

SYSTEMATIC LITERATURE REVIEW ON METHODS, APPROACH AND METRICS FOR THE DESIGN OF DROP-TESTED RIGID PLASTIC PACKAGING

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Abstract: The One of the significant challenges in the industry, specifically in the design of rigid plastic containers (DEPR), is creating a container that can withstand the drop test, as this test is one of the requirements of the ASTM D2463(Daver & Demirel, 2012) standard. Additionally, we apply approaches that allow us to reduce time and improve resistance to the drop test. However, there is no state-of-the-art review that provides insights into the various engineering approaches focused on improving drop test resistance in rigid container design. The objective of this study is to provide a literature review of the different approaches applied to packaging design and engineering calculations aimed at enhancing drop test resistance (PC), and to understand the metrics used for evaluation. This study proposes a state-of-the-art review of research conducted on the design of rigid containers to improve resistance to the drop test. It includes a review of a total of 35 studies, examining applications of methods, approaches, and metrics in packaging design, utilizing mathematical approaches, statistical approaches, and machine learning approaches

Keyword: Packaging design, Rigid plastics, Drop test, Methods, Approach, Metrics

1. INTRODUCTION

The global plastics industry in 2015 reached 380 million tons of production, with Asia being the region with half of the world production (51% of the total), and China the main producer of plastics with 30% of the world production in 2018, followed by North America (NAFTA) with 18% and Europe with 17% (Modarres& Hamed,2014).

The plastics industry is transversal to most industrial sectors such as the footwear industry (sneakers), the mining industry (oxygenation ducts), construction (pipes, windows), health (medical devices, drug containers and laboratory equipment) containers and packaging (pots, bottles and personal care products). In addition, the plastic packaging market is growing and displaces traditional materials such as glass and metal, due to its lower weight, greater profitability and performance, but at the same time, it faces challenges such as sustainability (Yoxall& Gonzalez& Rowson,2017). Plastic containers can be rigid such as water bottles, or flexible such as grocery bags. Rigid plastic packaging (RPP) aims to protect the packaged product and reduce damage that may occur during use and transport (Zhang, 2022), in addition, to be functional because it allows its use (Puttapitukporn & Suvanumrat, 2011), to be attractive to facilitate the acquisition of the packaged product (Go& Lee &Hong & Kwac& kim,2020) and to identify the brand (Johannsdottir & Thorsteinsdottir, 2012). These are also the objectives of the rigid packaging design.

Alternatives to verify that the quality and safety of a rigid plastic packaging (RPP) are given by the hermeticity test and the drop test. The hermeticity test consists of being able to verify that a plastic container is capable of containing liquids, gases or other materials effectively without leaks or viewpage (Groot & Mattheij, 2011), generally involves exposing the container to different levels of pressure, vacuum or gases, and leak detection can be done by visual observation or with the help of specialized devices (Srikanth & Thiruppukuzhi & Sun ,1999). The rigid plastic packaging drop test (RPC) is an evaluation that is performed to measure the resistance of the container to accidental falls during handling, transport or storage. It is carried out by dropping the package from a certain height and observing its behaviour (Idah & Osunde, 2020).

EPR design plays a crucial role in product marketing and protection. A well-designed package can influence consumer purchasing decisions, improve user experience, and ensure product integrity during transportation and storage. The design involves decisions related to loads, kinematics, and material selection and considerations such as strength, reliability, deformation, tribology, costs, and space requirements (Euihark & Shiva, 2022), and must also comply with drop test restrictions. Therefore, methods, optimization approaches, and metrics for package design are being studied.

Generic State of the Art

Methods

A method for DEPR consists of following a guide of quality criteria and control points in the design of plastic containers and packaging. This guide provides information andrecommendations on the quality parameters to be

taken into account when designing rigid plastic containers, as well as the associated quality control techniques (Tahboub & Rawabdeh, 2004). One such method is proposed where a user-centred approach is promoted and emphasizes the importance of designing packages that are intuitive and easy to use for a variety of users. In (Michels & Bruch, 2019) the coordination of movement and interactions with the package are analysed in order to understand the users. In (Yoxall & Rowson, 2017) methods are applied in the context of the grocery market, considering ease of use. In order to increase the efficiency of the design, in (Ten Klooster & Huijben, 2020) methods such as bin raids, digital diary, visual questionnaire is combined to reduce the characteristics of DEPR.

Approach

It is a mathematical description that captures the essential characteristics of a phenomenon or system through the use of equations, relations and logical rules (Pavlovic & Fragassa& Vegliò& Vannucchi de Camargo& Minak,2020). In (Menrad & Goedecke & Manfred & Wagner,2013) different mathematical approaches are proposed that combine finite elements and probabilities to determine the optimal thickness in DEPR. In (Idah & Osunde, 2020) a finite element analysis (FEA) model is applied to analyse the strength and stress distribution. Similarly, in (Joutsela & Korhonen, 2014) FEA is applied to analyse the behaviour of slots under loads, in (Nielsen, 2019) to analyse the fluid-structure interaction (FSI), and in (Li & Xiong, 2020) neuroevolutionary algorithms are used to optimize a multi-objective FEA model.

Metrics

In relation to metrics for EPR, these refer to the measures that are used to evaluate the EPR (product) and the production (process). In the case of DEPR, the metrics are oriented to the EPR, so they generally refer to the PCEPR and tightness test metrics. One metric of DEPR is deformation (change in the shape or structure of the package), which can occur due to various reasons such as internal or external force, temperature, material quality, or exposure to incompatible chemical agents (Sormunen& Nevala& Sipilä,2016). Other metrics are failure height (Daver & Demirel, 2012), impact force (Shimada & Yamasaki, 1993), flow stress (Liu & Benson, 1997), strain rate (Ge-Zhang & Cui, 2022).

Other metrics are characteristic pulse time and internal pressure distribution during impact testing (Chwał & Muc, 2019), “Coefficient of Restitution” (CR) (Klimchuk & Krasovec, 2011), load vs. compressive displacement to evaluate the deformation behaviour of a bottle (Tang&Kong&Sapuan&Samin&Sulaiman,2006), and drop failure height (Nielsen, 2019).

Motivation

The main focus of most studies is on the importance of designing plastic containers that can protect the packaged product during transport and use, which involves finding a balance between its weight and mechanical strength. It is essential in DEPR to consider methods, approach and metrics, but information on these aspects is found individually and there is no literature review work that organizes all these works in a systematic way, in a way that helps researchers in DEPR

Purpose/objective-research question. Briefly explain the E.A.

