

Efficient design and use of sustainable packaging materials for the organic products of the TONAEM association of small producers from Villa del Carbón in the UAEM Valley of Mexico

Diseño y uso eficientes de materiales de embalaje sostenibles para los productos ecológicos de la asociación TONAEM de pequeños productores de Villa del Carbón, en el Valle de México de la UAEM

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Abstract

Small producers of healthy and sustainable food play a crucial role in the fight against hunger and poverty. This study aims to design and improve packaging using wooden baskets made from sustainable materials for transporting fruit and vegetables from the TONAEM association, located in Villa del Carbón, State of Mexico. The goal is to optimize the protection of products against shocks, vibrations, and temperature changes, as well as to maintain their freshness and quality through a design that allows for ventilation and humidity control. Training of personnel in loading techniques and compliance with food safety regulations is also being considered. A cost analysis and process optimization are being carried out to ensure logistical efficiency and the delivery of products in optimal conditions. The results will contribute to strengthening the competitiveness and sustainability of small producers in the region.

Resumen

Los pequeños productores de alimentos saludables y sostenibles desempeñan un papel crucial en la lucha contra el hambre y la pobreza. Este estudio tiene como objetivo diseñar y mejorar el embalaje utilizando cestas de madera fabricadas con materiales sostenibles para el transporte de frutas y verduras de la asociación TONAEM, ubicada en Villa del Carbón, Estado de México. El objetivo es optimizar la protección de los productos contra golpes, vibraciones y cambios de temperatura, así como mantener su frescura y calidad mediante un diseño que permita la ventilación y el control de la humedad. También se está considerando la formación del personal en técnicas de carga y el cumplimiento de las normas de seguridad alimentaria. Se lleva a cabo un análisis de costos, optimizando procesos para garantizar la eficiencia logística y la entrega de los productos en condiciones óptimas. Los resultados contribuirán a reforzar la competitividad y la sostenibilidad de los pequeños productores de la región.

Efficient design and use of sustainable packaging materials in the products of the TONAEM association, small producers from Villa del Carbón in the UAEM Valley of Mexico.		
Objectives	Methodology	Contribution

Sustainable materials, Packaging to protect and preserve organic products, Regulatory techniques.

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Materiales sostenibles, embalajes para proteger y conservar productos orgánicos, técnicas normativas

Area: Promotion of frontier research and basic science in all fields of knowledge

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Peer review under the responsibility of the Scientific Committee MARVID®- in the contribution to the scientific, technological and innovation Peer Review Process through the training of Human Resources for continuity in the Critical Analysis of International Research.



Introduction

In Mexico, around 30% of fruit and vegetable production is lost during post-harvest, mainly due to mechanical damage and moisture accumulation in inadequate packaging (García, Martínez, & Torres, 2022). This waste affects the profitability of small rural producers and local food security. In Villa del Carbón, the TONAEM association reports an average loss of 25% in the transport of its crops, attributable to cardboard and plastic boxes that do not offer sufficient ventilation or mechanical resistance (López & Ramirez, 2021).

Despite the abundance of experimental research on wooden packaging in vibration simulation chambers, there is a gap in theoretical studies that integrate computational modeling of mechanical damage and mass loss for this type of packaging. In particular, finite element models and mass transfer equations have not been applied to evaluate wild pine baskets under real transport conditions.

A quantitative theoretical-estimative methodological approach is proposed for the efficient design and use of sustainable packaging materials for organic products in sustainable baskets for the transport of perishable products from small producers in the TONAEM Association of Villa del Carbón. Baskets are made with different materials, identifying materials that meet the ideal characteristics for packaging organic products. In addition, a life cycle cost analysis and sustainable and reusable manufacturing analysis are carried out. In this way, we seek to estimate the potential reduction in mechanical damage and spoilage and evaluate the viability of the solution.

Development of the headings and subheadings of the article with the subsequent numbers.

Historical background

Origins and Historical Foundations

Since ancient times, packaging has been an essential practice for protecting and preserving perishable products. In 1550 BC, producers used natural materials such as palm leaves to wrap fragile goods such as eggs, establishing the fundamental principle of protection using reusable organic materials (Celorio, 1993).

Egyptian civilization developed the storage container manufacturing industry, creating the first organized food preservation systems that enabled long-distance trade.

Agri-food Packaging

Classical Period [750 AD - 1400 AD]

- China - Han Dynasty [750 AD]: Development of paper from natural fibers, setting the precedent for biodegradable packaging materials
- Medieval Europe: Adoption of preservation techniques using wooden containers, especially for the maritime transport of agricultural products

Industrial Revolution [19th century]

- 1850-1880: Mass production of cut and folded boxes, optimizing production efficiency
- Railways: Development of resistant packaging for long-distance land transport of perishable goods

Modern Era [20th Century]

- 1911: Invention of cellulose acetate—the first biodegradable plastic
- 1920s: Development of cellophane and PVC, introducing long-lasting synthetic materials
- 1930s: Emergence of nylon and polyester, revolutionizing the mechanical strength of packaging

Current context of small producers in the TONAEM association in Villa del Carbón

Historical evidence shows that civilizations that were successful in agricultural trade used reusable and locally available materials. Today's small producers can apply this principle by using certified local wood, replicating ancient strategies adapted to contemporary regulations.

Historical traders optimized the relationship between packaging cost and the value of the product being transported. For small producers, this translates into the need to evaluate life cycle costs rather than initial investment, following commercial patterns established by civilizations such as the Phoenicians.

