t_1 + t_2}{2} \quad (2)$$

Step 7. Physical parameters of both fluids at the average temperature:
Table 3 exhibits the physical parameters that are required to be considered for both fluids at the average temperature calculated in the previous step.

Table 3. Physical parameters that should be considered for both fluids.

Parameter	Hot fluid	Cold fluid	Units
Density	ρ_h	ρ_c	kg/m^3
Viscosity	μ_h	μ_c	Pa.s
Heat capacity	Cp_h	Cp_c	kJ/kg.K
Thermal conductivity	k_h	k_c	W/m.K

Source: Own elaboration.

Step 8. Heat load (Q):

- Using the data for the hot fluid:

$$Q = m_h \cdot Cp_h \cdot (T_1 - T_2) \quad (3)$$

- Using the data for the cold fluid:

$$Q = m_c \cdot Cp_c \cdot (t_2 - t_1) \quad (4)$$

Where both m_h and m_c are given in kg/s.

Step 9. Mass flowrate of one stream:

- Mass flowrate of the hot fluid:

$$m_h = \frac{Q}{Cp_h \cdot (T_1 - T_2)} \quad (5)$$

- Mass flowrate of the cold fluid:

$$m_c = \frac{Q}{Cp_c \cdot (t_2 - t_1)} \quad (6)$$

Step 10. Tube wall temperature (T_w):

$$T_w = \frac{1}{2} \cdot (\bar{T} + \bar{t}) \quad (7)$$

Step 11. Viscosity of both fluids at the tube wall temperature:

- Hot fluid (μ_{hw}) [Pa.s].
- Cold fluid (μ_{cw}) [Pa.s].

Step 12. Net free flow area of the inner tube (A_{ct}):

$$A_{ct} = \frac{\pi \cdot d_i^2}{4} \quad (8)$$

Step 13. Velocity of the tube-side fluid (v_t):

$$v_t = \frac{\frac{m_t}{3{,}600}}{\rho_t \cdot A_{ct}} \quad (9)$$

Step 14. Reynolds number of the tube-side fluid (Re_t):

$$Re_t = \frac{\rho_t \cdot v_t \cdot d_i}{\mu_t} \quad (10)$$

Step 15. Prandtl number of the tube-side fluid (Pr_t):

$$Pr_t = \frac{Cp_t \cdot \mu_t}{k_t} \quad (11)$$

Where Cp_t is given in J/kg.K.

Step 16. Nusselt number for the tube-side fluid (Nu_t):

- Laminar flow (Re_t < 2,300)

$$Nu_t = 1.86 \cdot (Re_t \cdot Pr_t)^{0.33} \cdot \left(\frac{d_i}{L_t}\right)^{0.33} \cdot \left(\frac{\mu_t}{\mu_{tw}}\right)^{0.14} \quad (12)$$

Valid for smooth tubes for the following conditions:

$0.48 < Re_t \cdot Pr_t < 16{,}700$

$0.0044 < \left(\frac{\mu_t}{\mu_{tw}}\right)^{0.14} < 9.75$

$\left(Re_t \cdot Pr_t \cdot \frac{d_i}{L_t}\right)^{0.33} \left(\frac{\mu_t}{\mu_{tw}}\right)^{0.14} \geq 2$

- Turbulent flow (2,300 < Re_t < 10^4) [Gnielinski's correlation]:

$$Nu_t = \frac{\left(\frac{f_t}{2}\right) \cdot (Re_t - 1{,}000) \cdot Pr_t}{1 + 12.7 \cdot \left(\frac{f_t}{2}\right)^{0.5} \cdot \left(Pr_t^{2/3} - 1\right)} \quad (13)$$

Where f_t is the Fanning friction factor for the tube-side fluid and is calculated using the following correlation:

$$f_t = (1.58 \cdot lnRe_t - 3.28)^{-2} \quad (14)$$

INQUIDE
Chemical Engineering and Development
Journal of Science and Engineering
Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

- Turbulent flow ($10^4 < Re_t < 5 \times 10^6$) [Prandtl's correlation]:

$$Nu_t = \frac{\left(\frac{f_t}{2}\right) \cdot Re_t \cdot Pr_t}{1 + 8.7 \cdot \left(\frac{f_t}{2}\right)^{0.5} \cdot (Pr_t - 1)} \quad (15)$$

Valid for $Pr_t > 0.5$.
Where:

$$f_t = (1.58 \cdot lnRe_t - 3.28)^{-2} \quad (14)$$

Step 17. Heat transfer coefficient for the tube-side fluid (h_t):

$$h_t = \frac{Nu_t \cdot k_t}{d_i} \quad (16)$$

Step 18. Net free flow area of the annulus (A_{ca}):

$$A_{ca} = \frac{\pi \cdot (D_i^2 - d_e^2)}{4} \quad (17)$$

Step 19. Velocity of the annulus fluid (v_a):

$$v_a = \frac{\frac{m_a}{3{,}600}}{\rho_a \cdot A_{ca}} \quad (18)$$

Step 20. Hydraulic diameter (D_h):

$$D_h = D_i - d_e \quad (19)$$

Step 21. Reynolds number of the annulus fluid (Re_a):

$$Re_a = \frac{\rho_a \cdot v_a \cdot D_h}{\mu_a} \quad (20)$$

Step 22. Prandtl number of the annulus fluid (Pr_a):

$$Pr_a = \frac{Cp_a \cdot \mu_a}{k_a} \quad (21)$$

Where Cp_a is given in J/kg.K.

Step 23. Nusselt number for the annulus fluid (Nu_a):

- Laminar flow ($Re_a < 2{,}300$)

$$Nu_a = 1.86 \cdot (Re_a \cdot Pr_a)^{0.33} \cdot \left(\frac{D_h}{L_t}\right)^{0.33} \cdot \left(\frac{\mu_a}{\mu_{aw}}\right)^{0.14} \quad (22)$$

Valid for smooth tubes for the following conditions:
$0.48 < Re_a \cdot Pr_a < 16{,}700$

$$0.0044 < \left(\frac{\mu_a}{\mu_{aw}}\right)^{0.14} < 9.75$$

$$\left(Re_a \cdot Pr_a \cdot \frac{D_h}{L_t}\right)^{0.33} \left(\frac{\mu_a}{\mu_{aw}}\right)^{0.14} \geq 2$$

- Turbulent flow ($2{,}300 < Re_a < 10^4$) [Gnielinski's correlation]:

$$Nu_a = \frac{\left(\frac{f_a}{2}\right) \cdot (Re_a - 1{,}000) \cdot Pr_a}{1 + 12.7 \cdot \left(\frac{f_a}{2}\right)^{0.5} \cdot \left(Pr_a^{2/3} - 1\right)} \quad (23)$$

Where f_a is the Fanning friction factor for the annulus fluid and is calculated using the following correlation:

$$f_a = (1.58 \cdot lnRe_a - 3.28)^{-2} \quad (24)$$

- Turbulent flow ($10^4 < Re_a < 5 \times 10^6$) [Prandtl's correlation]:

$$Nu_a = \frac{\left(\frac{f_a}{2}\right) \cdot Re_a \cdot Pr_a}{1 + 8.7 \cdot \left(\frac{f_a}{2}\right)^{0.5} \cdot (Pr_a - 1)} \quad (25)$$

Valid for $Pr_a > 0.5$.
Where:

$$f_a = (1.58 \cdot lnRe_a - 3.28)^{-2} \quad (24)$$

Step 24. Equivalent diameter for heat transfer (D_e):

$$D_e = \frac{D_i^2 - d_e^2}{d_e} \quad (26)$$

Step 25. Heat transfer coefficient for the annulus fluid (h_a):

$$h_a = \frac{Nu_a \cdot k_a}{D_e} \quad (27)$$

Step 26. Fouled overall heat transfer coefficient based on the outside area of the inner tube (U_f):

$$U_f = \frac{1}{\frac{d_e}{d_i \cdot h_t} + \frac{d_e \cdot R_t}{d_i} + \frac{d_e \cdot ln\left(\frac{d_e}{d_i}\right)}{2 \cdot k_m} + R_a + \frac{1}{h_a}} \quad (28)$$

Step 27. Log-mean temperature difference (ΔTm):

- For parallel flow:

$$\Delta Tm = \frac{(T_1 - t_1) - (T_2 - t_2)}{ln\frac{(T_1 - t_1)}{(T_2 - t_2)}} \quad (29)$$

- For counterflow:

$$\Delta Tm = \frac{(T_1 - t_2) - (T_2 - t_1)}{ln\frac{(T_1 - t_2)}{(T_2 - t_1)}} \quad (30)$$

Step 28. Heat transfer surface area (A_o):

$$A_o = \frac{Q \cdot 1{,}000}{U_f \cdot \Delta Tm} \quad (31)$$

Where Q is given in kW.

Step 29. Heat transfer area per hairpin (A_{hp}):

$$A_{hp} = 2 \cdot \pi \cdot d_e \cdot L_t \quad (32)$$

Step 30. Number of hairpins (N_h):

$$N_h = \frac{A_0}{A_{hp}} \quad (33)$$

Step 31. Clean overall heat transfer coefficient based on the outside heat transfer area (U_c):

INQUIDE
Chemical Engineering and Development
Journal of Science and Engineering
Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

$$U_c = \frac{1}{\frac{d_e}{d_i \cdot h_t} + \frac{d_e \cdot ln\left(\frac{d_e}{d_i}\right)}{2 \cdot k_m} + \frac{1}{h_a}} \quad (34)$$

Step 32. Cleanliness factor (CF):

$$CF = \frac{U_f}{U_c} \quad (35)$$

Step 33. Total fouling (R_{ft}):

$$R_{ft} = \frac{1 - CF}{U_c \cdot CF} \quad (36)$$

Step 34. Percentage over surface (OS):

$$OS = 100 \cdot U_c \cdot R_{ft} \quad (37)$$

Pressure drop and pumping power

Step 35. Frictional pressure drop of the tube-side fluid (Δp_t):

$$\Delta p_t = 4 \cdot f_t \cdot \frac{2 \cdot L_t}{d_i} \cdot N_h \cdot \frac{\rho_t \cdot v_t^2}{2} \quad (38)$$

Where for laminar flow (Re_t < 2,300):

$$f_t = \frac{16}{Re_t} \quad (39)$$

Correction of the Fanning friction factor for laminar flow (f_{ct}):

$$f_{ct} = f_t \cdot \left(\frac{\mu_t}{\mu_{tw}}\right)^m \quad (40)$$

Where m = - 0.58 for heating and - 0.50 for cooling under laminar flow.

Step 36. Pumping power for the tube-side fluid (P_t):

$$P_t = \frac{\Delta p_t \cdot m_t}{\eta_p \cdot \rho_t} \quad (41)$$

Where m_h is given in kg/s and η_p is the isentropic efficiency of the pump.

Step 37. Frictional pressure drop of the annulus fluid (Δp_a):

$$\Delta p_a = 4 \cdot f_a \cdot \frac{2 \cdot L_t}{D_h} \cdot \rho_a \cdot \frac{v_a^2}{2} \cdot N_h \quad (42)$$

Where for laminar flow (Re_a < 2,300):

$$f_a = \frac{16}{Re_a} \quad (43)$$

Correction of the Fanning friction factor for laminar flow (f_{ct}):

$$f_{ca} = f_a \cdot \left(\frac{\mu_a}{\mu_{aw}}\right)^m \quad (44)$$

Where m = - 0.58 for heating and - 0.50 for cooling under laminar flow.

Step 38. Pumping power for the annulus fluid (P_a):

$$P_a = \frac{\Delta p_a \cdot m_a}{\eta_p \cdot \rho_a} \quad (45)$$

Where m_a is given in kg/s and η_p is the isentropic efficiency of the pump.

2.3. Purchase cost of the designed DPHE

According to [14], the purchase cost of a unfinned DPHE can be calculated using the following correlation on a U.S. Gulf Coast Basis referred to Jan. 2007:

$$C_{2007} = 1{,}600 + 2{,}100 \cdot A_0^{1.0} \quad (46)$$

Where A_0 - Heat transfer surface area calculated using equation (31), which must range from 1.0 to 80.0 m^2 [14].

Since the unfinned DPHE purchase cost calculated by equation (46) is based on Jan, 2007, this cost must be updated to 2026 using the following correlation [15]:

$$C_{2026} = C_{2007} \frac{CEPCI_{2026}}{CEPCI_{2007}} \quad (47)$$

Where:

C_{2007} – Purchase cost of the unfinned DPHE based on Jan, 2007, calculated using equation (46).

$CEPCI_{2026}$ – Chemical Engineering Plant Cost Index based on Jan, 2026 = 840.9 [16].

$CEPCI_{2007}$ – Chemical Engineering Plant Cost Index based on Jan, 2007 = 509.7 [14].

C_{2026} – Purchase cost of the unfinned DPHE based on Jan, 2026.

3. Results.

3.1. Total number of hairpins and percent over surface

Following next are the numerical results of the several key design parameters calculated by the methodology to size the unfinned DPHE, specifically the total number of hairpins, the cleanliness factor and the percent over surface.

Step 1. Definition of the initial parameters for the streams: Table 4 exposes the numerical values of the initial parameters that must be defined for each fluid.

Table 4. Numerical values of the initial parameters for both fluids.

Parameter	Hot fluid (tomato juice)		Cold fluid (chilled water)		Units
Mass flowrate	m_h	14,000	m_c	-	kg/h
Inlet temperature	T_1	90	t_1	5	ºC
Outlet temperature	T_2	30	t_2	40	ºC
Maximum allowable pressure drop	ΔP_{mh}	300,000	ΔP_{mc}	300,000	Pa

Fouling factor[1]	R_h	0.0003	R_c	0.000176	m².K/W

[1] The values of the fouling factors for both fluids were taken from suggestions reported by [13].
Source: Own elaboration.

Step 2. Definition of the geometric dimensions for the hairpins:
Table 5 indicates the values of the geometric data for the hairpins.

Table 5. Values of the geometric data for the hairpins.

Parameter	Symbol	Value	Units
Length	L_t	4.0	m
Internal diameter annulus	D_i	0.00779	m
Internal diameter inner tube	d_i	0.0525	m
External diameter inner tube	d_e	0.0603	m
Thermal conductivity metallic material of the inner pipe	k_m	54	W/m.K

Source: Own elaboration.

Step 3. Definition of the flow arrangement inside the double-pipe heat exchanger:
Taking into account suggestions reported by [13][17][18], the chosen flow arrangement for this heat exchange system is counterflow.

Step 4. Allocation of fluids inside the double-pipe heat exchanger.
In [3] is stated that it is appropriate to use a DPHE when the heated medium is placed in the annulus with a relatively small cross section area and the heating medium (e.g., steam, hot water, hot process stream) flows in the inner pipe. Following the suggestions of this study, as well as recommendations reported by [14], the hot fluid (tomato juice) will be located in the inner pipe, while the cold fluid (chilled water) will be located in the annulus.

Step 5. Consider insulation of the double-pipe heat exchanger against heat losses.
The designed DPHE will be insulated to prevent unwanted heat losses in the equipment.

Step 6. Average temperature of both streams:

- Hot fluid (T):

$$\bar{T} = \frac{T_1 + T_2}{2} = \frac{90 + 30}{2} = 60\ ºC \quad (1)$$

- Cold fluid ($\bar{t}$):

$$\bar{t} = \frac{t_1 + t_2}{2} = \frac{5 + 40}{2} = 22.5\ ºC \quad (2)$$

Step 7. Physical parameters of both fluids at the average temperature:

Table 6 presents the values of the physical parameters that are defined for both the tomato juice and chilled water at the average temperature calculated in the previous step, which were taken from [19] for the tomato juice, and [20] for the chilled water.

Table 6. Values of the physical parameters defined for both fluids.

Parameter	Hot fluid (tomato juice)		Cold fluid (chilled water)		Units
Density	ρ_h	1,006.3	ρ_c	997.658	kg/m³
Viscosity	μ_h	0.021	μ_c	0.000943	Pa.s
Heat capacity	Cp_h	4.079	Cp_c	4.1825	kJ/kg.K
Thermal conductivity	k_h	0.630	k_c	0.6029	W/m.K

Source: Own elaboration.

Step 8. Heat load (Q):

- Using the data for the hot fluid:

$$Q = m_h \cdot Cp_h \cdot (T_1 - T_2) \quad (3)$$

$$Q = \frac{14{,}000}{3{,}600} \cdot 4.079 \cdot (90 - 30) = 951.77\ kW$$

Step 9. Mass flowrate of the cold fluid (chilled water):

$$m_c = \frac{Q}{Cp_c \cdot (t_2 - t_1)} = \frac{951.77}{4.1825 \cdot (40 - 5)} = 6.50\ kg/s \quad (6)$$

Step 10. Tube wall temperature (T_w):

$$T_w = \frac{1}{2} \cdot (\bar{T} + \bar{t}) = \frac{1}{2} \cdot (60 + 22.5) = 41.25\ ºC \quad (7)$$

Step 11. Viscosity of both fluids at the tube wall temperature:
For a value of the tube wall temperature of 41.25 ºC, the tomato juice (hot fluid) and chilled water (cold fluid) will present the following values for the viscosities [19][20]:

- Tomato juice (μ_{hw}) = 0.03018 Pa.s.
- Chilled water (μ_{cw}) = 0.00064 Pa.s.

Since the tomato juice was located in the inner tube and the chilled water was located in the annulus, the following new nomenclature presented in Table 7 will be applied for the flowrates, physical parameters and fouling factors of both streams.

Table 7. New nomenclature to be applied for both streams.

Parameter	Hot fluid (tomato juice)	Cold fluid (chilled water)

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

	Former nomenclature	New nomenclature	Former nomenclature	New nomenclature
Flowrate	m_h	m_t	m_c	m_a
Density	ρ_h	ρ_t	ρ_c	ρ_a
Viscosity	μ_h	μ_t	μ_c	μ_a
Heat capacity	Cp_h	Cp_t	Cp_c	Cp_a
Thermal conductivity	k_h	k_t	k_c	k_a
Fouling factor	R_h	R_t	R_c	R_a

Source: Own elaboration.

Table 8 shows the results of the parameters calculated in steps 12 to 25.

Table 8. Results of the parameters calculated in steps 12 to 25.

Step	Parameter	Symbol	Value	Units
12	Net free flow area of the inner tube	A_{ct}	0.00216	m^2
13	Velocity of the tube-side fluid (tomato juice)	v_t	1.785	m/s
14	Reynolds number of the tube-side fluid	Re_t	4,492	-
15	Prandtl number of the tube-side fluid	Pr_t	135.97	-
16	Fanning friction factor for the tube-side fluid	f_t	0.00998	-
	Nusselt number for the tube-side fluid[1]	Nu_t	99.45	-
17	Heat transfer coefficient for the tube-side fluid	h_t	1,194	W/m^2.K
18	Net free flow area of the annulus	A_{ca}	0.00191	m^2
19	Velocity of the annulus fluid (chilled water)	v_a	3.411	m/s
20	Hydraulic diameter	D_h	0.0176	m
21	Reynolds number of the annulus fluid	Re_a	63,521	-
22	Prandtl number of the annulus fluid	Pr_a	6.542	-
23	Fanning friction factor for the annulus fluid	f_a	0.00496	-
	Nusselt number for the annulus fluid[2]	Nu_a	303.17	-
24	Equivalent diameter for heat transfer	D_e	0.0403	m
25	Heat transfer coefficient for the annulus fluid	h_a	4,531.13	W/m^2.K

[1] Since 2,300 < Re_t < 10^4, Gnielinski's correlation was employed to calculate Nu_t.
[2] since 10^4 < Re_a < 5 x 10^6, Prandtl's correlation was utilized to calculate Nu_a.
Source: Own elaboration.

Table 9 breakdowns the results of the parameters calculated in steps 26-34.

Table 9. Results of the parameters calculated in steps 27-40.

Step	Parameter	Symbol	Value	Units
26	Fouled overall heat transfer coefficient based on the outside area of the inner tube	U_f	561.46	W/m^2.K
27	Log-mean temperature difference[1]	ΔTm	36.07	ºC
28	Heat transfer surface area	A_o	47	m^2
29	Heat transfer area per hairpin	A_{hp}	1.515	m^2
30	Number of hairpins	N_h	32	-

31	Clean overall heat transfer coefficient based on the outside heat transfer area	U_c	793.33	W/m^2.K
32	Cleanliness factor	CF	0.708	-
33	Total fouling	R_{ft}	0.000521	m^2.K/W
34	Percent over surface	OS	41.29	%

[1] Calculated for counterflow arrangement.
Source: Own elaboration.

3.2. Pressure drop and pumping power

Table 10 presents the results of the parameters calculated in steps 35-38, which comprise the calculation of the pressure drop and pumping power for both fluids.

Table 10. Results of the parameters calculated in steps 35-38.

Step	Parameter	Symbol	Value	Units
35	Frictional pressure drop of the tube-side fluid	Δp_t	312,558 3.08	Pa atm
36	Pumping power for the tube-side fluid	P_t	1.51	kW
37	Frictional pressure drop of the annulus fluid	Δp_a	1,678,128 16.56	Pa arm
38	Pumping power for the annulus fluid	P_a	13.67	kW

Source: Own elaboration.

3.3. Purchase cost of the designed DPHE

Using correlation (46), and for a value of A_o of 47 m^2, the purchase cost of the unfinned DPHE based on Jan, 2007 is:

$$C_{2007} = 1{,}600 + 2{,}100 \cdot A_0^{1.0} \quad (46)$$

$$C_{2007} = 1{,}600 + 2{,}100 \cdot 47^{1.0} = USD\ \$\,100{,}300$$

Then, the purchase cost of the unfinned DPHE based on Jan, 2026 is:

$$C_{2026} = C_{2007} \cdot \frac{CEPCI_{2026}}{CEPCI_{2007}} \quad (47)$$

$$C_{2026} = 100{,}300 \cdot \frac{840.9}{509.7} \approx USD\ \$\,165{,}500$$

4. Discussion

The heat load of the heat exchange system was 951.77 kW, while it was required a mass flowrate of 6.50 kg/s of chilled water at 5 ºC, to cool down 14,000 kg/h of tomato juice from 90 ºC to 30 ºC. In [12] an unfinned DPHE was designed to cool down 4,320 kg/h of a stream of liquid cow's milk using chilled water as coolant available at 2 ºC. In this study, the hot fluid (cow's milk) was located in the annulus, while the cold fluid (chilled water) was located in the inner pipe, thus obtaining a heat load of 235.14 kW and a required mass flowrate of chilled water of 9.32 kg/s.

According to the results of Table 8, the velocity of the tomato juice (tube-side fluid) was 1.785 m/s, which is within the range proposed by [14] of 1-2 m/s for process fluids flowing in tubular heat exchangers, while the velocity of the chilled water (annulus fluid) was 3.411 m/s, which is above the range proposed by [14] of 1.5-2.5 m/s for water flowing in tubular heat exchangers. The velocity of the annulus fluid was 1.91 times higher than the velocity of the tube-side fluid. In [12] the calculated velocities of the tube-side fluid (chilled water) and the annulus fluid (liquid cow's milk) are 16.64 m/s and 0.92 m/s, respectively.

The Reynolds number of the tube-side fluid (tomato juice) had a value of 4,492, thus indicating that this fluid flows in the transition zone, while the annulus fluid (chilled water) flows in the turbulent zone because the value of its Reynolds number (63,521) is above 10,000 [13]. The Reynolds number of the chilled water was 14.14 times higher than the Reynolds number of the tomato juice. The tomato juice had this low value of the Reynolds number mainly because the relatively high value of its viscosity (0.021 Pa.s) and also because the low value of the internal diameter of the inner tube (0.0525 m). In [12], the Reynolds number of the tube-side fluid (chilled water) and the annulus fluid (liquid cow's milk) are 291,629 and 16,796, respectively, therefore both fluids flowing under turbulent regime.

The calculated value of the Prandtl number for the tomato juice was 132.97, and was 20.78 times higher than the Prandtl number of the chilled water (6.542). This difference is largely due to the higher value that presents the viscosity of the tomato juice (0.021 Pa.s) compared to the viscosity of the chilled water (0.000943 Pa.s). In [12], the Prandtl number of the tube-side fluid (chilled water) and the annulus fluid (liquid cow's milk) are 11.19 and 7.16, respectively.

The Nusselt number of the tube-side fluid (tomato juice) was 99.45, while the value of this parameter for the annulus fluid (chilled water) was 303.17. The Nusselt number for the chilled water was 3.05 times higher than the Nusselt number for the tomato juice, which is because the higher number of the Reynolds number that presented the chilled water (63,521) compared to the Reynolds number of the tomato juice (4,492). However, it should be mentioned that the equations employed to calculate the Nusselt numbers for both fluid were different, i.e. the Gnielinski's correlation was employed to calculate the Nusselt number for the tomato juice, while the Prandtl's correlation was utilized to calculate the Nusselt number for the chilled water, based on the values of the Reynolds number for both fluids. In [4] an unfinned DPHE was designed to cool down 5 kg/s of a stream of hot engine oil (annulus fluid) from 65 to 55 ºC using sea water (tube-side fluid) as coolant. The calculated

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

Nusselt number for the tube-side fluid (cold sea water) fluctuated from 422.0330 to 798.6098 for a range of the tube-side friction factor of 0.002-0.004, depending on the set of correlation employed to calculate these parameters, while the calculated Nusselt number for the annulus fluid (hot engine oil) was 34.693 for a value of the friction factor of 0.024. In [12], the Nusselt number of the tube-side fluid (chilled water), which was calculated using the Prandtl's correlation and amounted 1,237.84, is 12.44 times higher than the Nusselt number of the annulus fluid (liquid cow´s milk), which was also calculated using the Prandtl's correlation and amounted 99.49.

The heat transfer coefficient for the annulus fluid (4,531.13 W/m^2.K) was 3.78 times higher than the heat transfer coefficient for the tube-side fluid (1,194 W/m^2.K). This occurred mainly because the higher value obtained of the Nusselt number for the water compared to the value of this parameter for the tomato juice. In [4] the heat transfer coefficient for sea water flowing inside the tubes ranged from 12,885 W/m^2.K to 24,382 W/m^2.K, depending on the correlations employed to calculate the Nusselt number. Likewise, the heat transfer coefficient for the engine oil flowing in the annulus for the unfinned DPHE is 64.549 W/m^2.K. In [12], the heat transfer coefficient of the tube-side fluid (chilled water) is 26,531.78 W/m^2.K, while the heat transfer coefficient of the annulus fluid (liquid cow's milk) is 1,175.24 W/m^2.K, that is, the heat transfer coefficient for chilled water is 22.58 higher than the heat transfer coefficient for the liquid cow's milk.

The values of the fouled and clean overall heat transfer coefficients were 561.46 W/m^2.K and 793.33 W/m^2.K, respectively, and were within the range reported by [21] of 280-850 W/m^2.K; the range reported by [14] of 350-900 W/m^2.K, while the fouled overall heat transfer coefficient was within the range proposed by [13] of 370-750 W/m^2.K, whereas the clean overall heat transfer coefficient was higher than the range reported by these authors. The values of the overall heat transfer coefficient reported by the literature are for sensible heat transfer with no phase change using water as coolant, fitting adequately to our heat transfer system. In [12] the fouled and clean overall heat transfer coefficients have values of 774.31 W/m^2.K and 1,030.11 W/m^2.K, respectively.

The calculated log-mean temperature difference had a value of 36.07 ºC, with a heat transfer surface area of 47 m^2, a heat transfer area per hairpin of 1.515 m^2, thus resulting in a total number of hairpins of 32, which can be considered high and atypical for a DPHE [13]. We consider that the reasons behind this high value for the total number of hairpins were the high value of the heat load (951.77 kW), and the relatively low values obtained for the fouled overall heat transfer coefficient (561.46 W/m^2.K) and the log-mean temperature difference (36.07 ºC). Likewise, the flowing of the tube-side fluid (tomato juice) under the transition zone, a zone that must be avoided in designing heat exchangers [17], could have influenced in obtaining such a high value for the total number of hairpins, because the low value obtained for the Reynolds number of the tomato juice reduced the value of the overall heat transfer coefficient under fouling conditions (U_f), therefore increasing the heat transfer surface area (A_o) and consequently increasing the total number of hairpins. In [4], the total number of hairpins for an engine oil/sea water unfinned DPHE are 85 and 87 under clean and fouled conditions, respectively. In [12], the log-mean temperature difference, the heat transfer surface area, and the heat transfer per hairpin are 23.51 ºC, 12.92 m^2 and 0.629 m^2, respectively, thus obtaining a total number of hairpins of 21.

The cleanliness factor, which is a term developed for the steam power industry that relates the overall heat transfer coefficient when the heat exchanger is fouled to when it is clean [13], had a value of 0.708, a result that can be considered below the value proposed by [13] of 0.85 for typical tubular heat exchangers. This occurred because the relatively high value for the clean overall heat transfer coefficient (793.33 W/m^2.K). In [4] the cleanliness factor had a value of 0.9819 for a range of the Nusselt number of 422.0330 – 798.6098 during the design of an unfinned DPHE. In [12], the cleanliness factor has a value of 0.752 for an unfinned DPHE.

The percent over surface was 41.29%, which could be considered high compared to the average value recommended by [13] of not be more than about 30 %. Thus, this is a rather large heat exchanger, which could be reduced to satisfy the process specifications with more frequent cleaning. It may be preferable to use a 30% over surface design to decrease the investment cost, and then the cleaning scheduling could be arranged accordingly. Therefore, the proposed design may be modified and rerated [13]. In [4] the percent over surface fluctuated from 1.8400 % to 1.8455 % for a range of the Nusselt number of 422.0330 – 798.6098 during the design of an unfinned DPHE. In [12], the value of the percent over surface is 32.96%.

The frictional pressure drop for the tube-side fluid (tomato juice, 312,558 Pa or 3.08 atm) slightly surpassed the maximum allowable limit set by the heat exchange system (300,000 Pa), while the frictional pressure drop of the annulus fluid (chilled water) had a quite high value (1,678,128 Pa or 16.56 atm), which was 5.59 times higher than the maximum allowable limit set by the process for this stream (300,000 Pa). This high value obtained for the frictional pressure drop of the chilled water is principally because the high value of the chilled water velocity 3.411 m/s, the high number of hairpins required (32) and the low value of the hydraulic diameter (0.0176 m). In [17] it is stated that, if the calculated pressure drop is excessive, it will be necessary to increase the flow area, either by increasing the tube diameters or installing more branches in parallel. The frictional pressure drop of the annulus fluid was 5.37 times higher than the pressure drop of the tube-side fluid. The results of our study agree with those reported

by [4], where the pressure drops of the annulus fluid (hot engine oil) are higher than the pressure drops of the tube-side fluid (sea water), for both fouled and clean conditions. However, the results of our study are not consistent with those reported by [12], where the frictional pressure drop of the tube-side fluid (chilled water) is 122.51 times higher than the frictional pressure drop of the annulus fluid (liquid cow's milk).

Finally, the pumping power of the annulus fluid (13.67 kW) was 9.05 times higher than the pressure drop of the tube-side fluid (1.51 kW), primarily because the quite high value of the pressure drop obtained for chilled water compared to the value of this parameter for the tomato juice. This result agrees with those reported by [4], where the value of the pumping power for the annulus fluid is higher than the pumping power for the tube-side fluid, both for the unfinned clean and unfinned fouled DPHE designed in this study. However, the results of our study regarding this parameter disagrees with those reported by [12], where the pumping power of the tube-side fluid (chilled water) is 110.5 kW, while the pumping power for the annulus fluid (liquid cow's milk) is 114.58 W.

The purchase cost of the unfinned DPHE based on Jan, 2026 was around USD $ 165,500 for a heat transfer surface area (A_o) of 47 m^2. In [12] the purchase cost of an unfinned DPHE designed to cool down a stream of liquid cow's milk is USD $ 45,600, based on May 2025 for a heat transfer surface area of 12.92 m^2 and applying the same correlation reported by [14].

5. Conclusions.

In the present paper, an unfinned DPHE was designed from the thermo-hydraulic point of view, to cool down a stream of hot tomato juice using chilled water as coolant and by applying the design methodology reported by [13]. Several key design parameters were calculated such as heat load (951.77), the required mass flowrate of chilled water (6.50 kg/s), the fouled overall heat transfer coefficient (561.46 W/m^2.K), the total number of hairpins (32), the cleanliness factor (0.708) and the percent over surface (41.29%). Likewise, the frictional pressure drop and pumping power were also calculated for both fluids. It is concluded that the designed DPHE cannot be implemented in the requested heat transfer service because the high values obtained for the total number of hairpins and percent over surface, which is mainly due to the flowing of the tube-side fluid (tomato juice) in the transition zone. This conclusion can be corroborated taking into account the quite high value obtained for the frictional pressure drop of the annulus fluid (16.56 atm), which is 5.59 times higher than the maximum allowable limit set by the process for this stream, which in turn increased the pumping power for this fluid to a significant value (13.67 kW). The designed DPHE will cost around USD $ 165,500 based on Jan, 2026. It's recommended to increase the diameter of both pipes and redesign the unfinned DPHE to decrease the pressure drop of the annulus fluid, as well as to avoid designing the unfinned DPHE with one of the fluids flowing in the transition zone.

6. Acknowledgements (if applicable)

7.- Author Contributions (Contributor Roles Taxonomy (CRediT))

1. Conceptualization: Amaury Pérez Sánchez
2. Data curation: Laura Thalía Álvarez Lores, Laura de la Caridad Arias Águila.
3. Formal analysis: Amaury Pérez Sánchez, Laura Thalía Álvarez Lores, Lizthalía Jiménez Guerra.
4. Acquisition of funds: Amaury Pérez Sánchez.
5. Research: Amaury Pérez Sánchez, Laura Thalía Álvarez Lores, Laura de la Caridad Arias Águila.
6. Methodology: Laura Thalía Álvarez Lores, Heily Victoria González, Arlette de la Caridad González Abad.
7. Project management: Amaury Pérez Sánchez, Lizthalía Jiménez Guerra.
8. Resources: Laura Thalía Álvarez Lores, Lizthalía Jiménez Guerra, Heily Victoria González.
9. Software: Amaury Pérez Sánchez, Laura Thalía Álvarez Lores, Arlette de la Caridad González Abad.
10. Supervision: Amaury Pérez Sánchez, Laura Thalía Álvarez Lores.
11. Validation: Amaury Pérez Sánchez, Laura de la Caridad Arias Águila, Lizthalía Jiménez Guerra.
12. Display: Heily Victoria González, Arlette de la Caridad González Abad.
13. Wording - original draft: Lizthalía Jiménez Guerra, Heily Victoria González, Arlette de la Caridad González Abad.
14. Writing - revision and editing: Amaury Pérez Sánchez, Laura Thalía Álvarez Lores, Laura de la Caridad Arias Águila.

8. Appendix.

Nomenclature.

A_o	Heat transfer surface area	m^2
A_{ca}	Net free flow area of the annulus	m^2
A_{ct}	Net free flow area of the inner tube	m^2
A_{hp}	Heat transfer area per hairpin	m^2
Cp	Heat capacity	kJ/kg.K
CF	Cleanliness factor	-
d_e	External diameter inner tube	m
d_i	Internal diameter inner tube	m
D_e	Equivalent diameter for heat transfer	m
D_h	Hydraulic diameter	m
D_i	Internal diameter annulus	m

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

f	Fanning friction factor	-
f_c	Corrected Fanning friction factor	-
h	Heat transfer coefficient	W/m^2.K
k	Thermal conductivity	W/m.K
k_m	Thermal conductivity metallic material of the inner pipe	W/m.K
L_t	Tube length	m
m	Mass flowrate	kg/h
N_h	Number of hairpins	-
Nu	Nusselt number	-
OS	Percent over surface	%
P	Pumping power	kW or W
Pr	Prandtl number	-
Δp	Frictional pressure drop	Pa
ΔP_m	Maximum allowable pressure drop	Pa
Q	Heat load	kW
R	Fouling factor	m^2.K/W
Re	Reynolds number	-
R_{ft}	Total fouling	m^2.K/W
t	Temperature cold fluid	ºC
$\bar{t}$	Average temperature cold fluid	ºC
T	Temperature hot fluid	ºC
T_w	Tube wall temperature	ºC
$\bar{T}$	Average temperature hot fluid	ºC
ΔTm	Log-mean temperature difference	ºC
U_c	Clean overall heat transfer coefficient	W/m^2.K
U_f	Fouled overall heat transfer coefficient	W/m^2.K
v	Velocity	m/s

Greek symbols

ρ	Density	kg/m^3
μ	Viscosity	Pa.s
μ_w	Viscosity of the fluid at the tube wall temperature	Pa.s
η_p	Isentropic efficiency of the pump	-

Subscripts

1	Inlet
2	Outlet
a	Annulus fluid
c	Cold fluid
h	Hot fluid
t	Tube side fluid

9.- References.

[1] K. Silaipillayarputhur, T. A. Mughanam, A. A. Mojil, and M. A. Dhmoush, "Analytical and Numerical Design Analysis of Concentric Tube Heat Exchangers – A Review," *IOP Conf. Series: Materials Science and Engineering*, vol. 272, p. 012006, 2017. https://doi.org/10.1088/1757-899X/272/1/012006

[2] N. Nwokolo, P. Mukumba, and K. Obileke, "Thermal Performance Evaluation of a Double Pipe Heat Exchanger Installed in a Biomass Gasification System," *Journal of Engineering*, pp. 1-8, 2020. https://doi.org/10.1155/2020/6762489

[3] J. Havlik, T. Dlouhy, and J. Krempasky, "Heat Transfer in Double Pipe Heat Exchangers With Small Tube Spacing," *Journal of Fluids Engineering*, vol. 147, pp. 1-10, 2025.

[4] C. Ezgi and Ö. Akyol, "Thermal Design of Double Pipe Heat Exchanger Used as an Oil Cooler in Ships: A Comparative Case Study," *Journal of Ship Production and Design*, vol. 35, no. 1, pp. 12-18, 2019. https://doi.org/10.5957/JSPD.170009

[5] A. Peccini, J. C. Lemos, A. L. H. Costa, and M. J. Bagajewicz, "Optimal Design of Double Pipe Heat Exchanger Structures," *Industrial & Engineering Chemistry Research*, vol. 58, pp. 12080-12096, 2019. https://doi.org/10.1021/acs.iecr.9b01536

[6] Z. T. Alkanan, A. B. Altemimi, A. R. S. Al-Hilphy, F. Cacciola, and S. A. Ibrahim, "Application and Effects of Ohmic-Vacuum Combination Heating on the Quality Factors of Tomato Paste," *Foods*, vol. 10, p. 2920, 2021. https://doi.org/10.3390/foods10122920

[7] G. I. Igile, O. O. Ekpe, N. M. Essien, S. C. Bassey, and M. A. Agiang, "Quality Characteristics of Tomato Juice Produced and Preserved with and without its Seeds," *Donnish Journal of Food Science and Technology*, vol. 2, no. 1, pp. 001-009, 2016.

