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Functional optimization of a Persian lime packing using TRIZ and multi-objective genetic algorithms

Alberto Alfonso Aguilar-Lasserre[a,*], Víctor Eduardo Torres-Sánchez[a], Gregorio Fernández-Lambert[b], Catherine Azzaro-Pantel[c], Guillermo Cortes-Robles[a], Missael Alberto Román-del Valle[a]

[a] Tecnológico Nacional de México/Instituto Tecnológico Nacional de México, Instituto Tecnológico de Orizaba, División de Estudios de Posgrado e Investigación, Av. Oriente 9, 852, C.P. 94320 Orizaba, Veracruz, Mexico

[b] División de Estudios de Posgrado e Investigación, Instituto Tecnológico Superior de Misantla, Km. 1.8, Carretera a Loma del Cojolite s/n, C.P. 93821 Misantla, Veracruz, Mexico

[c] Université de Toulouse, Laboratoire de Génie Chimique LGC UMR 5503 CNRS INP-ENSIACET, 4, Allée Emile Monso, BP 84234, F-3143 Toulouse, France

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A B S T R A C T

This article proposes a novel approach that uses a mathematical model optimized by Genetic Algorithms harmonized with the Russian theory of problem solving and invention (TRIZ) to design an export packing of Persian Lime. The mathematical model (with functional elements of non-spatial type) optimizes the spaces of the Persian Lime Packing, maximizes the Resistance to Vertical Compression and minimizes the Amount of Material Used, according to the operation restrictions of the packing during the transport of the merchandise. This approach is developed in four phases: the identification of the solution space; the optimization of the conceptual design; the application of TRIZ; and the generation of the final proposal solution. The results show the proposed packing (with 28% less cardboard) supports at least the same vertical load with respect to the nearest competitor packing. However, with the same number of packings per pallet and pallets per container, the space used by the packing assembled and deployed in the container is greater by 10% and 38% respectively. Besides, TRIZ includes innovative non-spatial elements such as the airflow and the friction of the product inside the packing. The contribution of this approach can be replicable for the packing design of other horticultural products of the agri-food chain.

1. Introduction

The exportation of merchandises is a crucial activity that has increased in recent years due to the growth of global demand. According to Center (2016) in 2015 the value of exportation of international merchandises raised 16.2 USD billions, positioning Mexico in 13th rank with 80,857 USD millions in revenue by exportations.

The study reported in Quiñones Rivera (2015) highlights the ten principal categories of merchandises exported by Mexico, in which the fruit farming is raising approximately 6.372 USD thousand million during 2016 (SIAVI[1] 4, SE). Besides, the exportation of Persian lime like a fresh fruit leads the 667.618 millions of tons by year with an average value of 434.304 USD millions (Center, 2016), and 45 percent of the national total (Gil Camacho, 2015).

The exportation of Persian Lime as a fresh product is regulated both by national sanitary norms of the exporter country and the importer country. The simultaneous compliance of these norms is a complicated task for the exporters. As a result, the exporter companies have started innovating their packing with the purpose of satisfying all regulations. The reader can relate the applicable regulations for the packing, packaging, and export of citrus fruits, at http://eur-lex.europa.eu/; http://www.dof.gob.mx/; https://www.iso.org/.

In the increasing competition in the national and international fruit farmer's markets, companies and academics have strived to improve the production as a food security function. Some successful strategies include the use of renewable materials in packings and packaging, the implementation of flexible technology and standardized (Cheruvu, Kapa, & Mahalik, 2008), as well as the approaches for the design of products (Vinodh & Rathod, 2010). Particularly in the horticultural marker, the exporter company of fresh fruit wants to maximize the use

* Corresponding author.
E-mail address: albertoaal@hotmail.com (A.A. Aguilar-Lasserre).

[1] Sistema de Información Arancelaria Vía Internet. www.economia-snci.gob.mx.

of spaces inside a container, reduce the packing costs, and assure that the fruit keeps in the best possible conditions during handling and transportation. Considering these objectives, the scientific community has proposed several approaches and methodologies to integrate innovative elements of the design of new products, processes, wrappings, and loads of merchandises in which stands out the Theory of Inventive Problem Solving (TRIZ) (Ko, 2016; Russo, Bersano, Birolini, & Uhl, 2011; Zhang, Yang, & Liu, 2014). Meanwhile, for optimization, some algorithms on the artificial intelligence field have faced those problems (Liu, Tan, Xu, & Liu, 2014; Stawowy, 2008). Accordingly, "*the competitive advantage and the surviving of the organizations is based on how they take advantage of their capacities and the relation to their suppliers oriented to in an improving of their processes* (Jugulum & Sefik, 1998)".

This article presents an original work, which integrates the application of TRIZ and Genetic Algorithms (GA). The TRIZ methodology allows resolving contradictions detected in the design of the solution space, which was determined by some essential parameters for the packing design. Meanwhile, the GA tries to optimize functional requirements of the space given by TRIZ. Under this approach, the integration of TRIZ-GA is original, specially, as an emergent activity for the design of packings. To show the utility of this solving approach, a case of study focuses on the redesign of a packing for exportation of a company of Persian Lime localized in Veracruz-Mexico.

The result is a new packing presented to a Mexican enterprise, which offers a corporate identity and other advantages such as a reduced consumption of raw material. To depict the solving process, the article has been organized as follows: Section 2 highlights a literature review on design and eco-innovation packing and packaging. Section 3 presents the methodology for the conceptual design of a new export packing of Persian Lime in fresh fruit. The model uses a mathematical bi- criteria optimization model and the TRIZ basic solving tools (the Ideal Final Result, the concept of resource, and the Contradiction Matrix). Section 4 describes the application of GA and TRIZ through a case of study of a citrus exporter. Section 5 presents the results of the optimized packaging, the benefits and advantages achieved by the redesign, and finally, the concluding Section 6 presents the contribution of this article to the field of eco- innovation of packing and suggests future work in this field.

2. Literature review

Artificial intelligence (AI) deals with the design of intelligent computer systems, i.e. systems that exhibit the characteristics that we associate to intelligence into human behavior that refers to understanding language, learning, reasoning, and problem-solving (Barr, Feigenbaum, & Cohen, 1981). The AI field encompasses techniques such as expert systems, fuzzy systems and their hybrids, artificial neural networks (ANN), genetic algorithms (GA), artificial vision, robotics, agent-based systems, and other general machine learning methods and data extraction methods (Yan Chan, Kam Fung Yuen, Palade, & Yue, 2015). The use of these techniques has had an enormous growth during the last years in diverse disciplines of knowledge and fields of the industry with satisfactory results in the handling of the uncertainty. Lima-Junior and Carpinetti (2016) propose a multicriteria method for the selection and weighting of the criteria used in the supplier selection process. Chen (2013) establishes an approach to forecast the unit cost of a semiconductor through a Diffuse Neural Network in order to control the uncertainty this process entails. Akkawuttiwanich and Yenradee (2018) develop an approach using fuzzy Quality Function Deployment (QFD) to manage the Key Performance Indicators (KPIs) of the SCOR model. In medicine area, Savino, Battini, and Riccio (2017) propose a postural evaluation tool of complete body developed within a fuzzy inference engine. For cement industry, Sarduy, Yanes, Rodríguez, Ferreira, and Torres (2013) propose a model of energy consumption in mills supported by an ANN to predict the necessary energy consumption in the factory, and subsequently optimize such consumption with a simple GA. In the environmental field, Oliveira, Sousa, and Dias-Ferreira (2018) develop an Artificial Neural Network that uses Genetic Algorithms to estimate the annual amount of waste collected from households. One of the reasons for the great acceptance of AI is the application of these techniques in several problems from different fields of work, as well as its complementarity with other techniques of engineering, social, and administrative sciences. To support systematic creativity in product design, the TRIZ methodology in combination with other AI methodologies and/or techniques have proven to be one of the approaches most used by engineers to incorporate elements of innovation into their products (Chechurin, 2016). In the last ten years, the field of eco-innovation has been gaining importance in companies considering their products as a competitive advantage. It is common to find in these works the combination of methods like QFD and TRIZ to integrate aspects of sustainability into product design. In this field, Yang and Chen (2011) describe a model to accelerate the preliminary design of the eco-innovation product by integrating the advantages of case-based reasoning and the TRIZ method. The ecological innovation approach pursues that the sustainable product faces in the short term the increasing complexity of limited resources and ensures the best use of them in an environmental way (Ferrer Barragan, Negny, Robles Cortes, & Le Lann, 2012; Vinodh, Devadasan, Vimal, & Kumar, 2013).

The literature reports papers that integrate QFD, TRIZ and Fuzzy Sets with the aim of reducing the vagueness of the customer's opinion. TRIZ identifies important characteristics that product engineering should consider in their design and integrate them as elements of innovation in the product. In this context, the impact of the new design reflects the improvement of numerous features associated with limitation, safety, human health, as well as environmental issues (Bereketli & Erol Genevois, 2013; Liu & Cheng, 2016; Kiat Ng, Siong Jee, Jie Lee, & Ai Yeow, 2016; Zhang et al., 2014).