Each region developed packaging solutions based on local resources and specific climatic conditions. Villa del Carbón, with its forest resources and temperate climate, replicates conditions similar to European regions that successfully developed wooden packaging systems for perishable products.

Transition to Contemporary Sustainability

The historical evolution of packaging shows a cyclical pattern: natural materials → synthetic materials → return to sustainable natural materials. The 21st century marks a return to historical principles of sustainability, but with modern technology:

- 21st century: Movement toward a circular economy that replicates ancestral principles of reuse
- 2020-2025: International regulations [ISPM 15, NOM-144] favoring technologically treated natural materials
- Present: Integration of Sustainable Development Goals that recover historical concepts of harmony with the ecosystem

Identification of the problem

The current situation of small producers in the TONAEM association in Villa del Carbón reflects inefficiencies in the packaging and distribution system that cause material losses, increased costs, and underutilization of resources.

Therefore, a comprehensive redesign based on industrial engineering principles is required to optimize logistics flow, eliminate unproductive activities, improve the strength and durability of materials, establish controls to ensure quality and safety in handling, evaluate cost-benefit considering reuse and environmental impact, and select configurations that favor ventilation, storage, and operational efficiency throughout the entire production chain.

Box 1



Figure 1

Various products produced and marketed by the TONAEM Villa del Carbón association, *Own elaboration, 2025*

Justification

The economic and logistical losses resulting from the use of conventional packaging, such as cardboard and plastic boxes, which do not guarantee protection or preservation during transport, make it essential to seek innovative solutions. The design of sustainable wooden baskets is a viable alternative that offers greater mechanical strength, natural ventilation, and the possibility of reuse, significantly reducing the environmental impact associated with disposable materials. In addition, this approach complies with current food safety regulations that are part of the Sustainable Development Goals, promoting responsible production and consumption practices. (FAO, 2019). Therefore, optimizing the packaging system through efficient design will not only reduce losses but also strengthen the local agri-food value chain, promoting the sustainability and competitiveness of small producers in the region.

General objective

To develop an efficient model and use of sustainable packaging materials for organic products that preserves and optimizes the transport of perishable products from the TONAEM association, through computational simulation analysis and life cycle cost estimates.

Specific objectives

1. Analyze the properties and characteristics of common packaging materials.
2. Design technical specifications for baskets made of different materials manufactured in the CU UAEMex Valle de México Machining Laboratory

3. Evaluate compliance with food safety and environmental sustainability regulations and economic viability through life cycle cost analysis considering 5-8 reuses
4. Propose a replicable model for small producers with similar characteristics

Box 2

Table 1

Methodology for the efficient design of sustainable packaging materials for the organic products of the TONAEM association

Phase	Description	Tools and Activities	Expected results
Phase 1	Analyze the properties and characteristics of common packaging materials	Compare the properties and characteristics of different packaging materials for the baskets	Identify the most suitable material for the baskets based on their mechanical properties, strength, sustainability, and cost. A comparative report is produced detailing the advantages and limitations of each option.
Phase 2	Design technical specifications for baskets made of different materials manufactured in the CU UAEMex Valle de México Machining Laboratory	Manufacture of the three types of packaging in the laboratory... An Ishikawa cause-and-effect diagram of the contents was prepared.	Functional physical prototypes of the baskets, with their technical specifications documented [dimensions, materials, manufacturing processes]. In addition, identification of possible causes of defects or improvements through Ishikawa diagram analysis.
Phase 3	Evaluate compliance with food safety and environmental sustainability regulations and economic viability through life cycle cost analysis considering 5-8 reuses.	Create a matrix of variables for instruments based on environmental regulations and their economic viability and food safety. Comparative packaging performance matrix.	Validation of regulatory and environmental compliance of proposed materials and designs. Determination of the life cycle cost of each type of packaging and definition of the optimal number of reuses to ensure its profitability and sustainability.
Phase 4	Propose a replicable model for small producers with similar characteristics	Comparative analysis of results obtained in previous phases [properties, costs, regulations]. Design of a conceptual and operational model for sustainable packaging. Validation of the model through simulations or consultations with small local producers. Final documentation of the replicable model with technical, economic, and environmental indicators.	Comprehensive model of sustainable and replicable packaging, with technical, economic, and environmental guidelines that can be implemented by small producers.

Own development, 2025

Phase 1: Comparative analysis of packaging materials

A comparative study was conducted of the main material alternatives used in the packaging industry, considering their physical, functional, and environmental properties.

- Corrugated cardboard: has a low initial cost and is easy to handle due to its light weight. However, its resistance to moisture and loads is limited, which reduces its useful life and restricts its potential for reuse.
- Acrylic: offers good water resistance and low weight, which are favorable characteristics for transport. However, it has low ventilation, which promotes moisture condensation and accelerates the decomposition of perishable products. In addition, its environmental impact is high due to its difficult degradation.
- Wood: stands out for its high mechanical strength, excellent ventilation, and long service life, with the possibility of reuse in multiple cycles. It is a biodegradable material, provided it is managed properly. These properties make it a technically and environmentally superior option to cardboard and acrylic, especially in rural environments where logistical efficiency and sustainability are determining factors.

Box 3

Table 2

Properties and characteristics of common packaging materials

Characteristics	Corrugated cardboard	Acrylic	Wood
Versatility	High. Adapts to multiple formats and products.	High. Allows for customized and lightweight designs.	Moderate. Requires specific cutting and assembly processes.
Resistance	Good, although limited in the face of moisture and heavy loads.	Good, with acceptable resistance to moisture.	High, with excellent structural and mechanical capacity.
Weight	Lightweight, facilitating handling and transport.	Very light, optimal for reducing logistics costs.	Heavy, increases the total weight of the shipment.