This work focuses on answering the question What is the progress in the design of rigid plastic containers, regarding methods, approach and metrics? To do so, a systematic review of the scientific literature is carried out in journals indexed in Scopus and Web of Science (WoS) in the period 2009-2023 (June).

Contributions

The main contributions of this article are:

- Provide an overview of the design of rigid plastic containers specifically in design approach, methods and metrics in drop testing for DEPR.
- Provide the reader with a broad set of bibliographic references that will allow them to understand and investigate DEPR in greater depth.

Organization of the article

The article is organized into 6 sections. In section 2, a background is provided on the drop test on plastic containers and its engineering calculation aspects in the design of containers. In section 3, the methodology for the development of the state of the art is presented, which includes the research questions. In section 4, the research questions are answered and their discussion is presented in section 5 and finally, the conclusions follow in section 6.

2. METHODS

2.1.- EPR Design

The DEPR is multidisciplinary and involves a series of sequential steps:

- Definition of objectives and requirements: This is the beginning of the process, where the objective of the packaging is determined (storage, protection, presentation, etc.), and its requirements such as materials (type of plastic, resistance, transparency, etc.), dimensions, capacity, stacking and transport requirements, applicable regulations and standards [111].
- Sketch design: sketches are made that can be hand drawings or representations in graphic design software, then initial concepts of the EPR are developed by exploring various ideas and preliminary designs (Ma & Wang, 2004).

- Engineering design: the sketch is taken to a more realistic concept, considering the moulding process, machining restrictions and its physical properties such as the container's capacity and weight, where 3D focus is created (Daver & Demirel, 2012).
- Prototyping: A physical prototype is created with 3D geometry in 3D printing. The prototypes are used to evaluate the design, test its functionality and ergonomics (Ma & Wang, 2004).
- Design optimization: Based on the feedback from the prototypes, adjustments and improvements are made to the design using FEA techniques to validate the final designs (Denysiuk & Gaspar-Cunha, 2018).
- Graphic design and labeling: Graphic arts are developed including labels, logos, product information and any other visual elements. This must be consistent with the brand identity (Juárez-Varón & Polotskaya, 2020).
- Performance tests: Tests are carried out to evaluate the container's resistance to impacts, falls, temperature changes and other factors that may affect its integrity, where sealing and tightness tests are also considered if the container is airtight (Euihark & Shiva, 2022).
- Mould design: Moulds are designed based on the type of moulding process and the joint lines of the containers in order to validate the filling and ejection systems mainly (Wu & Tovar, 2017).
- Packaging: The design of the container also has a direct relationship with the packaging and the customer's requirements (Euihark & Shiva, 2022).
- Recycling: A key role is played by the moulding processes and their materials since the degradation of plastic materials or recycling itself is complex (Denysiuk & Silva, 2019)
- **Figure 1** illustrates the **EPR design process** through a flowchart composed of several sequential stages.

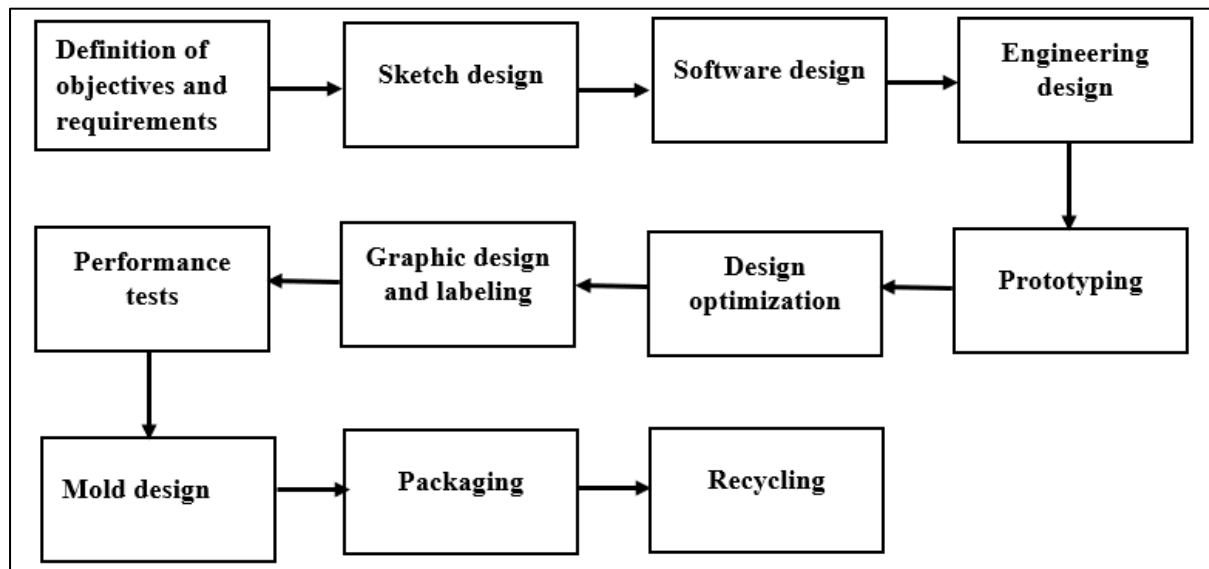


Figure 1. Design process EPR. Source: Own elaboration

2.2.-Drop test in EPR

The drop test (CT) in EPR is a mechanical strength test that consists of dropping a bottle filled with content (bulk) from a height onto a hard, flat surface, and then inspecting the EPR for signs of failure, such as cracks, deformations or leaks (Abbès & Safa, 2010). The test considers both input variables such as the weight of the container, type of material, height, diameter, thickness of the container, and elastic modulus; and output variables such as total deformation, plastic deformation, internal pressure, external pressure, elasticity limit, and equivalent static stress (Yang & Jones & Menary & Armstrong 2004). This test must be as realistic as possible (Groot & Matheij, 2011), and is generally governed by the ASTM D2463 standards (ASTM, 2010).

The design of an EPR has among its objectives to reduce the total deformation (DT), failure criterion (CF), and equivalent stress (TE), among others, which are measured during a drop test, and are approximated by the equations. DT is given by the creep strain (ΔF) and stress (ΔE), and is formulated by equation (1).

$$DT = \Delta F + \Delta E \quad (1)$$

Where ΔF and ΔE can be approximated as:

$$\Delta F = K \cdot \sigma^n \cdot t \quad (2)$$

$$\Delta E = E \cdot \epsilon \quad (3)$$

And where, K is a creep constant, σ is the applied stress on the material, n is the creep exponent related to the sensitivity of creep to the applied stress, which also depends on the material, t is the time, E is the modulus of elasticity or Young's modulus of the material, and ϵ is the unitary strain.