[8] C. L. Goodman, S. Fawcett, and S. A. Barringer, "Flavor, Viscosity, and Color Analyses of Hot and Cold Break Tomato Juices," *Journal of Food Science*, vol. 67, no. 1, pp. 404-408, 2002.

[9] S. Asadbeigi, E. Ahmadi, M. Goodarzi, and A. Sagharichian, "Analyzing and simulating heat transfer and designing a shell and tube heat exchanger for the pasteurization process of tomato paste: A CFD study," *Heliyon*, vol. 9, p. e21593, 2023. https://doi.org/10.1016/j.heliyon.2023.e21593

[10] S. M. Jafari, S. S. Jabari, D. Dehnad, and S. A. Shahidi, "Heat Transfer Enhancement in Thermal Processing of Tomato Juice by Application of Nanofluids," *Food Bioprocess Technol*, vol. 10, pp. 307-316, 2017. https://doi.org/10.1007/s11947-016-1816-9

[11] L. Pagliarini, U. Neviani, and S. Rainieri, "Numerical modelling and experimental validation of heat transfer enhancement and thermal mixing in a triple-tube heat exchanger for food processing," *International Journal of Numerical Methods for Heat & Fluid Flow*, vol. 35, no. 11, pp. 3749-3774, 2025.

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

[12] A. P. Sánchez, L. d. l. C. A. Águila, H. V. González, M. I. L. R. Veliz, and Z. M. S. Rodríguez, "Thermo-hydraulic design of an unfinned and finned double pipe heat exchanger for milk cooling. Part 1 - Unfinned heat exchanger," *Ingeniería Química y Desarrollo*, vol. 08, no. 01, pp. 88-101, 2026. https://doi.org/10.53591/fv3x4n54
[13] S. Kakaç, H. Liu, and A. Pramuanjaroenkij, *Heat Exchanger - Selection, Rating, and Thermal Design*, 3rd ed. Boca Raton, USA: CRC Press, 2012.
[14] R. Sinnott and G. Towler, *Chemical Engineering Design*, 6yh ed. Oxford, United Kingdom: Butterworth-Heinemann, 2020.
[15] J. R. Couper, D. W. Hertz, and F. L. Smith, "9. Process Economics," in *Perry's Chemical Engineers' Handbook*, D. W. Green and M. Z. Southard, Eds. 9th ed. New York, USA: McGraw-Hill Education, 2019.
[16] S. Jenkins, "Economic Indicators," *Chemical Engineering*, vol. 135, no. 3, p. 40, 2026.
[17] E. Cao, *Heat transfer in process engineering*. New York, USA: The McGraw-Hill Companies, Inc., 2010.
[18] A. M. Flynn, T. Akashige, and L. Theodore, *Kern's Process Heat Transfer*, 2nd ed. New Jersey, USA: John Wiley & Sons, Inc., 2019.
[19] Y. Choi and M. R. Okos, "The Thermal Properties of Tomato Juice Concentrates," *Transactions of the ASAE*, vol. 26, no. 1, pp. 305-311, 1983.
[20] M. Z. Southard, R. L. Rowley, and W. V. Wilding, "2. Physical and Chemical Data," in *Perry's Chemical Engineers' Handbook*9th ed. New York, USA: McGraw-Hill Education, 2019.
[21] S. M. Hall, *Rules of Thumb for Chemical Engineers*, 6th ed. Amsterdam, Netherlands: Elsevier, 2018.

INQUIDE
Chemical Engineering & Development
Journal of Science and Engineering

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

Evaluation of tartrazine (E-102) content in orange-flavored soft drinks marketed in Guayaquil using UV–Visible spectrophotometry.

Evaluación del contenido de tartrazina (E-102) en bebidas refrescantes sabor naranja comercializadas en Guayaquil mediante espectrofotometría UV-Visible.

Stefanie Bonilla Bermeo [1] * ; Carlos Valdiviezo Rogel [2] ; Luis Romero [3]; Michael Rendón Morán [4]

Received: 03/09/2026 – Accepted: 06/22/2026 – Published: 07/12/2026

Research Articles [X] Review Articles [ ] Essay Articles [ ]

* Corresponding author.

Abstract.
Tartrazine (E-102) is a synthetic colorant widely used in flavored beverages to improve their appearance. Its use must be controlled due to potential adverse effects associated with excessive consumption. The objective was to quantify the presence of tartrazine. (E-102) in orange-flavored non-carbonated soft drinks marketed in supermarkets in Guayaquil and to evaluate compliance with internationally established permissible limits. The applied experimental study, with a quantitative approach. Twelve samples of orange-flavored non-carbonated soft drinks from three commercial brands were collected through stratified sampling in supermarkets in Guayaquil. Tartrazine quantification was performed using UV–Visible spectrophotometry at 427 nm. A calibration curve was prepared using standard solutions, and the method was validated by quantifying its precision, accuracy, repeatability, and linearity. The average tartrazine concentrations obtained were 134.85 mg/L A, 99.45 mg/L B, and 54.61 mg/L C, by beverage brand, respectively. The results showed that samples corresponding to brand A exceeded the maximum limit of 100 mg/L established by international organizations. In brand B, values close to the regulatory limit were analized, whereas brand C showed concentrations considerably lower than the permitted value. After subjecting the findings to the Shapiro–Wilk test, data obtained from the statistical analysis, revealing variability in tartrazine content among the analyzed brands. One of the analyzed brands exceeded the permissible limits of tartrazine, highlighting the need to strengthen the control of additives in beverages.

Keywords.
Tartrazine, UV-Visible Spectrophotometry, Flavored Beverages, Food Colors

Resumen.
La tartrazina (E-102) es un colorante sintético utilizado en bebidas saborizadas para mejorar apariencia. Su uso debe ser controlado debido a posibles efectos adversos asociados al consumo excesivo. El objetivo fue cuantificar la presencia de tartrazina (E-102) en refrescos de naranja sin gas comercializadas en expendios de Guayaquil evaluando su cumplimiento con límites permisibles establecidos internacionalmente. El estudio experimental aplicado, con enfoque cuantitativo. Se recolectaron doce muestras de bebidas refrescantes no carbonatadas sabor naranja pertenecientes a tres marcas comerciales, mediante muestreo estratificado en supermercados de Guayaquil. La cuantificación de tartrazina empleando espectrofotometría UV-Visible a 427 nm. La curva de calibración se elaboró con patrones de referencia y se evaluó el desempeño analítico del método mediante parámetros de linealidad, exactitud, precisión y repetibilidad. Las concentraciones promedio de tartrazina obtenidas fueron 134.85 mg/L para la marca A, 99.45 mg/L para la marca B y 54.61 mg/L para la marca C. Los resultados evidenciaron que las muestras correspondientes a la marca A superaron el umbral máximo de 100 mg/L establecido por organismos internacionales. En la marca B se observaron valores cercanos al límite regulatorio, mientras que la marca C presentó concentraciones considerablemente inferiores al valor permitido. Tras someter los hallazgos al test de Shapiro-Wilk, los resultados del procesamiento estadístico revelaron que la muestra no seguía una distribución normal lo que evidenció variabilidad en el contenido de tartrazina entre las marcas analizadas. Una de las marcas analizadas superó los límites permisibles de tartrazina, evidenciando la necesidad de fortalecer el control de aditivos en bebidas.

Palabras clave.
Tartrazina, Espectrofotometría UV-Visible, Bebidas saborizadas, Colorantes alimentarios

1. Introduction

The growing consumer demand for visibly more attractive products, synthetic food colorants have been developed for use in food production, in order to improve certain aspects of the product. To achieve consumer attention, therefore, every food product must mention on the label that it contains artificial substances such as Tartrazine, because there are studies where this additive can cause complications in a low number of people who suffer from diseases such as asthma and attention deficit disorders, the latter more likely in children. Many countries do not allow the use of this dye and others control it more rigorously. Tartrazine is one of the dyes that raise serious consumer safety concerns at low doses relevant to real-life human exposure. The scientific literature continues to grow following the re-evaluation by the European Food Safety Authority (EFSA) in 2009 and the Joint FAO/WHO Expert Committee on Food Additives (JECFA) in 2016. [1] [2]

[1] University of Guayaquil/ stefanie.bonillab@ug.edu.ec ; https://orcid.org/0000-0002-9391-3698, Guayaquil; Ecuador.
[2] University of Guayaquil / carlos.valdiviezor@ug.edu.ec ; https://orcid.org/0000-0002-6550-9751, Guayaquil, Ecuador.
[3] Escuela Superior Politécnica del Litoral/ luisrome@espol.edu.ec; https://orcid.org/0000-0002-2417-4836, Guayaquil, Ecuador.
[4] Escuela Superior Politécnica del Litoral/ mgrendon@espol.edu.ec; https://orcid.org/0009-0004-4390-8294 , Guayaquil, Ecuador.

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

[3]Food additives, indispensable elements in modern diets, are widely used in restaurants to align with the demands of the consumer market and improve their gastronomic experience. However, the potential risks associated with excessive or prolonged consumption cannot be overlooked. [4]The Codex Alimentarius defines food additives as a substance that is deliberately incorporated into foodstuffs for the purpose of fulfilling specific technical functions (including organoleptic functions) in the manufacture, processing, treatment, packaging, storage or transport of that food. However, they stressed that the definition given by the Codex Alimentarius does not include the term contaminants or substances added to foods to maintain or enhance nutritional qualities. According to some studies, there were several food additives that had been used in the past, but are no longer authorized due to the evidence found of their side effects, a high frequency of possible health incidents, as well as medium and long-term toxicity. It is also important to note that, apart from synthetic food colourings, certain commercial additives of plant or animal origin have also been discontinued. The classification of naturally occurring dyes can be very complex due to the wide variety of intrinsic properties of the coloring substances. These can come from various natural sources and therefore have a wide range of chemical compositions that affect their properties, solubility and stability differently, and can have different origins, whether plant or animal. [5][6][7]

The reasons why this colorant is quantified are due to the high per capita consumption of flavored beverages in Ecuador, occupying the third place behind carbonated beverages and bottled water, likewise, within sugary drinks with 83% in the commerce of stores and supermarkets in the city of Guayaquil, in addition to the little control that exists of the national entities in the use of the colorant, since in the category of this beverage there is no maximum limit of the concentration of the colorant stipulated by the INEN regulations, who is the national regulation in controlling the use of additives in food. . [8]

Due to concerns about these potential health effects, the World Health Organization (WHO) and the Food and Agriculture Organization of the United Nations (FAO) have established internationally recognized standards in the Codex Alimentarius on the maximum allowable levels of this colorant depending on the type of food or beverage. [9]In addition, from a regulatory point of view, there is a growing attention and interest in the risk assessment of these dyes used in food products (i.e. azo dyes). In the case of azo dyes, a limiting factor for their use is their carcinogenicity potential, which occurs after their reduction to carcinogenic metabolites in the intestine. [10]

In recent research, there is consensus that synthetic food dyes have diverse impacts on consumers, especially the pediatric population, due to their influence on sensory appeal, which can encourage a preference for certain foods. The results revealed that these color additives are directly linked to a number of health problems, with a greater impact on children. [11]

In some studies, the identification and quantification of dyes in different beverages of mass consumption is carried out, using methods such as thin layer chromatography and other visible spectrophotometry in a reliable way to determine that they comply with permissible limits established in the regulations. A variety of matrix-dependent methods have been developed and applied to determine food dyes, employing different analytical techniques along with appropriate sample preparation protocols. The main techniques used for its determination are chromatography with spectrophotometric detectors and spectrophotometry, while sample preparation procedures depend largely on the food matrix. In food technology, food colourings of different origins are chemical substances that are incorporated into food matrices to maintain or enhance the organoleptic characteristics of the product, which may be affected or lost during processing or storage, and to preserve the desired colour. The most common and widely used classification is based on the distinction between soluble and insoluble coloring additives (dyes or pigments), which in turn can be categorized as natural or synthetic.[12][13] [14]

In recent years, research on the detection and quantification of synthetic food dyes has evolved towards the treatment of sensitive, analytical, selective and sustainable techniques. Recent studies in high-impact journals have reported the use of advanced methods such as electrochemical sensors based on nanomaterials, spectroscopy coupled to intelligent systems, and high-performance liquid chromatography with improved detectors, which allow the detection of tartrazine at trace levels with high accuracy and shorter analysis time. For example, recent research has shown that electrochemical sensors modified with nanoparticles have significantly lower detection limits compared to conventional methods, while techniques such as UHPLC coupled to spectrophotometric detectors continue to be the standard for analytical validation in complex matrices. [15] [16]Likewise, there has been a growing interest in more sustainable and low-cost methodologies, such as optimized UV-Visible spectrophotometry, which continues to be widely used in contexts where accessibility is required without compromising analytical reliability. These trends reflect the need to balance accuracy, cost, and applicability in the monitoring of food additives in consumer products.

It is evident that the analysis of trace food dyes is essential with the application of the appropriate analytical techniques, with high specificity and selectivity. Several studies have reported that there is a growing interest in monitoring the concentration of synthetic food dyes in various products. Therefore, this research aims to

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

determine the concentration of Tartrazine (E-102) or also called Yellow No. 5 in non-carbonated orange flavored beverages refreshed by UV-VIS. UV/VIS spectrophotometry. [17]

1.1. Food additives

These additives are incorporated to improve the appearance and preservation of the product. Although some provide nutrients, their main function is technological and sensory, anticipating the consumer's experience of nutritional value.[18]

Its inclusion in processing such as production and transportation or storage seeks to stabilize the product. These additives reinforce conservation against environmental or microbial factors, preventing or delaying spoilage and guaranteeing food safety. [19]

1.2. Dyes

From 400 B.C. When the Egyptians colored wine, the visual aspect has conditioned food decisions. Chemically, this occurs thanks to two groups: the chromophore, responsible for the tone, and the auxochrome, which allows it to be fixed. Until the nineteenth century, people relied solely on natural sources to stimulate that sense of desire and freshness that color brings to consumers. [20]

1.3. Designation "E" in Dyes

To supply the food trade with additives, the European Union implemented a system of codes (letter E followed by 3 or 4 digits). These numbers allow the chemical name and function of each substance to be equated, and it is mandatory to detail them on the labelling to ensure transparency and differentiate each ingredient unequivocally. For example: E1- colorant, E4- emulsifiers, stabilizers, thickeners and gelling agents, E3- antioxidants, E2- preservatives [21]

1.4. Classification of dyes according to their nature

1.4.1. Natural Colors

From animal, vegetable or mineral sources, these dyes stand out for their safety. As they lack sanitary restrictions and do not require certifications, they are freely included in the production of cosmetics, pharmaceuticals and food, consolidating themselves as a safe and versatile option in various industrial sectors compared to synthetic options.. [22]

During product production processes, the instability of natural dyes could degrade in the presence of high temperatures, inadequate storage, this leads to changes in water activity and pH and even to be photoensible. [23]

1.4.2. Synthetic Dyes

Known as artificial, which are obtained from chemical synthesis. These dyes were widely used at the beginning of the nineteenth century, starting in 1826. By decomposing indigo, the German researcher Unverdorben isolated aniline compounds for the first time, marking a milestone in the study of this dye. This is how it made room for the manufacture of many artificial colorants. Due to the low cost and greater dyeing and glossing power in the products, synthetic dyes stand out, however, in some studies harmful effects have been reported in infants affecting their behavior and generating attention deficit and hyperactivity. Therefore, in some European countries, the use of artificial colors has been restricted, giving priority to the use of colorants of natural origin, while in others it has been regularized by determining permissible limits established by the FDA [24] [25]

1.5. Dyes as food additives

The Food and Drug Administration (FDA) defines dyes and pigments as those compounds obtained through artificial synthesis or extracted directly from mineral, vegetable, or animal sources. The essential feature of these substances is their intrinsic ability to transfer color to cosmetic products, drugs, or foods, regardless of whether their original chemical structure underwent modifications during the process. [26]

1.6. Synthetic dye Tartrazine E-102

Tartrazine is a synthetic azo dye with a lemon-yellow coloration used as a food pigment (E102), also called "Food Yellow Cl 4". Azo food dyes are synthetic and come from aromatic amines, which contain an azo group of two nitrogen atoms bonded together (-N = N-) and unified to aromatic rings. [27] [28]
The average daily intake of tartrazine was established at 7.5 mg/kg [28]

1.7. Chemistry of the dye Tartrazine

The N5 yellow with mass is 534.4 g/mol and its chemical formula C16H9N4Na3O9S2, and structurally it has an azo group (–N=N–), joined by aromatic rings, tartrazine is therefore recognized as belonging to the azo dye family. [29]

1.8. Toxicology of the dye Tartrazine

E-102 or yellow E-5, is a very controversial dye since other studies showed that they could cause, respiratory conditions, allergic reactions even hyperactivity in children, since then, the maximum permissible limits and the daily intake which does not affect people's health, were investigated in laboratory rats and thus maintain control in the use of this food additive and that it is reported in the formulation and it is demonstrated on the label that contains tartrazine. [30]

1.9. Non-carbonated beverages

That which does not contain carbon dioxide in its composition, produced from drinking water that complies with the safety parameters established in Ecuadorian standards, and may contain sugar such as sweeteners, synthetic flavorings or of natural origin. [31]

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

1.10. Regulations for non-carbonated beverages of the colorant Tartrazine E-102

In Ecuador, the concentration of the colorant Tartrazine in non-carbonated beverages or according to the INEN 192 Standard "Flavored water-based beverages without gas, including fruit punches and lemonades and similar beverages", is not established in the regulation, Only NTE INEN 2304 of "Soft drinks or non-carbonated beverages. Requirements", there is no description of the concentration of tartrazine, it only indicates that it must not exceed the food additives established by the INEN 192 standard, which does not establish the maximum permissible limits for this colorant. In other similar beverages, in the NTE INEN 1101 version 2016 "Carbonated or carbonated beverages. Requirements", if it establishes a maximum concentration of 200mg/L of Tartrazine in its composition. The insufficient control of national regulations in this type of beverage leads to an unrestricted problem when using additives, causing a possible risk to the health of users. [32]

2. Materials and methods.

The research used as main materials orange-flavored non-carbonated soft drinks of three commercial brands, acquired in supermarkets in different sectors of the city of Guayaquil. Analytical reagents were used for the preparation of standard tartrazine (E-102) solutions, as well as distilled water and conventional laboratory equipment, including volumetric flasks, volumetric pipettes, and quartz cells. The instrumental analysis was used using a UV-Visible spectrophotometer, operated at 427 nm wavelength, specifically chosen because it coincided with the peak of maximum absorbance in the detection of the dye.

The methodology was experimental with a quantitative approach. A calibration curve was constructed from standard solutions of tartrazine, allowing the relationship between concentration and absorbance to be established. The samples were previously prepared and analyzed under controlled conditions, recording their absorbance values to determine their concentration by interpolation in the curve. Additionally, the performance of the analytical method was evaluated through parameters of linearity, accuracy, precision and repeatability. The data obtained were subjected to statistical analysis to verify their behavior and variability. The analysis and management of the experimental data were carried out with Microsoft Excel software**,** using integrated statistical tools for the calculation of parameters such as standard deviation, mean, coefficient of variation and linear regression analysis. The reproducibility of the method was evaluated from repeated measurements under controlled conditions, verifying the consistency of the results by analyzing the intra-assay variability. Although Excel is a general-purpose tool, its application in this study was adequate due to the characteristics of the data obtained and the type of analysis required, allowing reliable results to be obtained and comparable to the criteria established in the validation of analytical methods.

2.1. Raw material

The raw material analyzed was made up of orange-flavored non-carbonated soft drinks, corresponding to three commercial brands available in commercial premises in the city of Guayaquil. The samples were selected considering their high availability and consumption in the local market, guaranteeing representativeness. Units were acquired in different establishments located in different geographical areas, in order to minimize biases associated with a single point of sale. The products were in original sealed containers, within their expiration date and stored under normal commercial conditions.

The selected beverages presented similar physicochemical characteristics in terms of coloration, transparency and type of formulation, being homogeneous liquid matrices suitable for direct spectrophotometric analysis. The composition declared on the labeling included the presence of tartrazine (E-102) as an artificial color. Prior to the analysis, the samples were conditioned at room temperature and gently homogenized to ensure the uniformity of the system. No complex preparation treatments were performed, given the liquid nature of the matrix, which allowed adequate reproducibility in the analytical measurements.

2.2. Elaboration of the Mother Solution

a. The standard containing 99.0% to 100% purity was adjusted.
b. The standard of 10mg = 10.10mg can be adjusted to 100%. Purity
c. 10.10 mg standard weight of tartrazine dye on the analytical balance, and dissolved in a volume of 100ml, with distilled water it is taken to the gauging line.
d. Stays at room temperature and protected from light

2.3. Construction of the calibration curve

a. Starting from the stock solution, 5 dilutions with different concentrations of 6, 12, 18, 24, 30 mg/L were prepared in 10ml volumetric flasks by volume with distilled water.
b. The spectrophotometer is calibrated to 427nm, which corresponds to the maximum absorption of the dye at that wavelength. The concentrations of solutions were read in an ascending manner, using distilled water as a target.
c. By means of a scatter plot, absorbance vs. concentration was related
d. The equation of the curve line was determined.

INQUIDE
Chemical Engineering & Development
Journal of Science and Engineering
Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

2.4. Verification of the analytical method by UV-VISIBLE spectrophotometry

2.4.1. Selected Wavelength

For the colorant Tartrazine in beverages, the maximum wavelength was established in previous studies, which established 427nm as the maximum wavelength. [33]

2.4.2. Specificity

Matrix Effect Study. The method used in addition to the standard. Choosing a non-carbonated beverage that encompasses the possible interferents of the matrix and that does not contain the coloring that Tartrazine.

A 1:10 dilution in a 100ml volumetric flask from the selected drink.
The same aliquots of the tartrazine stock solution were taken, which was used to construct the calibration curve, and diluted at various concentrations of 6, 12, 18, 24 and 30 mg/L, in the volume filling with the 1:10 dilution of the chosen beverage.
The spectrophotometer is calibrated and read at 427nm wavelength. The solutions were read in ascending concentration, using the 1:10 dilution as the target of the selected drink.
The equation of the curve line was determined. [34]
Statistically, the effect curve was compared with the calibration curve matrix of the standard by means of the T-student test with the Microsoft Excel Data Analysis tool for related samples.

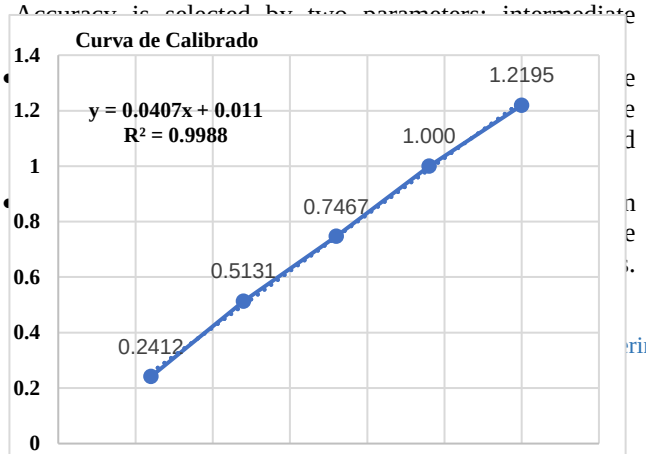
2.4.3. Accuracy.

According to the following steps:
With a flask without the analyte of interest, it is fortified with the standard tartrazine dye at three concentration levels. Being tall. medium and low in the order of 6, 18 and 30 mg/L respectively.
With the data collected from the calibration curve, the percentage of recovery carried out with the fortified matrix was calculated.
The reliability of the method was verified by the percentage of recovery, evaluated under the international AOAC criteria. For this calculation, the mathematical relationship was applied that allows the amount of analyte recovered to be contrasted with the real value added, thus guaranteeing the accuracy of the analysis:

$$\%\text{Recuperación} = \frac{\text{Valor obtenido } (\bar{x})}{\text{Valor real}} \times 100 \qquad (1)$$

2.4.4. Precision.

Accuracy is selected by two parameters: intermediate



- **Calculate** from the data obtained from intermediate accuracy and repeatability with the statistical parameters below:

$$\%\ \text{CV} = \frac{\text{S}}{\text{X}} \times 100\% \qquad (2)$$

X: Medium
S: Standard deviation.
% CV: coefficient of variation

The method is more accurate the lower the %CV, so according to the acceptance limit of this parameter it must be less than 2% [35]

2.4.5. Sample reading using UV/VIS spectrophotometer.

1. The samples were labeled according to the sector obtained.
2. 1:10 dilutions were prepared in 25ml volumetric flasks, flushed to volume with distilled water for each drink
3. It was performed in triplicate, the readings were timated, at 427nm wavelength.
4. The concentration of tartrazine from the equation of the line was determined in the samples, and multiplied by the dilution factor 1:10.

2.4.6. Statistical analysis of the samples.

1. SPPS Statistics was applied
2. Shapiro-Wilk test for each sample was applied
3. For each sample per beverage brand, the Shapiro-Wilk test was applied
4. Linear regression and correlation analysis were determined for each sample by beverage brand.

3. Results.

3.1. Construction of the Calibration Curve

The calibration curve was based on other studies with modification of the last point of the curve.

Table 1. Absorbance vs Tartrazine Concentration

CONCENTRATION OF TARTRAZINE mg/L	ABSORBANCE (ABS)
6	0.2412
12	0.5131
18	0.7467
24	1.000
30	1.2195

Source: Bonilla, et al, 2026

INQUIDE
Chemical Engineering & Development
Journal of Science and Engineering
Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

Figure 1. Calibration curve for the tartrazine standard.

3.2. Testing an analytical method using a UV-VISIBLE spectrophotometer

3.2.1. Specificity

Matrix Effect Study. He calculated the specificity of the method, adding the Standard to a blank matrix.

Table 2. Concentration of tartrazine in fortified matrix vs Absorbance
Source: Bonilla, et al, 2026

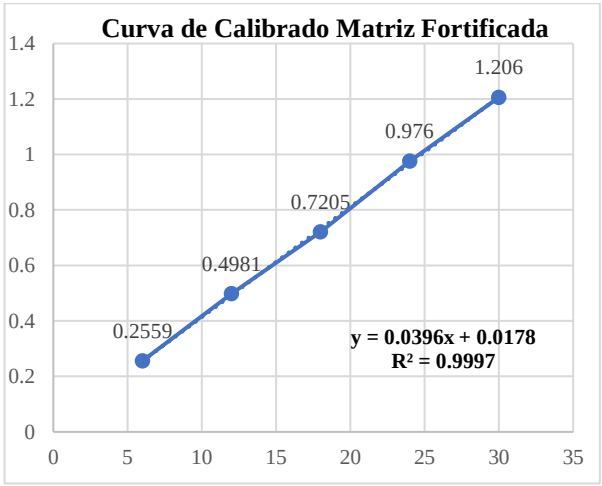


Figure 2. Fortified Matrix Calibration Curve

The evaluation of the specificity of the method by studying the matrix effect was carried out through a calibration curve in a fortified matrix, obtaining the linear relationship between the concentration of tartrazine. And absorbance. The equation of the line (y = 0.0396x + 0.0178) presented a high coefficient of determination (R^2 = 0.9997), this evidences the excellent linear correlation in the range of concentrations analyzed. This behavior indicates that the concentration of the analyte is directly proportional to the response of the method even in the presence of components of the matrix itself.

Likewise, the low dispersion of the experimental points with respect to the regression line suggests that there is no significant interference of the matrix in the determination of tartrazine. The near-zero intercept value (0.0178) confirms the minimal contribution of background signals or possible interfering compounds. Together, these results demonstrate that the method is specific for the quantification of tartrazine in the evaluated matrix, ensuring that the analytical signal obtained corresponds specifically to the analyte of interest.

The selectivity of the method was assessed by comparing the absorbances of a pure calibration curve and a matrix fortified with the same doses of tartrazine. By means of a unilateral student T-test, it was examined whether the matrix induced a significant increase in the signal, thus guaranteeing that the results obtained depended exclusively on the dye and not on external interferers. The hypotheses were evaluated:

Hi: If there is a significant difference

Ho: There is no significant difference

Decision: If $t_{critical} > t_r$ Ho is admitted, since there is no significant difference.

Table 3. Unilateral T-Student Test of Related Samples

Concentration of tartrazine mg/L	Absorbance (ABS)
6	0.2559
12	0.4981
18	0.7205
24	0.9760
30	1.2060

Prueba t-student	Abs. Standard curve	Abs. Fortified curve
Media	0.7441	0.7314
Variance	0.1495	0.1415
Observations	5	5
Pearson's correlation coefficient	0.9995	
Hypothetical difference of the means	0	
Degrees of freedom	4	
Tr Statistic	1.7528	
P-value a tail	0.0773	
Critical value of tcritic (one queue)	2.1318	

Source: Bonilla, et al, 2026

The value of t_r is 1.7528 and the critical value t is 2.1318, since critical t is greater than t_r, because the null hypothesis (Ho) was admitted. Therefore, no significant difference is observed in the absorbance means, and the matrix does not influence the readings in the absorbance spectrophotometer considered a specific method.

3.2.2. Accuracy.

The accuracy of the method was demonstrated by the percentage of recovery of the fortified matrices. The concentrations analyzed were made in triplicate at three concentration levels: high, medium and low of the fortified matrices.

Table 4. Percentage of recovery of fortified matrices.

Conc. Mg/l	Absorbance			Prom.	Conc. Obtained	% Recovery
6	0.2432	0.2423	0.2423	0.2426	5.6768	94.6128
18	0.7405	0.7408	0.7414	0.7409	18.2601	101.4450

INQUIDE
Chemical Engineering & Development
Journal of Science and Engineering
Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

30	1.2018	1.2035	1.2024	1.2026	29.9184	99.7278

Source: Bonilla, et al, 2026

The recovery study showed an adequate performance of the analytical method in the evaluated matrix. For the concentration levels of 6, 18 and 30 mg/L, recovery percentages of 94.61%, 101.45% and 99.73%, respectively, were obtained, values that are within the acceptable range for spectrophotometric methods. Likewise, the concentrations obtained (5.68, 18.26 and 29.92 mg/L) showed a high agreement with the theoretical concentrations, which indicates good accuracy of the method. The low variability between absorbance measurements reflects adequate accuracy. Overall, these results demonstrate that the method is reliable for the quantification of tartrazine in the analyzed matrix, without evidencing significant interferences that affect its recovery.

3.2.3. Precision.

Quantification was assessed using the Intermediate precision and repeatability method. The precision of the method was established by Standard Deviation (SD) and the criterion was admitted with the percentage of the Coefficient of variation (CV%).

3.2.3.1. Repeatability.

The readings were made in triplicate from three concentration levels of the standard's control solutions, with the same laboratory, equipment and analyst in a short period of time.

Table 5. Repeatability at 3 concentration levels.

Conc. Mg/l	Absorbance			Prom.	Ds	Cv%
6	0.2422	0.2369	0.2447	0.2413	0.0040	1.6508
18	0.7335	0.7458	0.7491	0.7428	0.0082	1.1068
30	1.2162	1.2262	1.2110	1.2178	0.0077	0.6344

Source: Bonilla, et al, 2026

The percentage of the coefficient of variation is located below the acceptance criterion in the 3 levels (low, medium and high), which must be <2%, for the first level it is 1.6508%, for the second level it is 1.1068% and finally the third level is 0.6344%.

3.2.3.2. Intermediate precision.

It was determined starting from the highest level of concentration, in three days the readings in triplicate, by the same laboratory, equipment and different analysts.

Table 6. Assessment of Intermediate Accuracy at the highest concentration level

Conc. mg/L	Absorbance			Prom.	Ds	Cv%
	Day 1	Day 2	Day 3			
30	1.2392	1.239	1.2162	1.2277	0.0118	0.9603
	1.2193	1.2199	1.2262			
	1.2434	1.2355	1.211			

Source: Bonilla, et al, 2026

At the highest concentration level, the standard deviation is 0.0118 and the coefficient of variation is 0.9603%, which is accepted as it must be <2%. Complying with the two parameters, it is evident that the method is Precise.

3.3. UV-VISIBLE spectrophotometric determination of Tartrazine in non-carbonated orange-flavored soft drinks.

Each sample was labeled following the collection parameters, which are assigned the codes for the respective marks, being A, B and C followed by the first letter of the selected sector, being N (North), S (South), O (WEST) and E (EAST), finally, numbered from 1 to 4 to distinguish from the chosen lot. To determine the concentration of Tartrazine in orange-flavored soft soft drinks, using the equation of the line arranged by the calibration curve and the response was multiplied by the Dilution Factor (FD), as follows:

$$y = mx + b \quad (3)$$

Example: In the sample with the code "AN1" it was analyzed as follows:

$$0.5712 = 0.0407x + 0.0110 \quad (4)$$

$$x = \frac{0.5712 - 0.0110}{0.0407} * 10 \quad (5)$$

$$x = 137.6413\ mg/L \quad (6)$$

Table 7. Concentrations of Tartrazine in samples of non-carbonated soft drinks.

Code	Tartrazina mg/L	Code	Tartrazine mg/L	Code	Tartrazine mg/L
AN1	137.6413	BN1	96.6585	CN1	55.6020
AN2	133.8329	BN2	96.5111	CN2	55.0614
AN3	136.6830	BN3	93.8329	CN3	55.2334
AS1	138.8206	BS1	99.8034	CS1	57.9361
AS2	139.2875	BS2	99.6069	CS2	58.4275
AS3	138.9926	BS3	99.5577	CS3	57.6904
AE1	133.0958	BE1	100.0491	CE1	52.2359
AE2	132.7273	BE2	99.4103	CE2	51.0319
AE3	132.3833	BE3	98.9189	CE3	50.8600
AO1	132.5799	BO1	103.5872	CO1	54.1523
AO2	131.9410	BO2	103.2678	CO2	53.6118
AO3	130.1794	BO3	102.1450	CO3	53.4398
Prom.	134.8471	**Prom.**	99.4457	**Prom**	54.6069
DS	3.2178	**DS**	2.8242	**DS**	2.5545
CV%	2.2938 %	**CV%**	2.8399 %	**CV%**	4.6779 %

Source: Bonilla, et al, 2026

The study demonstrated critical contrasts between the brands analyzed. The "A" mark systematically exceeds the

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

limit of 100 mg/L stipulated by the FAO and the regulations of Colombia and Mexico, complying only with Salvadoran legislation, which is less restrictive. On the other hand, the "B" mark presents an irregular conformity, exceeding international limits only in its first three samples (BO1-BO3). In contrast, the "C" brand stood out as the only product that respects global standards in all of its samples, ensuring responsible use of tartrazine and compliance with food safety specifications.

3.4. Statistical Analysis of Orange-flavored non-carbonated soft drinks.

3.4.1. Shapiro - Wilk.

It was statistically analyzed with the SPSS Statistics to check if the variable (Tartrazine Concentration) fits a normal distribution, the acceptance criteria for the hypothesis are as follows:

Hi: The samples do not have normal distribution. (Non-parametric data)

Ho: Samples have normal distribution (Parametric Data)

Table 8. Shapiro-Wilk Normality Test

1.	**Hypothesis**	Ho: the variable "tartrazine" comes from a normal population Hi: the variable "tartrazine" does not come from a normal population
2.	**Significance**	a – 5% – 0.05
3.	**Calculated Value**	0.846
4.	**P - value**	p= <0.001
5.	**Decision**	If p > α I accept my Ho, otherwise Hi is accepted 0.001< 0.05, because the Ho
6.	**Conclusion**	The variable "Tartrazine" does not come from a normal population, so the data are non-parametric.

Source: Bonilla, et al, 2026

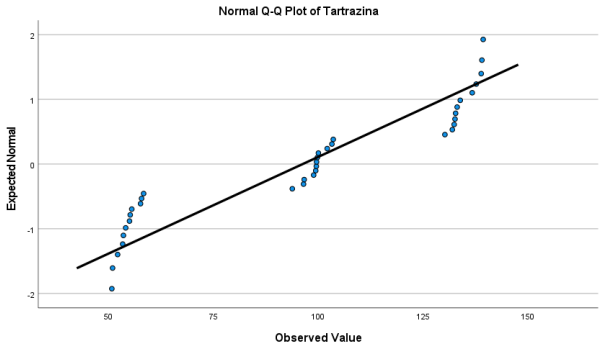


Figure 3. Normality of tartrazine

Figure 3 shows the normal Q-Q graph of tartrazine showing the comparison between the expected values and the values observed under a normal distribution. Almost all points are seen to line up close to the baseline, suggesting a general trend towards normality of the data. However, slight deviations are evident at the extremes, particularly in the lowest and highest values, indicating possible asymmetries or the presence of variability in the data. Overall, although the data show some adjustment to the normal distribution, these deviations justify that normality is not completely met, which is consistent with the data obtained by the Shapiro-Wilk test.

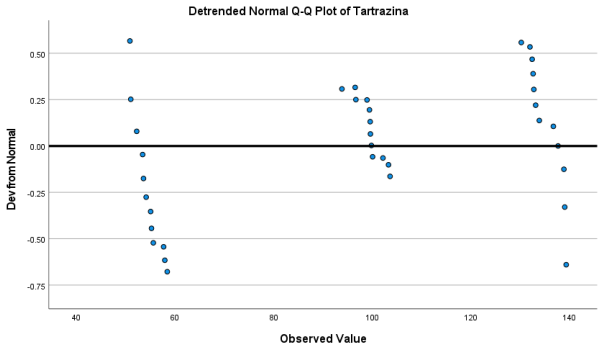


Figure 4. Normality without tartrazine tendency

Figure 4 shows the normal Q-Q graph with detrend complements the interpretation of Figure 3 Q-Q above by showing the deviations of the data from the normal distribution as a function of the baseline (zero). In this case, it can be seen that the points are not randomly distributed around the horizontal line, but present systematic patterns: negative values grouped at the lower end and positive values at the upper end. This behavior confirms the presence of deviations from normality, evidencing asymmetry in the distribution of the data. In accordance with the previous Q-Q graph, where slight separations of the line at the ends were already visible, the detrend graph reinforces that these deviations are not random but structural. Therefore, both graphs support the result of the Shapiro-Wilk test, indicating that the data do not have a normal distribution and present variability associated with the differences between concentrations of the samples analyzed.

3.5. Statistical analysis on each brand of non-carbonated orange flavored refreshing drink.

Using SPSS Statistics, the results obtained from each brand of beverages were statistically analyzed independently, by means of the Shapiro-Wilk test, it was determined if the data are non-parametric or parametric and to use an adequate analysis of Correlation between the two variables (Dependent: Absorbance and Independent: Tartrazine coloring), evidencing the degree of variance or relationship found between the samples, culminating with the linear regression analysis for Forecast the value of one variable from another.

