



Revista Internacional de Investigación e Innovación Tecnológica

Página principal: www.riit.com.mx

School Aquaponic System and Nutrition Education as a Technological Innovation Applied to Preschool Education in Hermosillo, Sonora: Narrative Review

Sistema Acuapónico Escolar y Educación Nutricional Como Innovación Tecnológica Aplicada a la Educación Preescolar de Hermosillo, Sonora: Revisión Narrativa

Félix-Gutiérrez, A.^a, Ruiz-Bustos, E.^a, González-Lomelí, D.^a, Díaz-Zavala, R.G.^a, Renganathan, P.^b, Rueda-Puente, E.O.^{c*}

^a Departamento de Ciencias Químico-Biológicas; Universidad de Sonora; C.P. 83000, Hermosillo, Sonora, México. ORCID: <https://orcid.org/0009-0009-4400-9377>, <https://orcid.org/0000-0002-9539-3569>, <https://orcid.org/0000-0001-6683-1008>, <https://orcid.org/0000-0001-9104-409X>.

^b Departamento of Bioecología y Educación Biológica. M. Aknullah Bashkir State Pedagogical University, 450000 Ufa, Russia. ORCID: <https://orcid.org/0000-0002-2975-4688>.

^c Departamento de Agricultura y Ganadería; Universidad de Sonora; C.P. 83000, Hermosillo, Sonora, México. ORCID: <https://orcid.org/0000-0002-9724-0558>^{*}.

a214206118@unison.mx; eduardo.ruiz@unison.mx; dgonzalez@psicom.uson.mx; giovanni.diaz@unison.mx; prabhakaran06@gmail.com; edgar.rueda@unison.mx^{*}

Technological innovation: Development and analysis of an intervention combining an aquaponics system and nutritional education for preschool children.

Industrial application area: Health sciences.

Received: December 8, 2025

Accepted: April 29, 2026

Resumen

Este artículo presenta una revisión narrativa sobre la relación entre alimentación y procesos cognitivos en la primera infancia, y examina la pertinencia de una innovación tecnológica basada en un sistema acuapónico escolar articulado con un programa de educación nutricional. A partir de literatura académica y documentos técnicos en ciencias nutricionales, neuropsicología del desarrollo y educación preescolar, se organiza un marco de referencia que vincula el estado nutricional, el funcionamiento cognitivo y las experiencias de aprendizaje activo en niñas y niños de 4 a 5 años. El sistema acuapónico se plantea como un módulo escolar de pequeña escala instalado en el preescolar, con un acuario, recirculación de agua hacia tubos de cultivo y producción de hortalizas como lechuga y tomate, articulado con actividades de educación nutricional y observación cognitiva. La evidencia revisada indica que ciertos patrones dietéticos y

deficiencias de micronutrientes se asocian con alteraciones en atención, memoria y autorregulación, mientras que los entornos pedagógicos que incluyen huertos o sistemas de cultivo estimulan la curiosidad, el lenguaje y la participación significativa. Se plantea que un sistema acuapónico escolar, acompañado de educación nutricional estructurada, puede funcionar como dispositivo integrador para promover salud y desarrollo en contextos escolares públicos. La principal limitación identificada es la escasez de estudios que integren acuaponía, evaluación cognitiva y currículo preescolar en América Latina. Se concluye que la propuesta constituye un modelo innovador aplicable al diseño de intervenciones educativas orientadas a la salud, cuya eficacia deberá evaluarse mediante estudios empíricos controlados.

Palabras clave: acuaponía, cognición infantil, educación nutricional, innovación tecnológica, preescolar.

Abstract

This article presents a narrative review of the relationship between diet and cognitive processes in early childhood and discusses the relevance of a technological innovation based on a school aquaponic system combined with a structured nutrition education program. Drawing on academic literature and technical documents in nutritional sciences, developmental neuropsychology, and preschool education, the article constructs a conceptual framework that links nutritional status, cognitive functioning, and active learning experiences in 4- to 5-year-old children. The aquaponic system is proposed as a small-scale school module installed in the preschool setting, including an aquarium, water recirculation through cultivation pipes, and the production of vegetables such as lettuce and tomato, integrated with nutrition education activities and cognitive observation. Reviewed evidence shows that specific dietary patterns and micronutrient deficiencies are associated with alterations in attention, memory, and self-regulation, while pedagogical environments that incorporate gardening or cultivation systems enhance curiosity, language, and meaningful participation. The article proposes that a school-based aquaponic system, integrated with nutrition education, can serve as a pedagogical device to promote health and development in public school settings. The main limitation identified is the lack of empirical studies that combine aquaponics, cognitive assessment, and preschool curricula in Latin America. It is concluded that the proposed model offers a solid foundation for the design of health-oriented educational interventions, whose effectiveness should be tested through controlled and replicable studies.