The history of packing, packaging and loading of containers of goods highlights the importance and complexity of solving this type of problem for any organization that seeks to reduce the logistics costs of distribution and/or maximize the spaces in merchandisés packing and/or containers for distribution to customers. "*This kind of situations in the life of companies is a challenging combinatorial optimization problem NP-Hard*" (Dokeroglu & Cosar, 2014), which has been tackled with various metaheuristics methods to find good solutions to the problem of packing, packaging and merchandise transports. Thomas and Chaudhari (2014) propose a search technique based on a genetic algorithm that combines a hyper-heuristic to obtain the optimal solution of the design process for two-dimensional rectangular block packaging. For the spatial design of containers for packaging goods, Leung, Wong, and Mok (2008) present a Generic Multi-objective Algorithm to define the optimum design of paperboard boxes to reduce the space not used by the box accommodation, as well as the size of the box required to maximize the space of a container.

With the objective of minimizing the number of containers in which the merchandise will be transported, Dokeroglu and Cosar (2014) propose a set of robust and scalable hybrid parallel algorithms that take advantage of parallel computing to obtain solutions to the Binary Packaging Problem of the same number of elements of the same size and shape. Liu et al. (2014) present a binary tree-based search algorithm to solve three-dimensional container loading problem (3D-CLP), which enhances the way to load a subset of rectangular pieces of irregular dimensions in a rectangular container to maximize the volume. In this way, Sridhar, Chandrasekaran, and Page (2016) develop an adaptive genetic algorithm to optimizes the packaging of goods and predicts the type of packaging in order to maximizes the benefit in a 3D container.

In these papers, it is observed that the problem of packing and packaging has been an attractive research topic to address real problems of the business sector, using frequently inventive techniques for the design of products like QFD, TRIZ, while GA has been implemented for optimizing spaces.

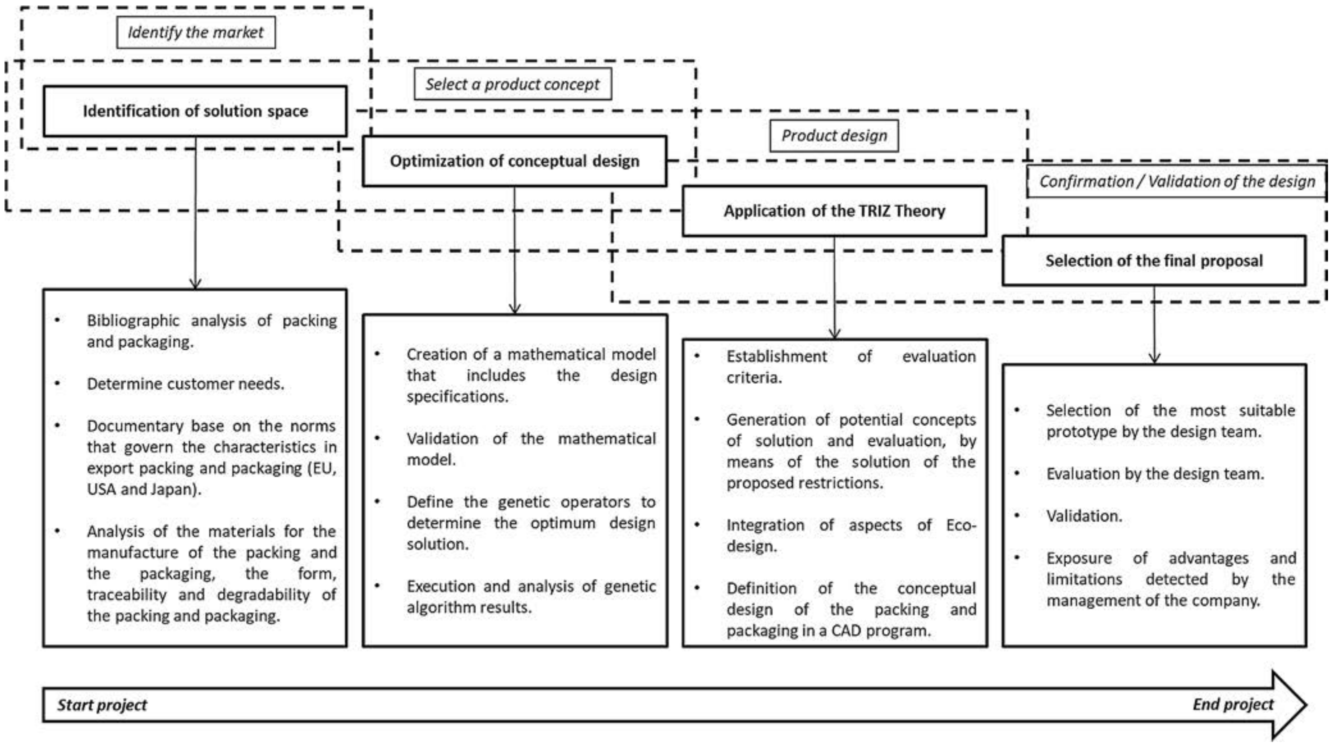


Fig. 1. Proposed methodology.

To attend the packing design for export fresh fruit, this article combines TRIZ and GA with the objective of integrating functional and inventive elements in an optimal way like functional requirements of space in an innovative packing for the horticultural industry.

3. Methodology

The proposed methodology is based on a sequence of activities that contribute to a new concept of functional Persian Lime Packing, which is constituted by four stages (Fig. 1).

(a) Step 1: Identification of solution space

First, a knowledge base is built through a specialized bibliography as well as national and international standards related to export criteria of Persian Lime. This knowledge base includes norms and legislation in packing, packaging and transportation for the fresh fruits export, and commercialization norms for citrus fruits.

After the design of the knowledge base, a panel of experts is integrated with four officials of two exporting companies of Persian Lime, a manufacture specialist of cardboard packaging, two fruit packers, and a supervisor of the fruit packing process. The experts panel contributes to the establishment of the main functions of the packing, the main requirements of the customers, the criteria for evaluation of the fruit, the material, form and degradability of the packing, the product traceability, among other aspects required by the client.

Finally, the Analytic Hierarchy Process (AHP) technique and the first stages of Quality Function Deployment (QFD) are used to prioritize the packing functional requirements. The aim of assigning a normalized value is to guide the packing redesign to the fulfillment of each of the Functional Requirements of higher priority required by the client and standardized for the export of fresh fruit.

(b) Stage 2: Optimization of conceptual design

This stage includes an adaptive method to solve search and optimization problems. A Multiobjective mathematical model is developed with two objective functions to maximize the Vertical Compression Resistance, and minimize the Amount of Material in the packing. These objectives are immersed in eleven constraints to find the optimal values of the packing design variables. The model is validated qualitatively and quantitatively; the first one, through the experts involved in the process who corroborate the logic of the mathematical model, and the second, using the NSGA II Genetic Algorithm to generate optimal values of an export packing design in fresh fruit. The mathematical model will be presented in the dedicated section.

(c) Stage 3: Application of the TRIZ theory

The optimized design from the mathematical model is harmonized with TRIZ, which gives the packing design new inventive elements for its manageability and functionality. The inventive elements are used to evaluate the concept of the solution derived from the previous stage, in relation to the fulfillment of the requirements demanded by the different normativities and requirements of the clients. In this process, contradictions that limit the obtaining of a better packing are common. This problem is solved by TRIZ's Matrix of Contradictions, which defines a database of known solutions linked to inventive principles capable of solving and overcoming the contradictions that may arise from possible solutions. Finally, the design is conceptualized through a CADD (Computer-Aided Design and Drafting) environment for its visual appreciation.

(d) Step 4: Settlement of the final proposal

In this stage, the final packing proposals with the best solution values are identified. For each of them, the advantages and limitations of the packing are described. Each packing alternative is constructed as a “packing prototype” and these are qualified by an expert panel, and packing and packaging personnel of the product (Persian Lime), based on: handling ease during the citrus packaging and the packing stacking on the pallets. The physical tests of vertical load and humidity resistance of the "packing prototype" are qualified by a supervisor of process and packing of fruit, in a cold store between 7 and 10 °C, during two weeks at room temperature. In both cases, it is sought that the packings do not have folds in the walls and the pallets do not present inclinations.

4. Case study: Persian lime packer in Mexico

Nowadays, any Mexican fruit exporter can find several packing suppliers that comply with the national and international regulations. However, these suppliers make generic packings with just a different label, without ergonomic properties, which does not help to create an identity to the product. This research focuses its contribution on the redesign of a packing for 110 caliber Persian Lime (10 lb.) for exporting to the European Community (Europe), and the United States of America (USA) market. The design objectives are to materialize the product identity, integrate ergonomic elements for manipulation also some elements for product transpiration, and to reduce the necessary raw material in the production stage. The importance of design basically lies in ensuring the product requirements expressed by both the customer and the health regulations applicable to fresh fruit specifications.

4.1. Space and structural elements of the packing design

The packing design involves three phases: the first one seeks to integrate the minimum regulatory elements defined by the commercial community in the country where the fruit is exported. The purpose is to understand the needs and define them as part of the functional elements of the packing. The second phase, supported by the QFD method, as well by a survey of four citrus exporters from Martinez de la Torre in the Citrus III District, in Veracruz-México. The customer requirements, structural elements, and competition elements of three representative packings used for this purpose are identified. Finally, the third phase is about of defining the functions that must be fulfilled by the packing for handling and transportation.