Main protection	Absorbs shocks and vibrations.	Offers some resistance to moisture.	Supports heavy loads and allows natural ventilation.
Ease of printing	High, allows for easy labeling and customization.	Moderate, allows for limited engraving or printing.	Low, requires additional techniques for labeling.
Common uses	Packaging for consumer products and e-commerce.	Food, pharmaceutical, and electronic product packaging.	Transportation of heavy or fragile products, especially agricultural or industrial.
Profitability	High in the short term due to low initial cost.	High in specific short-term applications.	High in the medium term due to its durability and reusability.
Environmental impact	Moderate: partially recyclable, but single-use.	High: non-biodegradable and with high environmental impact.	Low: biodegradable material from renewable sources if managed correctly.
Cost per use cycle	\$6–\$8 [single use].	\$6–\$8 [2–3 limited uses].	\$2–\$3.5 [5–8 reuses].
Regulatory compliance	Partial, requires additional treatment for food contact.	Partial, depends on composition and additives.	Full, complies with environmental and food safety regulations.

Own development, 2025

Phase 2: Design technical specifications for baskets made of different materials manufactured in the CU UAEMex Valle de México Machining Laboratory
General description

During August and September, three prototypes of packaging baskets were manufactured using different materials—corrugated cardboard, acrylic, and wood—with the aim of evaluating their physical behavior, structural strength, and technical feasibility in terms of their dimensions, manufacturing processes, and cost per cycle of use. The activities were carried out at the CU UAEMex Valle de México Machining Laboratory.

Box 4

Table 3

Technical specifications for the manufacture of prototype packaging baskets made of different materials

Material	Dimensions [Length × Width × Height]	Main manufacturing process	Assembly/Joining
Corrugated cardboard	45 cm × 33 cm × 29 cm	Manual cutting and assembly with industrial adhesive	Tabs and vinyl glue
Acrylic	40 cm × 25 cm × 15 cm	CNC laser cut and partially thermoformed	Transparent solvent adhesive
Wood	45 cm × 33 cm × 29 cm	Circular saw cutting, sanding, drilling, and nailing	Nails + contact adhesive

Tools and activities

- CAD design of technical drawings.
- Cutting and assembly of materials with CNC machinery, saws, and industrial adhesives.
- Photographic record of the manufacturing process.
- Preparation of Ishikawa diagram [cause-effect] to identify possible sources of defects [insufficient adhesion, moisture, deformations, etc.].
- Dimensional and structural comparison between the three finished prototypes.

Box 5

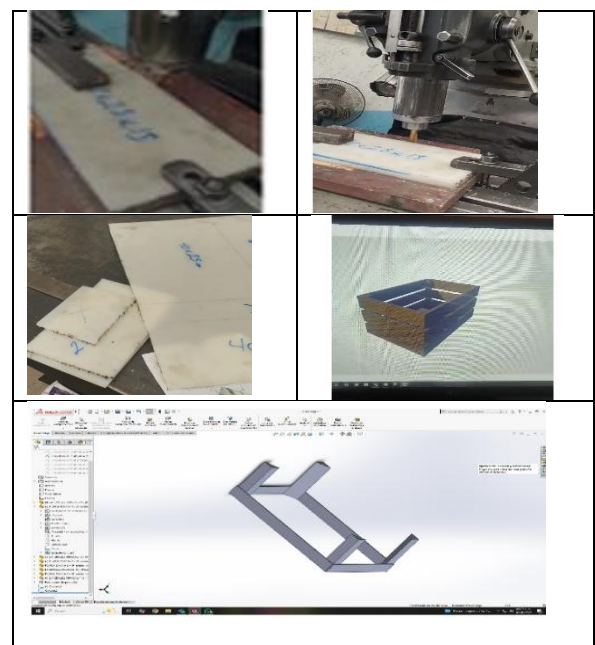


Figure 2

Design and manufacturing procedures for the different prototypes of packaging baskets at the CU UAEMex Valle de México Laboratory

Expected results

- Three functional physical prototypes of packaging baskets with their technical specifications documented [dimensions, materials, processes, and tolerances].
- Comparative analysis of structural performance, weight, and load capacity.
- Identification of causes of defects and opportunities for improvement using the Ishikawa diagram.
- Technical basis for Phase 3, in which economic viability and regulatory compliance will be evaluated.

Conclusion of the análisis

- Corrugated cardboard is the most economical and quickest option to manufacture, ideal for temporary or low-weight uses.
- Acrylic offers a professional finish and good strength, although its cost and environmental footprint are high.
- Wood stands out for its durability and sustainability, making it the most suitable for continuous reuse or heavy industrial transport.

