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APPLICATION OF QFD FOR THE PROPOSED DEVELOPMENT OF DISPOSABLE BIODEGRADABLE CUPS BASED ON POLYLACTIC ACID

APLICAÇÃO DO QFD NO PROJETO DE DESENVOLVIMENTO DE COPOS DESCARTÁVEIS BIODEGRADÁVEIS À BASE DE ÁCIDO POLILÁTICO

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Abstract

The present work presents the application of the Quality Function Deployment tool, “QFD” for its acronym in English, used to translate the needs of a consumer into technical specifications that are responsible for meeting customer expectations. In this case, the analysis is oriented toward the future conceptual manufacture of disposable biodegradable cups made mainly with polylactic acid (PLA). The preliminary stage of the QFD consisted of developing a series of survey questions aimed at a representative sample of university students, where the key requirements that a biodegradable cup must have according to customers were determined and their hierarchy of importance was established. Thus, based on consumer requests, technical specifications were proposed to satisfy their needs; specifically, the material composition, molding conditions, wall thickness, container geometry, surface finish, color and cost were

Resumo

O presente trabalho apresenta a aplicação da ferramenta Quality Function Deployment, conhecida pela sigla “QFD”, utilizada para traduzir as necessidades do consumidor em especificações técnicas responsáveis por atender às expectativas do cliente. Neste caso, a análise está voltada para a futura fabricação conceitual de copos descartáveis biodegradáveis produzidos principalmente com ácido polilático (PLA). A etapa preliminar do QFD consistiu no desenvolvimento de uma série de perguntas de pesquisa direcionadas a uma amostra representativa de estudantes universitários, onde foram determinados os principais requisitos que um copo biodegradável deve ter de acordo com os clientes e estabelecida sua hierarquia de importância. Assim, com base nas solicitações dos consumidores, foram propostas especificações técnicas para satisfazer suas necessidades; especificamente, foram definidos defined. The analysis showed that biodegradability constitutes the attribute most valued by the respondents, while the molding process and cup thickness represent the technical factors with the greatest influence. The QFD results showed correlations between customer requirements and technical specifications, resulting in quantitative prioritization oriented towards future experimental stages. The application of the QFD methodology led to a search of scientific literature.

Keywords: QFD. Polylactic Acid. PLA. Biodegradable Cup.

a composição do material, as condições de moldagem, a espessura da parede, a geometria do recipiente, o acabamento da superfície, a cor e o custo. A análise mostrou que a biodegradabilidade constitui o atributo mais valorizado pelos entrevistados, enquanto o processo de moldagem e a espessura do copo representam os fatores técnicos com maior influência. Os resultados do QFD mostraram correlações entre os requisitos dos clientes e as especificações técnicas, resultando em uma priorização quantitativa orientada para futuras etapas experimentais. A aplicação da metodologia QFD levou a uma pesquisa na literatura científica.

Palavras-chave: *QFD. Ácido Polilático. PLA. Copo Biodegradável.*

1 INTRODUCTION

The massive and uncontrolled production of single-use plastics increases the amount of greenhouse gas emissions, thus contributing to the increase in the Carbon Footprint measure (Paletta *et al*., 2019). The magnitude of the problem is such that Geyer *et al*. (2017) estimate that, up to 2015, the world population had generated 6300 million metric tons (MT) of plastic waste, and only 9% of the total waste had been recycled; on the other hand, 79% remained in landfills or in the environment. It is precisely this excessive production that influences massive waste leakage into the ocean; for example, Jambeck *et al*. (2015), in 2010, determined the amount of plastic waste from 192 coastal countries in that year, which was 275 million metric tons, of which between 4.8 and 12.7 million MT entered the ocean.

Complementing the above, the United Nations, through UNEP (2023), warned that the annual flow of plastic waste already reaches between 19 and 23 million tons into aquatic ecosystems. In addition, the Ellen MacArthur Foundation (2024), in collaboration with UNEP, states that there are currently more single-use plastics than ever before and that greenhouse gas emissions are expected to double by 2060.