CF consists of determining whether a plastic bottle fails during the drop test. A bottle is considered to fail if the material stress (σ) exceeds the failure stress ($\underline{\sigma}$), and is formulated as follows (4) (Reed & Lim, 1999):

$$\sigma \geq \underline{\sigma} \quad (4)$$

Von Mises TE is used to predict the onset of plastic deformation, it is:

$$TE = \sqrt{((\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_3)^2)/2} \quad (5)$$

Where, $(\sigma_1, \sigma_2, \sigma_3)$ It is the tension of the material in the 3 dimensions.

2.3 Aspects of PC-based EPR

This study has considered the aspects of PC-based EPR: design method, model and metrics.

Methods for EPR consist of following criteria, quality requirements and control points where the focus is on the user where methods are applied in the context of the food market, considering ease of use in order to increase the efficiency of the design (Yoxall & Rowson, 2017).

Approaches are focused on 3 stages in the design, simulation and moulding process, for this it considers mathematical, statistical, machine learning approaches or a combination of them in order to reduce uncertainty for PC (Menrad & Goedecke & Manfred & Wagner, 2013).

Metrics refer to the measurements of variations such as their cost, deformation, impact forces, stress distribution, impact resistance and tightness, which are applied in the engineering calculation for the design and drop test of EPR (Huang & Chen, 2018).

3. METHODOLOGY

The methodology used is based on 3 phases contemplated in various Systematic Literature Review studies such as the guidelines of (Kitchenham & Charters, 2007) in software engineering, (Shiguihara et al, 2021) in Bayesian networks, (Castañeda & Mauricio, 2021) in software factory, (Cabrera & Mauricio, 2017) in FEAenino entrepreneurship, (Santisteban & Mauricio, 2017) in start-ups, among others, and which are the following:

- Planning: The research questions and the search protocol are defined.
- Implementation: The articles are selected by applying the search protocol and the inclusion and exclusion criteria.
- Results: The statistics of the selected documents and the answers to the research questions are reported in sections 3.3 and 4 respectively.

3.1 Planning

To answer the research question, the following sub-questions have been raised:

- RQ1: What methods exist for DEPR?
- RQ2: What engineering approach exists in DEPR?
- RQ3: What metrics are considered in DEPR?

A search of articles from journals indexed in Scopus and Web of Science (WoS) has been carried out, in the period 2007-2023, considering the following search string:

("plastic bottle") AND ("drop test" OR "fall test" OR "drop testing" OR "drop impact") AND (model OR methods OR metric)

This chain was applied in "Abs-Title-Keywords" for Scopus y "Topic" para WoS, view **Table 1**.

Fountain	Search String
Scopus	TITLE-ABS-KEY ("plastic bottle") AND ("drop test" OR "fall test" OR "drop testing" OR "drop impact") AND (model OR methods OR metric) AND (LIMIT-TO (SUBJAREA , "ENGINEERING")) AND (LIMIT-TO (SUBJAREA , "MATERIALS SCIENCE")) AND (LIMIT-TO (SUBJAREA , "CHEMISTRY"))AND (LIMIT-TO (SUBJAREA , "COMPUTER SCIENCE"))AND (LIMIT-TO (SUBJAREA , "ENERGY")) AND (LIMIT-TO (SUBJAREA , "MATHEMATICS"))AND (LIMIT-TO (SUBJAREA , "MULTIDISCIPLINARY"))AND (LIMIT-TO (SUBJAREA , "DECISION SCIENCES")) DOCTYPE , "ARTICLE"))
WoS	("plastic bottle") AND ("drop test" OR "fall test" OR "drop testing" OR "drop impact") AND (model OR methods OR metric) Document Types: Article or Review Article Web of Science Categories: Engineering Manufacturing or Engineering Environmental or Engineering Multidisciplinary or Engineering Mechanical or Mechanics or Computer Science Software Engineering or Computer Science Interdisciplinary Applications or Mathematics Applications or Computer Science Theory Methods or Operations Research Management Science or Engineering Industrial or Mathematics Applied or Mathematics Publications Years: 2010 or 2011 or 2012 or 2013 or 2014 or 2015 or 2016 or 2017 or 2018 or 2019 or 2020 or 2021 or 2022 or 2023

Inclusion and exclusion criteria are outlined in **Table 2**.

Inclusion criteria	Exclusion criteria
Answer at least one research question Type: journal article Period: 2007-2023 Language: English	It corresponds to another study context such as flexible packaging. It corresponds to other study aspects such as economic and materials. Repeated articles

3.2 Development

The plan was executed, obtaining after applying the search string (view Table 1) a total of 19 articles. Next, the inclusion and exclusion criteria were applied (view Table 2), thus eliminating 2 articles for being duplicates and 3 articles for corresponding to a context other than EPR. In addition, 21 articles related to the engineering design and moulding process of containers were added, all of them within the study range, except for the work of (Reed et al., 2000), which was considered due to the simplicity of the model formulation. Of these articles, 19 are from journals indexed in Scopus and 2 are from conferences. Therefore, this study considers a total of 35 articles, all of them from journals indexed in Scopus and/or WoS, which are denoted by [A.] and are shown in table 1 of appendix A. In **Figure 2** presents the flowchart of the scientific article selection process, based on inclusion and exclusion criteria.

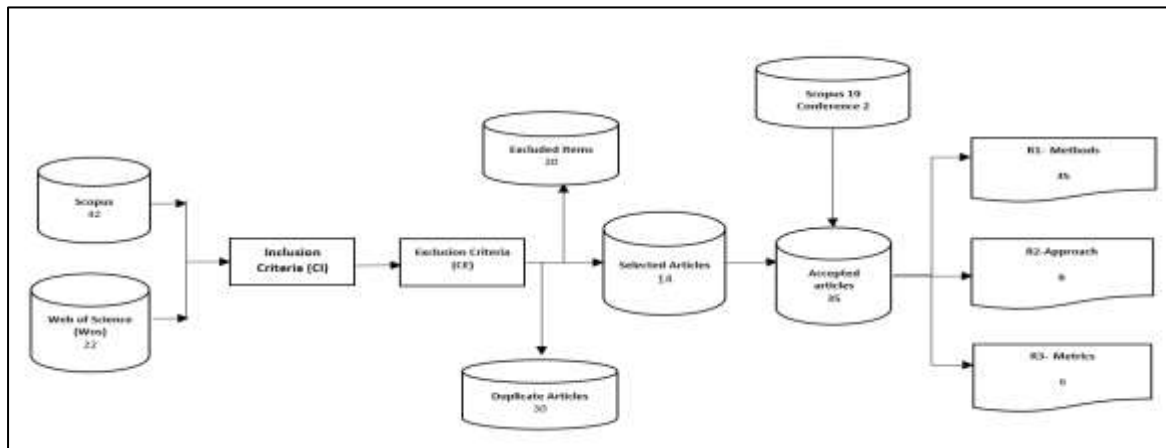


Figure 2. Flowchart for the selection of scientific articles. Source: Own elaboration

3.3 Results

Trend of publications

Figure 3. shows the number of publications per year, where a varied and growing trend of publications is observed, and with little or no publication since 2020, this could be explained by the reuse of plastic due to its negative environmental impact [115].