Box 6

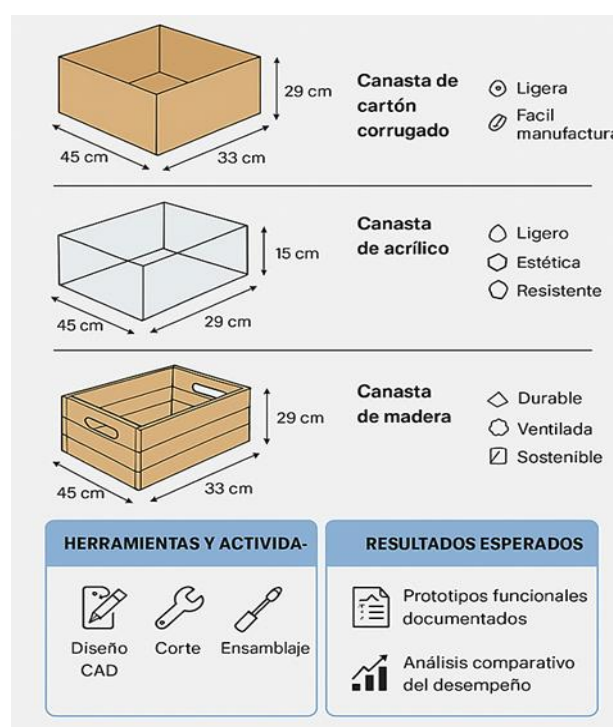


Figure 3

Activities, tools, and results of Phase 2

Own elaboration, 2025

Phase 3: Evaluate compliance with food safety and environmental sustainability regulations and economic viability through life cycle cost analysis considering 5-8 reuses

Matrix of variables and instruments

Variables for efficient design and use of sustainable packaging materials for organic products. The following matrix presents the quantitative variables considered to evaluate the performance of sustainable wooden baskets versus traditional packaging.

Box 7

Table 4

Matrix of quantitative variables for evaluating the performance of conventional packaging versus wooden baskets

Variable	Operational Definition	Type of Data	Estimation Method	Unit of Measurement	Material
Type of Packaging	Packaging classification by material	Nominal categorical	Technical Specification	Binary [0/1]	Wood / Acrylic / Cardboard
Mechanical damage [%]	Percentage of products with visible damage [dents, crushing, cuts]	Continuous quantitative	Finite element modeling + specialized literature	% of damaged products	Wood / Acrylic / Cardboard
Mass loss [%]	Estimated weight loss due to dehydration during transport	Continuous quantitative	Mass transfer equations according to material properties	% of initial weight	Wood / Acrylic / Cardboard
Structural strength	Estimated maximum load capacity based on material properties	Continuous quantitative	Structural engineering calculations	kg maximum load	Wood / Acrylic / Cardboard
Initial unit cost	Manufacturing cost per unit [material + labor]	Continuous quantitative	Direct cost analysis	MXN per unit	Wood / Acrylic / Cardboard
Number of reuses	Estimated cycles of use before deterioration	Discrete quantitative	Projection for material lifespan	Number of cycles	Wood / Acrylic / Cardboard
Cost per life cycle	Average cost per use considering multiple reuses	Continuous quantitative	Initial cost / number of reuses	MXN per cycle	Wood / Acrylic / Cardboard
Environmental impact	Estimated carbon footprint per packaging life cycle	Continuous quantitative	Theoretical life cycle assessment [LCA]	kg CO ₂ equivalent	Wood / Acrylic / Cardboard
Product shelf life	Estimated extension of freshness of perishable products	Continuous quantitative	Literature on preservation + modeling	Additional days	Wood / Acrylic / Cardboard
Ventilation efficiency	Air circulation capacity according to packaging design	Continuous quantitative	Air flow calculations	m ³ /min circulation	Wood / Acrylic / Cardboard

Own elaboration, 2025

Comparative packaging performance matrix

A scoring system from 1 to 5 [1 = worst performance, 5 = best performance] is used, based on criteria of efficiency, sustainability, and economic viability. This is an estimate and conceptual.

Box 8

Table 5

Performance score for different packaging materials according to specific criteria [efficiency, sustainability, and economic viability]

Variable	Wood	Acrylic	Corrugated cardboard	Observations
Mechanical damage [%]	5	4	2	Wood is more resistant to impact; acrylic is rigid; cardboard crushes easily
Mass loss [%]	4	5	3	Acrylic prevents moisture loss; wood allows some dehydration; cardboard is less resistant to moisture
Structural strength	5	4	2	Wood supports more weight; acrylic is less flexible; cardboard is limited
Initial unit cost	2	3	5	Cardboard is cheapest; acrylic is intermediate; wood is most expensive
Number of reuses	5	4	2	Wood lasts more cycles; acrylic reusable; cardboard limited
Cost per life cycle	5	4	3	Wood is cost-effective in the long term despite initial cost; cardboard is less durable
Environmental impact	4	3	5	Cardboard is recyclable; wood is sustainable; acrylic has a higher carbon footprint
Product lifespan	4	4	3	Wood and acrylic maintain freshness; cardboard is less insulating
Ventilation efficiency	5	3	4	Wood and cardboard allow for better ventilation; solid acrylic limits airflow

Box 9

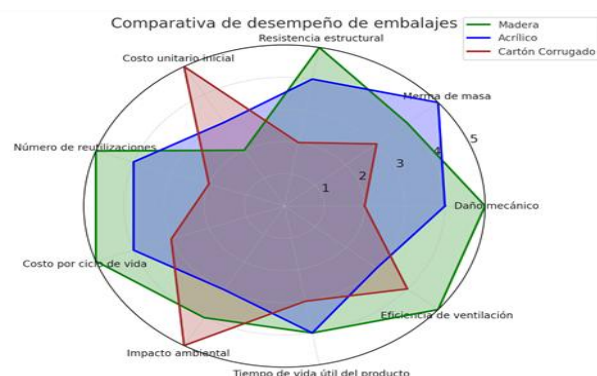


Figure 4

Performance score of different packaging materials according to specific criteria [efficiency, sustainability, and economic viability]

- Each axis represents an evaluation variable.
- The colors indicate the material: **green** = wood, **blue** = acrylic, **brown** = corrugated cardboard.
- The distance from the edge of the graph reflects better performance [closer to the edge = better score].