3.5.1. Statistical analysis: Brand "A" soft drink

3.5.1.1. Shapiro-Wilk.

Criteria for the admission of the hypothesis:

Ho: The samples have a normal distribution. (Parametric Data)

Hi: The samples do not have a normal distribution. (Non-parametric data)

Table 9. "Shapiro-Wilk" normality test for "A" brand beverage

1.	**Hypothesis**	Ho: the variable "tartrazine" comes from a normal population Hi: the variable "tartrazine" does not come from a normal population

2.	**Significance**	a – 5% – 0.05
3.	**Calculated Value**	0.884
4.	**P - value**	p= .098
5.	**Decision**	If p > α I accept my Ho, otherwise Hi is accepted 0.098 > 0.05, so Ho
6.	**Conclusion**	The variable "Tartrazine" in Brand "A" of soft drink comes from a normal population, therefore, the data are Parametric.

Source: Bonilla, et al, 2026

3.5.1.2. Linear correlation.

The drink with brand "A" corresponds to parametric data (they adjust to a normality), so a Pearson Correlation analysis was done

Table 10. Correlation of beverages with "A" brand

Correlation			
		Abs	**Tartrazina**
Abs	Pearson Correlation	1	0.997**
	Sig. (1-tail)		<0.001
	N	12	12
Tartrazina	Pearson Correlation	0.997**	1
	Sig. (1-tail)	<0.001	
	N	12	12
**. The correlation is significant at the 0.01 (1-tail) level.			

Source: Bonilla, et al, 2026

A positive correlation between the two variables greater than 0 and close to 1 is observed, being 0.997, so a high degree of relationship between them is found.

3.5.2. Statistical analysis: Brand "B" soft drink

3.5.2.1. Shapiro-Wilk.

Criteria for acceptance of the hypothesis:
Ho: The samples follow a normal distribution. (Parametric Data)
Hi: Samples do not tend to a normal distribution (Non-parametric data)

Table 11. "Shapiro-Wilk" normality test for brand "B" soft drink

1.	**Hypothesis**	Ho: the variable "tartrazine" comes from a normal population Hi: the variable "tartrazine" does not come from a normal population
2.	**Significance**	a – 5% – 0.05
3.	**Calculated Value**	0.942
4.	**P - value**	p= .524
5.	**Decision**	If p > α I accept my Ho, otherwise Hi is accepted 0.524 > 0.05, therefore Ho is accepted
6.	**Conclusion**	The variable "Tartrazine" in the Marde ca "B" soft drink comes from a normal population, therefore, the data are Parametric.

Source: Bonilla, et al, 2026

3.5.2.2. Linear correlation.

The brand "B" soft drink is parametric data fits a normality), therefore, a Pearson Correlation analysis was performed.

Table 12. Correlation of "B" brand soft drinks

Correlation			
		Abs	**Tartrazina**
Abs	Pearson Correlation	1	0.996**
	Sig. (1-tail)		<0.001
	N	12	12
Tartrazina	Pearson Correlation	0.996**	1
	Sig. (1-tail)	<0.001	
	N	12	12
**. The correlation is significant at the 0.01 (1-tail) level.			

Source: Bonilla, et al, 2026

Between the two variables, a positive correlation close to 1 and greater than 0 is demonstrated, with a value of 0.996, since a high degree of relationship is established between the samples.

3.5.3. Statistical analysis: Refreshing drink Brand "C"

3.5.3.1. Shapiro-Wilk.

Criteria for acceptance of the hypothesis:
Ho: The samples tend to be distributed normally. (Parametric Data)
Hi: The samples do not follow a normal distribution. (Non-parametric data)

Table 13. "Shapiro-Wilk" normality test for the "C" brand soft drink

1.	**Hypothesis**	Ho: the variable "tartrazine" comes from a normal population Hi: the variable "tartrazine" does not come from a normal population
2.	**Significance**	a – 5% – 0.05
3.	**Calculated Value**	0.945
4.	**P - value**	p= .576
5.	**Decision**	If p > α admits my Ho, otherwise Hi is accepted 0.098 > 0.05, so the Ho
6.	**Conclusion**	The variable "Tartrazine" in the "C" Brand beverage comes from a normal population, therefore, the data are Parametric.

Source: Bonilla, et al, 2026

3.5.3.2. Linear correlation.

The "C" mark of beverage is parametric data (they follow a normality), so a Pearson Correlation analysis was performed.

Table 14. Correlation of beverages with "C" mark

Correlation			
		Abs	**Tartrazina**
Abs	Pearson Correlation	1	1,000**
	Sig. (1-tail)		<0.001
	N	12	12
Tartrazina	Pearson Correlation	1,000**	1
	Sig. (1-tail)	<0.001	
	N	12	12
**. The correlation is significant at the 0.01 (1-tail) level.			

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

Source: Bonilla, et al, 2026

A perfect positive correlation is evidenced between the two variables, being 1,000, so a perfect degree of relationship between the samples is determined.

4. Discussion

The results achieved showed a significant variability in the content of tartrazine among the brands analyzed, highlighting that one of them exceeded the maximum permissible limit of 100 mg/L. This finding refers to possible deficiencies in quality control during industrial formulation, which represents a potential risk for the consumer. Recent studies have reported that azo dyes, such as tartrazine, are still widely used due to their stability and low cost, although their inadequate dosage can lead to regulatory non-compliance. [15]

From the analytical point of view, the UV-Visible spectrophotometric method used demonstrated high reliability, evidenced by excellent linearity ($R^2 = 0.9997$) and adequate recovery percentages. These results are consistent with recent research that emphasizes the usefulness of accessible and low-cost optical methods for the quantification of dyes in foods, which can achieve correlation coefficients greater than 0.99 and be comparable to more complex techniques such as HPL [36]

In relation to the statistical analysis, the non-normality of the data suggests a heterogeneous distribution of tartrazine content among commercial samples. This variability has been reported in recent studies, which indicate that differences in formulation, industrial processes and quality control directly influence the final concentration of dyes in feeds. In addition, these results reinforce the need to apply adequate statistical tools to interpret real data in food matrices.[16]

When compared with the current literature, it is observed that the presence of concentrations close to or above regulatory limits is not an isolated case. Several studies have raised concerns about the safety of tartrazine, including possible toxicological effects associated with prolonged use, which has led to recent scientific reviews focused on its biological effects and potential risks. [37][38]

Finally, the results of the present study are aligned with a growing trend in research: the development of more sensitive, sustainable and faster methods for the detection of food dyes, including fluorescent sensors and advanced electrochemical techniques. There is also a growing interest in replacing synthetic dyes with natural alternatives, driven by consumer demand and stricter regulations. In this context, the importance of strengthening monitoring and control systems to guarantee food safety is highlighted. [39]

5.- Conclusions

A sampling protocol was established in the city of Guayaquil, selecting one of the most popular commercial premises, in order to guarantee the representativeness of the non-carbonated, refreshing orange-flavored beverages available in the local market. A random stratified sampling was applied, which allowed obtaining representative samples of different commercial brands, optimizing the efficiency and validity of the data collection process according to the proposed objective.

The quantification of tartrazine (E-102) by UV-Visible spectrophotometry demonstrated that the analytical method used is suitable, reliable and reproducible for this type of matrix. Excellent linearity ($R^2 > 0.99$) was obtained, confirming the proportionality between absorbance and concentration. The specificity was verified by studying the matrix effect, evidencing the absence of significant interference from the components of the drink. Likewise, the accuracy presented recovery percentages between 94% and 101%, within the ranges accepted by the AOAC, and the precision, evaluated in terms of repeatability and intermediate precision, showed coefficients of variation less than 2%. However, the observed variability between brands, reflected in high standard deviations, suggests possible effects associated with the stability of the colorant, influenced by factors such as storage time, exposure to light and industrial processing conditions.

In relation to the objective of the study, it was found that one of the three brands analyzed (Brand A) presented concentrations of tartrazine higher than the maximum permissible limit of 100 mg/L stipulated by international regulations (FAO and regulations of countries such as Colombia and Mexico). This finding shows a potential non-compliance with food safety standards, which highlights the need to strengthen control and regulation methods in the Ecuadorian context, where there are currently no specific regulations for this additive in beverages. In this sense, the study provides relevant scientific evidence that contributes to the knowledge about the presence and variability of artificial colors in marketed beverages, and constitutes a starting point for other studies and the development of public policies aimed at consumer protection and the control of food additives.

6.- Author Contributions (Contributor Roles Taxonomy (CRediT))

1. Conceptualization: Carlos Valdiviezo.
2. Data curation: Stefanie Bonilla.
3. Formal analysis: Stefanie Bonilla.
4. Acquisition of funds: Not applicable.
5. Research: Stefanie Bonilla, Carlos Valdiviezo
6. Methodology: Luis Romero, Stefanie Bonilla, Carlos Valdiviezo, Michael Rendón.
7. Project management: Stefanie Bonilla

8. Resources: Carlos Valdiviezo, Michael Rendón.
9. Software: Not applicable.
10. Supervision: Carlos Valdiviezo
11. Validation: Stefanie Bonilla, Carlos Valdiviezo
12. Visualization: Luis Romero, Michael Rendón.
13. Writing - original draft: Luis Romero, Stefanie Bonilla
14. Writing - revision and editing: Stefanie Bonilla, Carlos Valdiviezo, Luis Romero, Michael Rendón.

7.- References.

[1] L. Ulloa, F. Zavala and M. Sisniegas, «Cytotoxic effect of Tartrazine on the mitotic index of meristem cells of Allium cepa.,» *REBIOL,*, vol. 35, nº 1, pp. 43-48. , 2015. https://revistas.unitru.edu.pe/index.php/facccbiol/article/view/874.

[2] K. Rovina , S. Siddiquee y S. M. Shaarani, « A Review of Extraction and Analytical Methods for the Determination of Tartrazine (E 102) in Foodstuffs,» *PubMed*, vol. 47, nº 4, pp. 309-324 , 2017. https://doi.org/10.1080/10408347.2017.1287558.

[3] P. Amchova, F. Sisk, and J. Ruda-Kucerova, "Safety of tartrazine in the food industry and potential protective factors," *Heliyon*, vol. 10, no. 18, 2024. https://doi.org/10.1016/j.heliyon.2024.e38111.

[4] B. XIa, M. R. Zainal Abidin, J. X. Wong, H. Dong y S. A. Karim, «Are Food Additives Utilized Judiciously? Novel Insights into Health Risks, Benefits, and Ethical Boundaries,» *Food reviews International*, vol. 42, nº 2, 2026. https://doi.org/10.1080/87559129.2025.2496947.

[5] M. Carocho , . P. Morales y . I. C. Ferreira , «Natural food additives: Quo vadis?,» *Trends in Food Science & Technology*, vol. 45, nº 2, pp. 284-295, 2015. https://doi.org/10.1016/j.tifs.2015.06.007.

[6] N. Martins, C. Lobo Roriz, . P. Morales , . L. Barros y I. C. Ferreira , «Food colorants: Challenges, opportunities and current desires of agro-industries to ensure consumer expectations and regulatory practices,» *Trends in Food Science & Technology*, vol. 52, pp. 1-15, 2016. https://doi.org/10.1016/j.tifs.2016.03.009.

[7] G. T. Sigurdson, . P. Tang, and M. M. Giusti, "Free Natural Colors: Food Colors of Natural Origin," *Annual Journal of Food Science and Technology*, vol. 8, pp. 261-280, 2017. https://doi.org/10.1146/annurev-food-030216-025923.

[8] G. Tamayo and A. Valvverde, "IAEN Digital Repository," June 2016. [Online]. Available: http://repositorio.iaen.edu.ec/handle/24000/4852. [Accessed 2018-07-13T14:14:34Z].

[9] R. Kobun, L. Acung y . S. Siddiquee, «Extraction and Analytical Methods for Determination of Sunset Yellow (E110)—a Review,» *Food Anal. Methods* , vol. 10, nº 3, p. 773–787, 2017. DOI:10.1007/s12161-016-0645-9.

[10] M. Oplatowska-Stachowiak y C. T. Elliott, «Food colors: Existing and emerging food safety concerns,» *Critical Reviews in Food Science and Nutrition*, vol. 57, nº 3, pp. 524-548 , 2016. https://doi.org/10.1080/10408398.2014.889652.

[11] Z. Birino de Oliveira, D. V. Silva da Costa, A. Quaresma da Silva Júnior, A. de Lima Silva, R. C. Ferrer de Santana, I. C. Gonçalves Costa, S. Freitas de Sousa Ramos, and G. Padilla, "Synthetic Dyes in Food: A Warning for Children's Health." *International Journal of Environmental Research and Public Health*, vol. 21, No. 6, p. 682, 2024. DOI: 10.3390/IJERPH21060682.

[12] R. Rodriguez Espinoza, . J. F. Rivero Méndez and J. L. Mendoza Bobadilla, "Evaluation of synthetic dyes in beverages marketed in the city of Trujillo in the period 2018 - 2019," *Journal of scientific and technological research*, vol. 2, no. 3, 2021. https://orcid.org/0000-0002-8867-9331 .

[13] K. Ntrallou, H. Gika y E. Tsochatzis, «Analytical and Sample Preparation Techniques for the Determination of Food Colorants in Food Matrices,» *MDPI: foods*, vol. 9, nº 1, p. 58, 2020. https://doi.org/10.3390/foods9010058.

[14] A. Aberoumand, «A Review Article on Edible Pigments Properties and Sources as Natural Biocolorants in Foodstuff and Food Industry,» *World Journal of Dairy & Food Sciences*, vol. 6, nº 1, pp. 71-78, 2011. https://idosi.org/wjdfs/wjdfs6(1)/11.pdf.

[15] S. S. Chaudhari, P. O. Patil, S. B. Bari y Z. G. Kha, «A comprehensive exploration of tartrazine detection in food products: Leveraging fluorescence nanomaterials and electrochemical sensors: Recent progress and future trends,» *Food Chemistry*, vol. 433, p. 137425, 2024. https://doi.org/10.1016/j.foodchem.2023.137425.

[16] F. S. Tamer, T. Oymak y . E. Dural , «Determination of seven synthetic colourants in pharmaceutics, foods, and beverages by a validated HPLC-PDA method: A risk assessment study,» *Journal of Food Composition and Analysis*, vol. 136, p. 106797, 2024. https://doi.org/10.1016/j.jfca.2024.10679.

[17] Y. Ni, Y. Wang y S. Kokot , «Simultaneous kinetic spectrophotometric analysis of five synthetic food colorants with the aid of chemometrics,» *Talanta*, vol. 78, nº 2, pp. 432-441, 2009. https://doi.org/10.1016/j.talanta.2008.11.035 .

[18] . Á. San Miguel Hernández,, J. A. Garrote Adrados, Á. San Miguel Rodríguez,, R. M. Lobo Valentín, . B. Martín Armentia,, A. Armentia Medina and J. M. Rodríguez Valencia, « Allergic hypersensitivity to food additives and enzymes in food biotechnology,» *Fundación Dialnet*, vol. 112, nº 3, 2015.

https://dialnet.unirioja.es/servlet/articulo?codigo=5647948 .

[19] G. Velázquez-Sámano, R. Collado-Chagoya, R. A. Cruz-Pantoja, A. A. Velasco-Medina and J. Rosales-Guevara, "Hypersensitivity reactions to food additives," *Revista alergia México*, vol. 66, no. 3, 2020. https://doi.org/10.29262/ram.v66i3.613 .

[20] K. B. Ayala Pastaz, J. A. Pineda Insuasti, A. S. Duarte Trujilo, C. P. Soto Arroyave and C. A. Pineda Soto, "Toxicity of synthetic dyes: from the global to Ecuador," *Revista Biorrefinería*, vol. 1, no. 1, 2018. https://www.cebaecuador.org/wp-content/uploads/2021/03/Biorrefineri%CC%81a-1-40-48.pdf.

[21] R. Sánchez Juan, «LA QUIMICA DEL COLOR EN LOS ALIMENTOS,» *Revista QuímicaViva*, vol. 3, 2013. https://www.redalyc.org/pdf/863/86329278005.pdf.

[22] D. Marcano, Introduction to the Chemistry of Dyes, Caracas, Venezuela: Scientific and Technological Dissemination Lesson. Academy of Physical, Mathematical and Natural Sciences, 2018. https://acfiman.org/wp-content/uploads/2023/01/introduccion-a-la-quimica-de-los-colorantes.pdf.

[23] E. Stich y S. Fallah, «Food color and coloring food: quality, differentiation and regulatory requirements,» de *Handbook on Natural Pigments in Food and Beverages (Second Edition)*, The Netherlands, Woodhead Publishing Series in Food Science, Technology and Nutrition , 2024. https://doi.org/10.1016/B978-0-323-99608-2.00008-2, pp. 3-31.

[24] C. Valdiviezo, S. Bonilla and E. Puebla Campoverde, «SPECTROPHOTOMETRIC DETERMINATION OF TARTRAZINE E-102 IN NON-CARBONATED BEVERAGES IN THE CITY OF GUAYAQUIL – ECUADOR..,» from *Dialogue of Transdisciplinary Knowledge in Connection with the Social Welfare of the Realities of the XXI Century*, Guayaquil, Ecuador., School of Writers, 2024. file:///Users/stefaniebonilla/Downloads/LIBROFINAL3011.pdf, pp. 9-30.

[25] F. Alcaire, A. Giménez y G. Ares, «Additives in foods marketed to children in Uruguay, an emerging Latin American country,» *Journal of Nutritional Science*, vol. 14, nº 6, pp. 1-18, 2024. DOI:10.1017/jns.2024.98.

[26] J. L. Belmonte Vázque, . I. J. A. Arroyo Córdoba, M. A. Vázquez Guevara, D. Cruz Cruz and E. Peña Cabrera, «Artificial dyes in food stuff,» *REVISTA NATURALEZA Y TECNOLOGIA UNIVERSIDAD DE GUANAJUATO*, vol. 10., p. 25, 2016. http://www.naturalezaytecnologia.com/index.php/nyt/article/view/204.

[27] P.E. and d. Council, 'Regulation (EU) No 231/2012,', *Official Journal of the European Union*, p. 295, 22 March 2012. https://www.boe.es/buscar/doc.php?id=DOUE-L-2012-80430.

[28] EFSA ANS Panel (EFSA Panel on Food Additives and N, «Scientific Opinion on the re-evaluation of gold (E 175) as a food additive,» *EFSA JOURNAL*, vol. 14, nº 1, 2016. https://doi.org/10.2903/j.efsa.2016.4362.

[29] M. Restrepo Gallego, «Substitution of dyes in foods,» *Lasallian Journal of Research*, vol. 4, nº 1, pp. 35-39, 2007. https://www.redalyc.org/pdf/695/69540106.pdf.

[30] I. Moutinho, L. Bertges, and A. RVC, "Prolonged use of the food dye tartrazine (FD&C yellow no. 5) and its effects on the gastric mucosa of Wistar rats," *PubMed*, vol. 67, no. 1, pp. 141-5, 2007. DOI: 10.1590/s1519-69842007000100019 .

[31] E. O. Chávez Cruz and R. D. Torres Rivera, "Determination of yellow No. 5 and No. 6 in non-carbonated beverages marketed at the Central Campus of the University of El Salvador," 1 8 2016. [Online]. Available: https://hdl.handle.net/20.500.14492/1698.

[32] N. INEN, 'Consejo Nacional de Competencias,' [Online]. Available: https://www.competencias.gob.ec/caja-de-herramientas-2/planificar-regular-y-controlar-el-transito-el-transporte-terrestre-y-seguridad-vial/normativa/normas-inen/.

[33] R. F. Rodriguez Espinoza, J. F. Rivero Mendez and J. L. Mendoza Bobadilla, "valuation of synthetic dyes in beverages marketed in the city of Trujillo in the period 2018 - 2019," *Journal of Scientific and Technological Research*, vol. 2, no. 3, 2021. DOI:10.47422/ac.v2i3.46.

[34] H. Zumbado, Instrumental Analysis of Food, University Press, 2021. https://www.researchgate.net/publication/348943895_Analisis_Instrumental_de_los_Alimentos, p. 68.

[35] A. I. d. l. Alimentos, Spectrometry of ultraviolet and visible molecular absorption, Cuba: Editorial Universitaria. Ministry of Higher Education. CubaISBN: 978-959-16-4542-5, 2021. https://www.researchgate.net/publication/348943895_Analisis_Instrumental_de_los_Alimentos.

[36] S. F. Hosseini, T. Heidari, A. Zendegi-Shiraz y M. Ameri , «Application of chemometrics based on digital image analysis for simultaneous determination of tartrazine and sunset yellow in food samples,» *Food Chemistry*, vol. 470, p. 142619, 2025. https://doi.org/10.1016/j.foodchem.2024.14261.

[37] Amchova, . F. Siska y . J. Ruda-Kucerova , «Safety of tartrazine in the food industry and potential

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

protective factors,» *Heliyon*, vol. 10, nº 18, 2024. https://doi.org/10.1016/j.heliyon.2024.e38111.

[38] M. Visternicu, A. Săvucă, V. Rarinca, G. Plavan, C. Ionescu, . A. Ciobica y I. Miruna Balmus, «Toxicological Effects of Tartrazine Exposure: A Review of In Vitro and Animal Studies with Human Health Implications,» *Toxics*, vol. 13, nº 9, p. 771, 2025. https://doi.org/10.3390/toxics13090771.

[39] . S. Jabee, . S. Bano y S. Ahmed, «Electrochemical Determination of Tartrazine and Carmoisine Dyes from Aqueous Solutions on Modified Electrodes,» *Bentham Science*, vol. 21, nº 9, pp. 1320 - 1332 , 2025. https://doi.org/10.2174/0115734110329759240902065018.

[40] O. Valverde and G. Tamayo, Universidad de Posgrados del Estado, June 2018. [Online]. Available: https://repositorio.iaen.edu.ec/handle/24000/4852. [Accessed 2018].

[41] P. Amchova, H. Kotolova y J. Ruda-Kucerova, «Health safety issues of synthetic food colorants,» *Regulatory Toxicology and Pharmacology*, vol. 73, nº 3, pp. 914-922, 2015. https://doi.org/10.1016/j.yrtph.2015.09.026.

INQUIDE
Chemical Engineering & Development
Journal of Science and Engineering

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

The Use of Artificial Intelligence in Small Businesses in the City of Guayaquil.

Uso de la inteligencia artificial en microempresas comerciales de la Ciudad de Guayaquil.

Francisco Javier Duque-Aldaz [1] * ; Jorge Meza-Clark[2]; Teresa Meza Clark[3]; Leonardo Cuadrado-Sagñay [4] ; Edwin Haymacaña Moreno[5]; Leonor Alejandrina Zapata Aspiazu [6]

Received: 04/28/2026 – Accepted: 06/05/2026 – Published: 07/12/2026

Research Articles [X] Review Articles [ ] Essay Articles [ ]

* Corresponding author.

Abstract.
Digital transformation has driven the integration of technologies such as artificial intelligence (AI) in the business environment, creating new opportunities to enhance management efficiency and competitiveness in microenterprises. The objective of this study was to analyze the adoption of artificial intelligence in microenterprises within the commercial sector of the Pedro Carbo Concepción urban parish, Guayaquil. A quantitative, descriptive, and cross-sectional non-experimental design was applied. Data were collected through surveys administered to 40 microentrepreneurs using a structured Likert-scale questionnaire. Statistical analysis included descriptive and inferential techniques, such as Cronbach's alpha for reliability assessment and one-sample t-tests, complemented by the evaluation of dimensions related to perceived benefits, operational efficiency, adoption intention, and contextual barriers. The results indicated a favorable perception of the benefits of artificial intelligence and its impact on operational efficiency, which was reflected in a positive disposition toward its adoption. Additionally, adoption intention was found to be influenced by the perceived value of technological benefits and process optimization. However, contextual and knowledge-related barriers were not perceived consistently, showing a limited effect on overall perceptions. It was concluded that perceived benefits and operational efficiency significantly drive the adoption of artificial intelligence, highlighting the need to strengthen training and technological access strategies in microenterprises.

Keywords.
Artificial Intelligence, Microenterprise, Commercial Sector, Business Environment, Urban Parish.

Resumen.
La transformación digital ha impulsado la incorporación de tecnologías como la inteligencia artificial en el ámbito empresarial, generando nuevas oportunidades de mejora en la gestión y competitividad de las microempresas. El objetivo del estudio fue analizar la adopción de la inteligencia artificial en microempresas del sector comercial en la parroquia urbana Pedro Carbo Concepción, Guayaquil. Se empleó un enfoque cuantitativo, de tipo descriptivo y diseño no experimental de corte transversal. La información se recolectó mediante encuestas aplicadas a 40 microempresarios, utilizando un cuestionario estructurado con escala Likert. Los datos fueron analizados mediante técnicas estadísticas descriptivas e inferenciales, incluyendo el cálculo de fiabilidad con alfa de Cronbach y pruebas t para una muestra, complementadas con el análisis de dimensiones relacionadas con beneficios, eficiencia operativa, intención de adopción y barreras contextuales. Los resultados evidenciaron una percepción favorable hacia los beneficios de la inteligencia artificial y su impacto en la eficiencia operativa, lo que se reflejó en una disposición positiva hacia su adopción. Asimismo, se identificó que la intención de adopción se encuentra influenciada por la valoración de los beneficios y la optimización de procesos. Sin embargo, las barreras relacionadas con el contexto y el conocimiento no se manifestaron de manera uniforme, mostrando un efecto limitado en la percepción general. Se concluyó que la percepción de beneficios y eficiencia impulsa la adopción de la inteligencia artificial, sugiriendo la necesidad de fortalecer estrategias de capacitación y acceso tecnológico en microempresas.

Palabras clave.
Inteligencia Artificial, Microempresa, Sector Comercial, Ámbito Empresarial, Parroquia Urbana.

1.- Introduction

Digital transformation has established itself as one of the main drivers of change in production and organizational systems globally, generating new forms of management, interaction and value creation in companies. In this context, the incorporation of emerging technologies, particularly artificial intelligence (AI), has made it possible to redefine business processes through the use of advanced algorithms capable of analyzing data, automating tasks, and supporting decision-making. Indeed, AI has gone from being an experimental technology to becoming a strategic component in business competitiveness, facilitating the optimization of resources, the anticipation of trends and the continuous improvement of operational processes. Various international studies show a growing adoption of these technologies in

[1] University of Guayaquil; franscico.duquea@ug.edu.ec ; https://orcid.org/0000-0001-9533-1635 ; Guayaquil; Ecuador.
[2] University of Guayaquil; jorge.mezacl@ug.edu.ec ; https://orcid.org/0000-0003-0512-8671 ; Guayaquil; Ecuador.
[3] University of Guayaquil; teresa.mezacl@ug.edu.ec ; https://orcid.org/0000-0002-5955-6893 ; Guayaquil; Ecuador.
[4] Independent Researcher; Leonardocuadradog@gmail.com ; Guayaquil; Ecuador.
[5] Bolivarian University Higher Institute of Technology; erhaymacana@itb.edu.ec; https://orcid.org/0000-0002-8708-3894 ; Guayaquil; Ecuador.
[6] Technical University of Babahoyo; lzapata@utb.edu.ec ; https://orcid.org/0009-0003-1497-2273 ; Babahoyo; Ecuador.
….

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

organizations of different sizes, which reflects their relevance in the contemporary digital economy.[1]

In emerging economies, digital transformation poses both significant opportunities and challenges. In Latin America, micro, small and medium-sized enterprises represent the core of the productive fabric, contributing substantially to employment and economic development. However, these organizations face structural limitations that hinder the incorporation of advanced technologies such as artificial intelligence, including restricted access to financing, the technological knowledge gap, and limited digital infrastructure. Despite these difficulties, the adoption of digital technologies is emerging as an essential condition to improve productivity, strengthen competitiveness and guarantee business sustainability in increasingly dynamic environments. In this sense, the analysis of the incorporation of artificial intelligence in this business segment is a topic of high scientific and practical relevance. [2]

In the specific context of Ecuador, and particularly in the city of Guayaquil, microenterprises play a fundamental role within the local economic system, being responsible for a significant proportion of commercial activity and job creation. However, their level of digitalization is still in their infancy, limiting their ability to take full advantage of the benefits offered by emerging technologies. Although initiatives aimed at promoting innovation and the use of digital tools have been promoted in recent years, barriers related to knowledge, accessibility and the perception of the value of artificial intelligence persist. Consequently, there is a need to understand not only the level of adoption of these technologies, but also the factors that influence their acceptance and use within microenterprises.

From a scientific and technical perspective, the central problem lies in the limited understanding of the determinants that explain the adoption of artificial intelligence in microenterprises in the commercial sector, especially in specific local contexts such as the urban parish of Pedro Carbo Concepción. Although the literature has extensively addressed technological adoption in large organizations, there is a gap in the analysis of these processes in microenterprises, where structural, cultural, and economic conditions generate particular dynamics. In this sense, it is necessary to develop research that integrates variables such as perceived benefits, operational efficiency, adoption intention and contextual barriers, allowing to build a comprehensive vision of the phenomenon.

In response to this need, the present study aims to analyze the use of artificial intelligence in microenterprises in the commercial sector of the urban parish Pedro Carbo Concepción, in the city of Guayaquil, through a quantitative approach based on the identification of key factors that affect its adoption. Through a field study, it seeks to establish a baseline that allows understanding the level of knowledge, perception and disposition of microentrepreneurs in the face of artificial intelligence, thus contributing to the development of strategies aimed at promoting digital transformation in this business segment. In this way, the research is positioned as a relevant contribution to interdisciplinary knowledge in the areas of engineering, business management and technological innovation.

1.1. Artificial intelligence and its application in the business environment.

Artificial intelligence has established itself as one of the most influential technologies in contemporary digital transformation, allowing computer systems to simulate cognitive capabilities of human beings, such as learning, reasoning and decision-making. In general terms, it is understood as the set of techniques and algorithms designed to process large volumes of data, identify patterns and generate answers or predictions autonomously. Its evolution has been closely linked to the development of computer science, statistics and data science, which has allowed its applications to be progressively expanded in various economic and productive sectors.[3]

In the business field, artificial intelligence has acquired strategic relevance, offering tools that contribute to improving operational efficiency, optimizing resources and strengthening the competitive capacity of organizations. Its implementation has extended to multiple areas, such as process automation, predictive analytics, inventory management, and data-driven decision-making. These applications allow companies to reduce errors, minimize costs and accelerate processes, facilitating more effective management in highly dynamic and competitive environments. In this context, artificial intelligence not only acts as a technological support, but as a key element in the redefinition of business models.[4]

However, the adoption of artificial intelligence in the business environment, especially in microenterprises, presents challenges associated with access to technological resources, the level of knowledge and the ability to adapt organizationally. Despite the potential benefits, many organizations are still in the early stages of incorporating these technologies, which shows the existence of gaps in terms of training and access. Consequently, the analysis of artificial intelligence in the business context not only involves understanding its operation and applications, but also evaluating the factors that facilitate or limit its adoption, as well as its impact on the sustainability and growth of companies.[5]

1.2. Models of technological adoption.

Technology adoption models constitute a fundamental theoretical framework to understand the factors that influence the acceptance and use of new technologies within organizations. These theoretical approaches seek to explain the behavior of individuals in the face of the incorporation of innovations, considering cognitive, attitudinal and contextual variables. Among the most relevant models is the Technology Acceptance Model (TAM), proposed by Davis, which states that the adoption of a technology depends

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

mainly on perceived utility and perceived ease of use. These factors determine the user's attitude and, consequently, their intention to use, becoming a widely used reference in studies related to the implementation of technological systems in organizational contexts.[6]

Subsequently, the evolution of these models gave rise to more integrative approaches, such as the Unified Theory of Acceptance and Use of Technology (UTAUT), developed by Venkatesh et al. This model broadens the perspective of TAM by incorporating new elements such as social influence and enabling conditions, recognizing that technological adoption does not depend only on individual perceptions, but also on the environment in which users operate. In this sense, the adoption of technologies such as artificial intelligence in the business environment is influenced both by the perception of benefits and by structural factors, such as access to resources, level of training and organizational support.[7]

In the context of microenterprises, technological adoption models acquire particular relevance, as they allow us to analyse the dynamics that condition the incorporation of innovative tools in environments with limited resources. The application of models such as TAM and UTAUT facilitates the identification of key factors that explain the intention to adopt, such as the perception of utility, expected operational efficiency and existing barriers. In this way, these models not only contribute to understanding user behavior, but also support the design of strategies aimed at promoting the effective adoption of emerging technologies, such as artificial intelligence, in the business sector.[8]

1.3. Benefits and operational efficiency of AI.

Artificial intelligence has established itself as a key tool for generating value in the business environment, mainly due to its ability to transform data into useful information for decision-making. Among the most relevant benefits associated with its implementation are the improvement of competitiveness, the reduction of errors and the optimization of resources, aspects that directly contribute to the strengthening of organizational performance. The ability to analyze large volumes of information in real-time allows companies to anticipate scenarios, identify opportunities, and minimize risks, which translates into sustainable strategic advantages in highly dynamic environments.[9]

In relation to operational efficiency, artificial intelligence plays a decisive role in facilitating the automation of processes and the continuous improvement of internal operations. The incorporation of intelligent systems makes it possible to reduce execution times, eliminate repetitive tasks and increase accuracy in key activities such as administrative management, resource planning and inventory control. In this way, artificial intelligence not only increases productivity, but also frees up time for business leaders to focus on strategic functions, favoring more efficient and results-oriented management.[10]

However, the impact of artificial intelligence on business profits and operational efficiency does not depend exclusively on the technology itself, but also on the ability of organizations to properly integrate it into their processes. In the case of microenterprises, this process can be conditioned by factors such as the level of knowledge, the availability of resources and the willingness to change. Therefore, although artificial intelligence offers a high potential to optimize management and improve business performance, its effective use requires an adequate articulation between technology, human skills and organizational strategies.[11]

1.4. Intention to adopt technology.

The intention of technological adoption is defined as the willingness or willingness of individuals and organizations to incorporate and use new technological tools in their activities. From the approach of technological acceptance models, this intention constitutes the main antecedent of the actual behavior of use, since it reflects the conscious decision to adopt an innovation. In this sense, the intention to adopt does not arise in isolation, but is influenced by cognitive and attitudinal factors such as the perception of usefulness, trust in technology and the valuation of expected benefits.[12]

In the business context, the intention to adopt acquires strategic relevance, since it determines the ability of organizations to adapt to dynamic and highly competitive environments. In particular, the adoption of technologies such as artificial intelligence implies not only a technical decision, but also an organizational commitment that involves investment, training, and change in work processes. Therefore, the predisposition to adopt these technologies is often associated with the perception that their implementation will generate substantial improvements in efficiency, decision-making, and business competitiveness.[13]

In the case of microenterprises, the intention to adopt technology is conditioned by various structural and contextual factors, such as the availability of resources, the level of knowledge and the perception of risk. Despite these limitations, evidence suggests that when microentrepreneurs recognize the potential value of emerging technologies, their willingness to invest and train for their implementation increases. Consequently, the intention to adopt is configured as a key element in the digital transformation process, since it represents the bridge between the perception of benefits and the effective incorporation of technology in business management.[14]

1.5. Barriers and context of adoption in microenterprises.

The adoption of technologies such as artificial intelligence in microenterprises does not take place in a homogeneous environment, but is conditioned by a set of structural factors that can facilitate or limit its implementation. Among the main barriers are a lack of technical knowledge, poor training in digital tools, and limited understanding of the benefits associated with these technologies. These constraints create uncertainty for decision-makers, reducing the likelihood of

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

investment in innovative solutions and delaying digital transformation processes in this business segment.[15]

In this context, the environment in which microenterprises operate plays a determining role in technological adoption. Factors such as access to technological infrastructure, the level of connectivity, the availability of financing, and institutional support have a direct impact on the ability of organizations to incorporate tools based on artificial intelligence. In emerging economies, where microenterprises predominate, these conditions tend to be more restrictive, which amplifies digital divides and limits the integration of advanced technologies into production and administrative processes.[16]

However, the perception of barriers is not uniform among microentrepreneurs, as it depends on variables such as previous experience, educational level and degree of familiarity with technology. In some cases, a lack of access or knowledge is combined with a perception of complexity or risk, reinforcing resistance to change. However, when these barriers are addressed through training strategies, technical support and provision of resources, it is possible to generate more favorable conditions for technological adoption. Consequently, the analysis of the context and barriers not only allows us to identify limitations, but also to guide actions that promote the effective incorporation of artificial intelligence in microenterprises.[17]

1.6. Relationship between study variables (conceptual model).

The relationship between the variables of the study is based on the models of technological adoption, which state that adoption behavior is not an isolated process, but the result of the interaction of various perceptual and contextual factors. In this sense, the intention to adopt artificial intelligence is configured as the central variable of the model, influenced by the perception of benefits and operational efficiency that individuals associate with technology. When microentrepreneurs identify that artificial intelligence contributes to improving competitiveness, optimizing processes and facilitating decision-making, their willingness to incorporate it into their business activities increases.[13]

Likewise, operational efficiency plays an important role within the conceptual model, acting as a factor that reinforces the perception of the usefulness of the technology. The idea that artificial intelligence saves time, reduces errors, and improves resource management has a positive effect on the valuation of benefits, which in turn affects adoption intent. In this way, a complementary relationship is established between operational efficiency and perceived benefits, since both dimensions contribute to consolidating a favorable perception towards the use of artificial intelligence within the business environment.[3][18]

On the other hand, variables related to context and adoption barriers introduce a moderating element into the model, influencing the intensity with which benefits and efficiency impact adoption intent. Factors such as the level of knowledge, technological accessibility, and the availability of resources can facilitate or limit this process, generating variations in the willingness of microentrepreneurs to adopt technology. Consequently, the relationship between variables should not be understood in a linear way, but as an interdependent system in which positive factors drive adoption, while barriers can attenuate or hinder its materialization in the business environment.[10]

2.- Materials and methods.