Currently there are seven different packing designs used to export of Persian lime in 10 lb. presentation: 3 for Europe, 3 for the United States, and 1 for Japan, all made of corrugated paperboard, usually measured in centimeters: 28 × 33 × 12 (length × width × height). Fig. 2 shows the packing for European Community customers (2.a.), and the United States market (2.b.), correspondingly.

Table 1 shows 17 Functional Requirements (FR) of the innovative packing to export Persian Lime.

4.2. Importance and relation of functional requirements

Two techniques are useful to assign a weighted and normalized importance value for each Functional Requirements (FR): the AHP and the QFD, which also can identify the customer's needs and expectation. The AHP allows to guide the process of redesign of the packing prioritizing the FR with a customer-centered approach, whereas QFD allows to rethink the normalized value, making it more reliable considering not only the perspective of the user, but also a benchmarking of other exporter's packings. Table 2 contains a hierarchical list of the 17 FR's. Each FR has a prioritization score according to four values that are also a set of evaluation guidelines: target value, Improvement rate, Strategic value, and the Competitive importance.

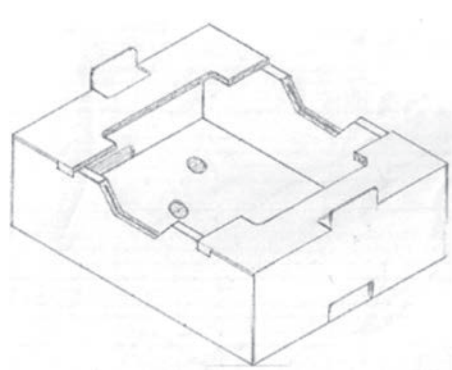
The QFD produces enough information to build a Pareto Analysis for the allocation of each element to another, that is, to determine if there is a relationship between them. Table 3 represent the FR list according to the normalized importance described in Table 2. In the other hand, Table 4 describes the paired matrix of the FR to identify the type of relationship between them, that is, to determine if any of them has an allocation another in a positively or negatively way. For example, a comparison between the I_{FR} 1, which represents the Vertical Compression Resistance, with I_{FR} 9 about an Adequate Ventilation, thereby it determines that there is a relationship between them, because if it is necessary to increase or maintain the resistance to compression of the packing, in this context, the cuts made for ventilation will influence this factor. In this case, it put an asterisk (*) in the intersection in Table 4.

The FR 6 and FR 17, with order of importance 16 and 17 each one, are omitted in Table 4 because they have no relation with other FR, according to the results of the paired comparisons, being unnecessary its presentation. Table 5 describes the total number of times that each FR occurs or relates to others, both in rows and columns. It can be seen, the factor that is most related to others is fruit protection during transportation, followed by resistance to vertical compression, and humidity.

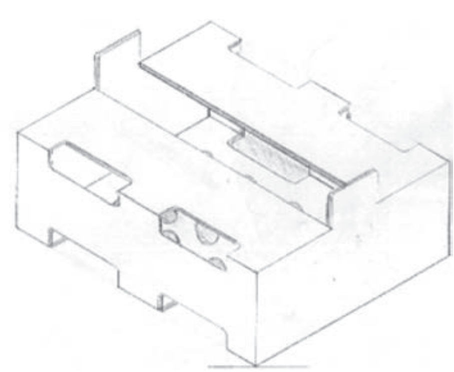
4.3. Performance measures of functional requirements

A Key Performance Indicator (KPI) is a technical measurement that allows evaluating the capacity to satisfy a client requirement. Generally, the method selected to measure product performance can be done in a laboratory without having to interact with the customer. Analyzing these performance measures often leads to improvements in the product and the generation of inventive ideas. In this sense, the suggestion is to implement at least one KPI for each FR.

The packing design performance measures were defined by some experts packaging manufacturers who provided the measurement test for each FR and its performance measure currently used in that specialized field. The performance measures selected for each RF and the units of measurement are presented in Annex A.



a. Europe packing.



b. USA packing.

Fig. 2. Packing representation 10 lb. for the European market (a) and USA market (b).
Source: Archive of the exporter San Gabriel.

Table 1
Functional requirements of innovative packing.

N° FR	Functional requirements for a citrus packing	Function				
		Structural	Transport	Handling	Conservation	Sustainable
1	Ensure lime protection during transport	✓	✓			
2	Allow the arrangement of limes in a compact way	✓		✓		
3	Ensure that limes do not protrude from the packing	✓				
4	Provide adequate ventilation to all limes		✓		✓	
5	Do not press too much limes in the accommodation	✓				
6	Facilitate unit handling of packing			✓		
7	Secure stowage		✓	✓		
8	Ensure hygienic, free of foreign material and odor				✓	
9	Packing with suitable resistances to humidity	✓	✓			
10	Ensure the stability of the fruit inside the packing				✓	
11	Allow identification of the packing using the external code	✓	✓			
12	Packing capable of withstanding low temperatures		✓		✓	
13	Packing with resistance to high vertical compression	✓	✓			
14	Environmentally friendly packing – low environmental impact					✓
15	Manufacture material for the interior of the boxes the least porous possible	✓	✓			
16	Allow maximum use of the pallet when stowed		✓	✓		
17	One-piece packing design			✓		

Table 2
Quality planning table.

N° FR	Functional requirements for a citrus packing	Strategic value				
		Target value[ǂ]	Improvement rate	Strategic value	Competitive importance	Normalization of importance (%)
1	Ensure lime protection during transport	5	1.67	1.50	25.00	**11.94**
2	Allow the arrangement of limes in a compact way	4	1.33	1.50	8.00	**3.82**
3	Ensure that limes do not protrude from the packing	4	1.00	1.00	8.00	**3.82**
4	Provide adequate ventilation to all limes	4	1.33	1.00	8.00	**3.82**
5	Do not press too much limes in the accommodation	5	1.67	1.20	10.00	**4.78**
6	Facilitate unit handling of packing	3	0.75	1.00	1.50	**0.72**
7	Secure stowage	5	1.67	1.00	6.67	**3.18**
8	Ensure hygienic, free of foreign material and odor	4	1.33	1.00	12.00	**5.73**
9	Packing with suitable resistances to humidity	4	2.00	1.50	30.00	**14.33**
10	Ensure the stability of the fruit inside the packing	3	1.50	1.20	3.60	**1.72**
11	Allow identification of the packing using the external code	4	1.00	1.00	4.00	**1.91**
12	Packing capable of withstanding low temperatures	4	1.33	1.50	16.00	**7.64**
13	Packing with resistance to high vertical compression	5	2.50	1.50	60.00	**28.66**
14	Environmentally friendly packing – low environmental impact	3	1.50	1.50	6.75	**3.22**
15	Manufacture material for the interior of the boxes the least porous poss.	4	1.33	1.00	4.00	**1.91**
16	Allow maximum use of the pallet when stowed	4	2.00	1.20	4.80	**2.29**
17	One-piece packing design	5	1.00	1.00	1.00	**0.48**

[ǂ] (1) Nothing important. (2) Less important. (3) Important. (4) Very important. (5) Highly important.

4.4. Optimization of conceptual design

The standardized assessment of FR and their relationships integrate the elements to meet two objectives in packing design: maximizing the resistance to vertical compression Eq. (1), and minimizing the material quantity required for packing Eq. (2):

Goals:

RCV: *Resistance to Vertical Compression.*
CM: *Material Quantity in the Packing.*

where

$$Max \quad RCV = \left(\frac{PMA}{A_{carga}}\right)(FR) \tag{1}$$

$$Mín \quad CM = APL + APC + AFC + ATC \tag{2}$$

Variables related to vertical compression:

PMA: *Maximum applied pressure on a load area.*
A_{carga}: *Load area on which a dead weight will be applied.*

where

$$PMA = (P_{empa})(N_{empH} - 1)$$

$$A_{carga} = 2(N_{PA})(Gro)(A_{emp}) + 2[(N_{PB})(Gro)(B_{emp} - (N_{PA})(Gro))]$$

Parameters related to vertical compression:

P_{empa}: *Average packing weight.*
N_{empH}: *Maximum number of packings that are stacked above the pallet.*
N_{PA}: *Number of existing carton walls for side A of the packing.*
Gro: *Corrugated paperboard thickness.*
A_{emp}: *Length on side A of the packing, corresponding to the length of the packing.*
N_{PB}: *Number of existing carton walls for side B of the packing.*
B_{emp}: *Length on the side B of the packing, corresponding to the width of*

Table 3
Table of FR ordered by their importance (IFR).

N° FR	Functional Requirement	Importance
13	Packing with resistance to high vertical compression	1
9	Packing with suitable resistances to humidity	2
1	Ensure lime protection during transport	3
12	Packing capable of withstanding low temperatures	4
8	Ensure hygienic, free of foreign material and odor	5
5	Do not press too much limes in the accommodation	6
2	Allow the arrangement of limes in a compact way	7
3	Ensure that limes do not protrude from the packing	8
4	Provide adequate ventilation to all limes	9
14	Environmentally friendly packing – low environmental impact	10
7	Secure stowage	11
16	Allow maximum use of the pallet when stowed	12
15	Manufacture material for the interior of the boxes the least porous possible	13
11	Allow identification of the packing using the external code	14
10	Ensure the stability of the fruit inside the packing	15
17	One-piece packing design	16
6	Facilitate unit handling of packing	17

Table 4
Paired analysis of the functional requirements according to their importance (I_{FR}).