In summary, Phase 3 evaluates the performance of wood, acrylic, and corrugated cardboard packaging considering food safety, environmental sustainability, and economic viability through life cycle cost analysis with 5–8 reuses. The matrix analyzes key variables such as mechanical damage, mass loss, structural strength, unit cost, number of reuses, life cycle cost, environmental impact, product life span, and ventilation efficiency.

The conceptual comparison using a score of 1 to 5 shows that wood offers balanced and high performance in most criteria, acrylic excels in preservation but with higher cost and environmental footprint, and corrugated cardboard is economical and recyclable but limited in durability and protection. The results are complemented by a radar chart that allows for quick visualization of the strengths and weaknesses of each material.

Phase 4. Propose a replicable model for small producers with similar characteristics

Box 10

Table 6

Benefits and relevance of the different types of packaging baskets used [cardboard, acrylic, wood]

Relevance/Benefit	Wood	Acrylic	Corrugated cardboard
Economic relevance	Reduction in post-harvest losses [mechanical damage 15→8%, shrinkage 12→6%], potential increase of 15–20% in marketable value; initial cost \$12–17 MXN, cost per cycle \$2–3.5 MXN; competitive differentiation	Moderate reduction in losses [mechanical damage 15→10%, shrinkage 12→5%]; intermediate initial cost \$10–14 MXN, cost per cycle \$2.5–4 MXN; attractive to premium markets due to aesthetics	Limited reduction in losses [mechanical damage 15→12%, shrinkage 12→8%]; low initial cost \$6–8 MXN, cost per cycle \$3–4 MXN; accessible to mass markets

Social Relevance	Greater local food security, replicable technical training, scalable community development	Contributes to availability of fresh food; attractive design facilitates education on handling; limited community outreach	Contributes to basic food availability; easy distribution; less impact on technical training
Environmental Relevance	80–85% reduction in non-biodegradable waste; sustainable forest management; climate change mitigation	Moderate reduction in plastic waste through reuse; partially recyclable; intermediate carbon footprint	High recyclability and low initial production impact; limited by lower durability and higher waste generation due to frequent replacement
Technical Benefits	4–5 day shelf life extension; structural strength up to 25 kg; adaptable design	Extended shelf life 3–4 days; structural strength 15–20 kg; transparent and resistant design	Extended shelf life 2–3 days; structural strength 10–15 kg; lightweight and foldable design
Logistical Benefits	Standardization of dimensions; improved traceability; time optimization	Moderate standardization; easy to clean; safe transport for delicate products	Easy handling and storage; lightweight; quick replacement
Environmental Benefits	Contribution to multiple SDGs; circular economy	Reusable, less plastic waste generation; contributes to SDGs 12 and 13	Highly recyclable; contributes to SDG 12; limited effect on climate change mitigation

Own elaboration, 2025

After all of the above, the specifications of the prototype for efficient design and use of sustainable packaging materials for organic products are proposed

Input parameters:

- Basket dimensions: 45 cm x 33 cm x 29 cm
- Material: Scots pine [density: 520 kg/m³]
- Board thickness: 1 cm
- Spacing between boards: 4 cm [ventilation]
- Maximum load: 25 kg

Simulation conditions:

- Ambient temperature from 15 to 35°C

- Relative humidity of 60 to 85%
- Transport time 24 to 72 hours
- Transport vibrations between 2 and 5 Hz

Comparison scenarios:

- Scenario 1: Corrugated cardboard [reference]
- Scenario 2: Acrylic [reference]
- Scenario 3: Wooden basket [proposal]

Estimated Output Variables:

- % Mechanical damage
- % Mass loss
- Cost per cycle [MXN]
- Number of reuses
- Environmental impact [kg CO₂ eq]

Materials and methods

Packaging development proposal

In the small producer community of Villa del Carbón, wood is considered the best option for packaging and packing the perishable organic products of the TONAEM Association for several reasons. They consider several advantages of using wood in the form of a basket for packaging:

1. Physical protection

Strength: Wood is sturdy and can support the weight of the products, protecting them from damage during transport. **Cushioning:** It acts as a good shock absorber against impacts and vibrations.

2. Ventilation

Breathability: Wooden boxes allow air to circulate, which helps keep perishable products fresh by reducing moisture buildup.

3. Sustainability

Renewable Material: Wood is a renewable resource, especially if it comes from sustainable sources.

4. Biodegradability

At the end of its useful life, wood decomposes naturally, reducing its environmental impact.

5. Thermal Insulation

Temperature Regulation: Wood provides a certain level of insulation, helping to maintain more stable temperatures inside the packaging.

6. Customization

Adaptability: Wood can be easily cut and molded to fit different product shapes and sizes.

7. Reuse

Durability: Wooden boxes can be reused several times, making them an economical choice in the long term.

Main types of packaging wood

Hardwoods: Oak, walnut, cherry, holm oak, olive, chestnut, elm.

Softwoods: Poplar, pine, birch, cedar.

Pine wood is mainly used for the construction of wooden packaging.

- Scots pine [packaging].
- Radiata pine or Insigne pine [packaging and structures].
- Pinaster pine or Galician pine [packaging].
- Black pine [packaging]

In the case of our product, we will use Scots pine for packaging.