The research was quantitative, descriptive in scope, and the design was cross-sectional, non-experimental, since data collection was at a single moment or point in time. The population under study was made up of microenterprises in the commercial sector located in the urban parish of Pedro Carbo Concepción, Guayaquil. The information was taken from the directory of the Superintendence of Company, Securities and Insurance which registered 279 microenterprises in the commercial sector in the parish object of the investigation, the selection criterion was that the companies remain active until the year 2025, another of the criteria that was considered was that these microenterprises do not have more than ten collaborators under dependency, and its sales do not exceed one hundred thousand dollars per year. For the study, non-probabilistic convenience sampling was considered. This decision was taken due to the limitations derived from the insecurity that the country is going through, which could compromise the integrity and willingness of microentrepreneurs. [19]

The data collection technique was the survey and the instrument was the questionnaire itself that was designed in the Google Forms application, this questionnaire had 17 questions which were validated by experts, ensuring its reliability. The questionnaire was addressed to managers or managers of microenterprises. As for the data collection process, it was carried out in three working days, managing to survey 14 microentrepreneurs on the first day, on the second day there were 18 respondents and on the third day 8 more were achieved. In this way, it was possible to survey a total of 40 microentrepreneurs. The data processing was carried out using the SPSS v.22 software, which allowed the corresponding analysis to be carried out for the presentation and interpretation of the results.[20]

3.- Results.

The results obtained not only reveal a current panorama of the use of Artificial Intelligence in Microenterprises, but also offer a valuable perspective to drive an effective transformation that translates into sustainable competitive advantages. The relevant findings of the research are presented below:

Table 1.- Summary of case processing

		N	%
Cases	Valid	40	100,0

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

	Excluded [from]	0	0,0
	Total	40	100,0

a. Elimination by list is based on all procedural variables.

Table 1 shows the summary of the processing of the cases used in the statistical analysis. It is evident that the entire sample (N = 40) was considered valid, with no excluded records, which guarantees the completeness of the data set. This aspect is methodologically relevant, since it indicates the absence of missing values in the variables analyzed under the list elimination procedure, strengthening the consistency of the subsequent analysis and avoiding biases derived from the loss of information.

Table 2.- Reliability statistics

Cronbach's alpha	N of elements
0,953	17

Table 2 presents the reliability statistics of the instrument, showing a Cronbach's alpha value of 0.953 for a total of 17 elements. This coefficient indicates an excellent level of internal consistency, suggesting that the questionnaire items are highly correlated with each other and consistently measure the overall construct associated with the use of artificial intelligence in microenterprises.
Overall, the results of both tables allow us to affirm that the instrument used has a high psychometric quality, supported both by the integrity of the data and by the high reliability of the questionnaire. This implies that the measurements made are stable and consistent, providing a solid basis for the development of subsequent statistical analyses, as well as for the interpretation of the dimensions evaluated in the study.

Likewise, the high value of Cronbach's alpha observed in Table 2 suggests a strong homogeneity between the items, which can be interpreted as an adequate operationalization of the phenomenon studied. However, from a more advanced methodological perspective, such high levels of reliability could also indicate some redundancy between items, an aspect that could be explored in future analyses using techniques such as factor analysis.

In summary, Tables 1 and 2 show that the study has complete data and a highly reliable instrument, which supports the internal validity of the results obtained and strengthens the credibility of the conclusions derived from the statistical analysis.

Dimension 1: Benefits of AI; questions: P2, P3, P6, P9, P11, P14

Table 3.- Reliability statistics

Cronbach's alpha	N of elements
0,911	6

Table 3 presents the reliability statistics corresponding to the Benefits of AI dimension, made up of six items (P2, P3, P6, P9, P11 and P14). The value of Cronbach's alpha obtained (α = 0.911) shows excellent internal consistency, which allows us to affirm that the elements that make up this dimension maintain a high degree of homogeneity and coherently measure the same construct. This result provides methodological soundness to the analysis, as it supports the reliability of the dimension as a valid measure of the perception of the strategic and operational value of artificial intelligence in the microenterprises studied.

Descriptive statistics

Table 4. Descriptive Statistics of the Benefits of AI Dimension

AI Benefits	N	Minimum	Maximum	Media	Standard deviation
	40	1,00	4,83	3,7750	1,02778

Table 4, corresponding to the descriptive statistics of the dimension, shows that the AI Benefits variable has a mean of 3.7750, with a standard deviation of 1.02778, within a range of values ranging from 1.00 to 4.83. These results allow us to identify a favorable overall assessment of the benefits associated with the use of artificial intelligence, given that the mean is clearly above the theoretical midpoint of the Likert scale used. Likewise, the standard deviation indicates a moderate dispersion of responses, suggesting that while there is an overall positive trend, there is also some variability in the intensity with which respondents perceive these benefits.

Table 5.- Statistics on the distribution of the AI Benefits dimension

AI Benefits	N	Asymmetry		Curtosis	
	Statistician	Statistician	Standard Error	Statistician	Standard Error
	40	-1,413	0,374	0,985	0,733

Table 5 delves into the shape of the distribution of the Beneficios_IA dimension using the coefficients of asymmetry and kurtosis. The asymmetry value of -1.413 reveals a left-leaning distribution, implying a higher concentration of responses at the high levels of the scale. In other words, there is evidence of a marked tendency for participants to positively value the benefits of artificial intelligence. On the other hand, kurtosis of 0.985 indicates a relatively concentrated distribution, with a moderate accumulation of responses around the top of the scale. Together, both indicators reinforce the idea that the perception of the benefits of AI is not only favorable on average, but also consistent in its positive orientation.

T-test

Table 6.- Statistics for a sample

AI Benefits	N	Media	Standard deviation	Standard Error Mean

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

	40	3,7750	1,02778	0,16251

Table 6 complements this evidence by reintroducing the basic statistics required for the t-test for a sample. It confirms that the mean of the dimension is 3.7750, with a standard deviation of 1.02778 and a standard error of the mean of 0.16251. This last indicator shows that the estimation of the mean presents an adequate level of precision, which strengthens confidence in the results obtained for this dimension.

Table 7.- Test for a sample

AI Benefits	Test Value = 3					
	t	Good luck	Sig. (bilateral)	Mean difference	95% difference confidence interval	
					Bottom	Superior
	4,769	39	0,000	0,77500	0,4463	1,1037

Table 7 shows the results of the t-test for a sample, performed using the neutral point of the scale (3) as the test value. The statistics obtained (t = 4.769; df = 39; p = 0.000) indicate that the observed mean of the AI Benefits dimension is significantly higher than the neutral value, which allows us to reject the hypothesis of indifference or neutrality in the perception of the respondents. The mean difference of 0.77500 confirms that the positive assessment is not casual or marginal, but statistically relevant. Similarly, the 95% confidence interval for the difference, between 0.4463 and 1.1037, remains completely above zero, which reaffirms the robustness of the result and supports the conclusion that microentrepreneurs perceive real and significant benefits in the use of artificial intelligence.

In an integrated manner, Tables 3, 4, 5, 6 and 7 allow us to argue that the Benefits of AI dimension has a statistically sound structure, both from the psychometric and descriptive and inferential point of view. The high reliability of the construct, together with a mean above the neutral point, a biased distribution towards positive valuations and a statistically significant difference with respect to the theoretical reference value, show that the microentrepreneurs analysed clearly recognise the strategic and operational potential of artificial intelligence to improve competitiveness, optimise resources, reduce errors and strengthen business management.

In analytical terms, these findings allow us to conclude that the perception of the benefits of artificial intelligence constitutes a favorably positioned dimension within the group studied, which suggests the existence of a positive attitudinal basis for future processes of technological adoption. This result is especially relevant, as it indicates that, even though there may be structural or knowledge barriers, the recognition of the value of AI is already present in a considerable proportion of respondents.

Dimension 2: Operational efficiency; questions P1, P7, P8, P10

Table 8.- Reliability statistics

Cronbach's alpha	N of elements
0,832	4

Table 8 presents the reliability statistics corresponding to the Operational Efficiency dimension, composed of four items (P1, P7, P8 and P10). The value of Cronbach's alpha obtained (α = 0.832) shows a high internal consistency, which indicates that the items included maintain an adequate correlation with each other and coherently measure the construct associated with process optimization and decision-making through the use of artificial intelligence. This result allows us to consider the dimension as statistically reliable for analysis and interpretation.

Descriptive statistics

Table 9. Descriptive statistics of the Operational Efficiency dimension

Operational Efficiency	N	Minimum	Maximum	Media	Standard deviation
	40	1,25	5,00	3,9062	1,09440

Table 9, relating to the descriptive statistics, shows that the Operational Efficiency variable has a mean of 3.9062 and a standard deviation of 1.09440, with values ranging from 1.25 to 5.00. The average obtained, located above the midpoint of the scale (3), shows an overall positive perception regarding the impact of artificial intelligence on improving operational efficiency. On the other hand, the standard deviation reflects a moderate dispersion of the responses, which suggests the coexistence of diverse assessments, although with a predominance of favorable perceptions.

Table 10. Statistics on the distribution of the Operational Efficiency dimension

Operational Efficiency	N	Asymmetry		Curtosis	
	Statistician	Statistician	Standard Error	Statistician	Standard Error
	40	-1,239	0,374	0,508	0,733

Table 10 allows us to delve into the shape of the distribution of the variable using the coefficients of asymmetry and kurtosis. The asymmetry value of -1.239 indicates a left-leaning distribution, implying a higher concentration of responses at the high levels of the scale. This confirms the tendency of respondents to perceive the impact of artificial intelligence on operational efficiency favorably. As for kurtosis, the value of 0.508 suggests a slightly concentrated distribution, although relatively close to a normal distribution, which supports the stability of the data's behavior.

T-test

INQUIDE
Chemical Engineering & Development
Journal of Science and Engineering
Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

Table 11.- Statistics for a sample

	N	Media	Standard deviation	Standard Error Mean
Operational Efficiency	40	3,9063	1,09440	0,17304

Table 11 presents the statistics required for the t-test of a sample, confirming the mean of the dimension (3.9063), as well as its standard deviation (1.09440) and the standard error of the mean (0.17304). This last indicator shows adequate precision in the estimation of the mean, which is relevant for the inferential interpretation of the results.

Table 12.- Test for a sample

	Test Value = 3					
	t	Good luck	Sig. (bilateral)	Mean difference	95% difference confidence interval	
					Bottom	Superior
Operational Efficiency	5,237	39	0,000	0,90625	0,5562	1,2563

The results in Table 12 correspond to the t-test for a sample, performed using the neutral point of the scale (3) as a reference value. The statistic obtained (t = 5.237; df = 39; p = 0.000) indicates that the observed mean is significantly higher than the reference value, which allows us to reject the hypothesis of neutrality in the perception of operational efficiency. The mean difference of 0.90625 shows a considerable positive deviation from the midpoint. Likewise, the 95% confidence interval for the difference, between 0.5562 and 1.2563, remains completely above zero, which reinforces the statistical strength of the result obtained.

In an integrated manner, Tables 8, 9, 10, 11 and 12 show that the Operational Efficiency dimension presents a statistically consistent behavior, supported by an adequate reliability of the instrument, an average above the neutral point, a biased distribution towards positive valuations and a statistically significant difference with respect to the reference value. Taken together, these results allow us to affirm that microentrepreneurs perceive favorably the impact of artificial intelligence on process optimization, time savings, improved decision-making and inventory management.

From an analytical perspective, these findings suggest that operational efficiency is one of the areas where artificial intelligence is best valued by respondents, which could be interpreted as a key factor in driving its adoption in the context of microenterprises. The consistency between the descriptive and inferential indicators reinforces the evidence that this dimension is positioned as a relevant element within the analysis model developed in the research.

Dimension 3: Intention to adopt, questions: P4, P15, P16, P17

Table 13.- Reliability statistics

Cronbach's alpha	N of elements
0,914	4

Table 13 presents the reliability statistics of the Intention to adopt dimension, composed of four items. The value of Cronbach's alpha obtained (α = 0.914) shows excellent internal consistency, which indicates that the items that make up this dimension are highly correlated and coherently measure the willingness of microentrepreneurs to adopt tools based on artificial intelligence. This result supports the robustness of the construct and guarantees the reliability of the measurements made.

Table 14. Descriptive statistics of the AI adoption intent dimension

	N	Minimum	Maximum	Media	Standard deviation
Intent to Adopt	40	1,00	5,00	3,7813	1,04112

Table 14 shows the descriptive statistics of the dimension, where it is observed that the variable Intention to adopt has a mean of 3.7813 and a standard deviation of 1.04112, within a range between 1.00 and 5.00. These results show that the intention to adopt artificial intelligence is above the midpoint of the scale, reflecting a favorable predisposition on the part of respondents towards the implementation of this type of technology. The standard deviation suggests a moderate dispersion, evidencing the existence of variability in the responses, although with a predominance of positive assessments.

Table 15. AI Adoption Intent Distribution Statistics

	N	Asymmetry		Curtosis	
Intent to Adopt	Statistician	Statistician	Standard Error	Statistician	Standard Error
	40	-0,900	0,374	-0,129	0,733

Table 15 analyzes the characteristics of the distribution of the variable using the coefficients of asymmetry and kurtosis. The asymmetry of -0.900 indicates a left-leaning distribution, implying that a significant proportion of respondents tend to be in the upper categories of the scale, reflecting a favorable disposition towards AI adoption. Regarding kurtosis, the value of -0.129 suggests a relatively close to normal distribution, with a slight tendency to disperse, indicating a moderate variability in responses without extreme concentrations.

T-test

Table 16.- Statistics for a sample

	N	Media	Standard deviation	Standard Error Mean
Intent to Adopt	40	3,7813	1,04112	0,16462

Table 16 presents the statistics necessary for the t-test of a sample, where it is confirmed that the mean of the dimension is 3.7813, with a standard deviation of 1.04112 and a standard error of the mean of 0.16462. This last value shows an adequate level of precision in the estimation of the average, which allows the results to be considered as statistically reliable.

Table 17.- Test for a sample

Intent to Adopt	Test Value = 3					
	t	Good luck	Sig. (bilateral)	Mean difference	95% difference confidence interval	
					Bottom	Superior
	4,746	39	0,000	0,78125	0,4483	1,1142

Table 17 shows the results of the t-test for a sample, taking the neutral point of the Likert scale as a reference value (3). The statistic obtained (t = 4.746; df = 39; p = 0.000) indicates that the observed mean is significantly higher than the reference value, which allows us to reject the hypothesis of neutrality in the intention to adopt. The mean difference of 0.78125 shows a relevant positive deviation from the midpoint. Likewise, the 95% confidence interval for the difference, between 0.4483 and 1.1142, remains completely above zero, confirming the statistical strength of the result.

In an integrated manner, Tables 13, 14, 15, 16 and 17 show that the AI Adoption Intent dimension presents a statistically consistent and favorable behavior. The high reliability of the construct, together with a mean above the neutral point, a distribution with a tendency towards high values and a statistically significant difference with respect to the reference value, allow us to conclude that microentrepreneurs show a positive predisposition towards the adoption of technologies based on artificial intelligence.

In analytical terms, these results suggest that, beyond the perception of benefits or efficiency, there is a concrete willingness of respondents to invest, train and adopt technological tools, which is a key element for the effective implementation of artificial intelligence in the field of microenterprises. This finding acquires special relevance within the study model, as it shows that the acceptance of technology is not limited to the perceptual plane, but is projected towards the behavioral intention of adoption.

Dimension 4: Context/barriers; Questions: P5, P12, P13

Table 18.- Reliability statistics

Cronbach's alpha	N of elements
0,343	3

Table 18 presents the reliability statistics corresponding to the "Context / barriers" dimension, made up of three items (P5, P12 and P13). The value of Cronbach's alpha obtained (α = 0.343) shows a low internal consistency, which indicates a weak correlation between the items that make up this dimension. This result suggests that the elements included are not homogeneously measuring a single construct, and may reflect the coexistence of different conceptual factors, such as the level of knowledge, the perception of accessibility, and the identification of limitations. From a methodological point of view, this finding indicates that the dimension should be interpreted with caution, since its low reliability limits the internal robustness of the construct.

Descriptive statistics

Table 19. Descriptive statistics of the dimension Context and barriers

Background Barriers	N	Minimum	Maximum	Media	Standard deviation
	40	2,00	4,33	3,0917	0,59909

Table 19 presents the descriptive statistics of the variable "Context barriers". A mean of 3.0917 is observed, slightly higher than the neutral point of the scale (3), with a standard deviation of 0.59909. These values indicate that the perception of context and barriers is at a level close to neutrality, with relatively low variability among respondents. The range of responses, between 2.00 and 4.33, suggests the absence of extreme assessments, evidencing a moderate and relatively homogeneous perception regarding the factors that condition the adoption of artificial intelligence.

Table 20. Statistics on the distribution of the dimension Context and barriers

Context barriers	N	Asymmetry		Curtosis	
	Statistician	Statistician	Standard Error	Statistician	Standard Error
	40	-0,241	0,374	-0,779	0,733

Table 20 delves into the shape of the distribution of the variable using the coefficients of asymmetry and kurtosis. The skewness value of -0.241 indicates a slightly left-leaning distribution, suggesting a slight trend towards valuations above the midpoint, although without a marked concentration. On the other hand, kurtosis of -0.779 reflects a flatter distribution compared to normal, indicating a moderate dispersion of responses without significant accumulations around a specific point. Taken together, these indicators confirm that the variable presents a relatively balanced behavior, without pronounced biases in the perception of the respondents.

T-test

Table 21.- Statistics for a sample

Context barriers	N	Media	Standard deviation	Standard Error Mean
	40	3,0917	0,59909	0,09472

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

Table 21 presents the statistics required for the t-test of a sample, which confirms a mean of 3.0917, a standard deviation of 0.59909 and a standard error of the mean of 0.09472. This last value indicates adequate accuracy in the estimation of the mean, allowing an inferential evaluation to be made with a reasonable level of confidence.

Table 22.- Test for a sample

Context barriers	Test Value = 3					
	t	Good luck	Sig. (bilateral)	Mean difference	95% difference confidence interval	
					Bottom	Superior
	0,968	39	0,339	0,09167	-0,0999	0,2833

The results in Table 22 correspond to the t-test for a sample, taking the neutral point of the scale (3) as a reference value. The statistic obtained (t = 0.968; df = 39; p = 0.339) indicates that there is no statistically significant difference between the observed mean and the reference value. In this sense, it is not possible to reject the hypothesis of neutrality in the perception of context and barriers. The mean difference of 0.09167 is small, and the 95% confidence interval between -0.0999 and 0.2833 includes zero, reinforcing the absence of statistically significant evidence.

In an integrated manner, Tables 18, 19, 20, 21 and 22 show that the "Context / barriers" dimension presents a different behavior than that observed in the dimensions previously analyzed. The low reliability of the construct, together with a mean close to the neutral point and the absence of statistical significance in the t-test, indicate that there is no clearly defined perception regarding the conditions that facilitate or limit the adoption of artificial intelligence. Likewise, the relatively balanced distribution of the data suggests that the opinions of microentrepreneurs are dispersed and do not converge in a consistent position.

In analytical terms, these results allow us to interpret that the context and the barriers associated with artificial intelligence are not a factor clearly perceived or homogeneously evaluated by the respondents. This situation could be explained by differences in the level of knowledge, access to technological resources or previous experiences with digital tools, which generates diverse perceptions and makes it difficult to consolidate a uniform construct. Consequently, this dimension is presented as a less defined element within the analysis model, which suggests the need to deepen its measurement or conceptually redefine its components in future research.

4.- Discussion

4.1. Interpretation of the results

The results of the study show that the dimensions associated with the perceived benefits, operational efficiency and intention to adopt artificial intelligence show a consistent and favorable behavior within the analyzed group, which allows us to infer the existence of a positive attitudinal basis towards the incorporation of these technologies in microenterprises. This finding is aligned with the postulates of the Technology Acceptance Model (TAM), which establishes that perceived utility is a determining factor in the intention of technological adoption. In this sense, evidence suggests that microentrepreneurs clearly recognize the strategic and operational value of artificial intelligence, which translates into a favorable predisposition towards its implementation.[21][22]

Likewise, the operational efficiency dimension reinforces the previous interpretation, by demonstrating that respondents perceive that artificial intelligence contributes to optimizing processes, reducing times and improving business management. This result confirms what Davenport and Ronanki pointed out, who indicate that the application of solutions based on artificial intelligence allows for increased organizational productivity through automation and advanced data analysis. Consequently, operational efficiency not only acts as a perceived benefit, but also as an element that strengthens the perception of usefulness of the technology, consolidating its influence on the intention of adoption.[23][24]

On the other hand, the dimension of intention to adopt reflects that the acceptance of artificial intelligence is not limited to the cognitive level, but is projected towards a specific behavioral disposition. This finding is especially relevant, as it shows that microentrepreneurs not only recognize the potential benefits, but also express interest in investing, training, and adopting these technologies. In theoretical terms, this result is in agreement with the UTAUT model, which postulates that the intention of use is influenced by both the performance expectation and the facilitating conditions.[25]

In contrast, the dimension related to context and barriers presents a differentiated behavior, characterized by low internal consistency and a perception close to the neutral point. This result suggests that the factors associated with knowledge, accessibility, and structural limitations are not perceived homogeneously by the respondents. From an analytical perspective, this indicates that adoption barriers are not a clearly defined factor within the group studied, which could be due to individual differences in terms of experience, access to resources, or level of familiarity with the technology. Consequently, while profits and efficiency drive adoption, barriers do not emerge as a dominant element in the collective perception.

4.2. Comparison with previous studies

The findings obtained in the present study show a high coherence with the previously developed literature on the adoption of emerging technologies in the business environment. In particular, the positive relationship between perceived benefits and adoption intent has been widely documented in studies based on the TAM model, where perceived utility is established as the main predictor of

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

technological acceptance. In this sense, the results obtained reinforce the empirical validity of this model in microenterprise contexts, especially in emerging economy environments.[21][26]

Similarly, the influence of operational efficiency on technology adoption coincides with recent studies highlighting the role of artificial intelligence in optimizing business processes. Research such as that of the McKinsey Global Institute indicates that companies that implement solutions based on artificial intelligence achieve significant improvements in productivity and decision-making. In this sense, the results obtained not only confirm these trends, but also provide empirical evidence from the specific context of microenterprises, a segment less explored in the literature.[27]

However, divergences are identified in relation to the role of adoption barriers. While several studies highlight the lack of knowledge and resources as significant obstacles to the implementation of digital technologies, in this study these barriers are not manifested in a forceful or homogeneous way. This difference suggests that, in the context analyzed, the perception of benefits could be compensating or attenuating the influence of structural limitations, which constitutes a relevant contribution to the understanding of the processes of technological adoption in microenterprises.[28][29]

4.3. Theoretical and practical implications

From a theoretical point of view, the results of the study contribute to strengthening technology adoption models by showing that the relationship between perceived benefits, operational efficiency, and adoption intent remains consistent in microenterprise contexts. In particular, the applicability of the TAM model is expanded by incorporating operational efficiency as a complementary dimension that reinforces the perception of utility. Likewise, evidence is provided that suggests that barriers do not always act as determining factors, which invites us to reconsider their relative weight within traditional models of technological adoption.

In practical terms, the findings have direct implications for business management and the design of digital transformation strategies. Evidence of a favorable perception towards artificial intelligence suggests the existence of an environment conducive to the implementation of technological solutions in microenterprises. In this sense, training and technical support programs could be developed aimed at consolidating this positive predisposition, facilitating the transition to more digitized management models. Likewise, the identification of operational efficiency as a key factor allows adoption strategies to be focused on practical applications that generate visible results in the short term.

Additionally, from an applied perspective, the results open the possibility of promoting technology transfer schemes adapted to the needs of microenterprises, considering their structure and limitations. This could include the development of accessible AI tools, low-cost platforms, and financing programs that facilitate investment in technology. Consequently, the study not only contributes to academic knowledge, but also offers guidelines for the effective implementation of artificial intelligence in the business sector.

4.4. Limitations and future projections

Despite the contributions made, the study has some limitations that must be considered when interpreting the results. First, the sample size, composed of 40 microentrepreneurs, limits the ability to generalize the findings to broader populations. Likewise, the use of non-probabilistic convenience sampling restricts the representativeness of the results, which could introduce biases associated with the selection of participants.

Secondly, limitations related to the measurement of the context and barriers dimension are identified, which presented a low internal consistency. This result suggests the need to redefine or expand the items used to more accurately capture the conditions that affect technology adoption. From a methodological approach, future research could incorporate factor analysis to validate the structure of the constructs and improve the psychometric quality of the instrument.

Finally, future lines of research are proposed aimed at deepening the analysis of the adoption of artificial intelligence in microenterprises. Among them, the need to expand the sample size, incorporate additional variables such as organizational culture or technological leadership, and develop longitudinal studies that allow analyzing the evolution of adoption over time stands out. It is also pertinent to explore the real impact of artificial intelligence on business performance, moving from perception to objective measurement of results, which would contribute to strengthening the link between academic research and practical application.

5.- Conclusion.

5.1. Synthesis of findings

The results of the study show that the microenterprises analyzed present a favorable perception of artificial intelligence, particularly with regard to its ability to generate strategic benefits and improve operational efficiency. These dimensions are consolidated as key factors in the understanding of the phenomenon studied, reflecting that microentrepreneurs not only recognize the potential value of these technologies, but also identify their applicability in the optimization of internal processes and in the improvement of decision-making. In this sense, the objectives set out in the research are met in a coherent manner, as it is possible to identify the main elements that influence the valuation of artificial intelligence in the business environment.

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

Likewise, it is observed that the intention to adopt technology is manifested as a favorable dimension within the analyzed group, which suggests that there is a concrete predisposition towards the incorporation of tools based on artificial intelligence. This finding is particularly relevant, as it evidences a transition from perception to potential action, which reinforces the coherence between the results obtained and the methodological approach adopted. On the other hand, the dimension related to the context and barriers does not present a defined behavior, which indicates that these factors are not perceived in a homogeneous way, reflecting the diversity of structural conditions existing in microenterprises.

5.2. Scientific and technical contributions

From a scientific point of view, the study provides empirical evidence that strengthens the understanding of the processes of adoption of artificial intelligence in microenterprises, a context that has been relatively little explored in the literature. In particular, it is evident that the dimensions of perceived benefits and operational efficiency act as determining elements in the intention of technological adoption, which contributes to validate and expand existing models of technological acceptance, such as TAM and UTAUT, in smaller-scale business contexts. In this way, the study not only confirms previous theoretical postulates, but also contextualizes them in specific economic realities.

In technical terms, the research presents a relevant methodological contribution by structuring an analysis model based on clearly defined dimensions and evaluated by instruments with adequate internal consistency. This approach allows a more systematic approach to the study of the adoption of artificial intelligence, facilitating its replicability in other contexts. Likewise, the integration of descriptive and inferential analyses provides robustness to the results, allowing a deeper interpretation of the phenomenon studied and contributing to the generation of applicable knowledge in the field of engineering and business management.

5.3. Theoretical implications and practical applications

On a theoretical level, the results of the study reinforce the validity of technology adoption models by showing that the perception of benefits and operational efficiency are key factors for the acceptance of artificial intelligence. This evidence suggests the need to consider these elements as central dimensions in future conceptual models, especially in microenterprise environments. Likewise, the limited definition of adoption barriers raises the possibility of reviewing their treatment in the literature, proposing more specific approaches that allow for a more accurate capture of the diversity of contextual conditions.

From a practical perspective, the findings of the study offer relevant implications for business management and the design of digital transformation strategies. The existence of a favorable predisposition towards artificial intelligence suggests that microenterprises could benefit from programs aimed at strengthening technological training and facilitating access to digital tools. In this sense, opportunities are identified to promote innovation processes through the implementation of solutions adapted to the needs of this business segment, as well as to promote support policies that reduce existing technological gaps. Similarly, the results can serve as a basis for the development of technology transfer initiatives that contribute to improving the competitiveness and sustainability of microenterprises.

5.4. Projections and lines of future research

Despite the contributions made, the study highlights the need to deepen the analysis of the adoption of artificial intelligence in microenterprises. In this sense, future research could expand the sample size and use probabilistic sampling designs to improve the representativeness of the results. It is also suggested to incorporate additional variables related to organizational, cultural, and technological aspects, in order to enrich the analysis model and capture in a more comprehensive way the factors that influence technological adoption.

Similarly, it is recommended to develop longitudinal studies that allow analyzing the evolution of the adoption of artificial intelligence over time, as well as исследования that integrate mixed methods to complement the quantitative perspective with qualitative evidence. Finally, it is pertinent to explore the real impact of artificial intelligence on business performance, shifting the focus from perception to the objective measurement of results, which would strengthen the link between scientific research and its practical application in the business environment.

6.- Acknowledgements (if applicable)

Not applicable.

7.- Contributions of authors (Taxonomy of contributors' roles - CRediT)

1. Conceptualization: Jorge Meza-Clark, Leonardo Cuadrado-Sagñay
2. Data curation: Teresa Meza Clark, Leonardo Cuadrado-Sagñay
3. Formal analysis: Francisco Javier Duque-Aldaz
4. Acquisition of funds: Not applicable.
5. Research: Teresa Meza Clark, Leonardo Cuadrado-Sagñay
6. Methodology: Jorge Meza-Clark, Leonardo Cuadrado-Sagñay
7. Project management: Leonor Alejandrina Zapata Aspiazu
8. Resources: Edwin Haymacaña Moreno, Leonor Alejandrina Zapata Aspiazu
9. Software: Francisco Javier Duque-Aldaz
10. Supervision: Francisco Javier Duque-Aldaz
11. Validation: Leonor Alejandrina Zapata Aspiazu
12. Visualization: Edwin Haymacaña Moreno, Leonor Alejandrina Zapata Aspiazu

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

13. Writing - original draft: Jorge Meza-Clark; Teresa Meza Clark
14. Writing - revision and editing: Teresa Meza Clark, Edwin Haymacaña Moreno, Francisco Javier Duque-Aldaz

8.- Appendix.

Not applicable.

9.- References.

[1] D. Weglarz, C. Pla-Garcia and A. I. Jiménez-Zarco, "Acceptance of Generative Artificial Intelligence in the creative industry: the role of the UTAUT model, recognition and brand trust in its adoption," *RETOS*, vol. 15, no. 29, 2025.

[2] F. J. Duque-Aldaz, E. R. Haymacaña Moreno, L. A. Zapata Aspiazu y F. Carrasco Choque, «Prediction of moisture content in the cocoa drying process by simple linear regression.,» *Inquide*, vol. 6, nº 2, 2024.

[3] V. Badenes-Plá and J. Molares-Cardoso, «Artificial intelligence in the face of the challenges of the fashion industry. Benefits and applications in the commercialization and marketing phase," *Razón y Palabra*, vol. 27, no. 118, 2023.

[4] A. Pereira, T. P. Donadon Homem and F. O. Teixeira, "Application of artificial intelligence to monitor the use of protective masks," *Revista Científica General José María Córdova*, vol. 19, no. 33, 2021.

[5] C. A. Payá-Santos, "The performance of intelligence in Spain in the public, business and academic sphere," *Revista Científica General José María Córdova*, vol. 21, no. 44, 2023.

[6] L. M. Pereira-González, A. Basantes-Andrade, M. Mora-Grijalva, and A. Galárraga-Andrade, "Latent dimensions in the adoption of ChatGPT in the university: CHASSIS model," *Alteridad*, vol. 20, no. 2, 2025.

[7] A. Hernández Arias, «New scenarios and organizational environments for the adoption of disruptive technologies,» *Compendium*, vol. 26, nº 51.

[8] F. J. Duque-Aldaz, F. R. Rodríguez-Flores and J. Carmona Tapia, «Identification of parameters in ordinary differential equation systems through the use of artificial neural networks,» *Revista San Gregorio*, vol. 1, nº 2, 2025.

[9] H. A. Hernández, L. V. Taquez Hoyos, and D. C. Cortez Mosquera, "Use of Artificial Intelligence in Project Management," *RHS*, vol. 13, no. 2, 2025.

[10] M. Domínguez Vargas and C. P. Méndez Cruz, "Impact of Digitalization on the Efficiency of Cooperatives," *Transcend, accounting and management*, vol. 9, no. 27, 2024.

[11] A. Santamaría Barraza, "The Influence of the Use of Strategic Planning of Operational Capacity on the Operations Management of Logistics Companies in Panama," *Research and Critical Thinking*, vol. 12, no. 3, 2024.

[12] K. Mansilla-Obando and G. R. Llanos, "Adoption of Micromobility Applications in Chile: TAM and Collaborative Consumption," *RETOS.*, vol. 16, no. 31, 2026.

[13] J. Cabero-Almenara, A. Palacios-Rodríguez, J. Barroso-Osuna, and C. Siles-Rojas, "Immersive Technologies at the University: Faculty Profiles and Obstacles to Their Integration," *ITEN*, Vol. 29, No. 1, 2026.

[14] S. Cardona-Acevedo, A. Valencia-Arias, and J. Valencia, "Emerging technologies to optimize environmental sustainability in the textile industry: a systematic review," *RETOS*, vol. 16, no. 31, 2026.

[15] T. ALLAN, "Adoption of public policies in multilevel government contexts: explaining provincial responses to Covid-19 in Argentina," *SAAP Journal*, vol. 18, no. 2, 2024.

[16] M. R. Jury, "Eastern Caribbean Sea level rise in global context," *Journal of Environmental Sciences*, vol. 60, no. 1, 2026.

[17] E. Barrera Duque and C. Torres Castillo, "The Entrepreneur's Mindset of Radical Innovations in the Colombian Context: Case Studies," *Estudios Gerenciales*, vol. 41, no. 174, 2025.

[18] G. J. Morocho Choca, L. Á. Bucheli Carpio y F. J. Duque-Aldaz, «Fuel oil fuel dispatch optimization through multivariate regression using local storage indicators.,» *Inquide*, vol. 6, nº 2, 2024.

[19] G. E. Castro Rosales, A. D. Torres Alvarado, L. S. Zalamea Cedeño, F. J. Duque-Aldaz y F. R. Rodríguez-Flores, «Comprehensive Ergonomic Proposal for the Reduction of Musculoskeletal Risks in Soap Production: An Approach Based on Statistical Analysis and Postural Evaluation,» *Inquide*, vol. 7, nº 2, 2025.

[20] E. Haymacaña Moreno, L. A. Zapata Aspiazu, F. J. Duque-Aldaz, G. F. Cabezas García y R. A. Sánchez Ancajima, Time series modeling of secondary school enrollment in Ecuador: a Box–Jenkins analysis (1971–2023), Inquide, 2026.

[21] F. D. Davis, «Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology,» *JSTOR*, vol. 13, nº 3, 1989.

[22] D. Navarro, F. Suárez and S. Navajas, Perspectives on Digital Transformation, Fintech and Financial Inclusion: Latin America and the Caribbean, DID, 2025.

[23] T. H. Davenport y R. Ronanki, «Artificial Intelligence for the Real World,» *Harvard Business Review*, 2018.

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

[24] L. A. Zapata Aspiazu, E. Haymacaña Moreno, F. J. Duque-Aldaz, F. G. Cabezas García y R. A. Sánchez Ancajima, «ARIMA vs. Hybrid Models with Machine Learning for Forecasting Ecuador's GDP.,» 2026.

[25] V. Venkatesh, M. G. Morris, G. B. Davis y F. D. Davis, «User Acceptance of Information Technology: Toward a Unified View,» *MIS Quarterly*, vol. 27, nº 3, pp. 425-478, 2020.

[26] A. C. Lustosa Rosario, B. B. Yaacov, C. Franco Segura, E. Arias Ortiz, E. Heredero, J. Botero, P. Brothers, T. Payva, and M. Spies, "Digital Transformation in Higher Education Latin America and the Caribbean," IDB, 2021.

[27] McKinsey Global Institute, «The state of AI in 2025: Agents, innovation, and transformation,» 2025.

[28] J. Hirs and F. Vargas, "Priorities for Business Digitalization in Latin America and the Caribbean," IDB, 2023.

[29] UN. ECLAC, Overcoming the Development Traps of Latin America and the Caribbean in the Digital Age: The Transformative Potential of Digital Technologies and Artificial Intelligence, ECLAC, 2025.

INQUIDE
Chemical Engineering & Development
Journal of Science and Engineering

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

Effectiveness of purple cabbage-based slimming diets in people with obesity from the Cleotilde Guerrero O Foundation.

Efectividad de dietas adelgazantes a base de col morada en personas con obesidad de la Fundación Cleotilde Guerrero O.

Mirian Villavicencio Párraga, [1] Marina Arteaga Peñafiel [2] ; Katherine Zavala Villavicencio [3] ; Alex Villao Villacrés [4]; Arellys Sornoza Arteaga [5] ; Ricardo Quimis Mantuano [6]

Received: 03/15/2026 – Accepted: 05/19/2026 – Published: 07/12/2026

Research Articles [X] Review Articles [ ] Essay Articles [ ]

* Corresponding author.

Abstract.
This study demonstrated the benefits of weight-loss diets based on red cabbage, known for its phytochemical and antioxidant content, and considered a potentially beneficial source for weight loss and improved metabolic health. The objective was to evaluate the effectiveness of red cabbage-based weight-loss diets in obese individuals at the Cleotilde Guerrero O Foundation in Guayaquil, Ecuador. The research was conducted using a quantitative approach and a quasi-experimental design. Participants with significant obesity followed a dietary program focused on incorporating red cabbage into their daily diet. The results revealed that the red cabbage-based weight-loss diets had a positive impact on weight loss. A significant decrease in body mass index (BMI) and waist circumference was observed, suggesting a beneficial effect on cardiovascular and metabolic health. This study supports the idea that red cabbage may play an important role in weight-loss diets for obese individuals. However, further research is needed to fully understand the mechanisms behind these effects and to determine optimal red cabbage consumption guidelines in weight-loss programs. This study at the Cleotilde Guerrero O Foundation indicates that diets incorporating red cabbage may be effective in helping obese individuals lose weight and improve their metabolic health.

Keywords.
Weight loss, body mass, metabolism, nutrition, obesity, health.

Resumen.
El presente estudio permitió demostrar los beneficios de las dietas adelgazantes basadas en la col morada conocida por su contenido de fitoquímicos y antioxidantes, se considera una fuente potencialmente beneficiosa para la pérdida de peso y la mejora de la salud metabólica. El objetivo es evaluar la efectividad de las dietas adelgazantes elaboradas a base de col morada en personas con obesidad de la Fundación Cleotilde Guerrero O de la ciudad de Guayaquil. La investigación se efectuó a través de un enfoque cuantitativo y un diseño cuasi experimental e incluyó a un grupo de participantes con exceso de obesidad que fueron sometidos a un programa de dieta que se centró en la incorporación significativa de col morada en su alimentación diaria. Los resultados revelaron que las dietas adelgazantes basadas en la col morada tuvieron un impacto positivo en la pérdida de peso de los participantes. Se observó una disminución significativa en el índice de masa corporal (IMC) y la circunferencia de la cintura, lo que sugiere un efecto beneficioso en la salud cardiovascular y metabólica. Este estudio respalda la idea de que la col morada puede desempeñar un papel importante en las dietas adelgazantes para personas con exceso de obesidad. Sin embargo, se requieren investigaciones adicionales para comprender completamente los mecanismos detrás de estos efectos y para determinar las pautas óptimas de consumo de col morada en programas de pérdida de peso. Este estudio en la Fundación Cleotilde Guerrero O indica que las dietas que incorporan la col morada pueden ser efectivas para ayudar a las personas con exceso de obesidad a perder peso y mejorar su salud metabólica.