I_{FR}	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1		*	*	*					*	*	*	*			
2	*		*	*					*		*		*		
3	*	*			*	*	*	*	*		*				
4	*	*								*	*		*		
5			*												
6			*				*	*							*
7			*			*		*							*
8			*			*	*		*						*
9	*	*	*					*			*			*	
10	*			*											
11	*	*	*	*					*			*			
12	*										*				
13		*		*											
14									*						
15						*	*	*							

Table 5
Relationships by functional requirement.

I_{FR}	Functional requirement	Total
1	Packing with resistance to high vertical compression	14
2	Packing with suitable resistances to humidity	12
3	Ensure lime protection during transport	16
4	Packing capable of withstanding low temperatures	10
5	Ensure hygienic, free of foreign material and odor	2
6	Do not press too much limes in the accommodation	8
7	Allow the arrangement of limes in a compact way	8
8	Ensure that limes do not protrude from the packing	10
9	Provide adequate ventilation to all limes	12
10	Environmentally friendly packing – low environmental impact	4
11	Secure stowage	12
12	Allow maximum use of the pallet when stowed	4
13	Manufacture material for the interior of the boxes the least porous possible	4
14	Allow identification of the packing using the external code	2
15	Ensure the stability of the fruit inside the packing	6

the packing.
H_{emp}: *Packing height.*

Parameters related to the Vertical Reduction of Compression Resistance Packing:

FR: *Reduction Factor in the Resistance to Vertical Compression, where:*

$$FR = \left(\frac{1}{F_{Hum}}\right)\left(\frac{1}{FA_{corte}}\right)\left(\frac{1}{FP_{corte}}\right)$$

F_{Hum}: *Reduction factor in the resistance compression due to changes in humidity, where:*

$$F_{Hum} = (0.58)(0.93^{H_{final}-H_{inicial}})$$

$H_{inicial}$: *Moisture that the box has when leaving its manufacturing process.*
H_{final}: *Moisture that the box has when arriving at its destination already as packaging.*
FA_{corte}: *Reduction factor in the resistance compression per area of cuts in the packing, where:*

$$FA_{corte} = 1 - \sqrt{\%_{corte}} - [(0.08)(10(\%_{corte}) - 1)]$$

$\%_{corte}$: *Percent of cut damage in the packing.*
FP_{corte}: *Reduction factor in the resistance compression by the position of the cut in the packing, where:*

$$FP_{corte} = C_{sup}(0.20) + C_{med}(0.08) + C_{baj}(0.20)$$

C_{sup}: *Cut made in the upper area of the packing.*
C_{med}: *Cut made in the middle area of the packing.*
C_{baj}: *Cut made in the lower area of the packing.*

Generally, the corrugated paperboard packings for export follow a behavior of parallelepiped, reason to get its volume by the multiplication of its length, by its width and its height. However, the interest in the dimensions of the packing is based on the value of the area occupied by each side of the parallelepiped, that is, the sum of the areas of the packing.

Variables related to the material quantity in the packing:

APL: *Long wall area, where:*

$$APL = 2(A_{emp})(H_{emp})(N_{PA})$$

APC: *Short wall area, where:*

$$APC = 2(B_{emp})(H_{emp})(N_{PB})$$

AFC: *Packing fund area, where:*

$$AFC = (A_{emp})(B_{emp})$$

ATC: *Box top area, where:*

$$ATC = 2(A_{emp} - \varepsilon_A)(B_{emp} - \varepsilon_B)$$

ε_A: *Length of the packing that is not being used by the length of the lid.*
ε_B: *Length of the packing that is not being used by the width of the lid.*

4.4.1. Restrictions

In this study the restrictions may involve dimensional aspects of the packing, the use of spaces in the pallet, the cut openings, among others. For their definition, the Peer-to-Peer Analysis of FR was retaken, to know which of them were positively or negatively involved with the Resistance to Vertical Compression.

- Restriction of space on the pallet

$$0.97(A_t)(L_t) \le (A_{emp})(B_{emp})(N_{emp}) \le (A_t)(L_t) \quad (3)$$

The pallet dimensions will limit the space on which the packings are placed, this considers two points: they must be inside the pallet area and the free space on the pallet must be the smallest possible. In this way, Eq. (3) mathematically defines the area occupied by packings stacked at the first level of the pallet $(A_{emp})(B_{emp})(N_{emp})$ must be greater than or equal to 97% to the area of the pallet, but less than or equal to Total floor area $(A_t)(L_t)$; where:

N_{emp}: Number of packings stacked on the first level of the pallet.
A_t: Width of the platform.
L_t: Long of the platform.

- Use of airspace.

$$0.\ 90(H_{total}) \leq (H_{emp})(N_{empH}) \leq H_{total} \tag{4}$$

Determining the optimum height of a packing by taking full advantage of all available space in the containers is extremely important for the optimization of the new design. At that time, mathematically (4) defines that the height of the pallet $(H_{emp})(N_{empH})$ must be greater or equal to 90% of the height of the container but less than or equal to the total height of the container; where:

H_{total}: Total container height.

- Required volume packing.

$$(A_{emp} - 2(N_{PB})(Gro))(B_{emp} - 2(N_{PA})(Gro))(H_{emp} - 2(H_{PH})(Gro)) > VT_{lime} \tag{5}$$

To obtain the minimum volume required considering the thickness of the paperboard and the limés volume related to their size determined by caliber or the fruit's measure; Eq. (5) expresses that the space for accommodating the fruit within the packing, determined by the length, wide and height of the packing, must be greater than the total volume of the lime (VT_{lime}); where:

H_{PH}: Number of paperboard sheets that were designated for the bottom and top of the packing.
VT_{lime}: Total volume occupied by the fruit to be packed.

- Ventilation requirements

$$(r)(ve)(A_{corte})(sin\sigma) \leq Vent_{req} \tag{6}$$

Like all fresh fruit, circulating the air inside the packing, through cuts made to its walls, is essential. Based on the formula developed by Baldrich Orbea (n.d.), Eq. (6) expresses that the ventilation area of the packing defined by $(r)(ve)(A_{corte})(\sin\sigma)$, must be less or equal than to the ventilation required for the fruit perspiration; where:

r: Relation that maintains the air inlet and outlet cut in the packing.
ve: Velocity which air circulates inside the packing.
A_{corte}: Cutting area required for proper ventilation inside the packing.
$\sin\sigma$: Angle that forms the direction of the wind with the plane of the cut.
$Vent_{req}$: Ventilation required inside the packing.

However, the cutting area for ventilation should be restricted, as it is recommended that the cut should not be greater than 50% of the side area of the packing, to prevent the resistance to vertical compression diminishes potentially. In this sense, (7) recommends that the cut areas in the packing is not more than 50% of the area of the packing walls.

$$A_{corte} \leq 0.\ 50(A_{emp})(H_{emp}) \tag{7}$$

- Labeling space

$$(B_{emp})(H_{emp}) - A_{corte} > N_{let}\left(1.\ 6(Cat)\left(\frac{1.\ 6(Cat)}{3}\right)\right) \tag{8}$$

Eq. (8) describes the restriction that delimits the space for the label on the packing according to the Official Mexican Standard NOM-030-SCFI-2006. The labeling space, determined by the packing width and height respect to the cut area $(B_{emp})(H_{emp}) - A_{corte}$, must be greater than necessary area for the description of the character numbers needed of a label related to the category of the packing $N_{let}\left(1.\ 6(Cat)\left(\frac{1.\ 6(Cat)}{3}\right)\right)$; where:

N_{let}: Number of characters required for the packing label.
Cat: Packing category.

- Resistance to paperboard compression

$$5.876(ECT)(\sqrt{2(A_{emp} + B_{emp})(Gro)}) \geq (PMA)(FR) \tag{9}$$

The resistance value of the paperboard compression can be calculated with (McKee, Gander, & Wachuta, 1963), in such a way, as expressed in Eq. (9), the compression test result must be greater or equal than minimum compression expected in the packing material; where:

ETC: Value of the "edge" test performed on the paperboard based on the McKee constant of 5.876.

Finally, Eqs. (10), (11) and (12) represent three restrictions involving the humidity factor, the cut factor by ventilation and the cut position factor by ventilation, respectively; which are already described in the objective functions, but they are defined as restrictions to limit their behavior to conditions that are more closely related to the real system.

$$0.93^{H_{final} - H_{inicial}} \leq 1 \tag{10}$$

$$C_{sup}(0.20) + C_{med}(0.08) + C_{baj}(0.20) \leq 0.20 \tag{11}$$

$$1 - \sqrt{\%_{corte}} - [0.08(10(\%_{corte}) - 1)] \leq 1 \tag{12}$$

Finally, Eq. (13) frames a non-negativity restriction, where X defines all the optimization variables of the multiobjective mathematical model that maximizes the Vertical Compression Resistance (RCV) and minimizes the Amount of Material in the packing (CM), these which must be greater than or equal to zero.

$$X \in \{RCV, CM\} \geq 0 \tag{13}$$

The reader will find in Appendix A, the general model that optimizes the eco-packing for the export of Persian Lime.