Figure 3. Publications by year.

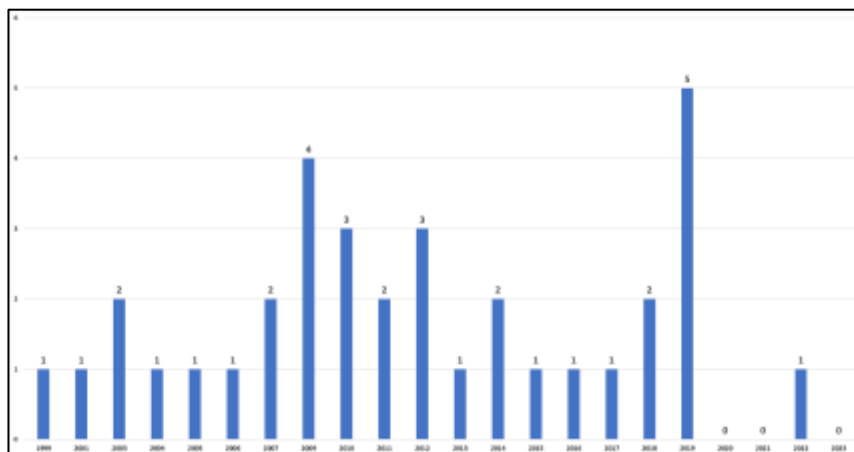


Table 3 shows the number of publications in journals and conferences from various sources. Note that 94% of the publications come from journals.

	Scopus	Web Science	Of Others	Total	Percentage (%)
Journal	31	2	0	33	94
Conference	1	0	1	2	6
Total	32*	2*	1	35	100

*: 30 articles are duplicates

Table 3 Number of publications by source

Publications by quartile

From **Figure 4**, it can be viewn that 69% of the selected articles are within Quartile 1 (Q1) and Quartile 2 (Q2), which indicates that the results that can be inferred are very reliable.

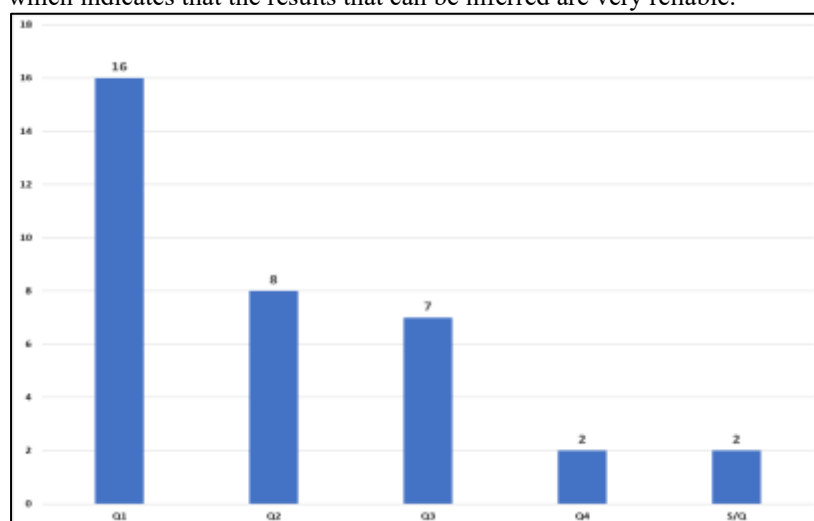


Figure 4. Number of articles selected by quartile.

Publications by continent of affiliation

Figure 5 shows that Asia and Europe have the largest affiliation of researchers (67 out of 78 researchers), grouping together 86%, where Asia has 45%, Europe 41% and Oceania 8%. Likewise, no participation from Latin American countries is revealed.

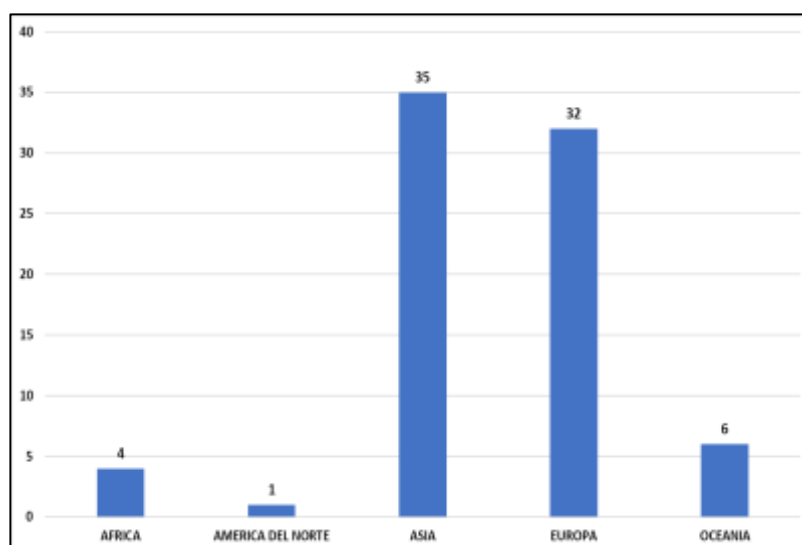


Figure 5. Publications by affiliation.

4. ANALYSIS

In this section we answer the research questions, based on the selected articles.

4.1.- RQ1: What DEPR methods exist?

For presentation purposes we consider the glossary of acronyms given in **Table 4**.