Keywords: aquaponics, cognitive development, nutrition education, preschool, technological innovation.

1. Introduction

Early childhood is a period of heightened biological and social sensitivity, during which cognitive functions are consolidated and eating patterns are established that tend to persist into adulthood¹. In Mexico, this process occurs

amidst a food transition characterized by the coexistence of chronic malnutrition.

This can lead to micronutrient deficiencies and high prevalence of childhood overweight and obesity, a phenomenon known as the double burden of malnutrition. Various analyses of

national surveys have documented the presence of stunted growth and excess weight, as well as the association between low fruit and vegetable consumption and a higher risk of overweight².

In this context, nutritional sciences face the challenge of developing interventions that go beyond the one-way transmission of information and sustainably modify the food environment and learning experiences. One emerging strategy is the establishment of school gardens and, more recently, aquaponic systems, understood as production units that integrate aquaculture and hydroponics in a water and nutrient recirculation circuit^{3,4}.

In these systems, fish metabolic waste is transformed by microorganisms into compounds usable by plants, while the roots help purify the water, allowing for efficient resource use and the production of nutrient-dense vegetables⁵.

In addition to its agronomic interest, school aquaponics is emerging as a Science, Technology, Engineering, and Mathematics (STEM) learning environment that allows children to observe biological and physicochemical processes, formulate questions, take simple measurements, and connect these phenomena to their daily diet. Recent studies on school gardens and orchards show modest but consistent effects on fruit and vegetable consumption, food recognition, and, in some cases, academic performance, which supports its incorporation^{6,7,8}.

The basic education curriculum reform in Mexico, embodied in the 2022 Study Plan of the New Mexican School (NEM), emphasizes the collective construction of knowledge based on local issues, healthy living, and environmental stewardship as central themes for classroom work⁹.

Within this framework, an aquaponics system installed in a kindergarten can be conceived as a technological innovation in nutritional sciences that integrates food production, health education, and cognitive development in public school settings.

Despite the growing interest in school gardens, nutrition education, and active learning environments, the available literature remains fragmented. Previous studies have mainly examined nutrition education programs, school gardens, or early childhood cognitive development as separate fields; however, there is limited evidence integrating a school aquaponic system, structured nutrition education, and cognitive observation in preschool children within the same conceptual model. This gap is especially relevant in public preschool settings, where educational strategies must respond simultaneously to child health, food literacy, environmental awareness, and curricular demands. Therefore, this narrative review seeks to synthesize the conceptual and empirical contributions that support the proposed technological innovation, understood as an integrated model that links school aquaponics, nutrition education, and observable cognitive processes in early childhood^{2-9,21,22}.

2. Materials

2.1 Aquaponic System in Preschool

The school aquaponic system is conceived as a small-scale module, designed for installation in public kindergartens in Hermosillo, Sonora, and to operate simultaneously as a fresh vegetable production unit and as a permanent educational resource. It incorporates the principles of aquaponics described for small-scale integrated fish and plant systems^{5,10,11}, adapting them to the space, safety, and maintenance constraints of the preschool level.

Its main function is to integrate, in a single structure, the raising of ornamental fish and the

cultivation of nutritionally valuable vegetables under a shade house-type structure. This allows children to observe the water cycle, plant growth, and the fish-plant interaction, while the school obtains a supplementary source of pesticide-free food.

The installation begins with the construction of a shade house approximately 5 m long by 4 m wide, delimited by 2 m high wooden posts anchored in 20 L buckets filled with fine sand as a structural substrate. The perimeter walls, also made of wood, are placed on this base, and the entire structure is covered with high-density polyethylene (HDPE) shade netting, providing approximately 30% shade. This covering helps to reduce direct sunlight, regulate temperature and humidity, and promote air circulation, creating a stable and safe microenvironment for the plants and for children's guided interaction with the system. Inside the shade house, an aquarium with a capacity of 100 L is installed, capable of housing up to 50 ornamental fish, primarily zebra danios (*Danio rerio*) and some goldfish (*Carassius auratus*).