As an alternative that helps address the problem of residual pollution, the conceptual proposal of disposable biodegradable cups is proposed. The raw material evaluated corresponds to polylactic acid (PLA), a thermoplastic polyester of renewable origin that has been widely studied for packaging applications and single-use articles due to its compostable character under controlled conditions and its possible partial substitution of conventional plastics (Jamshidian *et al*., 2010; Ncube *et al*., 2020). Based on this approach, the technical composition of the product is defined from PLA for disposable cups, considering that any pigment or processing modifier must later be selected according to criteria of safety, processability, cost and performance.

Nevertheless, the manufacture of a material oriented towards the production of biodegradable cups lacks meaning if the proposed technical solutions of the product do not coincide with the expectations of the final user. For this reason, Quality Function Deployment (QFD) was carried out, a methodology created by Drs. Yoji Akao and Shigeru Mizuno in Japan in 1960. The first practical use of the methodology came in 1972 at Mitsubishi (Cruz-Rivero *et al*., 2023).

The QFD methodology was responsible for translating customer needs (called "what's") into quantifiable design parameters (called "how's"), and their interactions were visualized in the resulting House of Quality matrix. It should be emphasized that the present article is located only in the conceptual phase of the product, analyzing consumer perception and prioritizing the technical requirements obtained, giving rise to a future article referring to the experimental preparation of the proposed biodegradable cup.

Therefore, a data collection tool was applied to understand customer needs in the biodegradable cup market. For this purpose, a structured questionnaire was applied to a representative sample of university students; the sample size was obtained with Cochran's equation for infinite populations (Cochran, 2000), using a confidence level of 95% and assuming maximum population variability.

The questions were formulated in such a way that the customer could express preferences regarding the physical aspects of the biodegradable cup, summarized in nine questions related to nine cup attributes. Thus, the answers obtained made it possible to assign relative importance to each surveyed attribute. The biodegradability attribute received the highest relative weight, with 16.36%, followed by surface finish with 14.54%. Thanks to the data obtained, the House of Quality matrix was constructed, where seven technical variables necessary to satisfy the nine customer requirements were proposed; these range from design, materials and specialized manufacturing.

Among the technical specifications, the molding process and wall thickness stood out, both with a technical importance degree of 19.54%, being the highest in the list and together adding 39.09%. In addition, the QFD tool yielded interesting data such as the correlation between technical specifications, where a strong negative correlation between cup wall thickness and low unit cost stands out. These data are of interest for balancing the structural robustness of the cup with its economic viability in a possible future experimental phase.

2 METHODOLOGY

2.1 Survey design and sample size

First, the preliminary work of the QFD was initiated, which consisted of developing nine questions directed at a representative sample of university students. The questions were formulated in such a way that customers could express their preferences regarding the physical aspects of the biodegradable cup, summarized in nine questions related to nine cup attributes. Thus, the answers obtained made it possible to assign the relative importance of each surveyed attribute, namely biodegradability, capacity in milliliters, low aspect ratio geometry, price, surface finish, heat resistance, wall thickness, flexibility and pigmentation. The survey sample size was obtained with Cochran's equation for infinite populations (Cochran, 2000), using a confidence level of 95% and assuming maximum population variability:

$$n = \frac{Z^2 * p * q}{E^2} \quad (1)$$

where:

- n = sample size,
- Z = z-value corresponding to the desired confidence level,
- p = expected proportion of success,
- q = 1-p = expected proportion of failure,
- E = tolerated margin of error.

The following values were used:

- Z = 1.96, which corresponds to a confidence level of 95%, a value regularly used in market studies because it reflects the reality of a population with a high degree of certainty (García-García *et al*., 2013).
- p = 0.5, because it is attributed to a conservative estimate
- q = 1−p = 0.5,
- E=0.05, representing a standard error of 5%, recommended in research on user perception.