Case study: prototype model for basket manufacturing

The basket consists of:

- 9 strips 7 cm wide by 45 cm long, with a thickness of 1 cm
- 6 strips measuring 7 cm wide by 33 cm long, with a thickness of 1 cm
- 4 equilateral triangles with 3 cm sides and a length of 29 cm

The first step is to assemble the body of the box by joining the 4 triangles with the first 4 boards, which will serve as a support for placing the others. Half-inch stainless steel wood nails are used to prevent corrosion contamination of the products, and the result is as shown in the following figure:

Box 11



Figure 5

AutoCAD design of the base structure of the proposed wooden basket model

The following boards are placed at a height of 4 centimeters apart to allow ventilation of the products and prevent moisture, as are the following ones. The result is a rectangular box as shown in the figure:

Box 12



Figure 6

AutoCAD design of the spacing between the boards of the wooden basket to allow ventilation of perishable products

The result is a box measuring 45 cm long, 33 cm wide, and 29 cm deep, as shown in the following image:

Box 13



Figure 7

This model was chosen as it is the best option for transporting and storing perishable products

Estimated manufacturing cost of the prototype basket model

The cost of manufacturing wooden baskets can vary significantly depending on several factors. Below are the main elements that influence the cost.

Box 13

Table 7

Factors involved in the cost of manufacturing a wooden basket

Factors affecting manufacturing cost

Factor	Impact on cost
Type of wood	Hardwoods → higher cost
Size and design	More material and time → more expensive
Production volume	High scale ↓ unit cost / Low scale ↑ cost
Labor	Varies by region, skill level, and automation
Raw materials	Fluctuates due to supply, demand, regulations, and transportation
Equipment/technology	Significant initial investment
Treatments/finishes	Increases the final cost

In-house production, 2025

Cost estimate

The cost of manufacturing wooden baskets varies and depends on multiple factors. To obtain a more accurate estimate, it is advisable to carry out a specific analysis based on local market conditions and project requirements.

To calculate the manufacturing cost of a wooden basket with specific dimensions [33 cm wide, 45 cm long, and 29 cm deep], we need to consider several aspects.

1. Calculating the volume of the box

First, we calculate the volume of the box to estimate the amount of wood needed:

$$V = \text{Ancho} * \text{Largo} * \text{Profundidad} \quad [1]$$

We convert the dimensions to meters to obtain the volume in cubic meters:

- Width: 0.33 m

- Length: 0.45 m
- Depth: 0.29 m

$$V = 0.33m * 0.45m * 0.29m = 0.0434 m^3 \quad [2]$$

2. Raw material cost

Assuming a raw material cost of between \$1 and \$3 per cubic foot, we first convert the volume to cubic feet:

$$1 m^3 = 35.3147 \text{ cubic feet} \quad 1 m^3 = 35.3147 \text{ cubic feet} \\ 0.0434 m^3 \approx 1.537 \text{ cubic feet} \quad 0.0434 m^3 \approx 1.537 \text{ cubic feet}$$

Now, we calculate the cost of the wood:

Scenario	Calculation	Cost
Low	$1,537 \times \$1$	\$1.54
High	$1,537 \times \$3$	\$4.61

3. Labor cost

Assuming a labor cost of approximately \$15 per hour and that it takes about 0.5 hours to manufacture a box:

$$\text{Labor cost} = 0.5 \text{ hours} \times \$15 = \$7.5$$

4. Additional costs

Considering additional costs such as processing, transportation, and others, we can estimate an additional cost of approximately \$3 to \$5.

5. Total estimated manufacturing cost

Adding up all costs:

Scenario	Raw materials	Labor	Additional	Total
Low	\$1.54	\$7.50	\$3.00	\$12.04
High	\$4.61	\$7.50	\$5.00	\$17.11

The estimated cost of manufacturing a wooden crate with the specified dimensions ranges from **\$12.04 to \$17.11**.

Modeling parameters

Box 13

Table 8

Modeling parameters for the wooden basket prototype according to the needs of the TONAEM Villa del Carbón association

Parameter	Input value	Justification
Basket dimensions	45 cm × 33 cm × 29 cm	Optimization for local products TONAEM
Base material	Scots pine [density: 520 kg/m ³]	Local availability and mechanical properties
Spacing between boards	4 cm	Balance between ventilation and structural strength
Maximum design load	25 kg	Based on typical transport volumes
Environmental conditions	15-35°C, 60-85% RH	Climate conditions in Villa del Carbón
Transport time	24-72 hours	Usual distribution routes

Implementation of the SDGs in the project

The project for the efficient design and use of sustainable packaging materials for TONAEM association products implements the UN Sustainable Development Goals (ODS) from the ONU as follows: (ODS 2) Zero hunger, as the project supports food security and the eradication of hunger by improving the preservation and transport of perishable foods, reducing losses due to decomposition and mechanical damage, which ensures that fruits and vegetables reach consumers in optimal conditions. (ONU, 2023).

(ODS 9) *Industry, innovation, and infrastructure*, as it promotes innovation through the efficient design of sustainable wooden packaging, strengthening the productive capacities of small producers and improving logistics infrastructure for more efficient and less polluting transport (INOVALABS, 2024).

(ODS 12) *Responsible consumption and production*. The use of sustainable and reusable materials for packaging reduces the consumption of non-renewable resources, contributing to sustainable production and consumption practices within the agri-food chain (ONU, 2023).

(ODS 13) *Climate action*. Reducing environmental impact through biodegradable packaging and reducing plastic waste helps mitigate climate change by reducing emissions and promoting a responsible circular economy.