Table 4. Glossary of acronyms for phases for methods

AEN: Nonlinear elastoplastic analysis. AES: Thickness analysis. AFG: Analysis of crack formation and propagation. AGE: Use of a genetic algorithm. ALE: Arbitrary Lagrange-Eulerian. ANF: Factor analysis. ANR: Artificial neural network. ASS: Mechanical analysis. CAD: Computer-aided design. CFD: Computational fluid dynamics. CON: Conclusion and decision making. CRN: Comparison of numerical and experimental results. DCF: Determination of failure criteria. DOE: Design of experiments. DPE: Determination of the theoretical final thickness. ERA: Evaluation of the resistance to stress cracking. FEA: Finite element analysis. FSI: Fluid-structure interaction. IDF: Identification of factors.	IDN: Design parameters for child-resistant drug packaging. IYP: Preform injection. MAT: Material selection. MTA: Taguchi method integration. MTD: Multi-criteria decision-making method. MYC: Samples and contact conditions. NRE: Number of slots in package. ONE: Neuro-evolutionary optimization. OPT: Optimization. PC: Drop test. PDI: Integrated design procedure. PMS: Moulding process. RDM: Sample collection. SDC: Select according to the identified criteria and assign respective weights according to their preferences. SIM: Simulation. VER: Verification of the results. VES: Input and output variables of the design.
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35 design methods have been identified in 35 studies, which are given by a combination of 2 to 6 phases (view Table 5), where in the “Method” column, the phases are given by their acronyms (view Table 3), in addition, a phase can be made up of 2 or more phases, and this is indicated with the “+” sign, for example, the PRC+PMS phase of the M01 method is given by the PRC and PMS phases.

Table 5. Methods applied to the design of rigid plastic containers

Id	Method (phases)	Product	Fountain
M01	AES,PMS,OPT	Packaging produced by extruded blow moulding process.	[A01]
M02	CAD, FEA, SIM,VER	1 litre lubricant oil container.	[A02]
M03	CAD, OPT, SIM, ASS+OPT	350 ml PET fruit juice container	[A03]
M04	DCF,SIM,PC,VER	Child-proof medicine containers	[A04]
M05	DCF,SIM,PC,VER	PET and HDPE water containers	[A05]
M06	FEA, PMS, ASS+OPT	Tomato container	[A06]
M07	FEA,AES,CAD,SIM,PC,OPT	2800 ml milk container	[A07]
M08	FEA,ASS,AES,ANR,SIM,ASS	500 ml PET container	[A08]
M09	IDF, DOE, ANF, OPT, PC+PMS.	Industrial container with a diameter of 395 and a height of 625 mm	[A09]
M10	IDF, PDI, PC, PDI,VER	Containers made of Polyethylene terephthalate (PET)	[A10]
M11	IDF,CAD,ANR,FEA,ONE,CON	Plastic containers used for storage	[A11]
M12	IDF,MTD,SDC	PET material containers considering slots in the body.	[A12]
M13	IDF,RDM,PC,MTA,PDI,IDN	PET material container with a volume of 1.5LT, with ISBM process.	[A13]
M14	IYP,PMS	PET material container	[A14]
M15	MAT, PMS, SIM, CAD, ERA	PP material container moulded by ISBM process	[A15]

M16	MAT,SIM,VER	Lubricating oil containers from 1 to 6 Liters	[A16]
M17	MTA,PMS, OPT, SIM, ASS+OPT	1 Liter PET material container	[A17]
M18	MYC,AES,PMS,FEA,ASS+OPT	Industrial application container	[A18]
M19	OPT,PMS,AFG,ASS+OPT	Packaging for spices.	[A19]
M20	OPT,PMS,ASS+OPT	Flexible air-dropped packaging.	[A20]
M21	PMS, AES	Semi-rigid plastic packaging	[A21]
M22	PMS, OPT, AES	Alternative packaging	[A22]
M23	PMS,OPT,ASS	PET and HDPE packaging	[A23]
M24	PMS,OPT,ASS+OPT	HDPE packaging	[A24]
M25	PC, SIM, FEA,SIM	Blow-moulded packaging with a volume of 780 ml.	[A25]
M26	PC,FEA,SIM,ASS+OPT,CFD	HDPE packaging using the extrusion-blow-moulding process	[A26]
M27	PC,SIM,FEA,PC+PMS,ASS	PET packaging.	[A27]
M28	SIM, AEN, DCF, CRN, PC+PMS	PET packaging moulded using the SBM process.	[A28]
M29	SIM, ANR, AGE	350ml PET material container for fruit juice.	[A29]
M30	SIM, OPT, PC+PMS, CAD	PET material container	[A30]
M31	SIM,AES,OPT,AES+OPT,DPE	PET material container	[A31]
M32	SIM,ASS	PP material container for cosmetic use.	[A32]
M33	SIM,OPT,ASS	PET material container	[A33]
M34	SIM,OPT,PMS, ERA	PET material container	[A34]
M35	VES,PMS,OPT	330ml PET material container moulded by ISBM process.	[A35]

4.2.- RQ2: What engineering calculation approach has been applied in DEPR?

3 methods and 1 model have been identified for engineering calculation in drop test in 8 applications (view Table 6)

Table 6. Methods and models for engineering calculation in drop test

Approach		Applications	Fountain
Method	Finite element analysis	Bottle structure during PC Application of loading and boundary conditions: considering axial static load and hydrostatic pressure to the inner surface of the bottle and distribution of Von-Mises stress in the bottle.	[A05][A23] [A21] [A23] [A08] [A20]
	Computational fluid dynamics	Bottle structure during PC but filled with liquid.	[A05][A23]

	Fluid-structure interaction	Simulation of water movement during PC.	[A23]
Model	Mass-spring	Used to simulate the interaction between the fluid inside the bottle and the bottle structure during PC. Used to describe the behaviour of containers during drop test.	[A21]

Eight methods for engineering calculation in design have been identified, which have been used in 21 applications (view **Table 7**), in addition, 9 models in 14 applications and 2 techniques in 6 applications (view **Table 8**).

Table 7. Methods for engineering calculation in design

Methods	Application
Design of experiments Process variables [A01].	Design of experiments Process variables [A01].
ANOVA Identification of factors related to mass and volume [A01].	ANOVA Identification of factors related to mass and volume [A01].
Determination of the removal torque for children [A04]	Determination of the removal torque for children [A04]
Finite element analysis Injection simulation [A03].	Finite element analysis Injection simulation [A03].
Simulation of the moulding process [A02].	Simulation of the moulding process [A02].
Simulation of the container load-displacement [A07].	Simulation of the container load-displacement [A07].
Levenberg-Marquardt model [A09].	Levenberg-Marquardt model [A09].
2D simulation [A14].	2D simulation [A14].