Substituting the values into the formula:

$$n = \frac{(1.96)^2 * 0.5 * 0.5}{(0.05)^2} = 384.16 \qquad (2)$$

The result was rounded to an “n” of 384. Therefore, on March 31, 2025, 384 surveys were administered to students from the TecNM campus Ciudad Madero. The reason for applying surveys to students lies in their acceptance of sustainable consumption, previously documented in studies that support Generation Z as “informed, socially conscious consumers committed to fostering innovation and sustainability” (Theocharis & Tsekouropoulos, 2025).

2.2 Survey results

Below, the survey results are presented, which serve as the basis for developing the so-called “what’s” of our Quality Function Deployment matrix, also known as the voice of the customer. The survey results were divided into nine criteria for proper organization.

2.2.1 Preference for capacity measured in ml

The most popular capacity was 250 ml, with a total of 233 responses. This figure represents 61% of the consumers surveyed, surpassing by a wide margin the options of 300 ml with 93 choices and 200 ml with 58 choices. This clear trend toward a specific volume made it possible to orient the product to a single capacity variant without losing market acceptance. Related to its 61% acceptance proportion, 6 out of 10 points were quantitatively assigned in the degree of consumer importance. This degree is key when implementing it in the Quality Function Deployment matrix to obtain the relative weight that each "what" has.

2.2.2 Color preference

The option of a white cup was the one most selected by respondents, with a total of 175 votes, representing 45% of the total surveyed, followed by blue with 116 votes, while red and green were further behind with 70 and 23 votes, respectively. Derived from its 45% acceptance proportion, 5 out of 10 points were quantitatively assigned to the degree of consumer importance.

2.2.3 Shape preference

The shape of cups that are wide in diameter but short in height was the most preferred by the surveyed public, with 64% acceptance. Among the advantages of a wide and short cup is offering a lower risk of tipping over. Derived from its 64% acceptance proportion, 6 out of 10 points were quantitatively assigned to the degree of consumer importance.

2.2.4 Composition preference

The overwhelming majority of respondents (94%) answered that they prefer to acquire a biodegradable cup rather than a regular polypropylene one. These results demonstrate the environmental awareness rooted in younger generations. Derived from its 94% acceptance proportion, 9 out of 10 points were quantitatively assigned to the degree of consumer importance.

2.2.5 Price willing to pay for a package of disposable biodegradable cups in MXN

The price point for a pack of disposable biodegradable cups, based on the data considered for the customer segment, is set at an approximate average of $72 MXN per pack; furthermore, it is recognized that some consumers might accept prices close to $100 MXN when the product is marketed as biodegradable (market figure for a 50-piece PLA pack). Even so, cost remains a significant constraint, as PLA cups are typically more expensive than conventional polypropylene or PET cups. Therefore, the economic requirement retains a qualitative weighting of 7 out of 10: it is not the primary attribute, but it does influence the product’s commercial acceptance.

2.2.6 Preferred surface type

A clear majority of 75.8% expressed a preference for choosing a smooth surface on the cups, compared with 24.2% who prefer them with roughness. A smooth surface would facilitate the molding of the container, thus benefiting both the user and the manufacturer. Derived from its 75.8% acceptance proportion, 8 out of 10 points were quantitatively assigned to the degree of consumer importance.

2.2.7 Common uses of the cup

Regarding the most common uses that respondents give to cups, 163 people chose the consumption of plain water, 116 people usually consume soft drinks, and 70 respondents regularly use them for alcoholic beverages. On the other hand, for coffee or tea, assuming these as hot beverages, 35 votes were obtained. The above means that 91% of consumers prefer cold beverages. Derived from the inclination of consumers not to drink hot beverages, with only 9% preference, 1 out of 10 points was quantitatively assigned to the degree of consumer importance.