Palabras clave.
Adelgazar, masa corporal, metabolismo, nutrición, obesidad, salud.

1.- Introduction

Obesity is a disease that is characterized by an excess of body fat that affects the physical and psychological health of individuals. It is usually measured through the body mass index (BMI), which relates the weight and height of a person, a person is considered obese if their BMI is equal to or greater than 30 kg/m². On the other hand, this problem is not simply cosmetic, but a major risk factor for a number of chronic diseases, including type 2 diabetes, cardiovascular disease, hypertension, and certain cancers. In addition, obesity can lead to reduced quality of life and increase healthcare costs associated with treating your comorbidities. [1][2][3]

Obesity has become an epidemic that affects the whole world, even more so developed or developing countries, becoming a burden on society because they exceed one billion cases according to the latest epidemiological studies, that is, today there are many more people with excess body weight than in ancient times. where there was greater

[1] University of Guayaquil; mirian.villavicenciop@ug.edu.ec ; https://orcid.org/0000-0001-6144-9467 , Guayaquil, Ecuador.
[2] University of Guayaquil; marina.arteagap@ug.edu.ec ; https://orcid.org/0000-0002-5378-9776, Guayaquil, Ecuador.
[3] Universidad Espíritu Santo; kzavala@uess.edu.ec; https://orcid.org/0000-0001-8888-336x , Guayaquil, Ecuador.
[4] University of Guayaquil; Alex.villaov@ug.edu.ec ; https://orcid.org/0000-0002-9143-2655 , Guayaquil, Ecuador.
[5] Milagro State University; Arianaarellyscristoviene@gmail.com ; https://orcid.org/0009-0005-9675-5479, Milagro, Ecuador.
[6] External researcher; rit.quimis.m@gmail.com ; https://orcid.org/0009-0000-3240-0947 , Guayaquil, Ecuador.

physical activity because individuals were engaged in activities such as the house and gathering that demanded more energy and a lower intake of food, where this was done to survive.[4]

In recent years, it has become a global public health problem that has reached epidemic proportions. In 2022, about 890 million people were obese, which corresponds to 16% of the population, in 2024, 35 million school-age children were part of this condition. 60% of the adult population and 33% of children and adolescents in Latin America and the Caribbean were obese in 2025, tripling since 1975. While, according to the Global Nutrition Report, in Ecuador more than 27% of women and 17% of men suffer from this disease. This [5] [6][7]condition is associated with an increased risk of chronic diseases, such as type 2 diabetes, cardiovascular disease, and certain cancers, What it requires Ongoing medical care and follow-up to improve the quality of life of affected individuals.[8]

Obesity has become one of the most pressing public health challenges worldwide. As obesity rates continue to rise, the relationship between obesity and these adverse health conditions has been documented in numerous epidemiological and clinical studies, underscoring the urgent need to address this global health issue. Given the growth of cases in recent years, it has been considered [9]treatments to reduce obesity, focusing in a variety of approaches, including diet modification, increased physical activity, behavioral therapy, and in some cases, bariatric surgery. In this context, slimming diets have become a commonly employed strategy for obesity management, and ongoing research seeks to identify foods and dietary patterns that can improve the effectiveness of these programs [10].

Slimming diets usually involve the controlled modification of caloric intake, resulting in a caloric deficit that leads to weight loss. These can vary in terms of nutritional approach, and can be low-carb, low-fat, based on specific dietary patterns (such as the Mediterranean diet or the ketogenic diet), or incorporate specific foods and nutrients with promising properties for weight loss and metabolic health. As food programs designed to promote weight loss in overweight or obese people, they often involve calorie restriction, portion control, and food selection with the goal of creating a caloric deficit, leading to loss of body fat. These can vary widely in terms of nutritional composition and approach, from low-carb diets to low-fat diets to diets based on specific eating patterns.[11][12]

However, slimming diets cannot be applied in all cases, since, in order to be implemented, they must have guidance from professionals in the area of health and nutrition due to the presence of physiological, metabolic and clinical conditions that determine in which cases this type of nutritional intervention can be performed. Additionally, it is pertinent to consider aspects such as age, medical history, physical activity levels, nutritional requirements, so targeted planning is required to reduce measures in a personalized way. In this sense, the supervision of a professional is necessary to ensure that the dietary plan is adequate, balanced, safe, especially aligned with the needs of the patients. On the other hand, a constant evaluation of the progress made is required to avoid possible nutritional deficiencies that favor healthy and sustainable results.

One of the Emerging proposals for weight loss, It is the exploration of specific foods and their bioactive components that can have a positive impact on weight reduction and improved metabolic health. In this search for effective strategies to combat obesity, phytonutrients, bioactive compounds present in a variety of plant foods, have emerged as an area of growing interest in research. These compounds have been shown to have a number of beneficial health properties, including antioxidant, anti-inflammatory, and potentially anti-obesity effects. Plant-based diets provide necessary calories, carbohydrates, proteins, and fats. As well as prebiotic fibers and phytochemicals that have an antioxidant effect and several of them are cardioprotective. [13][14]

The exploration of specific foods and bioactive components are part of a relevant line of research in engineering, chemistry and gastronomy that allows the development of nutritional strategies aimed at weight control where the chemical composition of the food, the transformation processes and the stability of the functional compounds that are found. In vegetables, they are used in a timely manner. While, from the gastronomic perspective, knowledge is obtained of the correct ways to prepare, preserve and consume food for the total use of the compounds in this sense. The study of vegetables is of vital interest, due to the anthocyanin fibers and polyphenols that regulate metabolism and reduce fats in the body.

One of the beneficial foods, which serves the purpose of reducing body fat and regulating metabolism, is purple cabbage (Brassica oleracea var. capitata f. rubra), also known as red cabbage or purple cabbage, due to its high content of phytochemicals and antioxidants, such as anthocyanins and flavonoids have been shown to have beneficial properties for health, including anti-inflammatory and antioxidant effects. In addition, this vegetable is a natural source of anthocyanins and other phytonutrients, it has stood out as a promising candidate to be incorporated into slimming diets. [15]

The analysis of the literature allows us to know the impact of anthocyanins on weight loss and improvement in metabolic health, reports heterogeneous results. Some studies argue that those foods that have this component lead to reducing body measurements and minimizing inflammation, others indicate that consumption does not generate a significant impact on daily calorie intake or lifestyle changes. However, they agree that foods

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

containing anthocyanins have properties that regulate metabolism and antioxidants. [16]

The anthocyanin found in purple cabbage regulates energy metabolism, because the AMP-activated protein kinase (AMPK) is an enzyme that generates a cellular energy balance that oxidizes fatty acids and minimizes lipids, although these are not always associated with weight loss. On the other hand, this compound influences the receptor activated by gamma peroxisome proliferators (PPAR-y), which is the cause of adipose tissue storage, which shows a regulatory effect on lipid metabolism. [17] [18]
In addition, anthocyanin is relevant to antioxidant activities because it reduces oxidative stress and chronic inflammation in the body that goes hand in hand with insulin resistance and is reflected in obesity. So this component of purple cabbage is part of the reactive oxygen species and regulates metabolism, accesses glycemic control with the activation of AMPK.Es necessary to consider the methods of consumption, dosage and characteristics of the population. [19]

In human studies, it has been proven that anthocyanins are one of the compounds in purple cabbage, which provides the necessary nutrients to achieve satiety and weight loss. However, its stability is limited to its stability, which is affected by temperature, because high temperatures generate degradation, that is, the loss of color and minimize its antioxidant properties. Therefore, the way it is cooked has a significant impact, therefore, it is recommended to consume this food steamed or sautéed to preserve its nutrients. In the case of consuming savory cabbage with vinegar or lemon dressing, it allows it to maintain its intense tones and greater stability. [20]
However, despite the fact that there are functional foods that reduce obesity through the nutrients of vegetables, as is the case of purple cabbage, which is supported by some studies where the presence of bioactive compounds is identified, there is still a scarcity of research applied to specific cases where the impact of dietary programs aimed at a specific segment of the population with obesity is analyzed. It supports the need to develop detailed studies that allow an accurate evaluation of the effects of cabbage consumption based on the consideration of anthropometric and metabolic indicators that contribute to evidence the potential of this food as a natural and functional nutritional strategy for weight control.

This research aims to evaluate the effectiveness of slimming diets made from purple cabbage in people with obesity from the Cleotilde Guerrero Foundation O in the city of Guayaquil. Specifically, the variation in body weight (kg) with the nutritional intervention based on the consumption of purple cabbage was determined, the change in the body mass index (BMI) in the morbidly obese population was assessed with the application of the nutritional plan, and the reduction of abdominal circumference (cm) was associated with the reduction of body fat.

In this context, the present study, carried out at the Cleotilde Guerrero O Foundation, aims to address this gap in knowledge. Through a carefully designed research design, the effectiveness of slimming diets made from purple cabbage in people with excess obesity will be evaluated. The results of this study are expected to provide insight into the usefulness of purple cabbage as a dietary component in the management of obesity and its potential benefits for metabolic health. Research in this area has the potential to offer more effective and personalized strategies to address the growing obesity epidemic and its consequences for public health and people's quality of life

This research is justified based on methodological feasibility due to the scientific contribution made in the field of nutrition and functional foods. anti-inflammatory processes generating visible and significant improvements in health indicators. [21]

In the specific case of developing research in Cleotilde Guerrero O, which frequently presents people with obesity problems, it entails implementing periodic monitoring of the participants and obtaining relevant information that in its analysis allows understanding the effects of the nutritional intervention. Likewise, to provide empirical evidence about the potential of vegetables in slimming diets and to integrate knowledge in nutrition, gastronomy and chemical engineering to highlight the functional properties of foods and their application in programs that promote health.

2.- Materials and methods.

The research was carried out through a quantitative approach and a longitudinal quasi-experimental design with pre-test-post-test measurements, in order to evaluate the effects of the purple cabbage-based slimming diet considering people with obesity. This design allows us to know the changes that occur in certain aspects, before and after the nutritional intervention in order to compare the results obtained at different times during the research process. It is important to note that the study is carried out in the context of a nutritional support program, aimed at people who are obese, therefore, healthy food strategies were implemented, such as the consumption of natural foods that have a functional potential.

This study was carried out as a pre-test-post-test clinical trial without a control group to investigate the effectiveness of slimming diets made from purple cabbage in people with obesity: a study carried out at the Cleotilde Guerrero O Foundation, with a study population were selected from those who sought medical attention at the Sra. Cleotilde Guerrero O Foundation in the Isla Trinitaria sector, Guayaquil corresponds to 50 adults, mostly diagnosed with morbid obesity, aged between 30 and 65 years. However, the sample to carry out the intervention was reduced to 15 people, due to aspects such as: voluntary abandonment of

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

the process, non-attendance at controls and non-compliance with the inclusion criteria that refer to non-compliance with the meal plan. In such a way, a probabilistic sample was considered for convenience.
It should be noted that the sample was not calculated formally, which generates limitations in the conduct of the study and may affect the representativeness of the results and their generalization.

The inclusion criteria allowed considering adults who currently have a diagnosis of obesity according to the body mass index, According to the parameters established by international health organizations in adults, it corresponds to values equal to or greater than 30 kg/m². To the same extent, fundamental ethical aspects are taken into consideration, informed consent for the performance of the evaluations scheduled in the intervention periods, and the confidentiality of the data obtained. In the characterization of the sample, demographic variables were considered, such as age and gender of the participants, which allowed an analysis to be carried out based on the distribution according to the age group to know the influence on metabolic behavior and the response of the organisms to the nutritional intervention aimed at losing body weight.

Anthropometric variables were considered, which allow evidence of the nutritional status and body composition of the participants, such as body weight, height, body mass index and abdominal circumference using balanced digital scales with a capacity of up to 150 kg and accuracy equal to or greater than 0.1 kg in order to guarantee the accuracy of the values obtained. the same that were obtained in the morning hours using light clothing. Meanwhile, the height was obtained through a height meter with an accuracy equal to or greater than 0.1 cm where the participants were placed in an upright position and with their feet together, as part of the protocols for anthropometric measurements to be classified in a category:

Table 1 Body mass index

IMC MIN	IMC MAX	Category	Nutritional Diagnosis
0	18,49	Low weight	---
18,5	24,99	Normal	Q---
25	29,99	Overweight	---
30	34,99	Mild Obesity	1
35	35,99	Medium Obesity	2
40	From now on	Morbid Obesity	3

Source: Data obtained from Vinueza et al., 2023 .[22]

The values obtained in the measurement of weights and heights allowed the calculation of the body mass index, which is one of the indicators used to determine the nutritional status in adults, for which the relationship of weight in kilograms and the square of height expressed in meters was considered, as shown in the equation:
BMI = weight (kg)/ height² (m²) (1) ,. [23] [24]

The abdominal circumference was obtained with the help of a flexible anthropometric tape measure that is placed in the abdominal region at the level of the navel where the participants are standing and breathing normally. This variable is important because it is one of the indicators that allows evidence of the accumulation of abdominal fat associated with a significant risk of metabolic and cardiovascular diseases. The procedure was carried out considering several moments of assessment. The first control was carried out in August where the demographic, anthropometric and laboratory variables referred to in the initial measurement are recorded.

After the collection of information, the nutritional plan based on purple cabbage was designed, it is prepared considering data such as weighing and measurement considering that it is mostly corresponding to an older adult population, where other foods such as: carbohydrates, vegetables, fats and fruits are combined to achieve a balance in the daily diet. However, the protagonist is red cabbage in various presentations, raw in salad or steamed, sautéed, creams and soups integrated into lunch and snacks that corresponds to a daily consumption of 150gr – 250gr/day that refers to one or two cups that provide the fiber that the body requires for optimal digestion, it generates satiety and favors the caloric deficit that it requires to reduce measures.

Table 2 Purple cabbage-based nutritional plan

	Breakfast	Mid-morning	Lunch	Mid-afternoon	Snack
Monday	1 cup oatmeal in water 4 pieces of papaya	1 green apple	60gr of grilled chicken1 cup of red coleslaw 1/2 cup of brown rice	1 x 250ml glass plain yogurt	250 ml red cabbage cream1 Cooking egg
Tuesday	1 cooked egg2 slices whole-grain toasted bread1 cup tea	1 pear	60 gr of grilled or steamed fish2 cup of red cabbage with lemon dressing.1 small potato, cooked.	1 cup tea 2 wholemeal crackers	1 cup of purple coleslaw60 gr of tuna in water
Wednesday	1 cup cooked lentils1 cup red coleslaw.	1 small banana	1 cup cooked lentils1 cup red coleslaw.	1 green apple	1 cup red cabbage1 cup shredded chicken cooked in water.

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

Thursday	60 gr of stewed meat1 cup of red cabbage	1 orange	60 gr of stewed meat1 cup of red cabbage	1 cup of yogurt	250 ml red cabbage soup with vegetables
Friday	250 ml red cabbage cream	4 pieces of papaya	60 gr of tuna in water1 cup of purple coleslaw1 cup of brown rice	1 cup tea2 Whole-grain crackers	250 ml red cabbage cream
Saturday	1 cup red cabbage salad1 scrambled egg	1 green apple	60 gr of stewed chicken1 cup of red cabbage1 small cooked potato	1 cup chamomile tea	1 cup red cabbage salad1 scrambled egg
Sunday	1 cup oatmeal in water1 small banana	4 pieces of melon	60 gr of baked fish1 cup of red cabbage1 cup of brown rice	1 cup of yogurt	250 ml red cabbage soup with vegetables,

Source: This nutritional plan is adapted to the needs of the participants of the Cleotilde Guerrero O Foundation, which is kept under pressure and glucose monitoring. The duration is 4 weeks, so it is suggested that in week 2 – 4 the participant can continue with the same sequence, or vary the days without repeating the same days during the week.

Additionally, necessary eating habits such as portion control and consumption of natural foods were generally recommended to achieve greater adherence of the participants to the established diet. The second assessment will be carried out in September to record updated information regarding anthropometric and laboratory variables, which allow comparison with the results obtained at the beginning and to know the variation between before and after the implementation of the diet based on the consumption of purple cabbage. This will allow us to know if changes were obtained in terms of body weight, body mass index, abdominal circumference.

Although the consumption of the foods established in the nutritional plan is carried out, where the daily consumption of purple cabbage is emphasized, there was no strict control of the daily caloric intake of the participants, nor a detailed record of the macronutrients, the intervention emphasizes the integration of cabbage as a functional food in a balanced diet. Therefore, the results obtained can not only be influenced by the consumption of this vegetable but also by the total energy consumption.

The reliability of the anthropometric measurements: standardized procedures were carried out to carry out the process of reconnecting information, that is, before carrying out the measurement, the equipment that would be used to carry out the activities was verified and calibrated. On the other hand, the participants were evaluated under similar conditions. That is, considering similar schedules in the control sessions to avoid alterations in the results, as well as the immediate intake of food or the performance of some intense physical activity that may affect the evaluation.
It is important to note that the measurements were carried out with the help of personnel trained in the area and following the relevant protocols for anthropometric studies in adult participants in order to reduce errors in the measurement and ensure that the data collected are consistent in the different phases.

The data obtained were recorded in a database with the help of the Microsoft Excel office automation tool to initially process the information collected, the review and purification of the recorded data was carried out before carrying out the statistical processing, The class classification of the information according to the demographic and anthropometric variables in order to facilitate the analysis and interpretation of them, this allowed the information to be structured in an orderly and systematic manner.
Next, a statistical analysis was carried out in Microsoft Excel where descriptive statistics were considered for the analysis of demographic and anthropometric variables to compare the values obtained initially and finally to make a diagnosis and identify changes in the evaluated indicators. The limited duration of the study was recognised as a possible limitation and the need for long-term follow-up to better understand the effects of slimming diets made from purple cabbage.

The ethical considerations that were taken into account for the collection of information and development of this research process are framed in the ethical principles established for research with the help of human beings, where those who participate were informed about the objectives and steps to be developed, they agreed to participate voluntarily, in addition the confidentiality of the data obtained was guaranteed, which will be used for scientific and academic purposes. To the same extent, the Cleotilde Guerrero O Foundation authorized the study to be carried out at its facilities

3.- Results.

The results obtained considered demographic, anthropometric and biochemical variables, carried out with the help of the participants of the Cleotilde Guerrero Foundation. The sample was made up of 15 people who mostly have obesity problems and participated in the first assessment corresponding to August 31, 2023 in the morning, which led to obtaining the following information:

Table 3 Initial evaluation of participants

Partic.	Age	Date of Birth Y-MM-DD	Weight (Kg)	Size (Mts)	Waist circumference (cms)
P1	57	1965-07-18	87,70	1,56	108,00
P2	32	1990-01-06	74,84	1,41	102,00
P3	40	1981-12-20	84,37	1,54	104,00

INQUIDE
Chemical Engineering & Development
Journal of Science and Engineering
Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

Partic.	Age	Date of Birth Y-MM-DD	Weigh t (Kg)	Size (Mts)	Waist circumfere nce (cms)
P4	51	1971-07-30	81,64	1,43	102,00
P5	56	1966-08-12	81,65	1,51	98,00
P6	48	1973-12-12	75,75	1,53	96,00
P7	62	1960-05-21	84,75	1,70	107,00
P8	63	1959-07-20	70,76	1,59	88,00
P9	56	1965-11-28	56,70	1,41	94,00
P10	48	1973-10-17	86,50	1,43	114,00
P11	27	1995-06-02	67,10	1,48	81,00
P12	25	1998-05-22	93,89	1,59	105,00
P13	53	1970-11-27	57,60	1,55	108,00
P14	52	1963-04-18	63,50	1,50	88,00
P15	52	1971-04-07	100,24	1,48	107,00

Source: data obtained during the sizing and weighing of the participants of the Cleotilde Guerrero O Foundation, dated August 31, 2023.

The database specifies the values obtained during the initial data collection process such as: age, date of birth, sex, weight, height and abdominal measurements of each of the participants. The same ones that allowed us to generate a comprehensive vision of the conditions in which the patients of this foundation were before the implementation of the purple cabbage in their daily food plan. It was found that 93.33% of the participants correspond to the female gender, ranging from 27 to 63 years of age, so it corresponds to people who are in the adult age group.

Anthropometric variables were contrasted with the Body Mass Index (BMI) for adults between 18 and 75 years of age, to determine the type of nutritional intervention accompanied by physical activity required by the participants, shown below:

Table 4 assessment and diagnosis of the needs of the participants

#	IMC	NUTRITIONAL	DIET	PHYSICAL
1	56,218	Morbid obesity	Hypocaloric	Requires
2	53,078	Morbid obesity	Hypocaloric	Requires
3	54,786	Morbid obesity	Hypocaloric	Requires
4	57,091	Morbid obesity	Hypocaloric	Requires
5	54,073	Morbid obesity	Hypocaloric	Requires
6	49,510	Morbid obesity	Hypocaloric	Requires
7	49,853	Morbid obesity	Hypocaloric	Requires
8	44,503	Morbid obesity	Hypocaloric	Requires
9	40,213	Morbid obesity	Hypocaloric	Requires
10	60,490	Morbid obesity	Hypocaloric	Requires
11	45,338	Morbid obesity	Hypocaloric	Requires
12	59,050	Morbid obesity	Hypocaloric	Requires
13	37,161	Morbid obesity	Hypocaloric	Requires
14	42,333	Morbid obesity	Hypocaloric	Requires
15	67,730	Morbid obesity	Hypocaloric	Requires

Source: Diagnosis made from BMI in contrast to the heights and weights obtained from the participants of the Cleotilde Guerrero Foundation

100% have type III obesity or morbid obesity because their BMI > 40.21. Therefore, they present problems with type II diabetes, cardiovascular problems, high blood pressure, joint pain and metabolic syndromes. Therefore, the information found made it possible to establish a timeline that will later be used to compare the results once the intervention of the purple cabbage-based diet has been applied. Subsequently, the second evaluation was carried out considering the same aspects, schedule and conditions similar to the previous one, on September 29, 2023 after the intervention with the diet based on purple cabbage, the values obtained include:

Table 5 Second evaluation of the participants

Partic.	Age	Date of BirthA-MM-DD	Weight (Kg)	Size (Mts)	Waist circumfer ence (cms)
P1	57	1965-07-18	87,70	1,56	105,00
P2	32	1990-01-06	74,84	1,41	92,00
P3	40	1981-12-20	84,37	1,54	103,00
P4	51	1971-07-30	81,64	1,43	104,00
P5	56	1966-08-12	81,65	1,51	96,00
P6	48	1973-12-12	75,75	1,53	92,00
P7	62	1960-05-21	84,75	1,70	104,00
P8	63	1959-07-20	70,76	1,59	85,00
P9	56	1965-11-28	56,70	1,41	86,00
P10	48	1973-10-17	86,50	1,43	110,00
P11	27	1995-06-02	67,10	1,48	79,00
P12	25	1998-05-22	93,89	1,59	96,00
P13	53	1970-11-27	57,60	1,55	105,00
P14	52	1963-04-18	63,50	1,50	81,00
P15	52	1971-04-07	100,24	1,48	112,00

Source: data obtained during the sizing and weighing of the participants of the Cleotilde Guerrero O Foundation, dated September 29, 2023.

Once the intervention is performed with the purple cabbage-based nutritional plan in 4 weeks, they represent significant changes that are shown in weight and abdominal circumference, as shown below:

Table 6 Variation in weight (KG) and abdominal circumference (cm)

	WEIGHT			WAIST CIRCUMFERENCE		
	Initial	Final	Variation (kg)	Initial	Final	Variation (cm)
P1	87,70	82,00	-5,70	108	105	3
P2	74,84	74,00	-0,84	102	92	10
P3	84,37	87,00	2,63	104	103	1
P4	81,64	83,00	1,36	102	104	-2
P5	81,65	81,00	-0,65	98	96	2
P6	75,75	74,00	-1,75	96	92	4
P7	84,75	82,00	-2,75	107	104	3
P8	70,76	69,00	-1,76	88	85	3
P9	56,70	58,00	1,30	94	86	8
P10	86,50	84,00	-2,50	114	110	4
P11	67,10	65,00	-2,10	81	79	2
P12	93,89	85,00	-8,89	105	96	9
P13	57,60	85,00	27,40	108	105	3
P14	63,50	65,00	1,50	88	81	7
P15	100,24	81,00	-19,24	107	112	-5

Source: The data were obtained from the weighing of the participants and processes with the help of the Microsoft Excel tool, using the formula, variation (weight or final perimeter – initial perimeter weight).

Fig. 1 shows the variations obtained in the 15 participants after the intervention of the nutritional plan, which shows a general trend towards a reduction in weight and abdominal circumference of the participants, where a greater decrease in measurements in the abdominal circumference variable is observed.

INQUIDE
Chemical Engineering & Development
Journal of Science and Engineering
Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

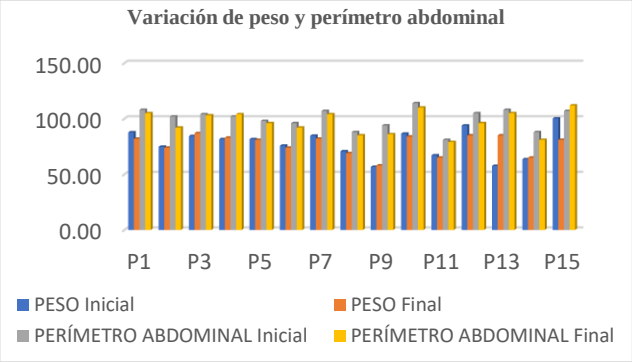


Fig. 1 Weight variations (Kg)

To the same extent, the presentation of the data in this matrix facilitated statistical processing to know the trends at the beginning and after the intervention with the purple cabbage-based diet, based on the weight of the participants according to their sex, as well as the abdominal circumference that shows the changes by comparing the measures obtained and determining the impact of the changes observed in the the participants of the Cleotilde Guerrero Foundation O:

Table 7 statistical analysis of anthropometric variables

	Weight	Perimeter
Media	-0,80	-3,47
Standard Deviation (SD)	9,490946413	3,96
95% confidence interval (CI)	2,450551826	1,022912121
Cohen's	-0,084220614	-0,875040452

Source: data obtained using Microsoft Excel formulas = average (participant weight or perimeter difference 1: participant weight difference or perimeter 15), = DESVEST. M(difference in weight or participant perimeter 1: difference in weight or participant perimeter 15), =DESVEST. M(difference in weight or perimeter participant 1: difference in weight or perimeter participant 15) /ROOT(#PARTICIPANTES)), =MEAN difference in weight or perimeter/STANDARD deviation weight or perimeter.

A reduction in the body weight of the participants of the Cleotilde Guerrero O Foundation was found, with a mean difference of 0.80kg± 9.49. This decrease shows high variability among participants. The 95% confidence interval (CI) was approximately -3.25 to 1.65 kg, which shows that this change is inconclusive. To the same extent, the effect size calculated through the Cohen's statistic was d=0.08, which refers to a very small effect.

On the other hand, the abdominal circumference shows a decrease in the mean from -3.47 cm ± 3.96 cm, which shows a tendency to reduce measurements more consistently. The 95% confidence interval (CI) obtained ranges from -4.49 to -2.45 cm, which suggests greater precision in the estimation. While the effect size was d= -0.88, which shows a large effect and refers to a relevant impact on the nutritional intervention.

On the other hand, to determine the difference in the evaluated group is real or random, it is pertinent to perform a Student t-test for related samples, where the following was obtained:

Table 8 t-test for related samples

	Weight		Waist circumference	
Media	77,0921429	76,6428571	99,5714286	96,0714286
Variance	168,223695	84,5549451	85,3406593	113,60989
Observations	14	14	14	14
Pearson's correlation coefficient	0,66134596		#N/A	
Hypothetical difference of the means	0		0	
Degrees of freedom	13		13	
Statistic t	0,17244928		3,18703238	
P(T<=t) a cola	0,43287007		0,00357186	
Critical value of t (one tail)	1,7709334		1,7709334	
P(T<=t) dos colas	0,86574014		0,00714372	
Critical t value (of colas)	2,16036866		2,16036866	

Source: Data obtained using Microsoft Excel, data, t-test for means of two paired samples.

The results obtained in the analysis of descriptive data, specifically the *Student t-test* for related samples, allow us to determine that body weight refers to a value of 0.86. That is, it does not represent a significant difference (p>0.05). On the other hand, the abdominal circumference refers to a result of 0.007 that shows a significant reduction, and leads to associate nutritional intervention with the decrease in adipose tissue.

4.- Discussion

The research carried out shows the variations in the anthropometric aspects of the participants after the nutritional intervention based on purple cabbage. Changes related to the variable weight and abdominal circumference were observed, which refer to significant indicators in the assessment carried out to achieve weight reduction in individuals with obesity. The results could indicate that foods that present bioactive compounds in a food plan proposed by professionals in the area and according to individual needs allow improving the parameters related to excess weight. Some studies suggest that diets where vegetables that have antioxidant compounds and fiber are used generate a loss of body weight due to the satiety that it causes and contributes to accelerating metabolism. [25][26]

The results are aligned with the fulfillment of the proposed objective, which includes analyzing the effectiveness of the purple cabbage-based slimming diet at the Cleotilde Guerrero O Foundation. So, the vegetable with a purple hue can contribute to weight loss, due to its high content of antioxidants, such as anthocyanins and flavonoids, which have beneficial effects on metabolism and fat burning. In addition, its high dietary fiber content can promote satiety and reduce total caloric intake. The consumption of this food is recommended to reduce obesity and overweight. In

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

addition, prevent diseases derived from excess body fat. [27][28] [29]

The findings are consistent with previous research that could indicate that the consumption of vegetables as a functional food proposal based on natural products can be considered in the hypocaloric diet to reduce adiposity in the body and in recent years has been part of the strategies of nutrition specialists to prevent chronic diseases. In particular, the bioactive compounds that emerge from the Brassica family affect the physiological process and control the weight of individuals. [30]

The descriptive statistical analysis leads to identify the behavior of the anthropometric variables that were assessed in the participants with the measurements made for their effect, the processing of the information through Microsoft Excel was considered and the calculation of the central trends and dispersions that refer to: the mean, standard deviation, minimum and maximum values of aspects such as body weight, height and abdominal circumference. The results show high values of body mass index in all participants, which are higher than 40 kg/m², which suggests a type 3 obesity work, according to the criteria indicated by *la World Health Organization* it is also considered morbidly obese. When cases of severe obesity were found in those attending the Cleotilde Guerrero O Foundation, the need to consider the application of a nutritional intervention aimed at weight reduction and control was highlighted. Consequently, the descriptive analysis shows a positive impact due to the dietary intervention based on Purple Cabbage. [31]

The analysis is comparative of the results obtained, suggesting that the consumption of vegetables that present phenolic compounds can contribute to the reduction of the indicators associated with obesity, which due to oxidative stress has generated a prominent adipose tissue. Although most of the studies carried out have been carried out in generalized settings, there is limited evidence that supports the feasibility of dietary interventions in a specific population. [32]

Therefore, the findings support the premise about the health benefits, due to weight loss, consuming purple cabbage may provide additional health benefits, such as reducing the risk of cardiovascular disease and improving digestive health due to its antioxidant and fiber content. To the same extent, it causes better self-esteem and minimizes depressive traits. [33]

Long-term sustainability, it is important to note that, although this study shows promising results, further research needs to be strengthened to determine the long-term sustainability of purple cabbage-based slimming diets. Adherence to this type of diet over time and its long-term effects can significantly reduce obesity and overweight statistics globally.

On the other hand, other aspects that were considered to achieve a favorable impact on weight loss were personalization and supervision, is vitally relevant, although purple cabbage can be beneficial in weight loss, it is crucial to keep in mind the importance of diet personalization and medical supervision. Nutritional needs can vary between individuals, and it is essential to adapt slimming diets according to the specific characteristics and requirements of each person. [34] [35]

The study allowed an analysis of the impact of purple cabbage-based diets to be carried out on a group of participants from the Cleotilde Guerrero O Foundation, where anthropometric variables such as body weight, body mass index height and abdominal circumference were considered. Thus, through the analysis of the data collected in the intervention period, it was identified that some indicators present problems, specifically weight and abdominal circumference. Factors that supported the integration of nutritious foods in a meal plan that allows weight control in people who are obese.

In addition, the nutritional plan was accompanied by the recommendation to perform physical activity of approximately 30 minutes a day, for example, walking, running, climbing stairs which are basic exercises recommended for people who are in the intervened age group, the same who access a caloric expenditure between 120 – 200 kcal per session performed. However, a detailed or quantified control of compliance with this suggested parameter was not carried out. Therefore, it is not possible to specify the influence of physical activities on the results obtained. Therefore, this may have acted as a confounding variable influencing weight reduction.
The results are aligned with the objective of the study aimed at evaluating the benefits of purple cabbage as a nutritional strategy to reduce measures. However, the data obtained are not generalizable to the entire population because they constitute exploratory evidence in a community context. The research carried out allows to minimize the gap in the literature by carrying out an analysis of the application of a diet based on purple cabbage considering a specific and real context to implement an innovative and low-cost nutritional proposal. From the perspective of chemical engineering applied to gastronomy, the research accesses the interpretation of the chemical composition of food and associating it with the impact of consumption on human health. Thus, the presence of active compounds in plants corresponds to a necessary and relevant line of research for the design of food strategies that are aimed at improving the quality of life of individuals regardless of their age. [36]

It is pertinent to recognize that the limitations for the development of the study must be considered in order to interpret the data obtained. In other words, the intervention carried out corresponds to a short period of implementation and assessment, which affects the evaluation of the long-

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

term effects and the determination of the benefits of the diet in relation to health indicators. In addition, the daily eating habits, physical activity index and other characteristics presented by the participants can affect the response to the nutritional intervention carried out and generate changes in the results. In addition, the daily eating habits, the physical activity index and other characteristics presented by the participants can affect the response to the nutritional intervention carried out and generate changes in the results observed. [37] [38]

In future research, a greater number of variable participants and periods should be considered to monitor and determine long-term changes. The results found reinforce the idea of the importance of promoting the consumption of natural foods that present bioactive compounds, as a strategy to encourage a balanced and healthy diet. In such a way, the information obtained from nutrition, gastronomy, chemical engineering allows the generation of innovative proposals based on scientific evidence [39]

By addressing the level of adherence and compliance with the diet by the participants. The effects on health and weight loss, which is important to establish the possible effects of purple cabbage-based slimming diets on the general health of the participants in which improvements in health markers such as blood glucose levels, blood lipids or blood pressure were observed, The results reported adverse effects associated with the consumption of purple cabbage.

It should be noted that the results obtained are not generalizable to the entire adult or elderly population with obesity 3 or morbid, since the sample size is small and was selected for convenience. However, the information presented shows important data in a community context where it is not frequently explored. Therefore, it can be classified as exploratory because it leads to the identification of the changes that can be associated with the implementation of a nutritional plan based on purple cabbage. So that it can serve as a basis for new research with a more representative design to verify the findings obtained.

5.- Conclusion.

The study provides scientific support for the relevance of natural foods that have functional properties in the context of nutrition. The colorada, due to its high level of nutrients, bioactive compounds and dietary fiber, is a vegetable with the potential to be implemented in healthy eating programs aimed at any sector of the population that has problems of overweight or obesity. By virtue of what has been found, it can be specified that research contributes significantly to expanding knowledge about food use. In nutritional interventions.

The link that exists by integrating nutrition, gastronomy, chemical engineering for the analysis of food and the benefits in human health, which allows structuring food strategies that improve the quality of life of the population.

From a practical point of view, the results collected show that purple cabbage is a vegetable that can be implemented in a nutritional intervention program not only for people with obesity but also for those who have weight control problems to minimize the existence of diseases in the future. However, it is important to note that slimming diets must be designed based on a personalized diagnosis where there is enough information to determine if the consumption of daily food is adequate considering factors such as age, health and metabolic characteristics.

Finally, it is recommended that in future research the study population be expanded, as well as the intervention periods and even integrate other variables that allow a more accurate evaluation, for example, considering biochemical and metabolic indicators that serve as a complement to the anthropometric evaluation and allow optimizing the implementation of balanced eating strategies.

6.- Contributions of the authors (Taxonomy of roles of collaborators - Credit)

1. Conceptualization: Marina Arteaga Peñafiel
2. Data curation: Katherine Zavala Villavicencio
3. Formal analysis: Alex Villao Villacrés
4. Acquisition of funds: Arelys Sornoza Arteaga
5. Research: Ricardo Quimis Mantuano & Marina Arteaga Peñafiel
6. Methodology: Katherine Zavala Villavicencio
7. Project management: Alex Villao Villacrés
8. Resources: Arellys Sornoza Arteaga
9. Software: Alex Villao Villacrés
10. Supervision: Marina Arteaga Peñafiel
11. Validation: Katherine Zavala Villavicencio
12. Visualization: Katherine Zavala Villavicencio
13. Writing - original draft: Mirian Villavicencio Párraga.
14. Writing - revision and editing: Mirian Villavicencio Párraga.

7.-References.

[1] C. D. Sánchez, "The stigma of obesity and its impact on health: a narrative review," *Endocrinology, Diabetes and Nutrition*, vol. 69, no. 10, pp. 868-877, 2022. https://doi.org/10.1016/j.endinu.2021.12.002

[2] Y. A. González and D. D. L. Vega, "Effectiveness of physical activity in the prevention and treatment of obesity: a review of the literature," *Digital Journal: Physical Activity and Sport*, vol. 10, no. 1, 2023. https://doi.org/10.31910/rdafd.v10.n1.2024.2516

[3] S. R. León and C. B. E. Jiménez, Obesity: causal attribution and stigmatization, Mexico City: UNAM, Faculty of Psychology, 2025.

[4] D. Micic, S. Polovina and V. Yumuk, "A Brief History of Obesity," *Acta Endocrinòlogica*

(Bucharest), vol. 20, no. 2, pp. 207-211, 2024. https://doi.org/10.4183/aeb.2024.207

[5] World Health Organization, "Obesity and Overweight," World Health Organization, 08 December 2025. [Online]. Available: https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight. [Accessed 03 March 2026].

[6] Pan American Health Organization, "World Obesity Day: A Global Challenge - PAHO/WHO | Pan American Health Organization," Pan American Health Organization, 03 March 2025. [Online]. Available: https://www.paho.org/es/noticias/3-3-2025-dia-mundial-obesidad-desafio-global. [Accessed 05 March 2026].