The system uses tap water from the municipal network, and pH is monitored using a digital pH meter (Mettler Toledo; model and country of manufacture to be recorded from the equipment label before implementation). The system also includes a low-power artificial white light to aid in algae control in the aquarium and ensure visibility during guided observations. To support aquarium maintenance and visibility, a 12 W, 60 cm artificial white light lamp (Cocofish) is installed. Fish feeding is standardized using an automatic dispenser (Perannu) programmed to provide small portions of balanced feed (Purina; flakes/particles of approximately 1.5 mm, 44% protein and 15% fat) every 12 h, ensuring a stable supply of nutrients to the system without overfeeding the organisms. The aquarium water, rich in nitrogenous organic waste produced by the fish, is

recirculated to the plant cultivation section via a pump and PVC piping.

The design incorporates four parallel PVC pipes with a nominal diameter of 3 in and a length of 4 m, with perforations every 25 cm to accommodate the plants. This configuration allows for the placement of 24 vegetative units, distributed equally between romaine lettuce (*Lactuca sativa* L. cv. Parris) and saladette tomato, Río Grande variety (*Solanum lycopersicum* L. cv. Río Grande). Because saladette tomato plants may exceed 1 m in height during development, they will be trained using tutors or a support system attached to the cultivation structure. This measure will help guide vertical growth, prevent stem bending, and reduce contact between leaves or fruits and wet surfaces. These species were selected for their nutritional value, relatively short growing cycle, and widespread presence in the local diet of families in Hermosillo.

The spacing between the planting holes prevents excessive competition for space and light, and facilitates the children's individual identification of each plant during observation activities. Prior to transplanting, the tomato and lettuce seedlings are produced in the nursery of the Department of Agriculture and Livestock at the University of Sonora, under controlled irrigation and phytosanitary management conditions.

The seeds are sown in germination trays with approximately 200 cells using peat moss as a substrate (Grow Depot México, country of manufacture: Mexico). During the nursery stage, the trays are irrigated with tap water, maintaining the substrate moist but not waterlogged, and adjusting irrigation frequency according to environmental conditions and seedling development. Phytosanitary management includes periodic visual inspection, removal of affected plant material, cleaning of trays and working

surfaces, and preventive handling measures consistent with good agricultural practices. Once the seedlings reach approximately 15 cm in height, or around 35 days after sowing, they are transferred to the preschool and placed in the holes of the recirculating system's tubes, thus ensuring traceability from the nursery to the school environment¹².

The system's operation is based on the symbiotic principle characteristic of aquaponics: fish waste is transformed by microorganisms into compounds that plants can assimilate, which in turn purify the water, returning it to the fish tank in improved condition. This closed cycle significantly reduces water consumption compared to conventional agriculture, minimizes the use of external inputs, and facilitates control of the growing environment. From a food security and safety perspective, vegetable production in these systems can improve the quality of food available in the school environment by providing fresh vegetables, free of pesticide residues, and produced under defined monitoring schemes and good agricultural practices^{12, 13, 14}.

During plant growth in the aquaponic system, pest and disease control in lettuce and tomato will be based on preventive and physical measures, including visual monitoring, removal of affected leaves, cleaning of the cultivation area, control of excess humidity, and avoidance of chemical pesticides in order to maintain food safety in the school environment.

From a pedagogical standpoint, the module is designed to be interpreted and used by teachers as an "extended classroom" or living laboratory. The visible arrangement of fish, tubes, roots, and foliage allows for structured observation paths and recording activities in which children point out, name, compare, and describe what they see: the movement of the fish, the flow of the water, the growth of the

lettuce and tomato, and the changes in leaf color.

These experiences are linked to open-ended questions that stimulate curiosity and causal explanation, while the use of instruments such as a thermometer, measuring tape, and graduated cylinders introduces initial concepts of measurement, quantity, and variation. In this way, the school aquaponics system is not limited to being agricultural equipment but is integrated as the material and symbolic axis of the intervention, around which nutritional education activities and the observation of cognitive processes in the preschool stage are organized.

2.2 Nutritional Education Program

The nutritional education program is conceived as the pedagogical core of the intervention, responsible for translating the content of nutritional and health sciences into meaningful experiences for 4- to 5-year-old children. Its design aligns with the formative fields and guiding principles of the New Mexican School model, so that the activities are not perceived as an external addition, but rather as an organic part of daily classroom work¹⁵.

Generally speaking, the program is structured as a sequence of twelve weekly sessions of 60-90 minutes, organized in a workshop format. Each session addresses a specific thematic area, for example: the origin of food, recognizing vegetables grown in the aquaponic system, the composition of a healthy plate, drinking plain water, identifying ultra-processed foods, and the relationship between sleep, movement, and learning. Each session is structured in three parts: beginning, development, and conclusion. This organization adopts proposals for dialogic education and active learning in early childhood, where prior knowledge is built upon, a central experience is proposed, and the

activity concludes with a collective synthesis linked to daily life^{16,17}.