2.2.8 Thickness preferred by consumers in disposable biodegradable cups

Seventy percent of respondents prefer a thick cup rather than a thinner one; this is related to a sensation of resistance or safety when holding a container and avoid deformation when pressure is applied. Derived from its 70% acceptance proportion, 7 out of 10 points were quantitatively assigned to the degree of consumer importance.

2.2.9 Results of flexibility preference in cups

Regarding consumer preferences with respect to the flexibility of a cup, 57.3% of respondents prefer a cup with a certain capacity for flexibility. Derived from its 57.3% acceptance proportion, 6 out of 10 points were quantitatively assigned to the degree of consumer importance.

2.3 Transformation of the voice of the customer

Starting with the first step of the QFD body we have the voice of the customer, which corresponds to the left-hand list of customer requirements mentioned earlier in the survey design. To correctly translate the voice of the customer, a relative weight of the "what" was calculated; each response was coded on an absolute importance scale from 1 to 10 derived from the degree of consumer acceptance importance. The total sum of importance values was 55. Then, the relative weight was calculated with the formula:

$$W_i = \left(\frac{I_i}{\sum_{k=1}^{n} I_k}\right) * 100 \qquad (3)$$

where:

- $\mathbf{I_i}$: (weight of customer importance **i**, is the value assigned after surveys for each customer requirement.
- $\sum_{\mathbf{k=1}}^{\mathbf{n}} \mathbf{I_k}$: Importances of customers **K**, is the total sum of the importances of all **n** (what's).
- $\mathbf{W_i}$: (Relative weight of the "What"), is the result of the relative weight of each requirement of customer **i**.

2.4 Technical specifications

On the other hand, thanks to the voice of the customer, a list of seven technical requirements was presented at the top of the matrix, which represents the proposed design variables responsible for meeting customer requirements. For the current reframing, these variables are material composition based on PLA for disposable use, compression molding process, 3 mm cup wall thickness, geometry of 7.43 cm width by 7.13 cm height, white colorant, smooth surface finish, and low unit cost.

Regarding the geometry, it was calculated considering a target of 250 ml, so the formula for the volume of a cylinder was used:

$$V = \pi r^2 h \qquad (4)$$

Considering a diameter of 7.43 cm, a height of 7.13 cm and a wall and base thickness of 0.3 cm. The volume is obtained by subtracting the thickness twice from the diameter and once from the height. Substituting into Equation 4 gives a total of 250.2 cm^3, equivalent to the desired 250 ml.

2.5 Direction of improvement of technical specifications

Just above the technical specification columns, there is a header that corresponds to the direction of improvement row. This row served as a compass for the correct design orientation of the product, because it allows the direction of a variable to be oriented in favor of satisfying the voice of the customer. It was divided into three directions, namely:

- Maximize “▲”: This refers to seeking an increase in the value of the technical variable because it produces benefits without penalties.
- Target “◇”: This appears when the variable has an optimal point where it is convenient to remain, because modifying it without criteria could lead to overpricing or to a poor product.
- Minimize “▼”: This was applied when it is necessary to reduce the magnitude of the technical parameter to create a competitive advantage; the common case in projects corresponds to minimizing costs.

2.6 Customer–technical specification relationship

At the center of the QFD matrix body is the interaction between customer requirements and the product technical specifications intended to satisfy them. These interactions are weighted by symbols that express how strong the relationship is between each user requirement and each technical element. The symbols used are the following:

- ● Strong relationship with a value of 9 points
- ○ Moderate relationship with a value of 3 points
- ▽ Weak relationship with a value of 1 point
- (Blank cell) No significant relationship with a value of 0 points.

2.7 Analysis of the directions of technical correlations

At the top of the QFD matrix are the technical characteristics of the product, and above them a triangular matrix can be seen, which allows its seven technical requirements to be correlated both positively and negatively. On the other hand, there were also apparently “null” correlations; in these, it was not necessary to identify the direction of the correlation of each pair of variables, since the strength of the correlation direction was not significant or was even null.