(ODS 15) *Life on land*. The project promotes the responsible use of sustainable forest resources for the manufacture of wooden baskets, protecting biodiversity and sustainably managing terrestrial ecosystems (REPAQ, 2022).

(ODS 17) *Partnerships for the goals*. It encourages collaboration between producers, academia (UAEM), and local actors to implement sustainable solutions, strengthening partnerships for sustainable development in the Villa del Carbón region.

That is why this project not only improves the local agri-food value chain, but also explicitly integrates the ODSs into its approach, contributing to sustainable development in social, economic, and environmental aspects (Pacto, 2025).

Expected results

The incorporation of wooden baskets is expected to contribute significantly to reducing losses associated with mechanical damage and mass loss, compared to conventional cardboard and plastic packaging systems. Similarly, an extension of the shelf life of products during transport is anticipated, as well as greater acceptance by producers and consumers. In addition, the greater structural strength and reusability of the baskets will improve the logistical efficiency of the distribution system. In terms of costs, although the initial manufacture of wooden baskets is more expensive, their reuse offsets the investment in fewer cycles, making them competitive with disposable materials. Environmentally, sustainable wood generates a smaller ecological footprint and greater biodegradability.

Estimates based on theoretical modeling

The expected results are based on analysis of specialized literature, computer modeling, and projections based on the physical properties of the materials. All estimates include confidence intervals based on variability reported in similar studies.

Box 14**Table 9**

Comparison of estimated performance of the wood basket vs. commonly used packaging [cardboard and acrylic]

Indicator	Cardboard/Plastic [Baseline]	Wooden Basket [Estimate]	Expected Improvement	Source of Estimate
Mechanical Damage [%]	12-18	6-10	Reduction 35-45	(Fernandez-Golfin, Díez, & Hermoso, 2007) + FEM modeling
Mass loss [%]	8-14	4-7	Reduction 40-50%	Diffusion equations + (IFORWORD, 2023)
Product shelf life	Baseline	+3-6 days	Significant extension	(WHO, 2023) + ventilation analysis
Structural resistance	8-12 kg	20-25 kg	Increase 100-150%	Structural calculations for Scots pine
Number of reuses	1-2 cycles	5-8 cycles	Increase 250-400%	(Tech, 2024) + wood durability

Estimated cost-benefit analysis

Conservative scenario:

- Initial basket cost: \$14.50 MXN
- Reuses: 5 cycles
- Cost per cycle: \$2.90 MXN
- Break-even point: Cycle 3

Optimistic Scenario:

- Initial basket cost: \$15.50 MXN
- Reuses: 8 cycles
- Cost per cycle: \$1.94 MXN
- Break-even point: Cycle 2

In terms of losses due to damage and shrinkage, the use of cardboard/plastic generates an additional economic impact per damaged or deteriorated product of between **10% and 15%** of the value of the batch. With wood, these losses are expected to be reduced to a range of **5% to 8%**, representing a potential savings of **20–40%** in shrinkage.

Box 15**Table 10**

Economic Projection by Life Cycle of the Prototype Wooden Basket Model

Concept	Cardboard/Plastic	Wooden basket	Economic Benefit
Initial unit cost	\$6-8 MXN	\$12-17 MXN	--
Life cycle cost	\$6-8 MXN/cycle	\$1.94-2.90 MXN/cycle	Savings 65-75%
Savings from reduced shrinkage	--	\$2-4 MXN/batch	ROI: 15-25%
Estimated environmental cost	\$1.50 MXN/cycle	\$0.30 MXN/cycle	80% reduction

Estimated environmental impact

Based on theoretical life cycle analysis (Packaging, 2025)

Carbon footprint per cycle:

- Cardboard/Plastic: 0.8-1.2 kg CO₂ eq
- Wooden basket: 0.15-0.25 kg CO₂ eq
- Estimated reduction: 75-85%

Waste generated:

- Cardboard/Plastic: 100% disposable per cycle
- Wooden basket: 12.5-20% per cycle [considering 5-8 uses]
- Waste reduction: 80-87.5%

Limitations of estimates

1. Modeling uncertainty: The results are theoretical projections that require experimental validation
2. Variability of conditions: Estimates assume controlled conditions that may vary in the field
3. Limited specific data: Some projections are based on analogies with international studies
4. External factors: They do not consider variables such as staff training or changes in transport routes

Discussion

The projected results for wooden baskets are consistent with the specialized literature on the preservation of perishable products. The estimated reduction in mechanical damage [35-45%] is in line with studies by (Fernandez-Golfin, Díez, & Hermoso, 2007) , which demonstrate the mechanical superiority of Scots pine over cellulosic materials. The projected mass loss [40-50% reduction] is consistent with research by (IFORWOORD, 2023) on the hygroscopic properties of wood that facilitate natural moisture regulation.

However, it is essential to recognize the inherent limitations of the theoretical-estimative approach. Projections are based on ideal management conditions and may overestimate benefits if variables such as staff training, extreme climate variability, or differences in transported products are not considered.

Economic Viability in the Local Context

The cost-benefit analysis suggests economic competitiveness from the third cycle of use onwards, which is conservative compared to international studies that report profitability from the second cycle. (BBVA, 2024) This difference can be attributed to specific conditions in the Mexican market, including local labor costs and availability of materials.

The projection of 5-8 reuses requires experimental validation, as factors such as UV exposure, extreme temperature variations, and handling during loading/unloading can reduce the expected useful life. However, documented experiences in Spain (FEDEMCO, 2023) suggest that this estimate is realistic for controlled conditions of use.