Table 8. Model and technique for engineering calculation in design

Approach	Application
Model	Visco-hyperelastic
	Hyperelastic and viscous variables [A03].
	Artificial neural network
	Simulation of cross-sectional moulding of the container [A02].
	Computational fluid dynamics
	Optimal thickness distribution based on the container geometry [A09].
	Drag force
	Determination of the optimal injection point location [A18]
	Removal torque
	Parameters for opening and closing capacity [A11]
	Variables for PC
	Displacement calculations, Tracking points at crack initiation [A12]

	Hyperbolic polynomial interpolation and quadratic function.	Damage limit curve for relatively sensitive products [A13]
	Optimization to reduce stress crack formation.	Comparative analysis of the optimized bottle and standard bottle based on stress crack formation [A30]
	Evolution of the Young's modulus of PP	Change in material stiffness over time due to aging, Evolution of maximum load versus concentration [A33]
Technique	Genetic algorithm	Determining uniform thickness of packaging [A02]. Multi-objective optimization in neuroevolutionary [A09] Validation of optimization results, [A18] Optimization of material usage in blow molded products [A26]. Optimization of packaging thickness distribution (Johannsdottir & Thorsteinsdottir, 2012).
	Fuzzy Neural-Taguchi Optimization with Genetic Algorithm	Variables to obtain container wall thickness, Application for training process variables, Factorial experiments [A24].

4.3.- RQ3: What metrics have been considered in DEPR?

4 metrics for PC assessment have been found in 7 studies, with container deformation being the most studied (view **Table 9**). In addition, 7 metrics have been identified for engineering calculation in design that have been used in 32 applications (view **Table 10**), some metrics are given by the combination of 2 other metrics, this is denoted using +.

Table 9. Metrics for PC assessment

Metrics	Application
Deformation of the packaging	HDPE material packaging [A4]. PET material packaging in ISBM process [A22]. PET and HDPE material packaging [A56]. HDPE material packaging [A4]. PET material packaging in ISBM process [A22]. PET and HDPE material packaging [A56].
Product damage	HDPE material packaging [A4].
Fault location	PET and HDPE material container [A11],[A56].
Packaging geometry	500 ml HDPE container [A20]. 210 litre detergent container [A46].

Where, the acronyms are as follows. HDPE: high density polyethylene; PET: Polyethylene Terephthalate

Table 10. Metrics for engineering calculation in design helps the moulding process, optimization,

Metrics	Application
Fault location	Objective to develop a database for the modular design of plastic packaging [A01].
Mechanical resistance + product damage	Study of redesign of the petaloid shape at the bottom of bottles to reduce crack formation and improve strength using FEA [A66]
Packaging geometry	Optimization of the extruded blow moulding process [A02]. Blow moulding process applying neural networks [A04]. Injection process optimization on process parameters to minimize shrinkage defects [A06]

	Application of Taguchi method for pharmaceutical packaging design [A07] Blow moulding process simulation to reduce weight and material costs [A10] Blow moulding container design optimization using FEA [A15] FEA simulation to validate geometry thickness in blow moulding process [A17] Glass blow moulding process optimization [A19] Blow moulding process simulation and improvement [A32] Moulding process optimization for injection point location [A35] Blow moulding process simulation using neural networks to determine optimal material distribution [A37] Filling channel simulation and optimization in injection process [A38] Design focusing on consumers' perceptual product evaluations using a Likert scale questionnaire [A39] Optimization of preform design to achieve optimal thickness distribution [A40] Study of sustainable packaging design [A50] Optimization of the blow moulding process specifically in the thickness distribution based on its geometry [A69]
Container geometry + Mechanical resistance	Optimizing the blow moulding process to achieve optimal distribution [A21] ISBM process simulation [A29] ISBM process packaging stress simulations [A18]
Product damage	Injection process optimization to reduce warpage [A14] ISBM process optimization, based on moulding process [A05]
Mechanical strength	ISBM process optimization for improved mechanical strength [A34] Top-loading simulation and determination of bottle weaknesses by blow moulding process using FEA [A33] Packaging analysis for load assessment using FEA [A31] Packaging assessment during the transport process [A27]
Deformation of the packaging	Reducing losses in packaging design by applying engineering calculations [A16] Simulations of packaging in the opening process focused on older people [A24] Simulations and analysis of packaging during the drop test view correlation [A26] RIM simulation of composite materials [A45] Optimization of the bottom of packaging by blow-moulding process to reduce the cracking phenomenon [A60]

Where, the acronym ISBM stands for Injection Stretch Blow Moulding

5. DISCUSSION

The result of the systematic literature review is a catalogue of methods, approaches and metrics for DEPR, which will help researchers and practitioners in DEPR. The information presented is reliable, as 69% of the reviewed studies belong to journals in the first and second quartile (Q1, Q2) and therefore strengthen the findings presented here. Each research question is discussed below

5.1. Methods

35 design methods have been identified, of which a total of 36 contemplate phases for DEPR, but each method includes 2 to 6 phases. The most commonly used phases are simulation (SIM), optimization (OPT) and blow moulding process (PMS), which appear in 35% of the methods (view Figure 6). This could be explained because most of the methods focus on the validation of the drop test resistance through simulations, and of the design in the blow moulding process, in addition to view the optimization of the container. However, there is no consensus on a standard method for DEPR.

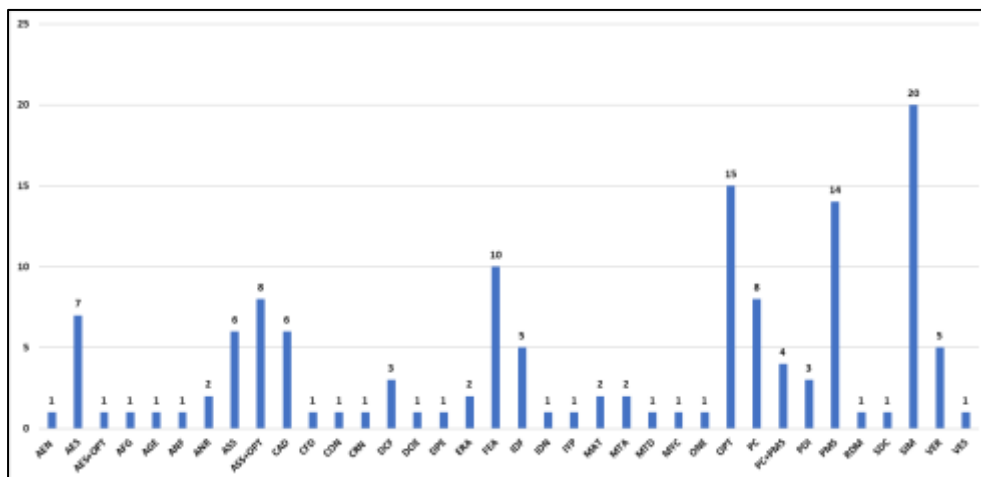


Figure 6. Frequency of phases of the methods for the DEPR.

In **Figure 6** we can observe the frequency of the main methods for the DEPR where these methods are mainly differentiated by the phases they include, which generally vary from 2 to 6 phases, with M17 and M18 covering the most frequent phases. However, there is no consensus on a standard method for the DEPR or a guide to identify the phases to be considered for the DEPR with certain requirements. Most of the DEPR methods focus on aspects such as functionality, sustainability, aesthetics and regulatory compliance, and the least used aspect is the user-centred approach with 1 study.