The methodological approach promotes active learning and critical thinking about the immediate environment. For example, when working on the topic "Where does my food come from?", children compare fresh products from the aquaponic system with ultra-processed foods they recognize from their school snacks; when addressing the "healthy plate," they create examples using food shapes and discuss which foods come from plants, which from animals, and which are industrially produced. This type of activity is consistent with evidence showing that nutrition education programs based on concrete experiences and structured play promote meaningful learning and changes in attitudes toward healthy foods^{3,18}.

The aquaponic system serves as a recurring setting for generating questions and explanations: the changes observed in the plants and fish provide a starting point for discussing care, growth, water, time, and ultimately, how these foods can reach your table. In this way, nutritional education is anchored in a concrete technological object, reinforcing the integration between health sciences, natural sciences, and early scientific thinking, as documented in school garden experiences and STEM projects in early childhood education^{4,19}.

The teaching materials are designed to support these experiences, not as an end in themselves. They include illustrated sheets and cards depicting foods and everyday habits; floor mats with a healthy plate diagram; posters of the water cycle and the "seed to plate" process in an aquaponic system; as well as short workbooks with simple graphic activities (matching, classifying, circling, coloring) that allow for recording comprehension without requiring reading skills.

Additionally, specific pictographic tools are used to assess knowledge of healthy living. These present everyday scenes with two or three possible options and ask children to choose "what is best for their health," a strategy that has proven effective in assessing nutritional knowledge in preschoolers^{18,19}.

Teacher participation is central to the program's success. Before the sessions begin, a training session will be held to review the objectives, content, and dynamics of each workshop. This session will include discussions on language mediation strategies and agreements on how to integrate the session's topic with other curricular activities.

Throughout the process, teachers are encouraged to incorporate spontaneous references to the aquaponics system and healthy living messages at other times during the school day (recess, assemblies, language activities) to reinforce the coherence of the educational environment. This teacher support is recognized as a key determinant of the success of school-based interventions in nutrition and lifestyles, as noted in recent reviews of basic education programs^{3,20}.

2.3 Instruments for Cognitive Observation

The evaluation of results in the proposed intervention relies on two types of complementary instruments: a) rubrics for observing cognitive performance in the classroom, and b) brief pictographic tests to assess knowledge of healthy living. The purpose is to have indicators sensitive to change that allow documenting the evolution of processes such as participation, expression, and identification, as well as certain basic concepts of nutrition and health care in children aged 4 to 5 years^{21,22}.

The cognitive observation rubrics are designed based on contributions from neuropsychological assessment of children—

in particular, the NEPSY-II and other instruments focused on executive functions, language, and attention in preschoolers^{23, 24}. Each rubric considers three domains: participation, expression, and identification. Participation records behaviors such as initiative to participate, persistence in the activity, and response to group activities; expression assesses the ability to verbalize ideas related to the topic, recount experiences, and use new vocabulary; and identification evaluates the recognition of key elements and the ability to establish simple relationships between them.

Each domain is scored on a three-level scale (requires support, in progress, achieved), accompanied by precise behavioral descriptors that facilitate inter-observer consistency. The assessment will be administered before and after the intervention. Prior training for teachers and support staff is planned to standardize criteria, as well as a pilot study with a small group^{25,26}.

Responses are recorded on a checklist that assigns one point for each choice considered healthy according to dietary and active lifestyle guidelines for children^{27, 28}. The total score is interpreted as an overall assessment of healthy lifestyle knowledge and is compared between intervention and control group measurements. To ensure content validity, the picture cards are developed in collaboration with nutrition and education specialists and undergo cognitive review with a small group of children to verify that the scenes are understandable and unambiguous²⁹.

Taken together, these instruments seek to offer an integrated view of the potential impact of the intervention on observable cognition and health knowledge adapted to the preschool stage.

2.4 Food Safety

Incorporating an aquaponics system in the school environment is not limited to the production of fresh vegetables; it also includes ensuring that these foods are safe for children to consume. In areas of medium and high marginalization, where access to good quality fruits and vegetables is limited, the possibility of growing lettuce and tomatoes free of pesticides and chemical residues represents a concrete opportunity to improve school nutrition¹⁰. By reducing dependence on commercially available products, which have high variability in their post-harvest handling, local food security is strengthened and safer consumption is promoted¹³.