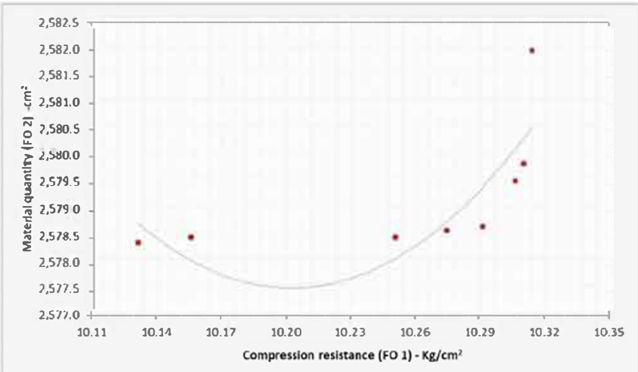
4.4.2. Packing design optimization

The optimization process was performed with two Genetic Algorithms. The first one is a monocriterion type by means of RISKOptimazer® in its version 5.5, developed by the work team PALISADE (http://www.palisade.com/). The second one is a multi-objective optimization tool implementing a variant of NSGA II developed in the Laboratory of Chemical Engineering at the Institute National Polytechnic of Toulouse (INP).

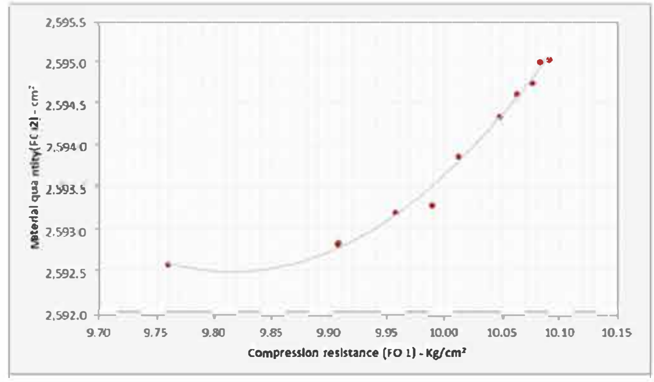
The monocriterion solution has as purpose to understand the behavior of the Functional Requirements (FR). The monocriterion optimization results are oriented to find the best value of each function. However, the multi-criterion optimization achieves an improvement balance between both functions. Table 6 describes the optimization

Table 6
Optimization criteria.

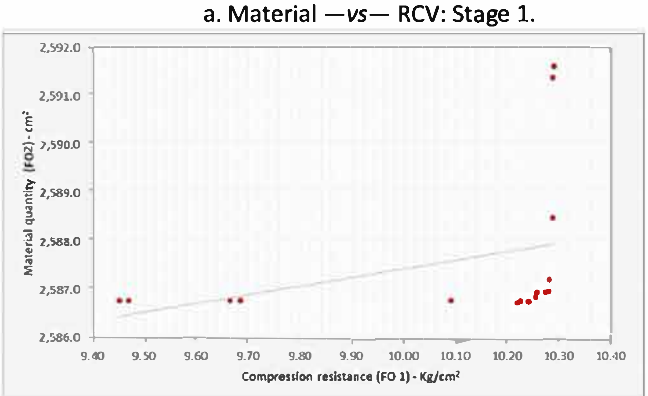
Optimization Criteria	Monocriterio optimization	Multi-criterion optimization
Population size	100	100
Number of iterations	1000	1000
Number of generations	200	200
Type of individual selection	Elitist	Elitist
GA used	RISKOptimazer 5.5	NSGA II Mixed
Crossing rate	0.9	0.9
Mutation rate	0.3	0.5
Runs number	10	8
Number of evaluations		
Max Resistance Compression	5 runs	4 runs
Min Use of Material	5 runs	4 runs



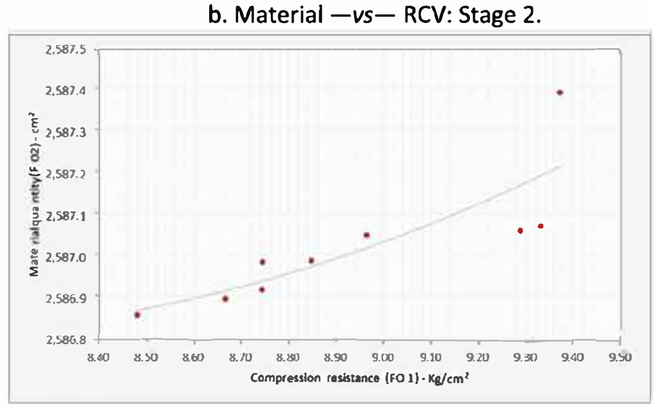
a. Material —*vs*— RCV: Stage 1.



b. Material —*vs*— RCV: Stage 2.



c. Material —*vs*— RCV: Stage 3.



d. Material —*vs*— RCV: Stage 4.

Fig. 3. Pareto Fronts of Multi-Criterion Optimization: Paperboard Quantity - vs - Compression Resistance.

criteria for the GA based on RISKOptimazer® and NSGA II.

The multi-criterion optimization carried out in eight scenarios, all of them under the same criteria shown in the Table 6, however, four scenarios maximize the vertical compression and minimize the paperboard quantity required for the packing at the same time. In the same way, the other four scenarios maximize the weight applied to the packing and minimize the paperboard quantity. In each of these scenarios, the initial variables values are modified to start the multi-criterion optimization from different points and it is possible to observe if the evolution has the same behavior.

5. Results

5.1. *Multi-criterion optimization*

Fig. 3 shows the Pareto sets which exhibit the multi-criterion optimization between the "paperboard quantity in the packing" - vs - "vertical compression resistance". The figure reveals that there is a contradiction between both parameters: a greater resistance in the packing demands to increase the paperboard quantity. Hence, although the paperboard material increases or decreases, the compression can be achieved, and the packing will not fracture by the applied weight.

Table 7 shows the optimal numerical values plotted in the Pareto Fronts of Fig. 3 estimated by the GA of each simulated scenario. This information shows that, when the packing maximizes the resistance to vertical compression, their results oscillate between 8.48 kg/cm^2 and 10.31 kg/cm^2. On the other hand, when it minimizes the quantity of material, its results are found between 2578.31 cm^2 and 2595.06 cm^2.

Fig. 4 shows the Pareto sets that exhibit the multi-criterion optimization results between the "Maximum Applied Weight" - vs - "Paperboard quantity in the packing", in which it is observed the same trend of needing a larger paperboard to put up with a higher applied weight.

In the same way, Table 8 shows the numerical values of each plotted point of the Pareto Front of Fig. 4; it is observed that the weight applied on the packing is maximized, the results oscillate between 239 kg and 429.81 kg. For material quantity minimization, the results are found between 2585.15 cm^2 and 2973.29 cm^2.

The results are conclusive when observing that the objective functions proposed for the packing design maintain a negative correlation, which limits the reach of better solutions, since while a function gets worse, the other improves and vice versa. Finally, the selection of the best solution considers four points: the importance of each FR in the packing design for the Persian Lime exportation; the expected improvements related to the paperboard quantity needed; the Resistance to Vertical Compression; and the last one, the maximization of the transportation spaces. Considering the importance for the exporter company to maximize the RCV about the weight applied to the packing, the best result is shown in scenario 7 of Fig. 4, with values of 423.53 kg and 2873.14 cm^2, corresponding to the maximum applied weight and the material quantity, this is shown in Fig. 5.

Although the GA could find optimal values for the new packing design, there is a contradiction which specifies that if the weight applied to the packing increases, then the material quantity will increase too. In this sense, the solution to the contradiction is based on improving the resistance to vertical compression and at the same time on decrease of the quantity of material required for the packing. Also, it is necessary to consider that the empty packing should occupy a smaller space -volume- for transport and storage. However, when required, the packing must take the appropriate dimensions to contain and protect the fruit, without altering the characteristics of the fruit. To deal this contradiction, TRIZ was used to solve the contradiction through the Contradiction Matrix.

Table 7
Numerical results of Pareto Fronts: Material quantity - vs - Resistance.

Optimization results: Values in Pareto Fronts									
Number		Stage 1		Stage 2		Stage 3		Stage 4	
		RCV	Material	RCV	Material	RCV	Material	RCV	Material
Quantity material - vs - Compression Resistance	01	10.13	2578.31	10.08	2595.03	10.29	2591.32	8.96	2587.05
	02	10.27	2578.54	10.06	2594.60	10.26	2586.86	9.37	2587.39
	03	10.31	2581.92	10.01	2593.85	10.29	2591.56	8.48	2586.85
	04	10.31	2579.78	9.96	2593.19	10.26	2586.95	8.74	2586.98
	05	10.31	2579.46	9.76	2592.56	10.28	2586.98	8.67	2586.89
	06	10.25	2578.41	9.91	2592.83	10.29	2588.43	9.33	2587.08
	07	10.16	2578.40	10.08	2594.73	9.45	2586.73	8.74	2586.91
	08	10.29	2578.62	10.05	2594.33	9.68	2586.73	9.29	2587.07
	09			9.91	2592.81	10.24	2586.78	8.85	2586.98
	10			9.99	2593.28	9.66	2586.73		
	11			10.09	2595.06	9.47	2586.73		
	12					10.22	2586.73		
	13					10.23	2586.78		
	14					10.28	2587.23		
	15					10.09	2586.73		
	16					10.27	2586.96		