Implications for Sustainability

The estimated reduction in carbon footprint [75-85%] positions wooden baskets as an environmentally superior alternative, aligning with the objectives of the Paris Agreement and specifically contributing to SDGs 12, 13, and 15. However, this environmental advantage critically depends on sustainable forest management of the raw material source.

The use of certified wild pine is essential to avoid negative impacts such as deforestation or biodiversity loss. Successful implementation requires establishing verified supply chains that comply with international standards [FSC or similar].

Identified Implementation Challenges

1. Training and Cultural Change

The transition from disposable to reusable packaging requires changes in established logistics practices. Small producers will need training in the handling, cleaning, and storage of wooden baskets, which implies additional costs not quantified in the model.

2. Initial Investment and Cash Flow

Although the analysis shows medium-term profitability, the 100-150% higher initial investment may represent a barrier for producers with limited resources. Financing mechanisms or government support programs are needed to facilitate adoption.

3. Regional Scalability

The model is designed for the specific conditions of Villa del Carbón. Replication in other Mexican regions will require adaptations considering local availability of materials, different climatic conditions, and characteristics of regional agricultural products.

Academic Contribution and Methodological Limitations

This study contributes to theoretical knowledge on the optimization of sustainable packaging for small producers, filling a gap identified in the literature on computational modeling applied to this sector. However, the main methodological limitations include:

- Lack of experimental validation: The results are projections that require empirical confirmation.
- Simplification of variables: The model does not fully consider product variability, extreme weather conditions, or human factors
- Reliance on analogies: Some estimates are based on international studies that may not fully reflect Mexican conditions

Prospects for Future Research

The theoretical results of this study lay the groundwork for experimental research to validate the projections made. The following is recommended:

Controlled experimental validation: Implement pilot tests with prototypes under real transport conditions

- Sensitivity analysis: Evaluate the impact of extreme weather variables and different types of products
- Adoption studies: Investigate sociocultural factors that facilitate or hinder implementation
- Regional scalability: Adapt the model for different agroecological regions of Mexico

Implications for public policy

The results suggest that government support for sustainable packaging solutions for small producers can generate multiple benefits: reduction of post-harvest losses, strengthening of local value chains, and contribution to national environmental goals. It is recommended to consider tax incentives or specific financing programs to facilitate the transition to sustainable packaging.

Conclusion

The use of wooden baskets as an alternative packaging for the TONAEM association's perishable products proves to be a technical and sustainable solution compared to traditional cardboard and plastic packaging. Their strength, ventilation capacity, and reusability significantly reduce spoilage and mechanical damage during transport, while optimizing logistical efficiency.

In addition, the proposed model contributes to reducing environmental impact through the use of a renewable and biodegradable material, provided it comes from certified sources. This strengthens the competitiveness of small producers, guarantees food safety, and links local practice to the Sustainable Development Goals, especially in terms of responsible production and consumption.

The quantitative methodological approach with a theoretical-estimative focus, although limited, is appropriate for establishing design parameters and informing initial investment decisions. The main contribution of the study lies in providing a solid conceptual framework to guide future experimental research and facilitate informed decision-making by producers and public policy makers.

The model is highly replicable in similar contexts, which broadens its potential impact on the smallholder sector in Mexico and Latin America, contributing to the development of more sustainable and resilient agri-food systems.

Declarations

Conflict of interest

The authors declare that they have no conflicts of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this paper.

Contribution of the authors

The second lead author, a graduate student in industrial engineering, was responsible for the manufacture and evaluation of materials in the industrial engineering machining laboratory [], as well as background research, technical standards, and specific project requirements.

The lead author, responsible for the project linked to the Sustainable Development Goals [SDGs] focused on the traceability of small producers, contributed methodological advice and the documentary and scientific support for the research.

The secondary co-authors participated by formulating material proposals and providing support in technical documentation and research associated with the development of the project.

Availability of data and materials

The availability of the data and materials generated in this research is based on the methodological process developed. In the first stage, materials potentially suitable for the manufacture of baskets for transporting organic products were identified and analyzed. Subsequently, these materials were acquired and technical information relating to their properties and characteristics was compiled.

The baskets were manufactured in the machining laboratory of the Centro Universitario del Valle de México, where the prototypes evaluated were obtained. In addition, a systematic review of standards, guidelines, and requirements applicable to the packaging and packing of organic products, as well as their preservation, was carried out. Finally, a comparative analysis of the types of baskets manufactured was carried out, based on the established regulatory and technical criteria. The data derived from the selection of materials, manufacturing processes, regulatory review, and comparison results are available upon reasonable request to the authors for academic and research purposes.

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Abbreviations

LCA	Life Cycle Assessment
BBVA	Banco Bilbao Vizcaya Argentaria
cm	Centimeters
CO ₂	Carbon dioxide
CNC	Computerized Numerical Control
CU	University Center
A.D.	After Christ
FAO	Food and Agriculture Organization of the United Nations
FEDEMCO	Spanish Federation of Wooden Packaging and Components
FEM	Finite Element Method
FSC	Forest Stewardship Council

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HR	Relative Humidity
Hz	Hertz
ISSN	International Standard Serial Number
Kg	Kilograms
m	Meter
m ³	Cubic meter
min	Minute
MXN	Mexican peso
ISPM 15	International Standard for Phytosanitary Measures No. 15
NOM-144	Official Mexican Standard 144
SDG	Sustainable Development Goals
WHO	World Health Organization

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