To ensure the safety of the vegetables, the systematic application of good agricultural practices and hygienic handling is planned, in accordance with the recommendations of the National Service for Agrifood Health, Safety and Quality¹². This includes cleaning and disinfecting surfaces, controlling the quality of irrigation water, using protective equipment, and training teaching and technical staff.

Additionally, a microbiological and bromatological monitoring scheme is proposed for the vegetables and recirculating water, based on the criteria established in the Official Mexican Standards for food and drinking water (Table 1). In addition to microbiological monitoring, water samples from the fish tank and recirculating system will be collected at baseline and during plant growth to evaluate the nutrient availability provided to the crops. The determinations will include P, K, Ca, Mg, Na, Zn, Cu, Mn, S, Fe, Ni, Mo, nitrate, ammonium, chlorides, sulfates, carbonates, and bicarbonates. This monitoring will allow the characterization of the nutrient conditions of the aquaponic water and will support the interpretation of plant growth and vegetable quality.

As a complementary analysis, plant tissue samples will be collected to evaluate the nutritional status of the crops produced in the aquaponic system. In lettuce, the analysis will be performed on leaf tissue, whereas in tomato, both leaf and fruit tissue may be analyzed. These determinations will help assess nutrient uptake by the plants and relate the nutrient conditions of the recirculating water to the nutritional quality of the harvested vegetables.

These analyses allow for the detection of fecal coliforms, *Salmonella* spp., *Escherichia coli*, *Vibrio cholerae*, helminth eggs, and phytopathogens, as well as characterizing the proximate composition of the vegetables (protein, fat, ash, and carbohydrates). The combination of good practices, microbiological monitoring, and explicit reference to current regulations ensures that the food derived from the aquaponic system is safe and nutritionally adequate for tasting activities or educational use within the school community.

Table 1. Food analysis to evaluate harvested vegetables.

Evaluated Parameter	Analysis Method	Objective	NOM*
Plant tissue nutrient analysis in lettuce leaves and tomato leaves/fruits	Foliar mineral analysis by ICP or atomic absorption, according to laboratory protocol	To assess nutrient uptake and nutritional status of vegetables produced in the aquaponic system.	Laboratory protocol / Not applicable
Proximate analyses (proteins, total fats, ash).	Specific methods (Kjeldahl, Soxhlet).	To determine the nutritional composition of foods.	NOM-086-SSA1-1994
Helminth eggs	Direct microscopy.	Detecting contamination by parasites.	NOM-113-SSA1-1994
<i>Salmonella</i> spp.	Selective cultures on solid media.	Identify the presence of <i>Salmonella</i> .	NOM-114-SSA1-1994
<i>Escherichia coli</i>	Selective cultures.	Check for <i>E. coli</i> contamination.	NOM-115-SSA1-1994
<i>Vibrio cholerae</i>	Selective methods.	Confirm the absence of <i>V. cholerae</i> .	NOM-116-SSA1-1994
Phytopathogens (fungi and bacteria)	Cultures in specific media.	Identifying pathogens in plant-based foods (phytopathogens).	NOM-008-FITO-1995

*NOM: Norma Oficial Mexicana= Official Mexican Standard.

3. Review Methods

This article was developed as a narrative review, with the aim of integrating relevant literature on school aquaponics, nutrition education, and cognitive processes in early childhood. The search for sources was conducted between January and November

2025, using academic databases such as Scopus, Redalyc, SciELO, and Google Scholar, as well as institutional documents and technical guides from the Government of Mexico, the FAO, the SEP (Mexican Ministry of Education), and the WHO. The main

methodological characteristics of the narrative review are summarized in Table 2.

Table 2. Summary of the narrative review method.

Component	Description
Databases and sources	Scopus, Redalyc, SciELO, Google Scholar, and institutional documents from the Government of Mexico, FAO, SEP, SENASICA, and WHO.
Search period	The search and selection of sources were conducted between January and November 2025.
Languages	Publications in English and Spanish were included.
Type of documents	Peer-reviewed articles, technical reports, institutional guidelines, books, and official documents related to nutrition, aquaponics, school gardens, preschool education, and developmental neuropsychology.
Inclusion criteria	Documents were included when they addressed: school gardens or aquaponic systems; nutrition education in preschool or early childhood; healthy eating and child development; cognitive processes such as attention, language, participation, self-regulation, or executive functions; and educational or community-based interventions applicable to children aged 4 to 5 years.
Exclusion criteria	Documents were excluded when they focused only on commercial aquaponic production without educational application; studies conducted exclusively in adult populations; publications not related to nutrition, cognition, preschool education, or school-based interventions; and sources without sufficient methodological or conceptual relevance for the objective of the review.
Analysis strategy	The selected literature was analyzed qualitatively and organized into three thematic areas: 1) aquaponics as a sustainable technology and pedagogical resource, 2) nutrition education at the preschool level, and 3) cognitive observation tools sensitive to change.