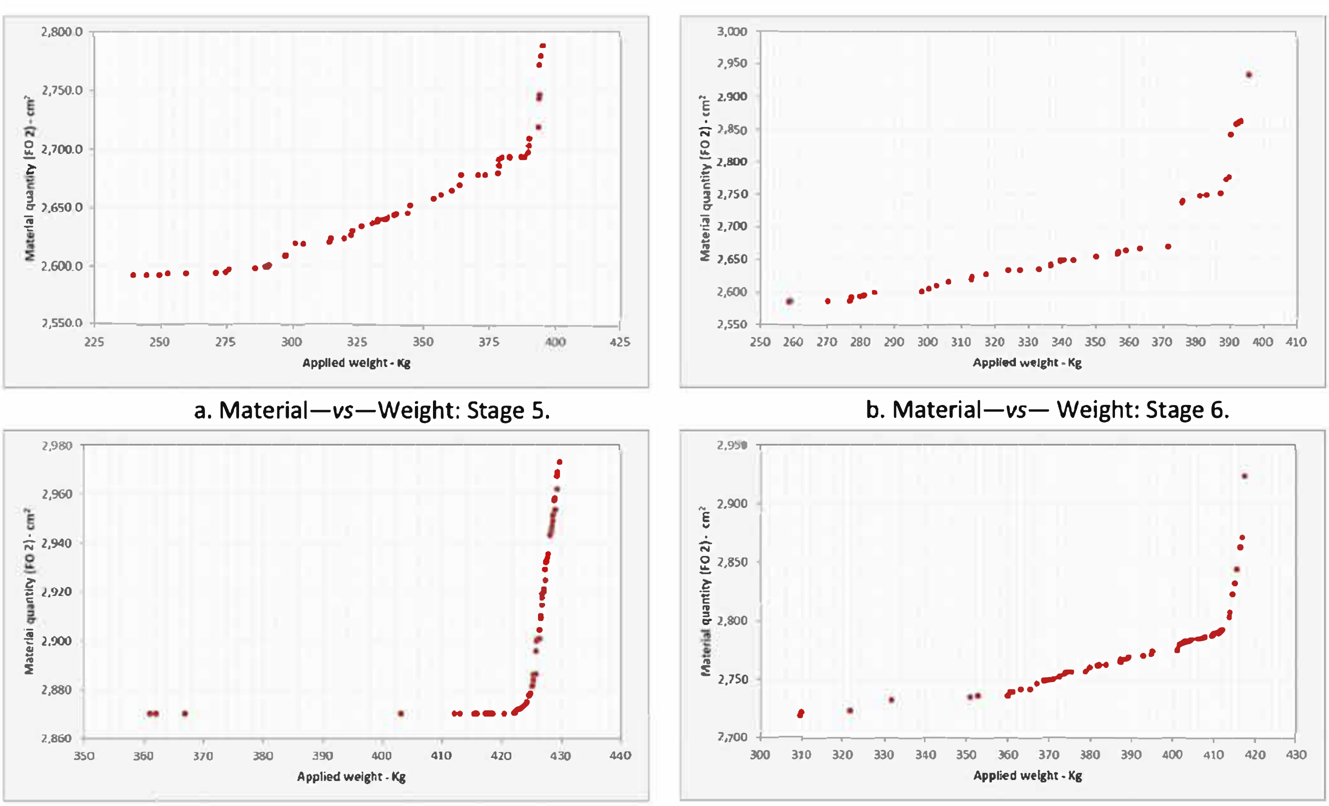
5.2. TRIZ theory application

The Contradiction matrix is a database of known solutions corresponding to inventive principles. This tool is useful to solve and overcome contradictions or problems the improvement of a characteristic usually generates the affectation or diminution of others. Table 9 lists the Inventive Principles identified in the Contradiction Matrix for each of the conflicting objectives.

5.2.1. Contradiction: "Substance Quantity-Vs-Resistance"

To solve the contradiction "Quantity of substance Vs Resistance", the principle of "Preliminary Action" was selected. The purpose was to modify the structure to minimize in advance the effect of the paperboard reduction for the manufacture of the packing. This solving strategy helps to resist the mechanical load when the paperboard is decreased.

Packing stack shows that the load weight can be concentrated on the edges; taking advantage of the above, it is possible to reduce the weight of the central parts load of the walls, of the lid, and the base of the packing. This solving strategy aims to reduce the material quantity in the walls of the packing and increase it as a reinforcement in the edges formed by those walls, which they will henceforth have to perform a



a. Material—*vs*—Weight: Stage 5.
b. Material—*vs*— Weight: Stage 6.
c. Material—*vs*— Weight: Stage 7.
d. Material—*vs*— Weight: Stage 8.

Fig. 4. Pareto Fronts of Multi-Criterion Optimization: Paperboard Quantity - vs - Maximum Applied Weight.

Table 8
Numerical results of Pareto Fronts: Paperboard Quantity - vs - Maximum Applied Weight.

Optimization results: Values in Pareto Fronts									
Number		Stage 5		Stage 6		Stage 7		Stage 8	
		Weight	Material	Weight	Material	Weight	Material	Weight	Material
Paperboard Quantity - vs - Maximum Applied Weight	01	344.16	2645.38	389.95	2776.85	418.56	2870.34	403.35	2782.38
	02	332.90	2639.66	390.49	2841.57	418.28	2870.33	373.92	2754.53
	03	345.27	2652.03	393.14	2861.45	417.35	2870.32	374.08	2755.72
	04	394.10	2746.10	392.09	2857.72	420.48	2870.35	404.54	2784.05
	05	297.93	2609.88	317.60	2627.67	423.15	2872.08	375.56	2756.27
	06	290.17	2599.68	383.37	2749.18	426.34	2901.02	395.11	2773.73
	07	394.93	2779.31	371.69	2669.82	427.54	2932.31	372.61	2752.37
	08	364.62	2677.88	393.59	2861.55	417.81	2870.33	407.84	2785.92
	09	395.51	2788.37	333.40	2634.73	428.63	2951.78	411.72	2791.17
	10	322.72	2626.73	350.37	2654.24	426.91	2919.20	417.28	2923.42
	11	252.94	2594.33	340.14	2649.60	426.87	2914.73	368.90	2749.29
	12	332.76	2638.22	387.49	2751.52	428.31	2945.78	382.39	2762.23
	13	291.56	2600.91	258.79	2586.25	422.27	2870.57	371.21	2750.46
	14	339.77	2645.15	270.45	2586.51	428.11	2943.64	387.50	2764.53
	15	239.96	2592.38	313.14	2618.64	415.93	2870.30	389.40	2768.79
	16	335.94	2640.65	388.99	2772.44	425.28	2886.18	401.80	2779.44
	17	304.48	2619.61	327.78	2633.34	424.85	2878.44	367.19	2746.51
	18	314.94	2623.71	336.82	2643.08	422.66	2871.97	388.83	2767.49
	19	290.97	2599.92	356.71	2659.26	422.15	2870.54	379.93	2760.28
	20	286.10	2598.85	336.81	2640.63	366.87	2870.29	387.51	2766.85
	21	387.51	2693.62	339.75	2647.65	429.47	2967.88	370.14	2749.65
	22	335.29	2640.28	375.89	2738.14	429.39	2967.35	402.55	2780.35
	23	320.17	2623.89	376.14	2739.45	426.89	2917.57	412.05	2791.87
	24	378.83	2691.00	357.11	2661.40	428.48	2949.27	404.47	2783.15
	25	378.81	2685.54	276.91	2587.27	426.62	2904.51	352.64	2735.57
	26	360.98	2664.73	284.18	2598.75	425.92	2900.77	369.73	2749.45
	27	245.11	2592.51	300.57	2605.25	428.93	2957.68	403.07	2782.14
	28	383.15	2692.91	324.13	2632.66	427.12	2919.67	411.10	2789.12
	29	271.35	2594.59	343.54	2649.93	425.21	2882.33	394.91	2771.40
	30	301.67	2619.48	381.31	2747.87	428.29	2944.79	310.01	2722.21
	31	364.08	2669.27	359.14	2663.89	424.68	2877.79	407.25	2785.19
	32	383.17	2693.42	281.13	2594.73	428.17	2944.26	392.92	2770.26
	33	336.59	2641.45	302.77	2609.59	429.10	2958.41	406.08	2784.32
	34	354.05	2657.37	281.03	2594.31	412.13	2870.29	401.18	2775.26
	35	275.17	2595.15	363.39	2666.13	428.46	2947.08	321.68	2722.98
	36	388.67	2693.64	258.39	2585.15	429.81	2973.29	361.28	2739.01
	37	373.68	2678.26	280.08	2593.28	429.34	2962.05	374.43	2755.81
	38	364.07	2669.26	306.21	2615.77	423.98	2873.93	415.44	2843.84
	39	378.51	2679.85	313.37	2623.85	426.67	2909.47	404.30	2782.86
	40	326.77	2634.19	393.59	2862.10	362.00	2870.29	410.08	2789.06
	41	297.57	2609.14	340.81	2649.80	413.13	2870.29	360.74	2739.00
	42	339.15	2643.65	339.84	2649.43	403.10	2870.29	331.66	2732.68
	43	394.59	2771.59	395.57	2932.96	425.67	2886.55	309.66	2719.43
	44	393.75	2743.04	277.38	2592.80	428.08	2943.30	413.80	2803.26
	45	276.26	2597.50	298.32	2600.67	429.52	2969.36	415.29	2831.82
	46	389.81	2697.13			427.46	2929.35	363.30	2741.10
	47	390.45	2709.05			428.54	2951.18	409.50	2786.74
	48	249.74	2592.82			360.95	2870.29	383.84	2762.30
	49	330.80	2637.09			428.92	2953.66	365.65	2741.17
	50	357.06	2661.13			427.25	2921.30	379.13	2757.01
	51	390.28	2702.80			428.04	2935.64	416.48	2863.02
	52	260.07	2594.34			425.87	2899.94	381.88	2762.01
	53	393.52	2718.81			425.01	2881.39	414.00	2807.01
	54	380.02	2692.73			427.85	2934.11	350.68	2734.78
	55	370.97	2678.08			415.54	2870.30	360.07	2736.10
	56	314.54	2620.39			425.28	2884.19	414.54	2822.23
	57	323.07	2630.30			424.26	2874.97	378.94	2756.46
	58					427.78	2932.72	416.92	2871.10
	59					427.43	2924.93		
	60					423.53	2873.14		
	61					361.01	2870.29		
	62					426.26	2900.86		
	63					425.73	2895.87		
	64					426.72	2910.23		