Correlation is of great help because it makes it possible to demonstrate the direction of correlation of the technical variables, allowing it to be determined which variables enhance one another and which ones present an inverse relationship, in which improving one can negatively affect another when higher priority is assigned to it.

2.8 Competitive evaluation

On the right side of the QFD matrix, a comparative table is usually found between the proposed product characteristics and two other competing products in the market.

In that section, each product is evaluated from 1 to 5, with 1 being very low performance and 5 being very high performance. The comparison is made through a line graph that facilitates the identification of the strengths of the proposed product, the areas of opportunity where competitors have an advantage, and those attributes in which all products have a similar performance. This evaluation helps guide decision-making focused on addressing areas of opportunity; however, due to the conceptual phase of the present work, this section remains pending for possible later definition of a precise formulation in terms of costs.

2.9 Technical importance rating

The Technical Importance Rating is the numerical value that reflects how much each technical requirement, the “how’s”, influences the total fulfillment of customer needs, the “what’s”, taking into consideration the strength of relationship between them and the relative weight of each customer requirement.

The formula for the Technical Importance Rating is:

$$TIR_j = \sum_{k=1}^{n} \left(W_k * R_{kj} \right) \qquad (5)$$

where:

- $\mathbf{TIR_j}$: Technical Importance Rating of technical requirement **j**,
- $\mathbf{W_k}$: relative weight of each of the "what's" (obtained using equation 3),
- $\mathbf{R_{kj}}$: value of the relationship between the list of customer requirements **k** and technical requirement **j**,
- $\sum_{\mathbf{k=1}}^{\mathbf{n}}$: the sum runs through all **n** (i.e. The list of "what's").

2.10 Relative weight of the technical specification

Once the Technical Importance Rating of each "how" has been obtained, the relative weight of each one is calculated to identify which technical aspects have the greatest weight in the development of the product. It is calculated as follows:

$$W_j = \left(\frac{TIR_j}{\sum_{h=1}^{m} TIR_h} \right) \qquad (6)$$

where:

- $\mathbf{W_j}$: Represents the relative weight of the specific TIR of a "how" evaluated among the sum of all TIR's,
- $\mathbf{TIR_j}$: It refers to a specific TIR,
- $\sum_{\mathbf{h=1}}^{\mathbf{m}} \mathbf{TIR_h}$: The sum of the TIR's for the entire list of How's ($\mathbf{m}$).

3 RESULTS

3.1 Relative weight of customer requirements

The results of the voice of the customer were calculated through Equation (3), where the percentages of the relative weight corresponding to customer requirements were obtained. These weights, together with their requirements, can be seen in Table 1.

Table 1

Transformation of the voice of the customer.

Customer requirement	I_i	(%)
Biodegradability	9	16 %
Smooth surface	8	14 %
Economical	7	13 %
Thick wall thickness	7	13 %
250 milliliter capacity	6	11 %
Low aspect ratio geometry	6	11 %
Flexibility	6	11 %
White pigmentation	5	9 %
Heat resistance	1	2 %

In the following sections, it is observed how these weights influence the relationship matrix with the technical properties of the product.

3.2 Results of the directions of the technical specifications

Once the technical specifications were evaluated, the most convenient direction was assigned to each of the variables, remembering that there are three: maximize, target and minimize. The results can be seen in Table 2.

From the directions, it is highlighted that the target direction was chosen for most variables, because they have an optimal point where it is convenient to remain. On the other hand, the only variable to be minimized was unit cost, which makes sense because the aim is to reduce the magnitude of the economic parameter to create a competitive advantage.

Table 2

Directions of the technical specifications.

Technical specification	Direction
PLA composition	◇
Compression molding	◇
3 mm wall thickness	◇
Geometry 7.43 cm (w) × 7.13 cm (h)	◇
White pigment	◇
Smooth surface finish by mold	◇
Low unit cost	▼

3.3 Result of the directions of the technical correlations

In this section, the directions of correlation of the technical variables were found. These could be either positive (+) or negative (-); on the other hand, there were also null or non-significant correlations, indicated as an empty space in the correlation pyramid, where the strength of the correlation direction did not represent enough importance to mention it.