Publications in Spanish and English that addressed school gardens or aquaponic systems, educational interventions focused on healthy eating in preschool children, as well as classic and recent texts on developmental neuropsychology and the assessment of executive functions were included. The selection was based on thematic relevance, the focus on school or community contexts, and applicability to populations between 4 and 5 years of age. The selected references included peer-reviewed articles, specialized books, institutional documents, and technical guidelines.

Based on the qualitative content analysis, the findings were organized into three main areas: 1) aquaponics as a sustainable technology and pedagogical resource, 2) nutritional education at the preschool level, and 3) cognitive observation tools sensitive to change. This integration allowed for the construction of a theoretical and methodological framework to

support a proposal for technological innovation in nutritional sciences applicable to the preschool level.

4. Results and Discussion of the Narrative Review

The proposed model offers an innovative alternative to traditional nutrition education approaches. Conventional strategies are often centered on verbal explanation, posters, or isolated classroom activities. Although these resources can be useful, they do not always provide repeated, concrete, and meaningful experiences with healthy foods. In contrast, the aquaponic system allows nutrition education to be linked to direct observation, care of living organisms, measurement, dialogue, and contact with vegetables.

A relevant contribution of this proposal is its integration with preschool education and the principles of the New Mexican School. The model allows teachers to address healthy

living, environmental care, early scientific thinking, language, and community participation through a single educational resource. As a result, the aquaponic system is presented as a technological innovation with educational, social, and public health transferability in preschool settings¹⁵.

The literature review suggests that school garden programs and nutrition education may contribute to improvements in knowledge and attitudes toward healthy eating in preschool children. Available evidence indicates that nutritional education programs based on concrete experiences and structured play are associated with increases in the recognition of fruits and vegetables, reported preference for these foods, and, in some cases, their actual consumption during the school day^{3,18}.

When nutrition education is anchored in a school aquaponic system, children may develop a better understanding of the origin of certain foods, the water cycle, and the relationship between environmental care and health, consistent with findings from school garden and orchard experiences^{4,19}.

The proposal also suggests potential benefits in observable cognitive processes, particularly in participation, expression, and the identification of relevant elements during classroom activities. Developmental neuropsychology frameworks indicate that attention, language, and self-regulation are fostered by learning environments that combine novelty, structure, and opportunities for intentional action^{21,22}.

The aquaponics system introduces a dynamic technological object that can act as a “trigger” for curiosity and language; at the same time, the organization of the workshops into beginning, development, and closing phases, with clear instructions and visual aids, provides the necessary structure for children to maintain their attention and organize their

contributions^{16,17}. In this way, the model may provide favorable conditions for observing participation, expression, and identification during classroom activities.

A third aspect relates to food safety and the wholesomeness of the vegetables produced in the aquaponics system. Previous studies have documented that the implementation of good agricultural and hygienic handling practices, along with microbiological and bromatological monitoring, allows vegetable products to remain within regulatory safety limits, even in small-scale production units^{12,13}. Provided that the project follows SENASICA recommendations and complies with the criteria established in the applicable Mexican Official Standards, the vegetables produced in the aquaponic system may be considered suitable for tasting activities or educational use within the school community.

However, the proposal faces significant limitations. Since this manuscript is a narrative review with a conceptual proposal, it does not provide quantitative results, statistical analyses, or direct measurements of intervention effects. The true magnitude of potential changes in healthy lifestyle knowledge, participation, expression, or cognitive observation scores can only be determined through future empirical studies with adequate design, implementation fidelity, and follow-up. Methodologically, randomization by school may reduce cross-group contamination, but requires enough schools to ensure adequate statistical power. Heterogeneity in infrastructure, organization, and teaching styles can introduce variability in implementation that will need to be documented and, as far as possible, controlled. Furthermore, because the cognitive indicators are based on observation and rubrics, there is a risk of observer bias; therefore, prior training, pilot testing, and standardized scoring procedures will be necessary^{25,26}.

The sustainability of the aquaponics system will depend on the schools' capacity to maintain it once the project is completed. The literature on school gardens suggests that long-term continuity may depend on teacher involvement, maintenance routines, and institutional support 3,29. Therefore, teacher training, family participation, maintenance routines, and formal agreements with educational authorities are suggested as critical conditions for long-term feasibility.