[7] Global Nutrition Report, "Global Nutrition Report | Country Nutrition Profiles - Global Nutrition Report,» Global Nutrition Report, 2025. [Online]. Available: https://globalnutritionreport.org/resources/nutrition-profiles/latin-america-and-caribbean/south-america/ecuador/. [Accessed 05 March 2026].

[8] S. A. Ramirez, C. G. P. Benavides, B. J. D. Guacho and U. J. R. Planta, "Obesity in older adults, risks and consequences," *RECIAMUC*, vol. 6, no. 1, pp. 319-331, 2022. https://doi.org/10.26820/reciamuc/6.(1).January.2022.319-331

[9] J. Joseph, V. Pradeep y Nisha, «Impact of an Information, Education, and Communication Package on Knowledge, Attitude and Quality of Life Regarding Obesity Among College Students in Kerala: A Mixed-Methods Study,» *Social Medicine*, vol. 19, nº 1, pp. 80-89, 2026. https://doi.org/10.71164/socialmedicine.v19i1.2026.2123

[10] M. San Martín, Healthy Transformation: Facing Obesity with a Personalized Method to Lose Weight, Buenos Aires: Tercero en discordia, 2025.

[11] F. Arrieta and P. Botet, «Recognizing obesity as a disease: a challenge,» *Revista Clínica Española*, vol. 221, nº 9, pp. 544-546, 2021. https://doi.org/10.1016/j.rce.2020.08.003.

[12] B. Carpenter, Healthy Habits for Weight Loss, Buenos Aires: Uranus, 2026.

[13] J. V. L. Montoya and C. D. A. Robles, "Anthropometric indices as predictors of obesity and metabolic risk in adolescents from Loja," *Scientific Journal of Health Sciences*, vol. 16, no. 2, pp. 52-60, 2023. https://doi.org/10.17162/rccs.v16i2.2021

[14] G. Mimbrero, Change your habits: Nutrition to prevent disease and live better, RBA Books and Publications, 2022.

[15] G. Vázquez, M. Piloni, L. A. Quintero, S. Soto and L. J. Ocampo, «Physicochemical evaluation of purple cabbage flour (Brassica oleracea var. capitata f. rubra) for alternative uses," *Research and Development in Food Science and Technology*, vol. 8, no. 1, pp. 222-229, 2023. https://doi.org/10.29105/idcyta.v8i1.31

[16] X. Ma, Z. Jin, Z. Rao, and L. Zheng, "Health Benefits of Anthocyanins Against Age-Related Diseases," *Frontal Nutrition*, vol. 12, p. 1618072, 2025. https://doi.org/10.3389/fnut.2025.1618072

[17] A. Escalante, C. Mendoza, G. Mahady, V. D. Luna, U. Gutierrez, and H. Chuck, "Dietary anthocyanin consumption and its association with a reduction in obesity biomarkers and obesity prevention." *Trends in food science and technology*, vol. 140, pp. 1-15, 2023. https://doi.org/10.1016/j.tifs.2023.104140

[18] T. Belwal, S. Fazel Nabavi, N. S. Mohammad, and S. Habtemariam, "Dietary anthocyanins and insulin resistance: when food becomes medicine," *Nutrients*, vol. 9, no. 10, pp. 1-22, 2017. https://doi.org/10.3390/nu9101111

[19] E. G. M. Villagrán, L. Li, W. Cheng, Z. Li, Q. Gao, J. sol and L. Hao, "Anthocyanins: a comprehensive review of their chemical properties and health impacts on glucose metabolism in gestational diabetes mellitus.", *Food, nutrition and health*, vol. 2, no. 28, pp. 1-16, 2025. https://doi.org/10.1007/s44403-025-00041-0

[20] J. Nuszkiewicz, J. Wróblewska, M. Wróblewski, and A. Woźniak, "Anthocyanin-rich purple plant foods: bioavailability, antioxidant mechanisms, and roles in redox regulation and recovery after exercise," *Nutrients*, vol. 17, no. 15, p. 2453, 2025. https://doi.org/10.3390/nu17152453

[21] E. Jean Wilson, N. Sirpu Natesh, P. Ghadermazi, D. R. Pothuraju, S. Pandey, J. T. Kaifi, J. R. Dodam, J. N. Bryan, C. L. Lorson, A. A. Watrelot, T. J. Joshua Chan, J. M. Foster, S. K. Batra, and Rachagan, "Red cabbage juice-mediated modulation of the gut microbiota improves intestinal epithelial homeostasis and relieves colitis., » *International Journal of Molecular Sciences*, vol. 25, no. 1, p. 539, 2023. https://doi.org/10.3390/ijms25010539

[22] A. F. Vinueza Veloz, E. C. Tapia Veloz, G. Tapia Veloz, M. Nicolalde Cifuentes and V. Carpio Arias, «Nutritional status of Ecuadorian adults and its distribution according to sociodemographic characteristics. Cross-sectional study," *Hospital Nutrition*, 2022. https://doi.org/10.20960/nh.04083

[23] A. Quetelet, «Social Physics or Essay on Man and the Development of His Faculties,» *REIS: Revista Española de Investigaciones Sociológicas*, vol. 87, pp. 305-324, 1999. https://dialnet.unirioja.es/servlet/articulo?codigo=759343

[24] G. Bauce, "Two formulas to calculate BMI, and its relationship with others," *Revista Digital de*

Postgrado, vol. 11, no. 1, pp. 11-11, 2021. https://doi.org/10.56183/iberojhr.v4i2.683

[25] S. Aucancela Sánchez, "Characterization of bioactive peptides derived from plant proteins and their antioxidant effect in functional foods in Ecuador," *Ibero-American Journal of Health Science Research*, vol. 4, no. 2, pp. 270-277, 2024. https://doi.org/10.56183/iberojhr.v4i2.683

[26] S. J. Espinoza, "Fiber as a satiety agent to combat obesity in children," *Polo del Conocimiento*, vol. 9, no. 10, pp. 631-646, 2024. https://doi.org/10.23857/pc.v8i5.5564

[27] O. Statilko, T. Tsiaka, V. J. Sinanoglou and I. F. Strati, 'Overview of the phytochemical composition of cultivars of Brassica oleraceae var . capitata," *Foods*, vol. 13, no. 21, 2024. https://doi.org/10.3390/foods13213395

[28] S. Laoutari, E. Christodoulou, and A. E. Koutelidakis, "A Narrative Review of the Mediterranean Lifestyle and Its Role in the Prevention and Management of Obesity," *Obesity*, Vol. 5, No. 2, 2025. https://doi.org/10.3390/obesities5020043

[29] N. Randeni, J. Luo, and B. Xu, "Critical Review of the Anti-Obesity Effects of Anthocyanins via PI3K/Akt Signaling Pathways," *Nutrients*, Vol. 17, No. 7, p. 1126, 2025. https://doi.org/10.3390/nu17071126

[30] M. Enrìquez, F. Villafuerte, and A. Figueroa, "Effects of bioactive components of fruits, vegetables, dairy, and medicinal plants on human nutrition," *ALLPA Journal of Agricultural Sciences*, vol. 6, no. 11, pp. 2-24, 2023. https://doi.org/10.56124/allpa.v6i11.0055

[31] M. Kaufer-Horwitz and J. F. Pérez Hernández, "Obesity: pathophysiological and clinical aspects," *Interdisciplinario*, vol. 10, no. 26, p. 147, 2022. https://doi.org/10.22201/ceiich.24485705e.2022.26.80973

[32] C. Porca Fernández, A. Calleja Fernández, L. Dalla-Rovese, A. Elbusto, P. Urones, M. García, M. Comas, O. Monasterio Jiménez, D. Novo and E. Sánchez, «Positioning 2024 of the SEEDO Dietary Guidelines (Spanish Society for the Study of Obesity),» *Hospital Nutrition*, nº 5, pp. 1-20, 2024. https://doi.org/10.20960/nh.05545

[33] E. Ankkuri, S. Lommi, J. Lahti, and V. Viljakainen, "Associations of mental health with subsequent weight development during a 4-year follow-up in adolescence," *Medrxiv*, pp. 1-34, 2025. https://doi.org/10.1101/2025.10.01.25337050

[34] D. Chaudhary, D. Guleria, H. Aggarwal, V. Mishra, A. Chauhan, L. Dufossé, and N. C. Joshi, "Nutrigenomics and Personalized Diets: Adapting Nutrition for Optimal Health," *Applied Food Research*, vol. 5, no. 1, pp. 1-12, 2025. https://doi.org/10.1016/j.afres.2025.100980

[35] S. J. Salas and S. A. Babio, Nutrition and Clinical Dietetics, Barcelona: Elsevier, 2025.

[36] M. Alcaraz González and J. Alcaraz González, "Chemical Interaction between Foods: The Role of Additives in Improving the Quality of Food Products," *Scientific Journal of Health and Human Development*, vol. 6, no. 1, pp. 1651-1678, 2025. https://doi.org/10.61368/r.s.d.h.v6i1.561

[37] J. F. Parodi, C. Valdiva Alcalde and I. Falvy Bockos, «Obesity in older adults: approach and comprehensive management,» *Revista Horizonte.Médico (Lima)*, vol. 25, nº 3, pp. 1-9, 2025. https://doi.org/10.24265/horizmed.2025.v25n3.14

[38] F. Vilugrón Aravena, T. Molina G., M. E. Gras Pérez and S. Font-Mayolas, «Eating habits, obesity and quality of life related to health in Chilean adolescents,» *Revista médica de Chile*, vol. 148, nº 7, pp. 921-929, 2020. http://dx.doi.org/10.4067/S0034-98872020000700921

[39] R. Urrialde, C. Gómez, B. Pintos, G.-G. Aránzazu and B. Cifuentes, "Bioactive compounds of plant origin: development of novel foods," *Hospital Nutrition*, vol. 39, no. 3, p. 39, 2022. https://dx.doi.org/10.20960/nh.04302

INQUIDE
Chemical Engineering & Development
Journal of Science and Engineering

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

Evaluation of Behavioral Competencies in the Ecuadorian Aquaculture Industry: A Correlational Analysis of Soft Skills in Administrative Personnel from Guayaquil

Evaluación de competencias conductuales en la industria acuícola ecuatoriana: análisis correlacional de habilidades blandas en el personal administrativo de Guayaquil

Jorge Meza-Clark[1]; Teresa Meza-Clark [2] ; Francisco Javier Duque-Aldaz [3] * ; Edwin Haymacaña Moreno[4]; Leonor Alejandrina Zapata Aspiazu;[5] Fernando Raúl Rodríguez-Flores [6]

Received: 04/25/2026 – Accepted: 06/08/2026 – Published: 07/12/2026

Research Articles [X] Review Articles [ ] Essay Articles [ ]

* Corresponding author.

Abstract.
The Ecuadorian aquaculture sector has experienced exponential growth, consolidating itself as a pillar of the national economy, where administrative management requires competencies that transcend technical knowledge. The present study aimed to examine the soft skills present in the administrative personnel of the Ecuadorian aquaculture sector. A structured questionnaire was administered to 88 administrative employees from five leading aquaculture companies in Guayaquil, assessing five dimensions: integrity, leadership, teamwork, communication, and problem-solving, using a five-point Likert scale. The instrument demonstrated excellent internal consistency, with an overall Cronbach's alpha of 0.944. The results revealed elevated levels of self-perception across all dimensions, with means ranging from 4.03 to 4.29, and significant positive correlations between all dimensions (r ranging from 0.452 to 0.839). The comparative analysis by sex did not evidence statistically significant differences ($p > 0.05$), although women presented slightly higher scores. The conclusions highlight the importance of strengthening competencies such as integrity in the sector and provide evidence for the design of equitable professional development policies in the Ecuadorian aquaculture industry.

Keywords.
Aquaculture, Communication, Leadership, Professional Competencies, Soft Skills, Teamwork, Aquaculture Sector

Resumen.
El sector acuícola ecuatoriano ha experimentado un crecimiento exponencial, consolidándose como un pilar de la economía nacional, donde la gestión administrativa requiere competencias que trascienden el conocimiento técnico. El presente estudio tuvo como objetivo examinar las habilidades blandas presentes en el personal administrativo del sector acuícola ecuatoriano. Se aplicó un cuestionario estructurado a 88 empleados administrativos de cinco empresas acuícolas líderes en Guayaquil, evaluando cinco dimensiones: integridad, liderazgo, trabajo en equipo, comunicación y resolución de problemas, con una escala de Likert de cinco puntos. El instrumento mostró una excelente consistencia interna, con alfa de Cronbach global de 0.944. Los resultados revelaron niveles elevados de autopercepción en todas las dimensiones, con medias que oscilaron entre 4.03 y 4.29, y correlaciones positivas significativas entre todas las dimensiones (r entre 0.452 y 0.839). El análisis comparativo por sexo no evidenció diferencias estadísticamente significativas ($p > 0.05$), aunque las mujeres presentaron puntuaciones ligeramente superiores. Las conclusiones destacan la importancia de fortalecer competencias como la integridad en el sector y proporcionan evidencia para el diseño de políticas de desarrollo profesional equitativas en la industria acuícola ecuatoriana.

Palabras clave.
Acuicultura, Competencias Profesionales, Comunicación, Habilidades Blandas, Liderazgo, Sector Acuícola, Trabajo En Equipo

1.- Introduction

The Ecuadorian aquaculture sector has experienced exponential growth in recent decades, consolidating itself as one of the fundamental pillars of the national economy. Ecuador has positioned itself as the main producer and exporter of shrimp in South America, recognized worldwide for the technical excellence of its aquaculture production and the superior quality of its products. However, in a highly dynamic and competitive global market, technical and productive excellence is no longer the only determining factor in maintaining sustainable competitive advantages. Accelerated changes in the work environment, particularly accentuated since the COVID-19 pandemic, have revealed the critical importance of competencies that transcend specialized technical knowledge, called soft skills.

This set of socio-emotional competencies, which enable people to interact effectively with others, make decisions, solve problems, think critically, communicate effectively, and build healthy relationships, has become essential in contemporary vocational training (World Health Organization, 1994). In the specific context of the

[1] University of Guayaquil; jorge.mezacl@ug.edu.ec; https://orcid.org/0000-0003-0512-8671; Guayaquil; Ecuador.
[2] University of Guayaquil; teresa.mezacl@ug.edu.ec ; https://orcid.org/0000-0002-5955-6893 ; Guayaquil; Ecuador.
[3] University of Guayaquil; franscico.duquea@ug.edu.ec ; https://orcid.org/0000-0001-9533-1635 ; Guayaquil; Ecuador.
[4] Bolivarian University Higher Institute of Technology; erhaymacana@itb.edu.ec; https://orcid.org/0000-0002-8708-3894 ; Guayaquil; Ecuador.
[5] Technical University of Babahoyo; lzapata@utb.edu.ec ; https://orcid.org/0009-0003-1497-2273 ; Babahoyo; Ecuador.
[6] University of Havana; fernan@matcom.uh.cu; https://orcid.org/0009-0002-8275-7631 ; Havana; Cuba.

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

aquaculture sector, where administrative management must coordinate complex technical processes, multidisciplinary teams and international business relations, soft skills emerge as indispensable elements for effective organizational performance.[1][2]

The scientific problem that motivates this research is based on the growing gap between the demands for behavioral competencies in the productive sector and the effective development of these skills in the administrative staff of Ecuadorian aquaculture companies. Despite the widespread recognition of the importance of soft skills for job performance, there is limited knowledge about how these competencies manifest themselves specifically in the aquaculture sector, which dimensions are most relevant to the organizational context of the industry, and how they relate to sociodemographic variables such as the sex and age of employees.

This limitation in the empirical understanding of the phenomenon represents a significant obstacle to the design and implementation of effective strategies for the development of human talent in the sector, which allow strengthening the behavioral competencies of administrative personnel and, consequently, improving organizational performance indicators. The absence of systematic studies that address this problem in the specific context of the Ecuadorian aquaculture industry configures a knowledge gap that justifies the realization of this research.[3]

The importance of the problem addressed transcends the academic field and is projected towards industrial and social dimensions of considerable magnitude. From an industrial perspective, the development of soft skills in administrative personnel in the aquaculture sector has the potential to directly impact the competitiveness of companies, improving the cohesion of work teams, the job satisfaction of employees, as well as organizational efficiency and effectiveness. In a global market environment where differentiation based exclusively on product quality is insufficient, organizational capabilities linked to human talent emerge as sources of sustainable competitive advantage.

From a social perspective, the strengthening of soft skills in the aquaculture sector contributes to the generation of healthier, more equitable and productive work environments, with positive impacts on the quality of life of workers and their families. Likewise, the research addresses a dimension of gender equity by exploring the possible differences in soft skills between men and women, contributing to the understanding of how organizational policies can promote the equitable development of competencies in work environments historically characterized by occupational segregation.[4]

The need to investigate this problem is based on the convergence of multiple factors that configure a scenario of urgency and relevance for the Ecuadorian aquaculture sector. The leading companies in the sector in Guayaquil have begun to implement specific strategies for the development of soft skills among their administrative staff, recognizing that these competencies are essential to face the challenges of an increasingly complex and demanding productive environment. According to Ekos Business (2021), this understanding is necessary in a context where automation and artificial intelligence are constantly transforming the work landscape, making human skills that cannot be replicated by machines increasingly valuable.

The development of these competencies would not only improve the functioning of the company's regular activities and work environment, but would provide a strategic impetus to position Ecuadorian aquaculture companies as strong competitors in the global market. In this framework, the following research question arises: what are the most common soft skills among managers in the aquaculture industry of the city of Guayaquil and how do they manifest themselves in their professional performance?, a question that guides the development of this study and guides the definition of its objectives and methodological strategies.[5]

1.1. Soft skills: definition, conceptual evolution and theoretical models.

The concept of soft skills, also called socio-emotional competencies, transversal skills or behavioral competencies, has undergone a significant evolution in the field of organizational psychology and human talent management since its first formulations in the 1970s. The term "soft skills" emerges as a distinct category from hard or technical skills, referring to a set of attributes, personality traits, social competencies, and communication skills that allow individuals to interact effectively in work and social settings.

Unlike technical competencies, which refer to specialized knowledge and operational skills specific to a trade or profession, soft skills are characterized by their transversal nature and their applicability in diverse contexts, which makes them fundamental elements for professional performance in complex organizational environments. From a historical perspective, interest in these competencies has progressively increased, driven by transformations in the world of work that have emphasized the need for professionals capable of adapting, collaborating and communicating effectively in multidisciplinary teams. [6]

The conceptual consolidation of soft skills has been driven by various theoretical frameworks that have provided complementary approaches for their understanding and measurement. One of the most influential references in this field has been the emotional intelligence model proposed by Daniel Goleman, who postulates that emotional and social competencies are predictive factors of professional success with greater explanatory power than traditional IQ. This approach has contributed to making visible the importance of dimensions such as self-awareness, self-regulation,

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

empathy and social skills in work performance, establishing a bridge between individual psychology and organizational dynamics. In a complementary way, the competency model developed by Spencer and Spencer has provided a methodological framework for the identification and evaluation of behavioral competencies, distinguishing between threshold competencies, necessary for basic performance, and differentiating competencies, which allow high-performance professionals to be distinguished. From a broader perspective, international organizations such as the Organization for Economic Cooperation and Development (OECD) and the World Economic Forum have incorporated soft skills into competency frameworks for the 21st century, recognizing their relevance in a context of technological transformation and changes in productive structures.

The evolution of the concept towards its current configuration has been marked by a growing recognition of its multidimensional nature and its situated character, aspects that have implied a progressive move away from one-dimensional approaches focused exclusively on personality traits. Recent research has emphasized that soft skills are not static or inherent attributes of individuals, but competencies that are developed and manifested in specific contexts, modulated by situational, cultural, and organizational factors.

This perspective has driven the development of models that integrate cognitive, emotional, and behavioral dimensions, recognizing that soft skills involve both the ability to process social and emotional information and the willingness to act effectively in interpersonal situations. In the organizational sphere, this evolution has led to a conceptualization of soft skills as key competencies for employability and professional development, particularly in productive sectors that require intensive human interaction and adaptation to changing environments.[7][8]

1.2. Soft skills in the organizational context: key dimensions.

The configuration of soft skills as a multidimensional construct has led to the identification of various competencies that, although interrelated, have conceptual and operational specificities that justify their differentiated treatment in organizational contexts. Integrity, understood as the coherence between values, principles and actions, is one of the fundamental dimensions in the workplace, as it is directly linked to the generation of trust, transparency in interpersonal relationships and compliance with ethical commitments.

This competence is manifested in observable behaviors such as the acceptance of mistakes, coherence between speech and action, compliance with established norms and resistance to external influences that may compromise personal principles. From an organizational perspective, integrity has been recognized as a critical factor for the work environment and organizational culture, particularly in sectors where operational decisions involve significant ethical considerations, such as in the aquaculture industry in relation to sustainability, animal welfare and regulatory compliance practices.[9]

Leadership, as a second relevant dimension, has been the subject of extensive theoretical development in the organizational literature, evolving from conceptions focused on personality traits to models that emphasize behaviors, styles, and processes of social influence. Contemporary approaches, particularly transformational leadership, highlight the ability of leaders to inspire, motivate, and intellectually stimulate their followers, fostering a sense of shared purpose and promoting the development of competencies in team members.

In the organizational context, effective leadership is manifested in behaviors such as taking initiative, proposing strategies for solving problems, building trust in the team, facilitating participation and promoting motivation. The relevance of leadership in the Ecuadorian aquaculture sector is particularly significant, given that hierarchical organizational structures and production processes that require effective coordination between different areas and levels demand figures capable of articulating work teams and managing the operational complexity inherent to the sector.[10]

Teamwork constitutes a third essential dimension, defined as the ability to collaborate effectively with others in the achievement of common goals, integrating interpersonal, communicative, and coordination skills. This competence is based on the willingness to share information, support colleagues, accept established agreements and contribute ideas for the benefit of the collective, as well as on the ability to manage conflicts and promote an environment of cooperation.

Specialized literature has documented that effective teamwork not only increases productivity and operational efficiency, but also contributes to the psychological well-being of workers and job satisfaction, aspects that are particularly relevant in productive sectors with high physical and emotional demands. In the Ecuadorian aquaculture context, where operations require constant coordination between multidisciplinary teams that integrate administrative, technical and operational personnel, teamwork emerges as a critical competency to ensure operational continuity and adaptation to changing environments.[11][12]

1.3. The measurement of soft skills: reliability, validity and evaluation methods.

The measurement of soft skills in organizational contexts has been a permanent methodological challenge, derived from the complex and multidimensional nature of these constructs, which are not directly observable and require to be inferred through behavioral indicators or self-reports. The operationalization of soft skills implies the translation

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

of theoretical constructs into specific dimensions and, subsequently, into concrete items that allow capturing the different facets of each competency evaluated. This process requires careful consideration of the psychometric properties of the measurement instruments, particularly with regard to their reliability and validity, aspects that determine the accuracy and relevance of the inferences made from the scores obtained.

Reliability, understood as the degree to which an instrument produces consistent and reproducible results, is commonly evaluated through Cronbach's alpha coefficient, which estimates the internal consistency of a scale from the correlations between the items that compose it, establishing minimum standards that allow the reliability of an instrument to be considered acceptable for research and organizational diagnostic purposes.[13]

The validity of the instruments for measuring soft skills is a complementary and essential aspect to ensure that the scores obtained effectively reflect the constructs they intend to measure, and not other factors unrelated to them. Construct validity, which assesses the degree to which an instrument measures the theoretical concept it intends to measure, is addressed through various strategies, including exploratory and confirmatory factor analysis, which allow examining the underlying structure of responses and verifying that items are grouped according to theoretically postulated dimensions.

Likewise, convergent and discriminant validity assesses the degree to which scores on a scale are associated with measures of related constructs and differ from theoretically distinct constructs, providing additional evidence on the relevance of the instrument. Content validity, on the other hand, guarantees that the items of the instrument adequately represent the conceptual domain of each construct evaluated, which is achieved through the review of specialized literature and the judgment of experts in the area of study, who evaluate the relevance, clarity, and representativeness of the proposed items.[14] [15]

Methods for assessing soft skills have evolved significantly from the first approaches based exclusively on self-report questionnaires, incorporating complementary strategies that allow for a more comprehensive and less biased approach to these competencies. Evaluation through self-perception questionnaires, such as the one used in this research, is the most commonly used method in organizational contexts, due to its ease of administration, low cost, and ability to capture the subjective perspective of the evaluated on their own competencies.

However, this method has recognized limitations, such as social desirability bias, acquiescence, and the tendency to central or extreme response, which can distort the scores obtained and affect the validity of the inferences made. To mitigate these limitations, complementary assessment methods have been developed, including heteroassessments, where supervisors, peers, or subordinates assess the competencies of the subject being assessed, and behavioral assessments, which are based on the observation of specific behaviors in simulated or real situations, such as assessment centers or situational tests.[16]

1.4. The Ecuadorian aquaculture sector: characterization, challenges and demand for soft skills.

The Ecuadorian aquaculture sector is one of the fundamental pillars of the national economy, positioning itself as the main producer and exporter of shrimp in Latin America and as one of the world leaders in the production of this species. The aquaculture industry in Ecuador has experienced sustained growth in recent decades, consolidating a production chain that integrates larval production, fattening, processing and marketing activities, generating direct and indirect employment for a significant portion of the country's coastal population.

The province of Guayas, and particularly the city of Guayaquil, have become the epicenter of this productive activity, housing the main companies in the sector and concentrating the centers of administrative and commercial decision-making. From an economic perspective, the aquaculture sector contributes substantially to the Ecuadorian trade balance, generating foreign exchange that exceeds billions of dollars annually, and constituting an engine of development for coastal communities that depend directly or indirectly on this productive activity.[17]

The industrial classification of the sector under code A0321.02 of the International Standard Industrial Classification (ISIC) REV. 4.0, corresponding to aquaculture in marine and brackish waters, places aquaculture companies within a specific normative and regulatory framework that establishes standards of production, animal health, traceability and environmental sustainability. This regulatory framework, which includes both national provisions and international market requirements, imposes significant challenges for organizations in the sector, demanding not only specialized technical skills, but also soft skills to manage regulatory complexity, coordinate multidisciplinary teams, and adapt to permanent regulatory changes.

The need to comply with international quality and sustainability standards, particularly in demanding markets such as the United States, Europe and Asia, has driven an organizational transformation in aquaculture companies, which have had to professionalize their management structures and strengthen the competencies of their human capital to maintain their competitiveness in global markets.[18]

The Ecuadorian aquaculture sector faces permanent challenges that configure a highly demanding and dynamic work environment, where soft skills emerge as critical competencies for professional performance. Variability in

oceanographic and climatic conditions, the incidence of diseases such as white spot syndrome and acute hepatopancreatic necrosis, fluctuations in international prices, and global trade tensions are factors of uncertainty that demand adaptive and problem-solving capacities at all organizational levels. Likewise, the growing pressure from consumers and international organizations towards sustainable and socially responsible production practices has raised the ethical and environmental standards that companies in the sector must meet, requiring professionals with solid skills in integrity, transparency and ethical decision-making. In this context, soft skills are not merely desirable attributes, but strategic competencies that determine the ability of organizations to anticipate and respond effectively to the contingencies of the environment, maintaining operational continuity and competitiveness in an increasingly demanding global market.[19]

1.5. Soft skills and sociodemographic variables: differences by sex and age.

The analysis of soft skills as a function of sociodemographic variables, particularly sex and age, has been a field of growing interest in organizational research, motivated by the need to understand how individual and contextual factors modulate the development and manifestation of these competencies in work environments. The specialized literature has documented differential patterns in the self-perception of soft skills between men and women, although the findings have not always been consistent, evidencing the influence of cultural, occupational and methodological factors on the observed results.

Some studies have reported that women tend to perceive themselves as having higher levels in dimensions related to communication, empathy and interpersonal skills, while men tend to have higher scores in competencies associated with leadership and problem-solving, although these differences tend to reduce when controlling for contextual and occupational variables. From a theoretical perspective, these differences have been attributed to differential socialization processes that emphasize different behavioral and attitudinal patterns in women and men, as well as to occupational segregation that concentrates each group in job roles that reinforce certain competency profiles.[20]

In the area of age differences, research has suggested that soft skills are not static attributes, but rather competencies that are developed and consolidated throughout the life cycle, influenced by work experience, professional maturity and exposure to diverse situations in organizational contexts. Longitudinal studies have documented that dimensions such as leadership, problem-solving, and communication tend to increase with age and career path, reflecting experiential learning and the accumulation of social and psychological capital over time.

On the other hand, other skills such as adaptability or flexibility could present differentiated trajectories, with higher levels in young populations facing changing work environments and demands for rapid adaptation. In the organizational context, these age trajectories have significant implications for the management of human talent, suggesting the need to design differentiated professional development strategies that recognize the particularities of each age group and enhance their specific strengths.[21]

The interaction between sex and age in the configuration of soft skills has received increasing attention in the literature, recognizing that patterns of competence development may differ between men and women throughout their professional careers. Recent research has suggested that gender differences in soft skills tend to fade with age and experience, which could reflect organizational socialization processes that modulate initial dispositions and promote adaptive behavior patterns based on the demands of the work environment.

This finding is consistent with theoretical perspectives that emphasize the situated and dynamic nature of soft skills, which are developed in interaction with organizational contexts and accumulated professional experiences. In the Ecuadorian aquaculture sector, where work populations with different trajectories and demographic characteristics coexist, understanding these interactions is relevant for the design of talent development policies that consider both age particularities and gender differences in the configuration of behavioral competencies.[22][23]

This research is aimed at the systematic examination of soft skills in the administrative staff of the Ecuadorian aquaculture sector, with the purpose of generating empirical knowledge that contributes to the understanding of these competencies in a productive context of high economic and social relevance. To this end, a general objective has been defined that articulates the central purpose of the study, as well as a set of specific objectives that operationalize the different dimensions of the research problem. This structure of objectives allows the problem raised to be addressed in a comprehensive way, ensuring coherence between the research questions, the methods used and the expected results.

The general objective of this research is to examine the soft skills present in the Ecuadorian aquaculture sector administrators and the professional development strategies implemented by the leading companies in the sector in the city of Guayaquil. This purpose is articulated around the need to characterize the soft skills profile of administrative personnel, identify the most developed competency dimensions and those that present the greatest opportunities for improvement, as well as understand the organizational practices aimed at strengthening these competencies in the specific context of the Ecuadorian aquaculture industry.

The specific objectives have been structured to address the different dimensions of the research problem in a systematic way. First, it seeks to describe the sociodemographic

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

characteristics of the sample, including the distribution by sex and age of the administrative staff of the participating aquaculture companies, in order to contextualize the findings and facilitate comparison between population subgroups. Secondly, it is proposed to evaluate the reliability and internal consistency of the measurement instrument used, by calculating Cronbach's alpha coefficient for each of the five dimensions evaluated (integrity, leadership, teamwork, communication and problem solving), as well as for the questionnaire as a whole, guaranteeing the psychometric validity of the measurements made. Thirdly, it is proposed to analyze the levels of self-perception of soft skills in the five dimensions evaluated, identifying the most developed competencies and those with relatively lower levels, as well as the variability in the responses of the participants. Fourthly, it seeks to determine the existing correlations between the different dimensions of soft skills, exploring the interdependent relationships that are established between the behavioral competencies evaluated and their configuration as a system of interrelated skills. Finally, it is proposed to compare the levels of soft skills between men and women, as well as between different age groups, in order to identify possible differences associated with these sociodemographic variables and explore their implications for the management of human talent in the sector.

These objectives are directly related to the methodology used in the research, which combines a quantitative design of descriptive-correlational scope with the application of a structured questionnaire that measures the five dimensions of soft skills, as well as with the expected results, which include the characterization of the competency profile of administrative staff, the identification of significant relationships between the dimensions evaluated, and the identification of differences by sex and age. The achievement of these objectives will generate relevant empirical evidence for decision-making in the field of human talent management in the Ecuadorian aquaculture sector, as well as for the design of professional development strategies aimed at strengthening soft skills in the administrative staff of companies in the sector.

This research makes significant contributions in the scientific, methodological and practical fields, contributing to the development of knowledge in the field of soft skills and its application in specific productive contexts. From a scientific perspective, the study contributes to the understanding of soft skills in a productive sector of high economic relevance such as Ecuadorian aquaculture, addressing a gap in empirical knowledge documented in the specialized literature. The research provides systematic evidence on the structure, levels and relationships between the different dimensions of soft skills in the management staff of aquaculture companies, as well as on the differences associated with sociodemographic variables such as sex and age. These findings enrich the existing knowledge about behavioral competencies in specific organizational contexts and contribute to the consolidation of a theoretical body that recognizes the importance of the sectoral context in the configuration of soft skills.

On the methodological level, the study provides the validation and application of a soft skills measurement instrument adapted to the context of the Ecuadorian aquaculture sector, providing evidence on its psychometric properties in this specific population. The reliability coefficients obtained, which far exceed the acceptable thresholds in all the dimensions evaluated, support the usefulness of the instrument for future research in the sector and provide a methodological basis for its application in other similar production contexts. Likewise, the research contributes to the development of systematic procedures for the evaluation of soft skills in the organizational field, integrating considerations on the reversal of negative items, the analysis of internal consistency, and the evaluation of differences between population subgroups. These methodological contributions are relevant for the academic and professional community interested in the measurement of behavioral competencies in diverse organizational contexts.

From a practical perspective, the study offers valuable information for the management of human talent in the Ecuadorian aquaculture sector, providing empirical evidence that can guide the design of professional development policies and programs. The findings regarding the levels of soft skills in the different dimensions evaluated allow us to identify areas of strength and opportunities for improvement, facilitating the prioritization of training interventions aimed at strengthening specific competencies. Particularly relevant is the identification of integrity as the dimension with relatively lower levels, which suggests the need to implement specific strategies for the strengthening of ethical and behavioral competencies in the sector's administrative staff. Likewise, the absence of significant differences by sex in the soft skills evaluated provides evidence that supports the design of equitable professional development policies that recognize the strengths of all employees regardless of their gender, and that promote equal opportunities in access to training and development programs.

Finally, the study contributes to the sustainable development of the Ecuadorian aquaculture sector by providing an empirical basis for decision-making in human talent management, recognizing that investment in the development of soft skills constitutes a strategic factor for organizational competitiveness in an increasingly demanding global market. The evidence generated allows companies in the sector to better understand the behavioral competencies of their administrative staff and design development strategies aligned with the needs of the productive environment, thus contributing to the training of more complete, adaptable professionals capable of facing the challenges of a constantly evolving sector. In a context where automation and artificial intelligence are transforming the labor landscape, the strengthening of

human skills that cannot be replicated by machines acquires strategic relevance, positioning companies that invest in the development of these skills as leaders in their respective markets and contributing to the positioning of the Ecuadorian aquaculture sector as a benchmark of excellence and sustainability in the region.

2.- Materials and methods.

2.1 Research design and approach

The present research is framed within a non-experimental design of descriptive-correlational scope, with a quantitative approach that allows to characterize the soft skills of the administrative staff of the Ecuadorian aquaculture sector and explore the relationships between the dimensions evaluated. The study adopts a cross-sectional design, since the data were collected at a single time point, which allows obtaining a snapshot of the state of soft skills in the population studied without intervention on the variables of interest. This design is appropriate to achieve the proposed objectives, since it allows describing the characteristics of the sample, establishing relationships between dimensions and comparing population subgroups without experimental manipulation. [24]

2.2 Population and sample

The study population included administrative employees of five leading aquaculture companies in the city of Guayaquil, classified under the industrial code A0321.02 of the International Standard Industrial Classification (ISIC REV. 4.0), corresponding to aquaculture in marine and brackish waters. The selection of the participating companies was made through intentional or convenience sampling, considering their position in the sector, their volume of operations and their willingness to participate in the research. The final sample consisted of 88 participants, distributed in 51 women (58.0%) and 37 men (42.0%), aged between 21 and over 30 years, of which 72 (81.8%) belonged to the age group of 21 to 30 years and 16 (18.2%) to the group of more than 30 years. The sample size was adequate for the statistical analyses proposed, considering the statistical power requirements for the correlation tests and comparison of means expected.[25]

2.3 Measuring instrument

The data collection instrument consisted of a structured self-administered questionnaire, designed to assess five dimensions of soft skills: integrity, leadership, teamwork, communication, and problem solving. The questionnaire included 50 items distributed in the five dimensions, with 10 items for integrity (P3 to P12), 12 items for leadership (P13 to P24), 8 items for teamwork (P25 to P32), 10 items for communication (P33 to P42) and 10 items for problem solving (P43 to P52). Additionally, the instrument incorporated two sociodemographic questions to characterize the sample: age (P1), with categories "21 to 30 years" and "over 30 years", and sex (P2), with categories "female" and "male". The soft skills items were presented on a five-point Likert scale, where 1 corresponded to "never", 2 to "almost never", 3 to "sometimes", 4 to "almost always" and 5 to "always". The questionnaire was designed and validated through expert judgment, considering the relevance, clarity and representativeness of the items for each dimension evaluated, and was subjected to reliability analysis using Cronbach's alpha coefficient, which yielded values greater than 0.70 in all dimensions and an overall value of 0.944, indicating an excellent internal consistency of the instrument.[26]

2.4 Data collection procedure

Data collection was carried out during the period between the months of [indicate period] of the year [indicate year], with prior authorization from the human resources departments of the participating companies and the signing of informed consents by the respondents. The questionnaire was administered digitally using online survey platforms, ensuring anonymity and confidentiality of responses. Participants received standardized instructions for completing the instrument, including an explanation of the purpose of the research, the voluntary nature of participation, and the absence of consequences derived from their responses. The estimated time to complete the questionnaire was approximately 15 to 20 minutes. Once the data were collected, the database was cleaned, verifying the integrity of the responses and the absence of outliers or inconsistencies that could affect the quality of the analyses.[27]

2.5 Data analysis

Data processing and analysis was performed using SPSS statistical software version 26.0 for Windows. Prior to the main analysis, the items written in the negative direction were inverted, specifically items P8, P10 and P12 of the integrity dimension, and item P45 of the problem-solving dimension, applying the transformation formula valor_invertido = 6 − valor_original. This transformation ensured that all items were oriented in the same direction, where higher scores indicated higher skill levels. Subsequently, the average scores per dimension were calculated for each participant, averaging the items corresponding to each construct.[28, 28]

The reliability analysis of the instrument was carried out using Cronbach's alpha coefficient, calculated both for each dimension and for the questionnaire as a whole, evaluating the internal consistency of the scales. For the descriptive analysis, measures of central tendency (mean and median), dispersion measures (standard deviation, minimum and maximum) and measures of distribution form (asymmetry and kurtosis) were calculated for each of the five dimensions. The normality of the distributions was evaluated by the asymmetry coefficient, considering values within the range of -2 to +2 as indicative of an approximately normal distribution. For the correlational analysis, Pearson's correlation coefficient was applied, evaluating the relationships between the five dimensions of soft skills. This analysis was performed both for the total sample and for the subgroups defined by sex and age, in

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

order to explore the stability of the relationships between dimensions in different population segments.