The results of the significant directions of the technical correlations can be seen in Table 3. It should be emphasized that the justification for the reason behind each symbol of the technical variable correlations will be addressed in the discussion.

Table 3

Directions of the technical correlations.

Pair of technical requirements	Sign
PLA composition ↔ Compression molding	+
PLA composition ↔ 3 mm wall thickness	+
Compression molding ↔ 3 mm wall thickness	+
Compression molding ↔ Geometry 7.43 cm (w) × 7.13 cm (h)	+
3 mm wall thickness ↔ Geometry 7.43 cm (w) × 7.13 cm (h)	+
Compression molding ↔ Smooth surface finish	+
3 mm wall thickness ↔ Smooth surface finish	-
3 mm wall thickness ↔ Low unit cost	-
White pigment ↔ Low unit cost	-

3.4 Weighted correlation between customer requirement and technical specification

In this section, each customer requirement was taken and evaluated in each of the technical specifications. The results of the interactions between the “what’s” and “how’s” are found in Table 4. These interactions were weighed with 9, 3, 1 and 0 points depending on the relationship strength, as explained in Section 2.6. The results obtained were key to weighing the degrees of importance of each technical specification, which will be seen in later sections.

Table 4

Relationship between customer requirements and technical specifications.

Customer requirement \ Technical specification	PLA composition	Compression molding	3 mm thickness	Geometry 7.43 cm (w) × 7.13 cm (h)	White pigment	Smooth surface finish by mold	Low unit cost
Biodegradability	9	3	3	1	1	1	1
250 ml capacity	1	3	1	9	0	0	3
Low aspect ratio geometry	3	9	9	9	0	0	3
Economical (price)	3	3	3	3	3	3	9
Smooth surface	1	3	0	0	0	9	1
Heat resistant	9	3	3	3	0	0	3
Thick wall thickness	1	9	9	1	0	1	3
Flexibility	9	3	9	3	0	0	3
White pigmentation	3	3	3	0	9	3	3

3.5 Results of the technical importance rating

The results of the Technical Importance Rating were calculated through Equation (5), where representative importance data of the QFD "how's" were obtained. The complete data can be observed in Table 5.

Table 5

Technical Importance Rating weightings.

Technical specification	Raw weighting
PLA composition	398.18
Compression molding	441.82
3 mm wall thickness	441.82
Geometry 7.43 cm (w) × 7.13 cm (h)	301.82
White pigment	136.36
Smooth surface finish by mold	225.45
Low unit cost	314.55

3.6 Results of the relative weight of the technical requirement

The results of the relative weight of each technical specification were calculated through Equation (6), where, thanks to the raw weighting, the relative weight of each technical requirement was calculated. This resulted in the list of "how's" with greatest relevance in the project, shown in Table 6.

Table 6

Results of the relative weights of the technical specifications.

Technical specification	Relative weight
PLA composition	18 %
Compression molding	20 %
3 mm wall thickness	20 %
Geometry 7.43 cm (w) × 7.13 cm (h)	13 %
White pigment	6 %
Smooth surface finish by mold	10 %
Low unit cost	14 %

4 DISCUSSION

4.1 Discussion of the relative weight of customer requirements (what's)

In the results section, it is observed that the most valued requirement yielded by the QFD corresponded to biodegradability, with a relative weight of 16%. This is not surprising, since it was derived from the young university age group in which the survey was carried out, an assertion based on previous literature (Theocharis & Tsekouropoulos, 2025). However, the remaining customer requirements are not far behind, such as a smooth surface, being economical, thick wall, 250 ml capacity, low aspect ratio geometry and white pigmentation.