Overall, the review and proposed design suggest that integrating a school aquaponics system with a nutrition education program has the potential to support knowledge, attitudes, and observable cognitive processes in early childhood, while also contributing to the educational use of fresh food production in school settings. However, the true magnitude of these effects, their duration, and their relevance in terms of public health can only be determined through the rigorous implementation of future empirical studies.

5. Ethical Considerations

This manuscript is a narrative review with a conceptual proposal; therefore, it does not report original data obtained from human participants. However, because the proposed model is intended for future implementation with preschool children, ethical safeguards must be considered before any empirical applications. Future studies should obtain approval from an institutional ethics committee, authorization from the participating educational institutions, informed consent from the parents or legal guardians, and age-appropriate assent from children.

The implementation should follow the principles of respect for persons, beneficence, and justice, ensuring voluntary participation, the right to withdraw without consequences, confidentiality of personal information, and

the minimization of physical, psychological, and social risks. Activities involving the aquaponic system should be supervised by trained personnel and conducted under hygiene, biosafety, and food safety procedures appropriate for school settings. These considerations are consistent with international ethical principles for research involving human participants and with Mexican regulations for health research in human beings^{31,32,33}.

6. Conclusions

The combination of school aquaponics, nutritional education, and cognitive development in preschoolers represents a field of technological innovation in health sciences. The aquaponic system described in this work is conceived not only as a vegetable production unit but also as a living laboratory where children can observe the origin of some foods, participate in their care, and connect these experiences with everyday decisions about what they eat. When integrated with a structured nutritional education program, the module becomes a pedagogical axis that allows for the development of content related to healthy living, early scientific thinking, and environmental stewardship.

From a public health perspective, this proposal aligns with efforts to address the double burden of malnutrition in Mexico by promoting the consumption of fresh vegetables, questioning the role of ultra-processed products in children's diets, and creating school environments more conducive to healthy food choices. In the educational sphere, it aligns with the principles of the New Mexican School model, which places community life, local territory, and healthy living as organizing principles of the curriculum. It also aligns with the Sustainable Development Goals related to zero hunger, good health and well-being, quality education, and climate action.

This article offers a guide for designing school-based interventions that integrate sustainable food production, health education, and early childhood cognitive development. Implementing the proposed randomized clinical trial will allow us to test the hypotheses formulated here, refine the instruments, and generate evidence that contributes to the debate on how to safely, appropriately, and sustainably incorporate innovative agri-food technologies into the preschool curriculum.

This narrative review provides a conceptual framework that should be expanded upon with future empirical studies.

7. Acknowledgments

We gratefully acknowledge the support of the Secretariat of Education and Culture, Innovation, Humanities, Technology and Innovation (SECIHTI).

8. References

1. Souza Martins, M., Posada Bernal, A., & Lucio Tavera, J. (2019). *Desarrollo infantil temprano: bases biopsicosociales*. Bogotá: Universidad Nacional de Colombia.
2. UNICEF. (2023). *Estado mundial de la infancia 2023: Para cada niño, una nutrición saludable*. Nueva York: Fondo de las Naciones Unidas para la Infancia.
3. Balderas-Mireles, B., Acosta-Santos, M., & Gómez-González, L. (2020). Impacto de intervenciones de educación nutricional en preescolares. *Revista Chilena de Nutrición*, 47(2), 138–145.
4. Cuevas-Nasu, L., Méndez-Gómez-Humarán, I., Shamah-Levy, T., & Rivera-Dommarco, J. A. (2014). La doble carga de la malnutrición en población infantil mexicana. *Boletín Médico del Hospital Infantil de México*, 71(3), 157–164.
5. Somerville, C., Cohen, M., Pantanella, E., Stankus, A., & Lovatelli, A. (2014). *Small-scale aquaponic food production: Integrated fish and plant farming*. FAO Fisheries and Aquaculture Technical Paper. No. 589. Roma: FAO.
6. Pham Quang Tiep. (2025). Project-based learning in science activities: Enhancing cognitive development and problem-solving competency in preschool children. *European Journal of Humanities and Social Sciences*, 3, 15–28.
7. French, L., Conezio, K., & Boynton, M. (2015). Exploring preschool children's science content knowledge. *Early Childhood Research Quarterly*, 31, 62–70. <https://doi.org/10.1016/j.ecresq.2014.12.004>
8. Saçkes, M. (2014). How often do early childhood teachers teach science concepts? Determining frequency of science teaching in early childhood. *European Early Childhood Education Research Journal*, 22(2), 169–184. <https://doi.org/10.1080/1350293X.2012.704305>
9. Secretaría de Educación Pública. (2023). *Criterios para la valoración de los aprendizajes esperados en educación preescolar*. SEP.
10. Félix Cuencas, L., López Tejeida, S., & de León Ramírez, J. J. (2024). *Acuaponia, cultivos del pasado para la*