5.2. Approaches

Three methods and the Mass-Spring model have been identified for engineering calculation in CP. The methods focus on the design of the geometry of the container, while the model is used to describe the behaviour of the containers during CP. The use of the Mass-Spring model could be explained by its low computational cost, simplicity and good approximation, unlike methods such as finite element analysis, computational fluid dynamics, and fluid-structure interaction, which require a lot of computational cost (view **Table 6**).

On the other hand, the identified methods are complementary because they cover aspects of CP. On the one hand, FEA focuses on the analysis of the geometry, but does not consider the content in the container, which is covered by the computational fluid dynamics method. In turn, this does not consider the interaction of the fluid with the structure, for example, the interaction of gaseous liquids and the container, but which is considered in the fluid-structure interaction method. It should be noted that FEA is the most applied method (view **Figure 7**), this could be explained by its ease in validating the resistance of the geometry of a container.

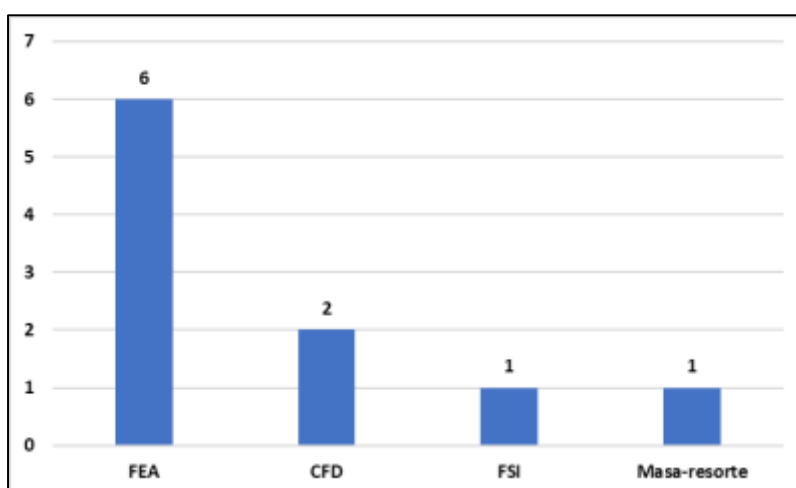


Figure 7. Types of engineering calculation approaches for drop test. Source: Own elaboration

Regarding the engineering calculation for DEPR, 9 methods (view **Table 7**), 9 models and 2 techniques (view **Table 8**) were identified. Firstly, the finite element methods stand out, which are generally applied to simulation, such as the simulation of the moulding process [A02], the simulation of the load-displacement of the container [A07] and the simulation of the wall thickness of the part as a function of the operating conditions [A28]. Secondly, there are the artificial neural network models with 6 applications, including the optimal thickness distribution as a function of the container geometry [A09], the minimization of the deviation of the container thickness [A25], and the analysis of the deformation of the container [A37]. Thirdly, there is the genetic algorithm technique with 5 applications, including determining the uniform thickness of the container [A02] and multi-

objective optimization in neuroevolutionary [A09]. DEPR through the joint application of FEA and CFD would bring many benefits in DEPR with liquids, such as more accurate prediction of failures, design optimization, time and cost savings, multiple analysis. However, it also constitutes a great challenge, since it requires the integration of 2 methods.

5.3. Metrics in DEPR

4 metrics have been identified for PC in 8 applications and for engineering calculation in design 7 metrics have been identified in 32 applications, some metrics are given by the combinations of other 2 metrics. The container deformation (DEN) and the container geometry are the most studied and used metrics for PC and for engineering calculation in design respectively, this could be explained because the first one allows to visualize the failure in the container in the PC and the second one facilitates the moulding process in the engineering calculation. The use of the metrics is very diverse as indicated in tables 9 and 10. In the study on the blow moulding process applying neural networks [A04].

6. CONCLUSIONS

- This work aimed to provide a systematic review of the literature related to DEPR for PC. 3 research questions were proposed related to the aspects of methods (RQ1), approach (RQ2) and metrics (RQ3). The search allowed to select 35 articles from 82 potential articles between WoS and Scopus. 86% of the affiliations come from Asia and Europe, it is important to note that the selected articles belong to first and second quartile journals (Q1, Q2), which guarantees that this study presents reliable results. And it includes aspects of DEPR not studied, such as methods for their verification.

RQ1: What methods exist for DEPR?

RQ2: What engineering approach exists in DEPR?

RQ3: What metrics are considered in DEPR?

- In this work, a systematic review of the literature related to DEPR was carried out with PC that answers the research questions on methods (RQ1), approaches (RQ2) and metrics (RQ3). The search allowed to select 35 articles from 64 potential articles between WoS and Scopus. 86% of the affiliations come from Asia and Europe, it is important to note that the selected articles belong to first and second quartile journals (Q1, Q2) in 69%, which guarantees that this study presents reliable results. And it includes aspects of the DEPR not studied, such as the methods for its verification.

- Regarding the methods, it is crucial to recognize that 35 design methods have been identified in the design of containers, which are divided into 2 to 6 phases. The most commonly used phases are simulation, optimization, and blow moulding process, which explains why most of the methods focus on the validation of the resistance to the drop test through simulations, where they view the optimization of the container. However, there is no consensus on a standard method for the DEPR. Regarding the 4 main approaches, 3 methods and 1 model have been identified. The methods of finite element analysis and computational fluid dynamics stand out. The complexity in the modeling should lead us to a joint application of FEA and CFD in the DEPR. It is suggested to develop comprehensive models that combine both methods for a more effective evaluation of the DEPR and in relation to the metrics, 4 metrics for PC for DEPR have been found, which correspond to a total of 8 applications. The categories have allowed us to identify the most commonly used trends in PRD, such as the DEN, which represents 38% of the total, but this also reveals that there is no consensus on a single specific metric for PRD.

- Challenges and Opportunities in PRD lie in the complexity of applying a single method, a valuable opportunity is presented to develop specific models at each stage of the process, including design, moulding and preparation for consumption. This multidimensional perspective offers possibilities for innovation and improvement in the packaging industry. The application of advanced methods in PRD: The literature reveals that, despite the challenges inherent to the complexity of PRD, the use of methods such as FEA and CFD provides an opportunity to address the problem from a multi-objective approach. This strategy allows to identify and examine critical variables that are fundamental in the effective development of PRD. The interrelation between methods, approaches and metrics in PRD: The existence of four main related metrics and 35 methods for PRD in consumer products is highlighted. It is essential to base future research on studies that establish a direct connection between the method used, the approach adopted and the metrics applied, in order to optimize the results in the design and production of packaging.