The comparative analysis by sex was performed using Student's t-test for independent samples, after verification of the assumption of homogeneity of variances by Levene's test. Descriptive statistics were calculated for each group (mean and standard deviation), the value of the t-statistic, the degrees of freedom, the level of significance and the size of the effect using Cohen's d. For the interpretation of the effect size, the conventional criteria were considered: 0.2 as a small effect, 0.5 as a medium effect and 0.8 as a large effect. The level of statistical significance was established at $\alpha = 0.05$ for all tests performed. Additionally, correlation analyses segmented by sex and age were carried out, in order to explore the consistency of the relationships between dimensions in the different population subgroups, calculating Pearson's coefficients and their corresponding levels of significance.[29]

3.- Results.

SECTION 1: METHODOLOGY – Instrument

Table 1.- Correct Structure of Dimensions

Dimension	Items	Quantity
Integrity	P3 – P12	10 items
Leadership	P13 – P24	12 items
Teamwork	P25 – P32	8 items
Communication	P33 – P42	10 items
Problem Solving	P43 – P52	10 items
Total	P3 – P52	50 items

The dimensional structure of the measurement instrument, presented in Table 1, establishes an operational framework for the evaluation of five fundamental behavioral competencies in the workplace: integrity, leadership, teamwork, communication, and problem solving. This five-dimensional configuration, composed of 50 items distributed asymmetrically (range of 8 to 12 items per dimension), responds to the inherent complexity of each construct evaluated, where dimensions such as leadership require a greater density of indicators to capture the multidimension of the phenomenon.

From a methodological perspective, the assignment of items P3 to P12 for the integrity dimension, with a total of ten items, allows addressing both attitudinal and behavioral aspects associated with ethical coherence and transparency in the organizational environment. Similarly, the leadership dimension, with twelve items (P13 to P24), operationalizes competencies linked to team management, initiative taking and the generation of trust, critical aspects in the management of human talent within the aquaculture sector, characterized by defined hierarchical structures and production processes that demand effective coordination.[30]

The teamwork dimension, consisting of eight items (P25 to P32), represents the smallest structure of the instrument, which suggests a more specific and delimited conceptualization of the construct, focused on interpersonal collaboration and group cohesion. On the other hand, communication and problem solving, each with ten items (P33 to P42 and P43 to P52 respectively), address dimensions related to communicative effectiveness and analytical capacity to face operational contingencies, particularly relevant competencies in the aquaculture sector, where decision-making in environments of high productive and sanitary variability requires precise communicative exchanges and rapid adaptive responses.

The proposed distribution of items presents a balanced coverage of the competencies evaluated, with an adequate relative weight for each construct, although the teamwork dimension, having a smaller number of items, could present limitations in terms of psychometric stability, an aspect that will be addressed in the reliability analysis. From the point of view of organizational engineering and human talent management, this dimensional structure offers an analytical framework that allows diagnosing strengths and areas for improvement in the soft skills of the administrative staff of the Ecuadorian aquaculture sector, facilitating the design of training interventions aligned with the demands of the productive environment.

Table 2.- Results of Cronbach's Alpha by dimension

Dimension	Items	Cronbach's alpha	Interpretation
1. Integrity	P3 - P12 (10 items)	0.724	Acceptable
2. Leadership	P13 - P24 (12 items)	0.913	Excellent
3. Teamwork	P25 - P32 (8 items)	0.894	Good/Excellent
4. Communication	P33 - P42 (10 items)	0.920	Excellent
5. Problem Solving	P43 - P52 (10 items)	0.938	Excellent
Total Questionnaire	P3 - P52 (50 items)	0.944	Excellent

The reliability coefficients obtained for the soft skills measurement instrument, presented in Table 2, show a differentiated psychometric behavior between the dimensions evaluated, with values ranging from 0.724 for completeness to 0.938 for problem solving, while the overall coefficient of the questionnaire reaches a value of 0.944. This set of results allows us to affirm that the instrument, as a whole, presents an outstanding internal consistency, far exceeding the minimum recommended threshold of 0.70 established in the specialized literature for basic research purposes, and placing itself in the range considered as excellent for the measurement of psychosocial constructs in organizational contexts.

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

The highest reliability value corresponds to the problem-solving dimension (α = 0.938), which indicates that the ten items that compose it (P43 to P52) maintain a high level of intercorrelation, coherently measuring the underlying construct related to analytical capacity and decision-making in the face of contingencies. This finding is particularly relevant from an engineering perspective, given that the Ecuadorian aquaculture sector faces permanent operational and sanitary challenges, where effective problem solving is a critical competence for production continuity. The high internal consistency suggests that the items manage to adequately capture the cognitive and procedural dimensions involved in this competence.

The communication dimension has a coefficient of 0.920, reflecting an excellent homogeneity among its ten items (P33 to P42), which address aspects related to expressive clarity, active listening and perception of the emotional state of the interlocutors. From the point of view of social engineering and organizational management, this result is consistent with the interdependent nature of effective communication in work environments that require coordination between multidisciplinary teams, as occurs in the aquaculture companies studied, where the accurate transmission of technical and operational information is essential.

The leadership dimension reaches a coefficient of 0.913, evidencing that the twelve items that make it up (P13 to P24) maintain a high internal consistency, supporting the validity of the constructed evaluated. This result acquires particular relevance in the context of the aquaculture sector, where organizational structures require leadership figures capable of articulating work teams, promoting motivation and managing production processes. The excellent reliability observed suggests that the instrument adequately captures the behavioral and attitudinal dimensions associated with leadership, including the capacity for initiative, the generation of confidence and the promotion of participation.

The coefficient obtained for teamwork (α = 0.894), although it is in the good to excellent range, is slightly lower than that observed in the previously analyzed dimensions. This difference could be attributed to the smaller number of items that make up this dimension (eight items, P25 to P32), since the alpha coefficient is sensitive to the number of elements that make up the scale. However, the value achieved far exceeds the threshold of 0.80 considered as good reliability, which allows us to affirm that the dimension consistently measures the construct associated with interpersonal collaboration and group integration.

The integrity dimension has the lowest coefficient of the instrument (α = 0.724), although it remains within the acceptable range. This result deserves particular attention from the psychometric point of view, since it suggests that the ten items that compose it (P3 to P12) present a moderate homogeneity, possibly due to the multifaceted nature of the construct integrity, which encompasses dimensions such as honesty, transparency, coherence between values and actions, and acceptance of errors. aspects that, although related, can manifest themselves in a differentiated way depending on the situational contexts. From an ethical and organizational perspective, this finding invites reflection on the complexity of measuring constructs linked to ethical behavior in work environments, where implicit norms and organizational incentives can influence participants' responses.

The overall coefficient of the questionnaire (α = 0.944) confirms that the instrument as a whole presents excellent internal consistency, exceeding the value of 0.90 that the specialized literature considers as indicative of outstanding reliability. This result validates the five-dimensional structure of the instrument and supports its usefulness for organizational diagnostic purposes in the Ecuadorian aquaculture sector, providing a solid empirical basis for decision-making in human talent management and design of soft skills development programs. The high overall reliability suggests that, although the dimensions evaluate differentiated constructs, all of them are oriented towards the measurement of a common domain related to interpersonal and behavioral competencies in the workplace, which is consistent with the theoretical framework underlying the instrument.

SECTION 2: RESULTS – Characterization of the sample

Table 3.- Descriptive statistics of the sample – Sociodemographic variables (n = 88)

Variable	Category	Frequency	Percentage
Age (P1)	21-30 years	72	81.8%
	More than 30 years	16	18.2%
Sex (P2)	Female	51	58.0%
	Male	37	42.0%

The characterization of the sample, presented in Table 3, reveals a demographic composition that presents relevant particularities for the interpretation of the results in the context of the Ecuadorian aquaculture sector. The age distribution shows a marked predominance of participants belonging to the age range of 21 to 30 years, which represents 81.8% of the sample (72 cases), while the group over 30 years of age constitutes only the remaining 18.2% (16 cases). This age asymmetry suggests a mostly young administrative labor population, which could reflect the dynamics of hiring and retaining talent in the aquaculture sector of the region, characterized by a growing demand for professionals in early stages of their occupational development.

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

From an organizational engineering and human resources management perspective, the concentration of the sample in the young age segment is consistent with the trends observed in productive sectors with high operational demand, where the incorporation of recently graduated personnel or those with limited experience responds both to the needs of generational renewal and to the availability of specialized training programs in the aquaculture area. This finding becomes relevant when considering that the soft skills evaluated in this study, particularly those related to leadership and problem solving, are usually developed and consolidated with experience and professional career, so the levels observed could be influenced by the relative youth of the sample.

Regarding the sex variable, the results indicate a slightly unbalanced distribution in favor of the female sex, which represents 58.0% of the participants (51 cases), compared to 42.0% corresponding to the male sex (37 cases). This proportion offers valuable information on the composition of administrative personnel in aquaculture companies in Guayaquil, suggesting a significant female presence in administrative roles, although slightly higher compared to the distribution typically observed in traditionally masculinized productive sectors. This data is particularly relevant from the perspective of gender equity studies in the workplace, especially considering that the Ecuadorian aquaculture sector has historically been characterized by a marked occupational segregation based on gender.

The majority female representation in the sample could be associated with the administrative nature of the positions evaluated, in contrast to the operational and technical areas of the aquaculture sector, where male participation tends to be predominant. From the point of view of human talent management, this distribution suggests the need for organizational policies that promote gender equity at both administrative and operational levels, as well as the development of leadership and decision-making competencies in work teams, considering diversity as a factor that enhances innovation and organizational effectiveness.

It is important to note that the sociodemographic characteristics of the sample, with its predominance of young and female participants, should be considered as contextual factors in the interpretation of the results related to soft skills. The youth of the sample could imply differential levels of development of certain behavioral competencies, particularly those that are consolidated with work experience and professional maturity, while the composition by sex raises questions about possible patterns of differential socialization in the development of interpersonal and communicative skills in the aquaculture work environment. These aspects will be addressed in the subsequent comparative analyses, which will allow evaluating whether the differences observed in the dimensions evaluated are statistically significant or respond to variations attributable to the sociodemographic characteristics of the participants.

SECTION 3: RESULTS – Descriptive statistics

Table 4.- Descriptive statistics by dimension (with inverted items)

Dimension	Media	Desv. East.	Minimum	Maximum	Asymmetry	Curtosis
Integrity	4.04	0.68	1.90	5.00	-0.82	0.94
Leadership	4.25	0.86	1.00	5.00	-1.21	1.73
Teamwork	4.26	0.94	1.00	5.00	-1.31	1.53
Communication	4.24	0.93	1.00	5.00	-1.31	1.74
Problem Solving	4.29	0.95	1.00	5.00	-1.35	1.69

The descriptive statistics presented in Table 4 reveal remarkably high levels of self-perception in all the dimensions evaluated, with means ranging from 4.04 for completeness to 4.29 for problem solving, on a Likert scale of 1 to 5 points. These values suggest that the study participants perceive themselves to have a high level of development in the behavioral competencies assessed, exceeding the midpoint of the scale and approaching the upper limit of response. From an organizational perspective, this finding is particularly relevant for the Ecuadorian aquaculture sector, since it indicates a favorable self-perception of soft skills in administrative personnel, which could constitute a significant intangible asset for companies in the sector.

The dimension with the highest mean corresponds to problem solving (M = 4.29, SD = 0.95), followed by teamwork (M = 4.26, SD = 0.94) and leadership (M = 4.25, SD = 0.86). These scores suggest that participants attribute greater development to competencies related to analytical capacity, group collaboration and team management, critical aspects for performance in productive environments characterized by the need for rapid response to operational and health contingencies, as occurs in the aquaculture sector. Communication reached a mean of 4.24 (SD = 0.93), placing it at a level similar to that of the previously mentioned dimensions, while integrity had the lowest mean (M = 4.04, SD = 0.68), although still in a range considered high.

It is important to note that all dimensions have means greater than 4.0, which in the Likert scale used corresponds to "almost always" in the continuum of response that goes

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

from "never" to "always". This pattern of responses could be influenced by a social desirability bias, a frequent phenomenon in studies of self-perception of psychosocial competencies, where participants tend to overestimate their abilities in dimensions positively valued by the organization and society. From a technical point of view, this finding suggests the need to complement self-perception measurements with behavioral performance evaluations or with third-party observations (heteroevaluations) to obtain a more objective approach to the real development of these competencies in the work environment.

The observed standard deviations reveal that the integrity dimension has the least variability (SD = 0.68), indicating greater homogeneity in participants' responses compared to the other dimensions. On the contrary, problem solving (SD = 0.95) and teamwork (SD = 0.94) show the greatest dispersions, suggesting a greater heterogeneity in the self-perception of these competencies among the participants. This differential variability could be associated with the nature of the constructs evaluated: while integrity refers to ethical and normative principles that tend to be internalized more uniformly, problem-solving and teamwork are more linked to situational experiences and particular work trajectories, which could generate greater differences in individual perceptions.

Distribution shape analyses reveal negative asymmetries across all dimensions, with values ranging from -0.82 for integrity to -1.35 for troubleshooting. These coefficients indicate a concentration of responses at the high values of the scale, consistent with the high means observed. Positive kurtoses, with values between 0.94 for integrity and 1.74 for communication, suggest leptocurtic distributions, characterized by a higher concentration of cases in the central zone and less extended tails than expected in a normal distribution.

From the perspective of organizational engineering and human talent management, these results suggest that administrative personnel in the Ecuadorian aquaculture sector perceive themselves to have a solid level of soft skills, particularly in dimensions related to problem solving and teamwork, critical competencies for performance in highly complex production environments. However, the relatively lower integrity score raises questions about organizational factors that could influence the self-perception of ethical conduct, as well as about institutional policies aimed at strengthening ethical coherence and transparency in labor practices in the sector. The elevation of scores in all dimensions above 4.0 invites reflection on the need to implement complementary evaluation mechanisms that allow contrasting self-perceptions with objective indicators of behavioral performance, thus contributing to a more comprehensive understanding of the development of soft skills in the Ecuadorian aquaculture context.

SECTION 4: RESULTS – Global correlations

Table 5.- Matrix of correlations between dimensions (Pearson)

Dimension	Integrity	Leadership	Teamwork	Communication	Problem Solving
Integrity	1.000				
Leadership	0.531	1.000			
Teamwork	0.514	0.736	1.000		
Communication	0.531	0.752	0.839	1.000	
Problem Solving	0.452	0.673	0.745	0.734	1.000

All correlations are significant with $p < 0.01$

The Pearson correlation matrix presented in Table 5 reveals positive and statistically significant associations ($p < 0.01$) between all dimensions of the instrument, with coefficients ranging from 0.452 to 0.839. This pattern of intercorrelations suggests that the five behavioral competencies assessed do not operate as independent constructs, but rather maintain interdependent relationships that reflect the systemic nature of soft skills in the organizational context. From a theoretical perspective, these findings are consistent with multidimensional models of psychosocial competencies, which postulate the existence of significant relationships between different behavioral dimensions, particularly those related to social interaction and work performance.

The highest correlation is observed between teamwork and communication ($r = 0.839$), which indicates that both dimensions share approximately 70.4% of their common variance. This strong partnership is conceptually coherent, since the effectiveness of collaborative work depends fundamentally on the ability of team members to exchange information clearly, express opinions in a timely manner, and understand each other's needs and emotional states. In the context of the Ecuadorian aquaculture sector, where productive operations require constant coordination between different areas and hierarchical levels, this interdependence between communication and teamwork acquires particular relevance, suggesting that training interventions aimed at strengthening one of these competencies could have positive effects on the other.

Similarly, the correlation between leadership and communication reaches a value of 0.752, reflecting that the ability to lead teams is closely linked to communication skills, particularly those related to the clear expression of ideas, the transmission of confidence and the facilitation of participation. This finding is consistent with the specialized

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

literature that identifies effective communication as one of the fundamental pillars of transformational and situational leadership. From the perspective of organizational engineering, this relationship suggests that leadership development processes in the aquaculture sector should incorporate intensive training components in communication skills, recognizing that the ability to influence work teams is mediated by the ability to establish effective communication channels.

The association between teamwork and leadership (r = 0.736) reinforces the notion that both competencies feed off each other in organizational contexts, where effective leaders are those capable of fostering collaboration and group cohesion, while cohesive work teams facilitate the exercise of leadership by generating environments of trust and participation. The aquaculture sector, characterized by operations that require coordination between multidisciplinary teams, could benefit from management strategies that simultaneously promote leadership development and teamwork, recognizing their interdependent nature.

The correlations between integrity and the other dimensions, although significant, present the lowest values in the matrix, ranging from 0.452 with problem solving to 0.531 with leadership and communication. This pattern suggests that integrity, understood as coherence between values and actions, transparency and acceptance of mistakes, maintains a more moderate relationship with the other behavioral competencies. From an ethical and organizational perspective, this finding could indicate that integrity constitutes a relatively independent construct within the set of soft skills, possibly because it refers to dimensions of a moral and normative nature that operate at a different level than the competencies more oriented to social interaction and the resolution of operational problems.

The correlation between integrity and problem solving (r = 0.452) is the lowest in the entire matrix, suggesting that the self-perception of ethical and transparent behaviors is limited to the perception of ability to identify causes of problems, generate alternative solutions, and evaluate results. This finding is particularly relevant from the point of view of human talent management, since it suggests that competencies linked to the ethical dimension and those associated with analytical-operational capacity could be developed through differential trajectories, requiring specific training strategies for each domain.

From a methodological perspective, the correlations obtained in all cases exceed the threshold of 0.30 considered as indicative of a practically significant association, and most of them are in the range of strong correlations (r > 0.70) or moderate correlations (r between 0.40 and 0.70). This pattern suggests that, although the dimensions maintain significant relationships that justify their inclusion in a common instrument, they present sufficient specificity to be considered differentiated constructs. The statistical significance of all correlations ($p < 0.01$) provides a solid basis for affirming that the observed relationships are not attributable to chance, reinforcing the validity of the instrument and supporting the relevance of the analysis of soft skills as a system of interrelated competencies in the context of the Ecuadorian aquaculture sector.

SECTION 5: RESULTS – Group comparisons

Table 6.- Correlations by Age Group

Correlation	21-30 years (n=72)	>30 years (n=16)
Integrity - Leadership	0.530**	0.516*
Integrity - Teamwork	0.516**	0.489*
Leadership - Communication	0.748**	0.781**
Team Work - Communication	0.835**	0.852**

The correlation analysis segmented by age groups, presented in Table 6, reveals patterns of association between the dimensions of soft skills that remain consistent in both the group of participants aged 21 to 30 years and in the group of participants over 30 years of age, with all correlations reaching statistical significance. This finding suggests that the relational structure among the behavioral competencies evaluated remains stable throughout the age ranges considered, indicating that the interdependence between the dimensions of the instrument is not substantially modified by the age of the participants.

The correlations observed in the group of young participants (21 to 30 years old) show coefficients ranging from 0.516 to 0.835, all of them significant with $p < 0.01$. On the other hand, the oldest group (over 30 years old) shows coefficients ranging from 0.489 to 0.852, with levels of significance that include both $p < 0.01$ and $p < 0.05$. This pattern of results suggests that, although the magnitudes of the associations show slight variations between both groups, the direction and nature of the relationships between the dimensions evaluated remain fundamentally invariant, which supports the stability of the measurement instrument in different age segments.

The highest correlation in both groups is observed between teamwork and communication, reaching 0.835 in the 21 to 30 age group and 0.852 in the over 30 age group. This consistency in the magnitude of the association suggests that the relationship between the ability to collaborate in teams and communication skills remains equally strong regardless of the age of the participants. From an organizational engineering perspective, this finding is relevant insofar as it indicates that the interdependence between these two competencies constitutes a stable phenomenon, suggesting that organizational development strategies aimed at strengthening teamwork could be implemented in a similar way in work populations of

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

different ages, taking advantage of the synergistic relationship with communicative competencies.

The correlation between leadership and communication also shows high and comparable values in both groups, with coefficients of 0.748 for the young group and 0.781 for the older group. This similarity suggests that the association between the ability to lead teams and communication skills remains robust across age ranges, supporting the notion that effective communication constitutes a cross-cutting component of leadership regardless of experience or career path. This result is particularly relevant for the design of leadership skills training programs for the aquaculture sector, since it suggests that interventions aimed at developing communication skills could have positive effects on leadership skills in both young professionals and those with more experience.

The correlations between integrity and the other dimensions show more moderate values in both age groups, with coefficients ranging from 0.489 to 0.530. Integrity, when assessed by items that inquire about the acceptance of errors, the coherence between values and actions, and transparency, maintains a systematically lower relationship with the dimensions oriented to social interaction and problem solving, a pattern that is consistently observed in both age groups. This finding reinforces the notion that integrity, understood as a competence linked to ethical and normative principles, could operate as a relatively independent construct within the soft skills ecosystem, maintaining more moderate relationships with the behavioral dimensions oriented to interaction and operation.

It is important to note that the correlations between integrity and leadership (0.530 in young people vs. 0.516 in older people) and integrity and teamwork (0.516 in young people vs. 0.489 in older people) show marginal differences between both groups, with slightly higher values in the younger age group. These differences, although minimal, could suggest that in younger populations the relationship between ethical and behavioral dimensions tends to be slightly closer, possibly due to organizational socialization processes that are still in early stages of consolidation. From the point of view of human talent management, this finding suggests that the integration between the ethical dimension and interpersonal competencies could be strengthened through early training interventions, particularly in young work populations where these associations show a tendency to be more pronounced.

The consistency of the correlation patterns between the two age groups is a methodologically relevant finding, since it supports the validity of the measurement instrument by demonstrating that the relationships between the dimensions evaluated do not present substantial variations attributable to the age of the participants. This stability is particularly significant for the application of the questionnaire in diverse organizational contexts, since it suggests that the factorial structure of the instrument remains invariant in different age segments, which facilitates its use as a diagnostic tool in heterogeneous work populations. The magnitude of the observed correlations, consistently moderate to strong in both groups, supports the notion that the soft skills assessed constitute a system of interrelated competencies whose structure remains stable throughout the working life cycle.

Table 7.- Correlations by group by sex

Correlation	Female (n=51)	Male (n=37)
Integrity - Leadership	0.547**	0.502**
Integrity - Teamwork	0.528**	0.491**
Leadership - Communication	0.758**	0.739**
Team Work - Communication	0.841**	0.832**

The sex-segmented correlation analysis, presented in Table 7, reveals patterns of association between the dimensions of soft skills that remain consistent in both the group of female participants and the group of male participants, with all correlations reaching statistical significance ($p < 0.01$). This finding suggests that the relational structure between the behavioral competencies evaluated does not present substantial differences attributable to the sex of the participants, indicating that the interdependence between the dimensions of the instrument constitutes a phenomenon that transcends gender differences in the context of the Ecuadorian aquaculture sector.

The correlations observed in the female group have coefficients ranging from 0.528 to 0.841, while in the male group the values range from 0.491 to 0.832. This range of coefficients, as well as the order of magnitude of the associations, is practically equivalent between both groups, which suggests that the structure of relationships between the competencies evaluated remains unchanged regardless of the sex of the participants. From a psychometric perspective, this consistency supports the validity of the instrument by demonstrating that the dimensions of the questionnaire maintain stable intercorrelation patterns in different population subgroups, which constitutes a relevant indicator of the robustness of the measure.

The highest correlation in both groups is observed between teamwork and communication, reaching 0.841 in the female group and 0.832 in the male group. This slight difference in favor of women, although minimal, could suggest a slightly closer integration between collaborative capacity and communication skills in the female population. However, the magnitude of the difference is so small that it does not allow conclusive statements to be made in this regard, and the similarity of the coefficients suggests that the relationship between these two competencies constitutes a transversal characteristic, present in an equivalent way in both sexes. From an organizational engineering perspective,

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

this finding is relevant insofar as it indicates that teamwork development programs in the aquaculture sector could be structured in a similar way for female and male populations, taking advantage of the synergistic relationship with communication skills that is consistently manifested in both groups.

The correlation between leadership and communication also shows very similar values between both sexes, with coefficients of 0.758 for the female group and 0.739 for the male group. This proximity in magnitudes suggests that the association between the ability to lead teams and communication skills remains robust and equivalent in women and men, supporting the notion that effective communication constitutes a fundamental component of leadership regardless of the gender of those who exercise management roles. From the perspective of gender equity in the workplace, this finding is particularly relevant, since it suggests that the mechanisms that link communication and leadership competencies operate in a similar way in both sexes, which could contribute to demystifying stereotypical conceptions about gender differences in leadership skills.

The correlations between integrity and leadership show values of 0.547 for the female group and 0.502 for the male group, while the associations between integrity and teamwork reach 0.528 in women and 0.491 in men. In both cases, the coefficients obtained in the female group are slightly higher than those observed in the male group, which could suggest a marginally closer relationship between the ethical dimension and interpersonal competences in the female population. These differences, however, are small enough to be interpreted with caution, and the statistical significance of both correlations in both groups supports the existence of positive relationships between integrity and the other dimensions regardless of sex.

It is important to note that, in general terms, women have slightly higher correlation coefficients than men in all the associations evaluated. This trend, although systematic, is of a small magnitude and does not allow conclusive differences to be established between the two groups. The homogeneity in the correlation patterns is a methodologically relevant finding, since it suggests that the factor structure of the instrument remains invariant in different sex groups, which supports the cross-cultural and gender validity of the questionnaire. From an organizational management perspective, this consistency suggests that the soft skills diagnoses made with this instrument can be interpreted in an equivalent way for female and male populations, without the need to establish differential scales according to the sex of the participants.

The coincidence in the patterns of correlation between men and women is particularly significant for the analysis of soft skills in the Ecuadorian aquaculture sector, since it suggests that the interdependence between the behavioral competencies evaluated constitutes a relatively stable phenomenon, which is not substantially affected by gender differences in socialization processes. professional development or work experiences. This stability of the relationships between dimensions regardless of sex, consistently observed in all the associations evaluated, reinforces the validity of the measurement instrument and provides a solid empirical basis to affirm that the structure of soft skills, at least in the context of the Ecuadorian aquaculture sector, presents a similar behavior in men and women. which facilitates the interpretation and comparison of results in diverse work populations and contributes to the understanding of behavioral competencies as universal constructs in the organizational field.

SECTION 6: RESULTS – Analysis by sex

Table 8.- Descriptive statistics by sex and test of homogeneity of variances.

Dimension	Female (n=51)	Male (n=37)	Levene (F)	p
	Medium (SD)	Medium (SD)		
Integrity	4.08 (0.68)	3.97 (0.70)	0.148	0.701
Leadership	4.35 (0.78)	4.11 (0.95)	1.875	0.174
Teamwork	4.36 (0.89)	4.12 (1.00)	0.861	0.356
Communication	4.32 (0.88)	4.12 (0.99)	0.443	0.507
Problem Solving	4.36 (0.93)	4.19 (0.98)	0.048	0.827

The analysis of descriptive statistics segmented by sex, complemented by the Levene test for the homogeneity of variances, presented in Table 8, reveals systematic but moderate differences in the means of self-perception of soft skills between women and men, accompanied by variances that do not present statistically significant differences between both groups. Women obtain higher average scores in all the dimensions evaluated, with differences ranging from 0.11 points in integrity to 0.24 points in leadership and teamwork, on a scale of 1 to 5 points. This consistent pattern suggests a trend towards a slightly higher self-perception of behavioral competencies in the female population of the Ecuadorian aquaculture sector, although the magnitude of these differences is small and will require statistical significance analysis to determine their relevance.

In the integrity dimension, women have a mean of 4.08 (SD = 0.68) compared to 3.97 (SD = 0.70) in men, which represents a difference of 0.11 points. This difference, while modest, suggests that women tend to perceive themselves as having slightly higher levels of ethical consistency, transparency, and acceptance of mistakes compared to their male peers. The similarity in the standard deviations (0.68 vs. 0.70) indicates comparable variability in both groups, which is confirmed by the Levene test ($F = 0.148$, $p = 0.701$), which shows that the variances do not show significant differences. From a psychometric perspective, the homogeneity of variances is a fundamental requirement

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

for the application of parametric tests for the comparison of means, and in this case it is satisfactorily fulfilled for all the dimensions evaluated.

The leadership dimension presents the most pronounced difference between the two groups, with a mean of 4.35 (SD = 0.78) for women and 4.11 (SD = 0.95) for men, which represents an advantage of 0.24 points in favor of the female sex. This difference, although moderate, is particularly relevant in the context of the aquaculture sector, where leadership roles have traditionally been occupied mostly by men. The higher standard deviation observed in the male group (0.95 vs. 0.78) suggests greater heterogeneity in leadership self-perceptions among men, with some participants reporting very low levels and others very high, while women present more concentrated responses around the mean. Levene's test confirms that this difference in variances does not reach statistical significance ($F = 1.875$, $p = 0.174$), although it is close to the conventional threshold, suggesting a trend towards greater variability in male responses.

In the teamwork dimension, women obtained an average of 4.36 (SD = 0.89) compared to 4.12 (SD = 1.00) in men, with a difference of 0.24 points, also favorable to the female sex. This disparity suggests that women perceive themselves to have greater competencies for group collaboration, the promotion of unity in the work environment and the acceptance of agreements established in teams. The higher standard deviation in the male group (1.00 vs. 0.89) again indicates slightly higher variability in men's responses, although Levene's test ($F = 0.861$, $p = 0.356$) confirms that this difference is not statistically significant.

Communication, a dimension that measures skills linked to expressive clarity, active listening and perception of the emotional state of others, has an average of 4.32 (SD = 0.88) in women and 4.12 (SD = 0.99) in men, with a difference of 0.20 points in favor of women. This result is consistent with the literature suggesting that women tend to develop stronger communicative competencies in relational contexts, possibly due to differential socialization patterns that emphasize emotional expression and empathy. The Levene test ($F = 0.443$, $p = 0.507$) confirms the homogeneity of variances between both groups, validating the use of parametric tests to evaluate the significance of this difference.

Problem solving presents the smallest difference between the two groups, with a mean of 4.36 (SD = 0.93) for women and 4.19 (SD = 0.98) for men, which represents an advantage of 0.17 points for women. This dimension, which assesses competencies linked to the identification of causes of problems, the generation of alternative solutions and the evaluation of results, shows the smallest difference between the sexes, which could suggest that analytical and decision-making skills are more equally distributed between men and women in the context of the aquaculture sector. Levene's test ($F = 0.048$, $p = 0.827$) confirms that the variances are practically equivalent in both groups, which constitutes the most robust result of homogeneity in the entire table.

The analysis of homogeneity of variances, evaluated by Levene's test, shows that in none of the dimensions is the null hypothesis of equality of variances rejected, with probability values ranging from 0.174 in leadership to 0.827 in problem solving. This finding is methodologically relevant, since the homogeneity of variances is a fundamental assumption for the application of Student's t-tests for independent samples, as well as for analyses of variance (ANOVA). The fulfillment of this assumption in all the dimensions evaluated supports the validity of the statistical comparisons made between both groups, providing a solid empirical basis to determine whether the differences observed in the means reach statistical significance.

From an organizational engineering and human talent management perspective, the pattern of observed results suggests that, although women tend to report slightly higher levels of soft skills in all dimensions, the magnitude of these differences is moderate and the homogeneity of variances indicates that the variability in responses is comparable between both sexes. This finding invites reflection on the factors that could be contributing to the observed differences, as well as on the need to implement gender equity policies that promote the equitable development of behavioral competencies in the aquaculture sector, recognizing both the strengths and the areas of opportunity presented by each of the groups. The consistency of the homogeneity of variances in all dimensions also suggests that the measurement instrument behaves stably in different sex groups, which constitutes an additional indicator of its validity and usefulness for organizational diagnostic purposes.

Table 9. Comparison of means between men and women (t-test)

Dimension	t	gl	p	Cohen's d
Integrity	0.726	86	0.470	0.16
Leadership	1.318	86	0.191	0.28
Teamwork	1.175	86	0.243	0.25
Communication	1.000	86	0.320	0.21
Problem Solving	0.847	86	0.399	0.18

Note: Cohen's d = effect size (0.2 = small, 0.5 = medium, 0.8 = large)

The analysis of the comparison of means using the t-test for independent samples, presented in Table 9, reveals that the differences observed in the self-perception scores of soft skills between women and men do not reach statistical significance in any of the five dimensions evaluated. The

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

probability values associated with t-statistics range from 0.191 for leadership to 0.470 for completeness, all of them well above the conventional threshold of 0.05 that would allow the null hypothesis of equality of means to be rejected. This finding suggests that, although women have consistently higher mean scores than men in all dimensions, these differences are not large enough to be considered statistically significant in the context of the sample analyzed.

In the integrity dimension, the t-statistic reaches a value of 0.726 with 86 degrees of freedom and an associated probability of 0.470, indicating that the 0.11-point difference observed between women (M = 4.08) and men (M = 3.97) could be due to chance in approximately 47% of the possible samples. This result suggests that, from a statistical point of view, there is insufficient evidence to affirm that men and women differ in their self-perception of integrity in the context of the Ecuadorian aquaculture sector. The leadership dimension has the highest t-value (t = 1.318, p = 0.191), which indicates that the difference of 0.24 points in favour of women, although the most pronounced of all the dimensions, does not reach statistical significance either, with a probability of type I error of 19.1%.

The dimensions teamwork (t = 1.175, p = 0.243) and communication (t = 1.000, p = 0.320) present similar patterns, with differences of 0.24 and 0.20 points respectively that do not reach statistical significance. Problem-solving shows the lowest t-value (t = 0.847, p = 0.399), consistent with the smallest difference observed between both groups (0.17 points), which reinforces the conclusion that analytical and decision-making skills are perceived similarly between men and women in the Ecuadorian aquaculture sector.

The effect size analysis, calculated using Cohen's d, provides complementary information on the practical magnitude of the observed differences, beyond their statistical significance. The coefficients obtained range from 0.16 for integrity to 0.28 for leadership, all of them in the range considered as small effect size according to conventional criteria (0.2 = small, 0.5 = medium, 0.8 = large). The leadership dimension has the highest effect size (d = 0.28), followed by teamwork (d = 0.25), communication (d = 0.21), problem solving (d = 0.18) and integrity (d = 0.16). These values indicate that, even in the case of the most pronounced difference, the magnitude of the association between sex and soft skills is small, explaining less than 2% of the total variance in leadership scores.

From an organizational engineering and human talent management perspective, the absence of significant differences between men and women in the soft skills evaluated is a relevant finding that suggests that gender does not operate as a determining factor in the self-perception of behavioral competencies in the context of the Ecuadorian aquaculture sector. This result is particularly significant from the point of view of gender equity in the workplace, since it suggests that the competencies associated with leadership, teamwork, communication, integrity and problem-solving are relatively equally distributed between men and women, at least in terms of the self-perception of these skills.

The findings obtained invite reflection on the nature of gender differences in the organizational sphere, suggesting that, in the specific context of the Ecuadorian aquaculture sector, perceptions of soft skills do not present significant biases associated with the sex of the participants. This conclusion, however, must be qualified by the inherent limitations of self-perception measurements, which could be influenced by factors such as social desirability, internalized gender stereotypes or organizational expectations, which could modulate participants' responses according to their sex.

The size of the small effect observed in all dimensions suggests that, even in those cases where the differences are close to statistical significance (such as in leadership, with p = 0.191 and d = 0.28), the practical magnitude of these differences is modest. This finding acquires relevance from an organizational policy perspective, since it indicates that strategies aimed at promoting the development of soft skills in the aquaculture sector do not necessarily require gender-differentiated approaches, at least in terms of self-perception of competencies. The homogeneity in response patterns between men and women suggests that training interventions could be designed with a universal approach, without the need to establish differentiated programs according to the sex of the participants, although always considering that gender equity in professional development requires comprehensive policies that transcend the field of behavioral competencies.

4.- Discussion

4.1. Interpretation of the results

The findings obtained in this research allow us to characterize the soft skills profile of the administrative staff of the Ecuadorian aquaculture sector, revealing high levels of self-perception in all the dimensions evaluated, with means ranging from 4.03 for integrity to 4.29 for problem solving. This pattern of results suggests that participants perceive a solid development of behavioral competencies, particularly in those related to analytical skills, group collaboration, and effective communication. The elevation of scores above 4.0 on a scale of 1 to 5 points could be interpreted as an indicator that administrative staff in the aquaculture sector value their interpersonal skills positively, although it could also reflect the influence of social desirability bias, a frequent phenomenon in self-perception studies where participants tend to overestimate their abilities in dimensions valued by the organization and society. From an organizational engineering perspective, this finding suggests that companies in the sector have a

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

favorable competency base on which to build talent development strategies, although it is recommended to complement self-perception measurements with behavioral performance evaluations or with third-party observations to obtain a more objective approach to the real development of these competencies.

The identification of problem solving as the dimension with the highest average is consistent with the demands of the aquaculture production context, characterized by permanent operational and health contingencies that require rapid adaptive responses and decision-making under uncertainty. This finding suggests that administrative personnel in the sector have developed analytical and decision-making skills that allow them to effectively face the challenges inherent to productive activity. In addition, the integrity dimension has the lowest mean, which could reflect the complexity of measuring constructs linked to ethical behavior in work environments where implicit norms and organizational incentives can influence participants' responses. This observation is particularly relevant from an ethical and organizational perspective, since it suggests that competencies linked to transparency, coherence between values and actions, and the acceptance of errors constitute an area of opportunity for the strengthening of the organizational culture in the aquaculture sector.

The correlation matrix reveals positive and significant associations between all the dimensions evaluated, with coefficients ranging from 0.452 to 0.839, indicating that soft skills do not operate as independent constructs, but as a system of interrelated competencies that influence each other. The highest correlation between teamwork and communication ($r = 0.839$) is conceptually coherent, since the effectiveness of group collaboration depends fundamentally on the ability of team members to exchange information clearly, express opinions in a timely manner, and understand the needs and emotional states of others. This interdependence is particularly relevant in the aquaculture sector, where production operations require constant coordination between different areas and hierarchical levels, and suggests that training interventions aimed at strengthening one of these competencies could have positive effects on the other, thus optimizing the resources allocated to talent development.

The comparative analysis by sex reveals that, although women obtain slightly higher mean scores in all dimensions, these differences do not reach statistical significance, as shown by the probability values obtained in the t-test ($p > 0.05$ in all cases). This finding is particularly relevant from the point of view of gender equity in the workplace, since it suggests that the competencies associated with leadership, teamwork, communication, integrity, and problem-solving are equally distributed between men and women in the context of the Ecuadorian aquaculture sector. The effect sizes, calculated using Cohen's d, are in the small range (0.16 to 0.28), confirming that even the most pronounced differences have a small practical magnitude. This result contributes to demystifying stereotypical conceptions about gender differences in leadership skills and other behavioral competencies, providing empirical evidence that supports the design of equitable professional development policies.