- alimentación del futuro. *Ciencia*, 75(4), 23–27.
11. Gobierno de México, Secretaría de Agricultura y Desarrollo Rural. (2024). Acuaponía: Un sistema sustentable que produce peces y plantas. <https://www.gob.mx/agricultura/articulos/acuaponia>
 12. SENASICA. (2021). Manual de buenas prácticas agrícolas. <https://www.gob.mx/senasica/documentos/manual-de-buenas-practicas-agricolas>
 13. Contreras Gómez, R., Cruz Hernández, A., & Velázquez Esqueda, M. (2016). Buenas prácticas agrícolas e inocuidad en hortalizas de consumo en fresco. *Revista Mexicana de Ciencias Agrícolas*, 7(3), 589–601.
 14. García-López, Z., Preciado Rodríguez, J. M., Contreras, A. D., Portillo, G. E., & Ortega Vélez, M. I. (2023). Cambios en la densidad del comercio minorista de alimentos en Hermosillo 2010–2021. *Revista Chilena de Nutrición*, 50(4), 433–444.
 15. Secretaría de Educación Pública (SEP). (2022). Plan de Estudios 2022. Educación Básica: Nueva Escuela Mexicana. Ciudad de México: SEP.
 16. Freire, P. (1970). *Pedagogía del oprimido*. México: Siglo XXI Editores.
 17. Vygotsky, L. S. (1978). *El desarrollo de los procesos psicológicos superiores*. Barcelona: Crítica.
 18. Miguel, A., Valencia, M. E., & Pérez-Lizaur, A. (2011). Educación alimentaria en niños preescolares con material gráfico. *Revista Chilena de Nutrición*, 38(3), 273–279.
 19. Cosco, N., Moore, R., & Smith, W. (2022). STEM learning in nature-based preschool gardens. *Children, Youth and Environments*, 32(1), 65–89.
 20. Wells, N. M., Lekies, K., Chawla, L., & Anderson, S. (2023). Outdoor learning and child development. *Early Childhood Research Quarterly*, 63, 1–12.
 21. Anderson, P. (2002). Assessment and development of executive function. *Child Neuropsychology*, 8(2), 71–82. DOI: 10.1076/chin.8.2.71.8724
 22. Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, 64, 135–168. <https://doi.org/10.1146/annurev-psych-113011-143750>
 23. Korkman, M., Kirk, U., & Kemp, S. (2007). *NEPSY-II: A developmental neuropsychological assessment*. San Antonio, TX: Harcourt.
 24. Gioia, G. A., Espy, K. A., & Isquith, P. K. (2003). BRIEF-P: Behavior Rating Inventory of Executive Function–Preschool Version. Lutz, FL: PAR.
 25. Brookhart, S. M. (2013). *How to create and use rubrics for formative assessment and grading*. Alexandria: ASCD.
 26. Moskal, B., & Leydens, J. (2000). Scoring rubric development: Validity and reliability. *Practical Assessment, Research & Evaluation*, 7(1), 1–10. DOI: 10.7275/0NCD-JP31
 27. Secretaría de Salud (SSA). (2018). *Guía de alimentación saludable para la población mexicana*. Ciudad de México: SSA.

28. Organización Mundial de la Salud (OMS). (2019). Guidelines on physical activity, sedentary behaviour and sleep for children under 5 years of age. Ginebra: OMS.
29. Thompson, R. (2023). School gardens and children's language development. *International Journal of Early Child Education*, 31(1), 45–58.
30. Naciones Unidas. (2024). Objetivos de Desarrollo Sostenible. <https://www.un.org/sustainabledevelopment/>
31. National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research. (1979). *The Belmont Report: Ethical principles and guidelines for the protection of human subjects of research*. U.S. Department of Health, Education, and Welfare.
32. Secretaría de Salud. (2012). Norma Oficial Mexicana NOM-012-SSA3-2012, Que establece los criterios para la ejecución de proyectos de investigación para la salud en seres humanos. *Diario Oficial de la Federación*.
33. Cámara de Diputados del H. Congreso de la Unión. (2014). Reglamento de la Ley General de Salud en Materia de Investigación para la Salud. *Diario Oficial de la Federación*.