- The exploration of methods in DEPR and the inherent complexity of packaging design drives continued research to unify methods. This is key to extend their applicability to different types of packaging and effectively link them with other aspects of study, thus improving their relevance and effectiveness. The application of FEA and CFD not only underlines the complexity of packaging design, but also opens up the possibility of applying other advanced mathematical techniques. These techniques can offer faster and more efficient solutions to these challenges. Using mathematical techniques and AI to Identify Faults, which can be instrumental in addressing irregularities in the packaging moulding process. These techniques can effectively identify failure points in containers that do not achieve uniform thickness, thus improving the quality and safety of the final product.

- This work was limited to the review of journal and conference articles indexed in Web of Science, Scopus, so an extension in other databases could broaden the results on methods, approaches and metrics.

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8. AUTHOR NOTE

The author declares that there is no conflict of interest regarding the publication of this article. The author confirms that the paper is free of plagiarism.

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Appendix A

Table 11. Selected articles

Id	Fountain	Id	Fountain	Id	Fountain
A01	(Tahboub & Rawabdeh, 2004)	A34	(Abdul-Kader & Watkins, 2015)	A67	(Ministerio de la Producción, 2020)
A02	(Chookaew & Ploysook, 2019)	A35	(Johannsdottir & Thorsteinsdottir, 2012)	A68	(Abdul-Kader & Watkins, 2015)
A03	(Papazetis & Vosniakos, 2020)	A36	(Min & Youlee,2000)	A69	(Johannsdottir & Thorsteinsdottir, 2012)
A04	(Lin & Hung, 2014)	A37	(Johannsdottir & Thorsteinsdottir, 2012)	A70	(Min & Youlee,2000)
A05	(Yoxall & Rowson, 2017)	A38	(Moayyedian & Marian, 2018)	A71	(Karalekas & Rapti & Papakaliatakis & Tsartolia,2001)
A06	(Idah & Osunde, 2020)	A39	(Smith, 2020)	A72	(Go& Lee &Hong & Kwac& kim,2020)
A07	(Huang & Chen, 2018)	A40	(Thibault & Diraddo, 2007)	A74	(Srikanth & Thiruppukuzhi & Sun ,1999)
A08	(Demirel & Daver, 2012)	A41	(Jaisawal & Agrawal, 2021)	A75	(Menrad & Goedecke & Manfred & Wagner,2013)
A09	(Denysiuk & Gaspar-Cunha, 2018)	A42	(Ryynänen & Rusko, 2014)	A76	(Kannan & Senthilkumaran ,2014)
A10	(Cascini & Morosi, 2020)	A43	(De Koeijer & Henseler, 2016)	A77	(Yang & Jones & Menary & Armstrong 2004)
A11	(Langley & Yoxall, 2005)	A44	(Lofthouse & Bhamra, 2017)	A78	(Klimchuk & Krasovec, 2011)
A12	(Roper & Kim, 2021)	A45	(Chwał & Muc, 2019)	A79	(Tang&Kong&Sapuan&Samin&Sulaiman,2006)
A13	(Meng & Lim, 2017)	A46	(Reed & Lim, 1999)	A80	(Coles & Mcdowell & Kirwan, 2004)
A14	(Karalekas & Tsartolia, 2001)	A47	(Petsangsri & Sakon, 2020)	A81	(Pavlovic & Fragassa& Vegliò& Vannucchi de Camargo& Minak,2020)
A15	(Biglione & Chhay, 2015)	A48	(Liu & Benson, 1997)	A82	(Berihun & Aswossie& Bogale& Mulatie,2022)

A1 6	(Euromonitor International, 2020)		A49	(Liu & Cui, 2020)		A83	(Huang & Wang & Du, 2019)
A1 7	(Demirel, 2017)		A50	(Rezaei & Kana, 2018)		A84	(Zhang & Liu& Song& Wang& Yang & Fan& Ding & Liqiang 2022)
A1 8	(Denysiuk & Silva, 2019)		A51	(Liu & Zheng, 2022)		A85	(Mercado-Colmenero & Rubia & Mata-Garcia & Rodriguez-Santiago & Martin-Doñate ,2020)
A1 9	(Thibault & Diraddo, 2007)		A52	((Ziping & Hairong & Yongchao, 2022))		A86	(Pastnak & Henriquez& La Saponara, 2020)
A2 0	(Ryynänen & Rusko, 2014)		A53	(Shimada & Yamasaki, 1993)		A87	(Bose,2016)
A2 1	(Reed & Lim, 1999)		A54	(Rojas & Guixeres, 2015)		A88	(Huang & Chen& Lu& Lin ,2018)
A2 2	(Rezaei & Kana, 2018)		A55	(Nielsen, 2019)		A90	(Yan & Menary& Nixon,2016)
A2 3	(Puttapitukporn & Suvanjumrat, 2011)		A56	(Puttapitukporn & Suvanjumrat, 2011)		A91	(Mu & Zheng&Xin,2021)
A2 4	(Yu & Lim, 2004)		A57	(Yu & Lim, 2004)		A92	(Demirel ,2017)
A2 5	(Huang & Huang, 2007)		A58	(Huang & Huang, 2007)		A93	(Strebel&Benson,1996)
A2 6	(Yu & Juang, 2010)		A59	(Yu & Juang, 2010)		A95	(Z Bo,2014),
A2 7	(Ge-Zhang & Cui, 2022)		A60	(Ge-Zhang & Cui, 2022)		A97	(Reed& Breedveld&Lim ,2000)
A2 8	(Bordival & Schmidt, 2008)		A61	(Bordival & Schmidt, 2008)		A98	(Karac&Ivankovic,2009)
A2 9	(Daver & Demirel, 2012)		A62	(Daver & Demirel, 2012)		A99	(Modarres& Hamed,2014)
A3 0	(Demirel & Daver, 2009)		A63	(Demirel & Daver, 2009)		A100	(Yoxall& Gonzalez& Rowson,2017)
A3 1	(Abbès & Safa, 2010)		A64	(Habeb & Alkahari, 2023)		A101	(Sormunen& Nevala& Sipilä,2016)
A3 2	(Abbès & Safa, 2010)		A65	(Demirel, 2009)		A102	(Khalaf& Almubarak& Khalaf& Yasir,2019)
A3 3	(Ministerio de la Producción, 2020)		A66	(Abbès & Safa, 2010)		A103	(Masood&KeshavaMurthy,2005).