column-like function. Consequently, the packing will support the weight required for the vertical stacking. These reinforced corners will be formed by paperboard obtained from the same cut sheet and even from scratch; this will safe more material in the manufacturing process. This action satisfies with the principle of “Discard and regenerate parts”, and this suggests investing or recovering the consumed elements of a system during its operation.

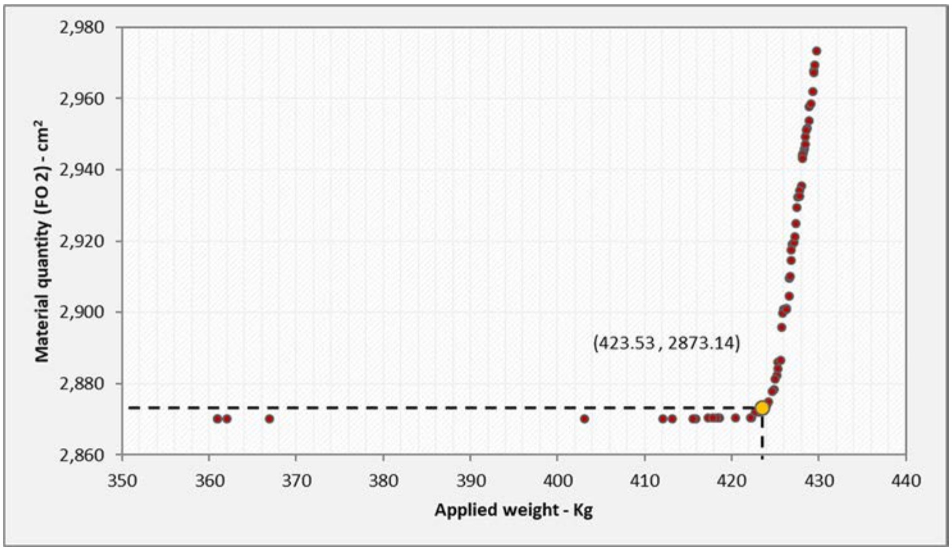


Fig. 5. Value selected for the design of the Persian Lime packing.

5.2.2. Contradiction: "Form-Vs-Volume"

To solve the "Form-Vs-Volume" contradiction of an object without motion, the application was started with the principle number 10, which suggests executing in advance the changes required by an object, totally or partially, also it suggests to ideally position an object so that these changes come into action at the right time and without loss of time. Therefore, to reduce the packing volume, the cutting of the sheet for the packing is redesigned, so that the storage of the packing uses less volume of space when it is disassembled or armed for the packaging of the fruit. Table 10 describes the design characteristics of the new packing.

5.3. Final packaging proposal

The optimum value of the GA and the solution of contradictions supported by TRIZ serve as support for the conceptual design of the Persian Lime export packing. Fig. 6 shows the packing plane with the characteristics described in Table 10, where it can be seen the measures corresponding to the optimization, as well as the necessary cuts for the proper ventilation of the fruit.

On the other hand, Fig. 7 shows the packing already assembled from a spatial perspective to appreciate in greater detail the solution of the contradictions found by the TRIZ methodology. In Fig. 7c, the corners are supported with a paperboard in a transverse form, likewise, the Fig. 7a and b show the packing with the ability to fold and deploy, giving it the characteristic to reduce its storage space.

The packing design for fresh fruit that guaranteed the fulfillment of regulations, in the national and international market, as well as those related to the customer, is a complex task that seeks to integrate aspects for its transportation, storage, and manipulation; in addition to giving the packing the functionality inside and outside of manufacturing.

Table 10
Characteristics of the final design.

New packing specifications		
Category	Variable	Value
Packing measurements	Side A	36.2
	Side B	26.3
	High	10.02
Packaging characteristics	Number of packings per level	12
	Number of packings at the top of the pallet	19
	Type of stowage	Tower
Cuts for ventilation	Cut-open area – Side A	10.42
	Cut-open area – Side B	5.34
	Number of holes on side A	4
	Number of holes on side B	–
	Cut location	Center
Type of construction material	Number of paperboard sheets on sides A of the packing	1.00
	Paperboard thickness	0.50
	ECT Value (Edge Crush Test)	8.5
	Required gauge (Type)	C
	Weight supported (RCV)	423.53
	Material quantity required (cm^2)	2873.14

Table 11 presents a comparison of the differences between the proposed innovative packing and the three packings currently used by exporting companies in Persian Lime.

The advantages of this new design are:

- Economic savings: the packing costs are attributed mainly to the paperboard quantity required in the manufacture process. Similarly,

Table 9
Inventive principles related to the contradiction of objectives.

Inventive Principle (IP)	Number (IP)	Contradiction	
		"Substance quantity - vs - resistance"	"Form - vs -Volume of an object without movement"
Sphericity	14	x	x
Property transformation	35	x	
Discard and regenerate parts	34	x	
Preliminary action	10	x	x
Investment	13		x
Internal placement	7		x

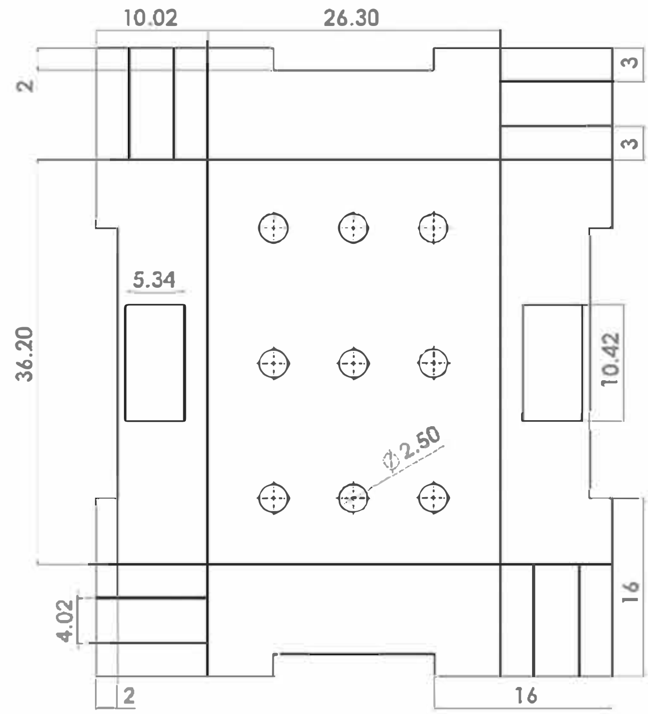


Fig. 6. Deployment of the new package box.

the packing weight and volume are a key factor for transportation costs. In this sense, if the material required to manufacture the new packing is approximately 30% smaller than the closest competitor, the proposed packing has an economical advantage in the market.

- Decrease in environmental impact: the new packing can reduce the negative impact to the environment due to the reduction of the raw material needed for its manufacture, which demands less energy, a reduced number of hours of paperboard production, and less paperboard quantity required in the manufacturing process.
- Functionality: packing design considers other requirements expressed by the company, such as "ease of packing assembly; spaces needed for the packaging of the fruit; packing stacking; and the use of space in the storage and transportation of fruit", this gives the packing a practical functionality in the manipulation and control of manufacturing and transportation operations.

6. Discussion and conclusions.

The fresh fruit packing can be considered as a problem of low complexity because of the uniform fruit size that is restricted to the same size (size of the fruit), however, due to its perishable nature and delicate handling, it requires non-spatial character, such as transpiration and the firm fruit arrangement, and the maximum stacking level allowed in packings. In other words, a set of applied knowledge is required that allows not only maintaining the physical product integrity, but also finding the ideal packing parameters for the company and customer benefit.

This article presented an innovative approach, the optimized design of fresh fruit export packing with a multiobjective mathematical model that codifies the knowledge of experts and technical characteristics that should be considered in the packing design for the purpose of exporting fresh fruit. First of all, the multiobjective mathematical model seeks to maximize the resistance to vertical packing compression during its function of stacking, strapping and transport of the product; and second of all, it seeks to minimize the amount of cardboard used in the packing. Both objectives are in conflict, when one improves, the other gets worse. In this sense, the genetic algorithm NSGA II Mixture generates optimal values of the functional packing elements. Likewise, to solve the contradiction of the objectives in the packing eco-design, TRIZ provides inventive elements, which are incorporated into the optimized design.