4.2. Comparison with previous studies

The findings obtained are in line with previous research that has documented high levels of self-perception of soft skills in working populations, although particularities linked to the sectoral context of the aquaculture industry are observed. Studies carried out in the field of manufacturing and services have reported similar patterns of favorable self-perception, with means that tend to exceed the midpoint of the scale, suggesting that the tendency to overestimate behavioral competencies is a widespread phenomenon in different organizational contexts. However, research on soft skills in the aquaculture sector specifically is limited, making it difficult to directly compare it with previous studies in the same production field. This knowledge gap highlights the original contribution of the present study, which provides systematic empirical evidence on the behavioral competencies of administrative personnel in an industry of high economic relevance for Ecuador.

In relation to sex differences in soft skills, the findings of the present study present partial coincidences with previous literature, which has reported inconsistent patterns in gender differences. Some research has documented that women tend to perceive themselves as having higher levels in dimensions related to communication and interpersonal skills, while others have not found significant differences, especially when controlling for contextual and occupational variables. The absence of significant differences by sex observed in the present study aligns with the most recent research suggesting that gender differences in soft skills tend to attenuate in professionalized work contexts, where organizational socialization processes and shared occupational roles modulate initial dispositions and promote adaptive behavior patterns based on the demands of the environment. This finding is consistent with theoretical perspectives that emphasize the situated and dynamic nature of soft skills, which are developed in interaction with organizational contexts and accumulated professional experiences.

In terms of age differences, previous research has suggested that soft skills develop and consolidate throughout the life cycle, influenced by work experience and professional maturity. Longitudinal studies have documented that dimensions such as leadership and problem-solving tend to increase with age and career path, reflecting experiential learning and the accumulation of social and psychological capital. In the present study, although no formal statistical comparisons were made by age due to the imbalance in group sizes, the observed correlation patterns between dimensions remained consistent in both age groups, suggesting that the relational structure of soft skills is stable in different population segments. This finding coincides

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

with research that has reported stability in the factorial structure of soft skills measurement instruments in different age groups, supporting their usefulness for diagnostic purposes and organizational development.

The high reliability of the measurement instrument, with Cronbach's alpha coefficients exceeding 0.70 in all dimensions and reaching 0.944 for the total questionnaire, is above the values reported in similar studies in organizational contexts. This result can be attributed both to the robustness of the instrument and to the homogeneity of the sample evaluated, and constitutes a relevant methodological contribution by providing a validated instrument for the evaluation of soft skills in the Ecuadorian aquaculture sector. The comparison with previous studies carried out in Latin America reveals that the reliability coefficients obtained are in the upper range of what was reported, which suggests that the instrument has adequate psychometric properties for its application in similar organizational contexts.

4.3. Theoretical and practical implications

The findings of the present research present relevant theoretical implications for the field of study of soft skills in organizational contexts, particularly with regard to the understanding of the relational structure between competency dimensions. The consistency of the correlations observed between the five dimensions evaluated supports the conceptualization of soft skills as a system of interrelated competencies, where the development of one dimension is positively associated with the development of the others, suggesting the existence of competence transfer mechanisms that could be the subject of future research. This finding contributes to the theoretical debate on the nature of soft skills, supporting perspectives that emphasize their systemic character and integrated development, in contrast to approaches that conceive them as independent constructs. Likewise, the stability of correlation patterns in different population subgroups (by sex and age) provides evidence on the invariability of the structure of soft skills in different population segments, which constitutes a contribution to the knowledge about the universality of these constructs.

From a methodological perspective, the validation of the measurement instrument in the context of the Ecuadorian aquaculture sector constitutes a significant contribution, providing a reliable tool for future research in the sector and in similar production contexts. The reliability coefficients obtained, which far exceed the acceptable thresholds in all dimensions, support the usefulness of the questionnaire for organizational diagnosis purposes and evaluation of talent development programs. This methodological contribution is particularly relevant in the Latin American context, where the availability of validated instruments for the assessment of soft skills in specific productive sectors is limited, and where the adaptation of international instruments requires systematic validation processes that consider the cultural and contextual particularities of the population evaluated.

The practical implications of the findings are particularly relevant for the management of human talent in the Ecuadorian aquaculture sector. The results suggest that, although the administrative staff of the sector presents favorable levels of self-perception in all dimensions, there are areas of opportunity for the strengthening of specific competencies, particularly in integrity, which could be addressed through the design of ethical and behavioral development programs. The absence of significant differences by sex in the soft skills assessed provides evidence that supports the design of equitable professional development policies, which recognize the strengths of all employees regardless of their gender. Likewise, the positive and significant relationships between all dimensions suggest that training interventions aimed at strengthening a specific competence could have multiplier effects on other dimensions, thus optimizing investment in talent development and generating a broader impact on organizational performance.

From an industry perspective, the findings of the study provide valuable insights for aquaculture companies looking to strengthen their organizational capabilities through the development of their human capital. The identification of problem solving as the dimension with the highest level of development suggests that companies in the sector have trained personnel to face the operational and sanitary contingencies that characterize aquaculture activity. However, the relatively lower score in integrity invites reflection on the organizational factors that could be influencing the self-perception of ethical conduct, as well as on institutional policies aimed at strengthening ethical coherence and transparency in labor practices in the sector. The implementation of training programs aimed at strengthening soft skills could significantly contribute to improving the organizational climate, job satisfaction and talent retention, critical factors for the sustainability and competitiveness of the sector in an increasingly demanding global market.

4.4. Limitations and future projections

The present research presents methodological limitations that must be considered for an adequate interpretation and generalization of the findings. First, the cross-sectional design of the study, although appropriate for the objectives set, does not allow establishing causal relationships between the variables evaluated, limiting the ability to determine whether soft skills levels influence organizational performance or if, on the contrary, they are the result of work experiences and contexts. This limitation suggests the need to develop longitudinal studies that allow examining the evolution of soft skills over time and their relationship with objective indicators of organizational performance, thus providing more solid evidence on the underlying causal mechanisms.

Second, the sample size (n = 88), although adequate for the statistical analyses performed, limits the ability to perform

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

more complex analyses, such as structural equation models or confirmatory factor analyses, and restricts the generalization of the findings to other populations in the Ecuadorian aquaculture sector or to other productive contexts. Likewise, the imbalance in the age distribution, with 81.8% of participants in the 21-30 age group, limits the ability to make robust age comparisons and to explore the interactions between sex and age in the configuration of soft skills. Future research could expand the sample size and seek a more balanced distribution by age groups, as well as include participants from different regions of the country or from different subsectors of the aquaculture industry, to assess the generalizability of the findings.

Thirdly, the exclusive use of self-perceptions as a method of assessing soft skills constitutes a significant limitation, given the potential social desirability bias and the tendency to overestimate socially valued skills. Future research could incorporate complementary assessment methods, such as hetero-assessments by supervisors or peers, as well as behavioural assessments based on the observation of specific behaviours in real or simulated situations, which allow self-perceptions to be contrasted with external perceptions and to obtain a more objective approach to the development of the assessed competencies. Triangulation of information sources would help mitigate the biases inherent in self-perception measurements and provide a more complete and accurate picture of the soft skills of the sector's administrative staff.

Finally, the need to deepen the analysis of the contextual and organizational factors that modulate the development of soft skills in the aquaculture sector is projected, including variables such as organizational climate, leadership style, talent management policies and professional development opportunities. Future research could address how these factors interact with individual characteristics to influence soft skills levels, as well as explore the relationship between assessed behavioral competencies and objective indicators of organizational performance, such as productivity, innovation, and talent retention. Likewise, it is suggested that studies be carried out to evaluate the effectiveness of specific training interventions for the development of soft skills in the sector, through experimental or quasi-experimental designs that allow determining the impact of structured training programs on the competencies evaluated, thus contributing to the design of evidence-based strategies for the strengthening of human talent in the Ecuadorian aquaculture industry.

5.- Conclusion.

5.1. Synthesis of findings

The objective of this research was to examine the soft skills present in the administrative staff of the Ecuadorian aquaculture sector and the professional development strategies implemented by the leading companies in the sector in the city of Guayaquil. The findings obtained allow us to conclude that the administrative staff of the sector presents high levels of self-perception in all the dimensions evaluated, with means ranging from 4.03 for integrity to 4.29 for problem solving, on a Likert scale of 1 to 5 points. This pattern of results suggests that participants perceive a solid development of behavioral competencies, particularly those related to analytical capacity, group collaboration and effective communication, competencies that are critical for performance in a sector characterized by the need for rapid response to operational and health contingencies, as occurs in the Ecuadorian aquaculture industry.

The reliability analysis of the measurement instrument confirmed its excellent internal consistency, with Cronbach's alpha coefficients exceeding 0.70 in all dimensions and reaching 0.944 for the total questionnaire. The problem-solving dimension had the highest reliability ($\alpha = 0.938$), followed by communication ($\alpha = 0.920$) and leadership ($\alpha = 0.913$), while integrity, although with a more moderate coefficient ($\alpha = 0.724$), exceeded the minimum threshold recommended for basic research purposes. The correlation matrix revealed positive and significant associations between all dimensions ($p < 0.01$), with coefficients ranging from 0.452 to 0.839, confirming that the soft skills assessed constitute a system of interrelated competencies, where the development of one dimension is positively associated with the development of the others.

Comparative analysis by sex revealed that, although women obtained slightly higher mean scores in all dimensions, these differences did not reach statistical significance ($p > 0.05$), with effect sizes in the small range (Cohen's d between 0.16 and 0.28). This finding suggests that gender is not a determining factor in the self-perception of soft skills in the context of the Ecuadorian aquaculture sector, which supports the design of equitable professional development policies. The correlation patterns between dimensions remained consistent in the different population subgroups (by sex and age), which indicates the stability of the soft skills structure in different population segments and supports the validity of the measurement instrument for its application in diverse labor populations.

5.2. Scientific and technical contributions

The present study makes significant contributions to scientific knowledge in the field of soft skills in organizational contexts, particularly in the Ecuadorian aquaculture sector, a productive area of high economic relevance for the country where empirical evidence on behavioral competencies was limited. The research provides a systematic characterization of the soft skills profile of administrative personnel in the sector, identifying the most developed dimensions (problem solving, teamwork and leadership) and those with relatively lower levels (integrity), information that contributes to understanding the configuration of behavioral competencies in a specific productive context and that can guide the design of strategies for the development of talent aligned with the needs of the sector.

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

From a methodological perspective, the study provides the validation of an instrument for measuring soft skills in the context of the Ecuadorian aquaculture sector, providing evidence on its psychometric properties in this specific population. The reliability coefficients obtained, which far exceed the acceptable thresholds in all dimensions, support the usefulness of the questionnaire for future research in the sector and provide a methodological basis for its application in other similar production contexts. This contribution is particularly relevant in the Latin American context, where the availability of validated instruments for the assessment of soft skills in specific productive sectors is limited, and where the adaptation of international instruments requires systematic validation processes that consider the cultural and contextual particularities of the population evaluated.

The study also contributes to the knowledge about gender differences in soft skills, providing empirical evidence that suggests that, in the context of the Ecuadorian aquaculture sector, behavioral competencies are equally distributed between men and women. This finding contributes to demystifying stereotypical conceptions about gender differences in leadership skills and other behavioral competencies, providing evidence that supports the design of equitable professional development policies in the sector. Likewise, the consistency of correlation patterns between dimensions in different population subgroups is a finding that supports the universality of the soft skills structure and suggests that organizational socialization processes can modulate initial dispositions, promoting adaptive behavior patterns according to the demands of the work environment.

5.3. Theoretical implications and practical applications

The findings of the present study present relevant theoretical implications for the field of study of soft skills in organizational contexts. The consistency of the correlations observed between the five dimensions evaluated supports the conceptualization of soft skills as a system of interrelated competencies, where the development of one dimension is positively associated with the development of the others, suggesting the existence of competence transfer mechanisms that could be the subject of future research. This finding contributes to the theoretical debate on the nature of soft skills, supporting perspectives that emphasize their systemic character and integrated development, in contrast to approaches that conceive them as independent constructs. Likewise, the stability of correlation patterns in different population subgroups provides evidence on the invariability of the structure of soft skills in different population segments, which constitutes a contribution to the knowledge about the universality of these constructs and their applicability in diverse organizational contexts.

The practical implications of the findings are particularly relevant for the management of human talent in the Ecuadorian aquaculture sector. The results suggest that, although the administrative staff of the sector presents favorable levels of self-perception in all dimensions, there are areas of opportunity for the strengthening of specific competencies, particularly in integrity, which could be addressed through the design of ethical and behavioral development programs. The implementation of training programs aimed at strengthening soft skills could significantly contribute to improving the organizational climate, job satisfaction and talent retention, critical factors for the sustainability and competitiveness of the sector in an increasingly demanding global market. The absence of significant differences by sex in the soft skills assessed provides evidence that supports the design of equitable professional development policies, which recognize the strengths of all employees regardless of their gender.

From an industry perspective, the findings of the study provide valuable insights for aquaculture companies looking to strengthen their organizational capabilities through the development of their human capital. The identification of problem solving as the dimension with the highest level of development suggests that companies in the sector have trained personnel to face the operational and sanitary contingencies that characterize aquaculture activity. The positive and significant relationships between all dimensions suggest that training interventions aimed at strengthening a specific competence could have multiplier effects on other dimensions, thus optimizing investment in talent development and generating a broader impact on organizational performance. In a context where automation and artificial intelligence are constantly transforming the labor landscape, the strengthening of human skills that cannot be replicated by machines acquires strategic relevance, positioning companies that invest in the development of these competencies as leaders in their respective markets and contributing to the positioning of the Ecuadorian aquaculture sector as a benchmark of excellence and sustainability in the region.

5.4. Projections and lines of future research

Based on the findings and limitations of this study, several lines of future research are projected that would allow deepening, validating or expanding the results obtained. First, it is suggested that longitudinal studies be carried out to examine the evolution of soft skills over time and their relationship with objective indicators of organizational performance, such as productivity, innovation and talent retention, providing more solid evidence on the underlying causal mechanisms and overcoming the limitations of cross-sectional design. The implementation of quasi-experimental designs that evaluate the impact of specific training interventions on the development of soft skills would allow to determine the effectiveness of structured training programs and would provide evidence for the design of strategies based on empirical data.

Secondly, it is recommended to expand the geographical and sectoral scope of the study, including participants from different regions of the country where aquaculture activity is carried out and from different subsectors of the industry, such as larval production, fattening, processing and marketing, as well as to include operational and technical

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

personnel to evaluate the differences in competence profiles according to the hierarchical level and the function performed. Expanding the sample size would allow for more complex analyses, such as structural equation models or confirmatory factor analyses, which would contribute to a deeper understanding of the structure and dynamics of soft skills in the sector.

Thirdly, it is suggested that complementary assessment methods be incorporated to contrast self-perceptions with external perceptions and to obtain a more objective approach to the development of the competencies assessed. The integration of heteroassessments by supervisors and peers, as well as behavioural assessments based on the observation of specific behaviours in real or simulated situations, would help mitigate the biases inherent in self-perception measures and provide a more complete and accurate picture of the soft skills of administrative staff in the sector. Finally, the need to deepen the analysis of the contextual and organizational factors that modulate the development of soft skills, including variables such as organizational climate, leadership style, talent management policies and professional development opportunities, is projected, which allows us to understand how these factors interact with individual characteristics to influence soft skills levels. thus contributing to the design of comprehensive strategies to strengthen human talent in the Ecuadorian aquaculture industry.

6.- Acknowledgements (if applicable)

Not applicable.

7.- Contributions of authors (Taxonomy of contributors' roles - CRediT)

1. Conceptualization: Jorge Meza-Clark; Teresa Meza-Clark
2. Data curation: Jorge Meza-Clark; Teresa Meza-Clark
3. Formal analysis: Francisco Javier Duque-Aldaz; Fernando Raúl Rodríguez-Flores
4. Acquisition of funds: Not applicable
5. Research: Edwin Haymacaña Moreno; Leonor Alejandrina Zapata Aspiazu
6. Methodology: Jorge Meza-Clark; Teresa Meza-Clark
7. Project management: Francisco Javier Duque-Aldaz; Fernando Raúl Rodríguez-Flores
8. Resources: Jorge Meza-Clark; Teresa Meza-Clark
9. Software: Francisco Javier Duque-Aldaz; Fernando Raúl Rodríguez-Flores
10. Supervision: Jorge Meza-Clark; Teresa Meza-Clark
11. Validation: Edwin Haymacaña Moreno; Leonor Alejandrina Zapata Aspiazu
12. Visualization: Jorge Meza-Clark; Teresa Meza-Clark
13. Writing - original draft: Jorge Meza-Clark; Teresa Meza-Clark
14. Writing - revision and editing: Francisco Javier Duque-Aldaz; Fernando Raúl Rodríguez-Flores

8.- Appendix (Only if they exist)

Not applicable.

9.- References.

[1] M. A. Baque Cantos and A. L. Román Choez, "PROFESSIONAL SKILLS AND LABOR PERFORMANCE IN THE SUINAV COMPANY OF THE CITY OF GUAYAQUIL," State University of the South of Manabí, 2025.

[2] L. O. Cujilema Estrella, J. M. Morocho Ordoñez, M. D. R. Carvajal Parra and P. Mesa Villavicencio, «Competencies for food productive development in the UEF UNE-Ecuador-2023,» *Multidisciplinary Scientific-Academic Journal*, vol. 9, no. 2, 2024.

[3] L. P. Sucari Gonzales and J. K. Fuster Gómez, "Soft Skills and Leadership Styles of the Administrative Staff of the Provincial Municipality of Pasco – 2024," Daniel Alcides Carrión National University, 2025.

[4] H. A. Hernández, L. V. Taquez Hoyos, and D. C. Cortez Mosquera, "Use of Artificial Intelligence in Project Management," *RHS*, vol. 13, no. 2, 2025.

[5] J. A. Asanza Choez and J. J. Abad Moreira, "EFFECTIVE LEADERSHIP AND ITS INFLUENCE ON THE FULFILLMENT OF GOALS IN LEADERSHIP SOLUTIONS UXPS S.A," Universidad Estatal del Sur de Manabí, 2026.

[6] B. R. Quispe Saenz and I. B. Pomalaza Buendia, "Transformative leadership and the development of managerial competencies in the District Municipality of Santa Ana de Tusi, Daniel A. Carrión Province, Pasco Region 2023," Daniel Alcides Carrión National University, 2024.

[7] R. García Rodríguez and K. V. Morán Nieto, "Basic professional skills in the handling of vegetative material and the training of agricultural technical high school students.," State University of the South of Manabí, 2026.

[8] H. S. Gómez León, K. C. Jiménez Huamali and J. A. Ricaldi Baldeón, "Soft skills and work performance of the collaborators of the regional directorate of housing, construction and sanitation - Pasco, 2021," Daniel Alcides Carrión National University, 2023.

[9] E. Sarmiento Leon, R. Sarmiento Huacho and M. A. Ventura Janampa, "Gamification and the

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

development of Soft Skills in students of the fourth grade of secondary school of the Daniel Alcides Carrión Educational Institution of Chipipata, Yanahuanca – 2024," Daniel Alcides Carrión National University, 2025.

[10] M. Domínguez Vargas and C. P. Méndez Cruz, "Impact of Digitalization on the Efficiency of Cooperatives," *Transcend, accounting and management*, vol. 9, no. 27, 2024.

[11] G. A. Falcon Justiniano and L. D. C. Muñoz Cornejo, "Soft skills and the labor efficiency of servers in the District Municipality of Tinyahuarco Foundry, 2022," Daniel Alcides Carrión National University, 2024.

[12] V. Badenes-Plá and J. Molares-Cardoso, «Artificial intelligence in the face of the challenges of the fashion industry. Benefits and applications in the commercialization and marketing phase," *Razón y Palabra*, vol. 27, no. 118, 2023.

[13] A. Santamaría Barraza, "The Influence of the Use of Strategic Planning of Operational Capacity on the Operations Management of Logistics Companies in Panama," *Research and Critical Thinking*, vol. 12, no. 3, 2024.

[14] K. Mansilla-Obando and G. R. Llanos, "Adoption of Micromobility Applications in Chile: TAM and Collaborative Consumption," *RETOS.*, vol. 16, no. 31, 2026.

[15] P. Valle Venegas and A. E. Yancan Camahuali, "Soft skills of the teacher and the development of scientific literacy in students of the Educational Institutions of the secondary level of the district of Yanacancha - Pasco," Daniel Alcides Carrión National University, 2025.

[16] J. D. Villanes Casimiro, F. Sánchez Cárdenas and L. Rojas Victorio, "Soft skills and labor performance of the workers of the ECOSERM Rancas Company, 2024," Daniel Alcides Carrión National University, 2025.

[17] E. Haymacaña Moreno, L. A. Zapata Aspiazu, F. J. Duque-Aldaz, G. F. Cabezas García y R. A. Sánchez Ancajima, Time series modeling of secondary school enrollment in Ecuador: a Box–Jenkins analysis (1971–2023), Inquide, 2026.

[18] F. J. Duque-Aldaz, E. R. Haymacaña Moreno, L. A. Zapata Aspiazu y F. Carrasco Choque, «Prediction of moisture content in the cocoa drying process by simple linear regression.,» *Inquide*, vol. 6, nº 2, 2024.

[19] A. K. Lopez Marcelo, A. Huacho Cornelio and R. Cuevas Cipriano, "Management leadership program for the development of soft skills in teachers of the Integrated Educational Institution No. 31756 Ricardo Palma, Pasco – 2023," Daniel Alcides Carrión National University, 2024.

[20] A. D. Carhuachin Yapias, J. A. Vargas Lopez and Y. A. Paita Panez, "Soft skills and business competitiveness in the Mining Construction Company Environmental Affairs and Transport Huayllay S.A. – 2023," Daniel Alcides Carrión National University, 2024.

[21] D. K. Peña Ponce and D. J. Pozo Cacao, "SOFT SKILLS IN THE DEVELOPMENT OF COMMUNITY PROJECTS OF THE PARISH DECENTRALIZED AUTONOMOUS GOVERNMENT OF CASCOL," State University of the South of Manabí, 2026.

[22] G. E. Castro Rosales, A. D. Torres Alvarado, L. S. Zalamea Cedeño, F. J. Duque-Aldaz y F. R. Rodríguez-Flores, «Comprehensive Ergonomic Proposal for the Reduction of Musculoskeletal Risks in Soap Production: An Approach Based on Statistical Analysis and Postural Evaluation,» *Inquide*, vol. 7, nº 2, 2025.

[23] L. A. Zapata Aspiazu, E. Haymacaña Moreno, F. J. Duque-Aldaz, F. G. Cabezas García y R. A. Sánchez Ancajima, «ARIMA vs. Hybrid Models with Machine Learning for Forecasting Ecuador's GDP.,» 2026.

[24] V. E. García Casas and F. J. Duque-Aldaz, "Improvement of capacities in the management of handling, hygiene and biosecurity protocols for the cabins-restaurants of the Playas canton in times of Covid-19," *Journal of Science and Research, vol* . 8, no. 3, 2022.

[25] G. J. Morocho Choca, L. Á. Bucheli Carpio y F. J. Duque-Aldaz, «Fuel oil fuel dispatch optimization through multivariate regression using local storage indicators.,» *Inquide*, vol. 6, nº 2, 2024.

[26] F. Duque-Aldaz, E. Pazán Gómez, W. Villamagua Castillo and A. López Vargas, «Occupational health and safety management system according to ISO:45001 in cosmetic and natural laboratory,» *Scientific Journal Science and Technology*, vol. 24, no. 41, 2024.

[27] V. E. García Casas, F. J. Duque-Aldaz and M. Cárdenas Calle, «Design of a plan of good manufacturing practices for restaurant cabins in

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

the canton General Villamil Playas,» *Magazine De Las Ciencias: Revista De Investigación e Innovación*, vol. 8, nº 4, 2023.

[28] F. J. Duque-Aldaz, F. R. Rodríguez-Flores and J. Carmona Tapia, «Identification of parameters in ordinary differential equation systems through the use of artificial neural networks,» *Revista San Gregorio*, vol. 1, nº 2, 2025.

[29] F. J. Duque-Aldaz, J. P. Fierro Aguilar, H. A. Pérez Benítez and G. W. Tobar Farías, «Affectation of environmental noise to Educational Institutions; set of actions from Citizen Participation and Educational Centers," *Journal of Science and Research*, vol. 8, no. 2, 2023.

[30] J. E. Estiven Pincay Moran, J. F. Ramírez Salcan, A. F. López Vargas, F. J. Duque-Aldaz, W. Villamagua Castillo y R. Sánchez Casanova, «Evaluation and Proposal for an Environmental Management System in a Mango Plantation,» *Inquide*, vol. 7, nº 1, 2025.

INQUIDE
Chemical Engineering & Development
Journal of Science and Engineering

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

INQUIDE
Ingeniería Química y Desarrollo

Guidelines for publication in the journal INQUIDE – Chemical Engineering and Development

1. General Information

INQUIDE – Chemical Engineering and Development is a multidisciplinary scientific journal edited by the Faculty of Chemical Engineering of the University of Guayaquil, located in Guayaquil, Ecuador. Published since January 2015, the journal has a biannual periodicity and focuses on original contributions in the area of science and engineering.

INQUIDE is a peer-reviewed journal that uses a peer-reviewed external review system, under the double-blind review methodology, following the publication standards of the Institute of Electrical and Electronics Engineers (IEEE). This system guarantees an objective, impartial and transparent review process, which facilitates the inclusion of the journal in databases, repositories and international reference indexes.

Currently, INQUIDE is indexed in:

1.- Latindex Catalog 2.0 (Regional Online Information System for Scientific Journals of Latin America, the Caribbean, Spain and Portugal).

2.- Dialnet (Dialnet Foundation, University of La Rioja).

3.- Network of Ecuadorian Editors and Scientific Journals (RERCIE).

4.- Crossref, with DOI (Digital Object Identifier) assignment for each published article.

The journal is published in electronic format (e-ISSN: 3028-8533) and accepts manuscripts in Spanish, English and Portuguese, promoting the dissemination of high-quality research at an international level.

2. Scope and Policy

2.1. Theme

INQUIDE – Chemical Engineering and Development publishes original contributions in the area of science and engineering, with a multidisciplinary approach. Research works carried out by national and international authors are accepted, as long as they meet the required scientific quality criteria.

2.2. Types of contributions

The journal prioritizes the publication of:

- Empirical research articles that present original and significant results.
- Technology development reports describing innovations or practical applications in engineering and science.
- Proposals for innovative models and solutions that contribute to the advancement of knowledge.
- State-of-the-art reviews that synthesize and critically analyze current knowledge in a specific area.
- Essay articles that present theoretical or methodological reflections relevant to the field.

2.3. Originality requirements

INQUIDE only publishes original and unpublished works written in Spanish, English or Portuguese. Manuscripts must not have been previously published in any print or electronic media, nor be in the process of arbitration or publication in another journal.

2.4. Arbitration process

All submitted articles will be subjected to a rigorous peer-review process under the double-blind review methodology. The evaluation is based on criteria of:

- Originality: The work must present novel contributions to the field.
- Relevance: The topic must be relevant to the areas of science and engineering.
- Topicality: The study should be based on recent literature and address contemporary issues.
- Scientific rigor: The methodology and results must be solid and well-founded.
- Compliance with editorial standards: The manuscript must follow the format and style guidelines of the journal.

The receipt of a manuscript does not imply a commitment to publication. The final decision to publish will be made by the Editorial Board, based on the recommendations of the specialized reviewers.

2.5. Required Documents

Authors must submit the following documents along with their manuscript:

1. Checklist: Available for download in https://1drv.ms/w/c/7bce1d25160b4657/EdRL-JU4fBVBqSt1GD7t1N8BZVFXYapjNxM8ji3Fa9LFhA?e=Z7OqeO.
2. Presentation and assignment of rights: Available for download in https://1drv.ms/w/c/7bce1d25160b4657/EZYnPTveWCtKgV5aNNZ1icQBdaFzvOYKCLwlhD7GC76hzg?e=ldbXMf .

2.6. Submission of manuscripts

Manuscripts must be submitted through the journal's Open Journal System (OJS), available at:
https://revistas.ug.edu.ec/index.php/iqd/information/authors.

Additionally, authors can send queries or complementary documents to the email:
inquide@ug.edu.ec or francisco.duquea@ug.edu.ec.

3. Presentation and structure of manuscripts

All manuscripts submitted to INQUIDE must follow the format established by the journal. The rules and requirements for the presentation and structure of the articles are detailed below:

3.1. Manuscript format

- Manuscripts must be written in Microsoft Word (formato.doc or .docx).
- The official template of the magazine can be downloaded from: https://1drv.ms/w/c/7bce1d25160b4657/EXSf2GX2MuJEn-hf5qwsswUBzx4-1vYE_6qKE8ba2UF62g?e=68U2h9 .

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

- The document must be in a double column, with the following margins: Top: 3.5 cm, Bottom: 3.5 cm, Left: 1.5 cm, Right: 1.5 cm
- Use Times New Roman font, size 10, justified, with single line spacing and 0 spacing.

3.2. Manuscript structure

3.2.1. Presentation and Cover Letter

1. Título (spanish) / Title (english):
   - It should be concise but informative, with a maximum of 20 words.
   - If the article is written in Spanish, the title in English should appear on the second line, and vice versa.
2. Authors and affiliation:
   - Include the full names and surnames of all authors, in the order of preference.
   - Specify the institutional affiliation of each author, including: Dependency and institution; Institutional email; ORCID; City and country.
   - Note: A maximum of 40% of authors may be affiliated with the University of Guayaquil.
3. Abstract (Spanish) / Abstract (English):
   - Maximum length of 250 words in both languages.
   - It should include:
     1. Justification of the topic.
     2. Objectives.
     3. Methodology and sample.
     4. Main results.
     5. Main conclusions.
4. Palabras clave (español) / Keywords (inglés):
   - Provide a maximum of 7 keywords in each language, directly related to the topic of the job.
   - It is recommended to use terms from the UNESCO Thesaurus.
5. Cover Letter:
   - Include a statement certifying that the manuscript is an original contribution, not submitted or under review in another journal.
   - Confirm authorship and acceptance of formal changes according to journal standards.
   - Download the Cover Letter format from:

https://1drv.ms/w/c/7bce1d25160b4657/EdRL-JU4fBVBqSt1GD7t1N8BZVFXYapjNxM8ji3Fa9LFhA?e=Z7OqeO
https://1drv.ms/w/c/7bce1d25160b4657/EZYnPTveWCtKgV5aNNZ1icQBdaFzvOYKCLwlhD7GC76hzg?e=ldbXMf

3.2.2. Manuscript structure

1. Introduction:
   - Present the research problem, context, rationale, and objectives of the study.
   - Include a review of the most relevant and current literature, both nationally and internationally.
2. Materials and methods:
   - Describe the methodology, materials, experimental design and procedures in a clear and detailed manner.
   - If an original methodology is used, explain its rationale and possible limitations.
3. Results:
   - Present results in a clear and organized manner, using tables, graphs, and figures when necessary.
   - Avoid duplication of data between text and tables/figures.
4. Discussion:
   - Interpret the results, relating them to the objectives of the study and the existing literature.
   - Discuss the theoretical and practical implications of the findings.
5. Conclusions:
   - Summarize the most important findings of the study.
   - Highlight the contributions of the work and propose future lines of research.
6. Acknowledgements (optional):
   - Acknowledge funding sources, collaborators, or institutions that supported the research.
7. References:
   - Follow the IEEE style for citations and the reference list.
   - Use the Microsoft Word reference manager to manage citations.
   - Make sure all references are cited in the text and vice versa.

3.3. Figures, tables and equations

- Figures and tables:
  - They must be numbered consecutively (Fig. 1, Table 1, etc.) and cited in the text.
  - The figures must have a minimum resolution of 300 dpi and be in JPG, PNG format.
  - Tables should have a title above and figures a title below.
- Equations:
  - Use the Microsoft Word equation editor.
  - Number the equations consecutively, placing the number in parentheses and aligned to the left.

3.4. Submission of the manuscript

- Manuscripts must be submitted through the journal's Open Journal System (OJS): https://revistas.ug.edu.ec/index.php/iqd/information/authors.
- Be sure to load:
  - The manuscript in Word format (.doc or .docx).
  - The figures in separate files, with the appropriate resolution and format.
  - The Cover Letter and other required documents.

4. Submission Process

The submission of manuscripts to INQUIDE must be carried out following the following steps and requirements:

4.1. Shipping platform

- All manuscripts must be submitted through the journal's Open Journal System (OJS), available at: https://revistas.ug.edu.ec/index.php/iqd/information/authors.

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

- Authors must register on the OJS platform before submitting.

4.2. Required Documents

At the time of submission, authors must upload the following documents:

1. Manuscript in Word format (.doc or .docx):
   - The paper should follow the format and structure established by the journal (see section 3).
   - Include full author data and their institutional affiliation.
2. Figures and tables:
   - Figures must be sent in separate files, in JPG, PNG format, with a minimum resolution of 300 dpi.
   - Tables should be included in the manuscript, following the format indicated in section 3.
3. Cover Letter:
   - Include a statement certifying that the manuscript is an original contribution, not submitted or under review in another journal.
   - Confirm authorship and acceptance of formal changes according to journal standards.

Descargue el formato de Cover Letter desde: https://1drv.ms/w/c/7bce1d25160b4657/EZYnPTveWCtKgV5aNNZ1icQBdaFzvOYKCLwlhD7GC76hzg?e=ldbXMf

4. Checklist:

- Make sure that the manuscript meets all technical and formatting requirements.

Download the checklist from: https://1drv.ms/w/c/7bce1d25160b4657/EdRL-JU4fBVBqSt1GD7t1N8BZVFXYapjNxM8ji3Fa9LFhA?e=Z7OqeO

4.3. Correspondence Manager

- One of the authors must be designated as **the correspondence officer**.
- This author will be the primary point of contact for all manuscript-related communications.

4.4. Confirmation of receipt

- Once the manuscript has been submitted, the OJS system will automatically send a confirmation email to the corresponding author.

4.5. Inquiries and Support

- For inquiries about the submission process or technical problems, authors can contact the editorial team through the following emails:
  - inquide@ug.edu.ec
  - francisco.duquea@ug.edu.ec

5. Editorial Process

INQUIDE's editorial process is designed to guarantee the quality, originality and scientific rigor of the published manuscripts. The process is described step by step below:

5.1. Initial review

Once the manuscript is received, the editorial team performs an initial review to verify the following aspects:

1. Theme: The manuscript must be within the thematic scope of the journal (science and engineering).
2. Format and structure: The manuscript must follow the format and structure established by the journal (see section 3).
3. Citations and references: All bibliographic references must be correctly cited in the text, following the IEEE style.
4. Originality: The manuscript will be subjected to a plagiarism check using specialized software. A maximum of 15% similarity to other works is accepted.

If the manuscript does not meet any of these requirements, the author will be asked to make the necessary corrections before continuing with the evaluation process.

5.2. Peer-Review

Manuscripts that pass the initial review will be subjected to a rigorous peer review process under the double-blind review methodology. This process includes the following steps:

1. Assignment of reviewers:
   - The editor will assign at least two reviewers specialized in the subject area of the manuscript.
   - The reviewers can be national or international experts.
2. Evaluation:
   - Reviewers will evaluate the manuscript based on criteria such as originality, relevance, scientific rigor, clarity, and contribution to the field.
   - Each reviewer will issue a report with one of the following results:
     - Publishable without changes.
     - Publishable with suggested changes.
     - Publishable with mandatory changes.
     - Not publishable.
3. Editorial decision:
   - The editor will analyze the reviewers' reports and make a final decision on whether to accept or reject the manuscript.
   - If the manuscript is accepted, the author will be notified to make the suggested changes (if applicable).
   - If the manuscript is rejected, the author will be notified and the paper will be archived.

5.3. Review Time

- The peer review process lasts a minimum of 4 weeks.
- At the end of this period, the author will be notified of the outcome of the evaluation and the recommendations of the reviewers.

5.4. Corrections and final version

- If the manuscript is accepted with changes, the author must send the corrected version within the deadline established by the editor.
- The editorial team will verify that the requested corrections have been correctly incorporated before proceeding with the publication.

5.5. Publication

- Accepted manuscripts will be published in the biannual issues of the journal (January and July).

Vol. 08 / Nº 02
e – ISSN: 3028-8533
ISSN – L: 3028-8533

- Authors will receive a notification once their work is available on the journal's platform.

6. Publication

INQUIDE – Chemical Engineering and Development publishes two issues a year, on the following dates:

- First issue: January 1.
- Second issue: July 1.

6.1. Shipping times

To ensure that manuscripts are considered in the corresponding issues, authors must take into account the following deadlines:

- Manuscripts for the January issue: Must be submitted by October 31 of the previous year.
- Manuscripts for the July issue: They must be submitted by April 30 of the same year.

6.2. Availability of Articles

- Once published, the articles will be available on the journal's electronic platform, accessible through: https://revistas.ug.edu.ec/index.php/iqd.
- Each published article will include a DOI (Digital Object Identifier), which guarantees its identification and permanent access.

6.3. Open Access Policy

INQUIDE is an open access journal, which means that all articles are freely available for reading, downloading and distribution, under a Creative Commons license.

7. Information on the use of Artificial Intelligence

INQUIDE recognizes the importance of maintaining high ethical standards in scientific research, especially in the use of Artificial Intelligence (AI). Therefore, the following guidelines are established:

7.1. Use of AI in research

- If Artificial Intelligence has been used at any stage of the research presented in the manuscript, authors must explicitly state this in the Cover Letter.
- Specify the sections of the manuscript where AI has been used, describing their function and scope.

7.2. Transparency and accountability

- Authors are responsible for ensuring that the use of AI does not compromise the originality, integrity, and scientific rigor of the work.
- The editorial team will evaluate the AI usage statement and may request additional information if necessary.

7.3. Accepting Manuscripts with AI

- The final decision on the acceptance of manuscripts that have used AI is at the discretion of the Editorial Board, based on transparency and compliance with the journal's ethical standards.

INQUIDE

We explore the unknown, solve the impossible.
Welcome to the frontier of knowledge.

Visits by country.

Principal Contact
Francisco Javier Duque-Aldaz
University of Guayaquil
francisco.duquea@ug.edu.ec
inquide@ug.edu.ec

Turn your research into a legacy.
Send us your paper and join a high impact scientific community.