A real problem linked to an export company in Persian Lime, proved the usefulness of this innovative approach for the optimized packing design of fresh fruit. The result of this techniques integration helped to design an optimal packing architecture based on 11 restrictions of inventive functions with 28% less paperboard composition compared to the best competitor. However, the space used by the assembled and deployed packing in the container is greater by 10% and 38%

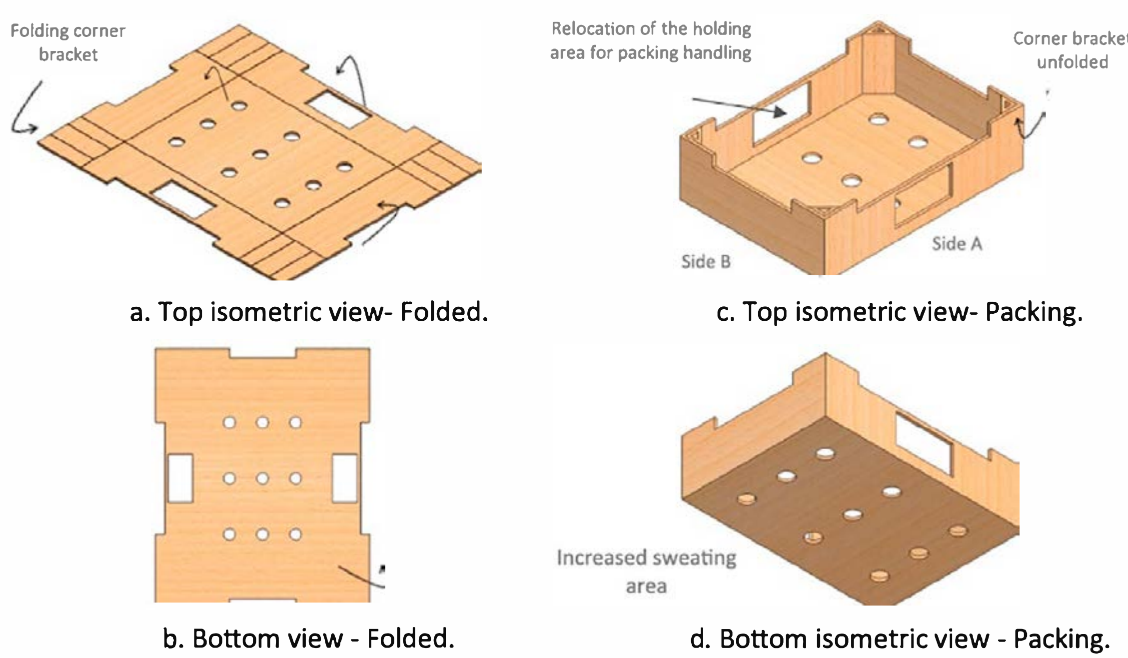


Fig. 7. Space view of new packing improvements.

Table 11
Comparison of conditions and characteristics between packings.

Packing characteristics	Unit	Proposed packing	Exporter A	Exporter B	Exporter C
Paperboard quantity required	cm^2	2873.14	5850.6	5736.6	3600
Caliber	cm	0.50	0.41	0.42	0.30
Volume used before arming	cm^3	1429	2398.75	2409.4	1033
Used volume armed	cm^3	9539.6	9979	9620.6	8614.7
Number of packings per pallet – without arming	pcs	600	600	500	600
Number of packings per pallet – armed	pcs	240	225	180	240
Number of pallets per container	pcs	20	20	20	20

respectively. This increase in the space occupied by the optimum packing was foreseen by the panel of experts, because within the functional design structure of the packaging and its stacking in the pallet, the spatial volume not occupied in the container by the competitor packing is taken into account. In addition, the economic savings of 30% in the packing proposed with respect to the closest competitor, becomes a competitive advantage, both for packing producers and users of these packings.

In view of these results, the innovative approach that harmonizes an Artificial Intelligence optimization technique with TRIZ as a method of innovation in products, expands the set of knowledge with respect to the structural optimization of export packings in agri-food chains, and It strengthens the way to reduce the gap in the design process and packing innovations supported by artificial intelligence techniques harmonized with innovation techniques.

6.1. Future work

The research results show the advantage of using less paperboard in its design, however, the packing trends in the world order has marked a path towards the packing design with compostable and/or biodegradable characteristics when they discarded in short times from non-wood celluloses, thus promoting a green and sustainable logistics in companies. In this study field, this research keeps open a work line on a packing design composed of non-wood organic materials from three sides: a deep study of organic waste evaluating physical and chemical properties (such as longitudinal measurements, diameters, densities, humidity percentages, solubility in water, cellulose, hemicellulose and lignin); second, a mathematical model with environmental aspects such as the minimization of greenhouse gases from the end of the useful life of the export packing; and third, the incorporation of Fuzzy Logic within the design methodology to model the subjectivity in the weight allocation process in the Hierarchy of the Functional Requirements of the fresh fruit export packing.

Finally, the combination of traditional and computerized methods improves decision-making skills in the day-to-day processes of experts; the harmonization of the AG with TRIZ as a methodological approach for the packing design, provides the opportunity to the designer and manufacturer to integrate express needs related to the praxis of the client process, allowing to generate competitive advantages to the organization. These competitive advantages stand out mainly in three benefits: economic, for its composition of paperboard, and volume for its transportation; sustainable, for consuming less energy for its manufacture and less recyclable material; and functional, for the fresh packing fruit in agri-food chains.

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Appendix A. Model that optimizes packing to export Persian lime in fresh fruit

$$MaxRCV = \left(\frac{PMA}{A_{carga}}\right)(\mathrm{FR}) \quad \text{Eq. (1)}$$

$$M\acute{i}nCM = APL + APC + AFC + ATC \quad \text{Eq. (2)}$$

Subject to:

$$0.97(A_t)(L_t) \le (A_{emp})(B_{emp})(N_{emp}) \le (A_t)(L_t) \quad \text{Eq. (3)}$$

$$0.90(H_{total}) \le (H_{emp})(N_{empH}) \le H_{total} \quad \text{Eq. (4)}$$

$$(A_{emp} - 2(N_{PB})(Gro))(B_{emp} - 2(N_{PA})(Gro))(H_{emp} - 2(H_{PH})(Gro)) > VT_{lime} \quad \text{Eq. (5)}$$

$$(r)(ve)(A_{corte})(\sin\sigma) \le Vent_{req} \quad \text{Eq. (6)}$$

$$A_{corte} \le 0.50(A_{emp})(H_{emp}) \quad \text{Eq. (7)}$$

$$(B_{emp})(H_{emp}) - A_{corte} > N_{let}\left(1.6(Cat)\left(\frac{1.6(Cat)}{3}\right)\right) \quad \text{Eq. (8)}$$

$$5.876(ECT)(\sqrt{2(A_{emp} + B_{emp})(Gro)}) \ge (PMA)(FR) \quad \text{Eq. (9)}$$

$$0.93^{H_{final} - H_{inicial}} \le 1 \quad \text{Eq. (10)}$$

$$C_{sup}(0.20) + C_{med}(0.08) + C_{baj}(0.20) \le 0.20 \quad \text{Eq. (11)}$$

$$1 - \sqrt{\%_{corte}} - [0.08(10(\%_{corte}) - 1)] \le 1 \quad \text{Eq. (12)}$$

$\mathrm{X} \in \{RCV, CV\} \ge 0$; where X represents all the optimization variables in the model — Eq. (13)

Annex A. Performance measures of the functional requirements of innovative packing

Functional requirement	Performance measure	Unit of measurement
Resistance to vertical compression	BCT – Box Compression Test	kg/mm^2
	ECT – Edge Crush Test	kg/cm
Resistant to humidity	Absorption of water by selected material	seg
	Changes in % moisture after transport	% Hum
Lime protection during transport	Mechanical resistance of the packing	kg/mm^2
Resistant to low temperatures	Performance of selected material	°C
Ensure hygiene, free of foreign material and odor	Detection by visual test	Unit
Do not press too much limes in the accommodation	Damaged units	Unit/box
	Packing dimensional analysis	mm
Limes in a compact way	Packing speed	Unit/hr
	Dimensional analysis of packing	mm
Provide adequate ventilation to all limes	Air circulation inside the packing	m^3/s
	Dimensional analysis of packing	m^3/s
Make unit handling of packaging easy	Easy to load/manipulate	Unit
Secure stowage	Mechanical resistance of the packing	kg/mm^2
Ensure that limes do not protrude from the packing	Dimensional analysis of packing	kg/mm^2
Ensure stability of the fruit inside the packing	Degree of inclination in which a lime shifts position within a full packing	
Identification of the packaging by external CODE	Dimensional analysis of packing	mm
	Ink performance	ppm
Environmentally friendly packing – low environmental impact	Analysis of the product at the end of its life cycle	–
Interior of non-porous boxes	Performance of the selected material	–
Maximum use of pallet when stowed for transport	Analysis of the available area on the pallet	mm
	Dimensional analysis of packing	mm
One-piece packing	Analysis of the packing assembly process	Unit

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