These aspects were strongly considered for the definition of the technical variables and for the justification of their correlations, a section that will be addressed in detail in the following subsection. Except for heat resistance, whose importance value was weighted very low by the university students themselves, this was because young people prefer cold beverages according to the survey carried out in the QFD preliminary stage. This data was valuable because from the beginning they allowed us to preview what is important to the customer and thus to have the capacity to propose technical specifications aligned with the needs previously identified.

4.2 Discussion of the direction of technical correlations and their relationship with scientific literature

The technical correlations obtained in the QFD matrix show that the proposed cup design depends mainly on the relationship between PLA composition, compression molding, wall thickness, geometry, surface finish and unit cost. In this sense, the positive correlations between PLA composition, compression molding and 3 mm wall thickness are coherent, since PLA is a thermoplastic material that can be processed by conventional forming methods and has been widely studied for packaging and single-use biodegradable applications (Jamshidian *et al*., 2010; Ncube *et al*., 2020). Therefore, the selection of PLA directly conditions the processing window, the mold design and the thickness that can be obtained in the final product.

The correlation between compression molding, wall thickness and the proposed geometry of 7.43 cm width by 7.13 cm height was also considered positive. This is because the mold is responsible for defining the final geometry of the cup, while the amount of material, temperature, pressure and molding time determine the consolidation of the polymer. For this conceptual design, the 3 mm wall thickness is not presented as an experimentally validated value, but as a proposed technical specification associated with greater rigidity, better grip sensation and dimensional stability for cold or room-temperature beverages. In addition, the proposed geometry gives a low flow length/thickness ratio, which would favor material filling during molding, considering that high flow length/thickness ratios generally increase resistance to polymer flow (Eladl *et al*., 2018; Xu, 2004).

The positive correlation between compression molding and smooth surface finish is also justified, since the final appearance of the molded PLA cup would depend strongly on the molded surface. A smooth mold can help obtain a smoother polymer surface, which is relevant because surface finish was one of the most important customer requirements. This agrees with the idea that mold quality directly affects the final appearance of molded thermoplastic parts (Narlıoğlu, 2022). Therefore, compression molding is not only related to shape formation, but also to the visual and tactile quality perceived by the user.

On the other hand, the negative correlations identified in the QFD matrix are mainly related to cost and possible surface defects. The 3 mm wall thickness was negatively correlated with low unit cost because a thicker cup requires more PLA per unit, which increases material consumption and therefore production cost. This is especially relevant because material cost can represent an important part of the total manufacturing cost in polymer products (Åkermo & Åström, 2000). Similarly, the negative correlation between wall thickness and smooth surface finish was assigned because thicker molded parts can be more susceptible to defects such as sink marks or surface irregularities if the process is not properly controlled (Huang *et al*., 2022).

Finally, the negative correlation between white pigment and low unit cost is explained by the need to add a compatible colorant or masterbatch to obtain the desired appearance. In this proposal, the white pigment is considered only as an appearance additive and not as a mechanical reinforcement. Therefore, its future selection should consider compatibility with PLA, safety for food-contact applications, processing behavior and cost. In general, the correlation analysis indicates that the main technical challenge is to balance cup rigidity, surface quality and biodegradability with the economic restriction of producing a disposable cup.

4.3 Discussion of the relative weights of the technical specifications (how’s)

The relative weights of the technical specifications show that the most relevant variables for the proposed biodegradable cup are compression molding and 3 mm wall thickness, both with 20% relative weight. These two “how’s” obtained the highest values because they are directly connected with several customer requirements at the same time, especially thick wall, low aspect ratio geometry, flexibility, surface quality and the general perception of resistance. This means that, for this conceptual proposal, the cup should not be designed only from the material perspective, but also from the forming process and the wall thickness that the mold can provide.

PLA composition was the third most important technical specification, with 18% relative weight. This result is coherent because biodegradability was the most important customer requirement in the QFD analysis. Therefore, the selection of PLA is justified as the central material decision for a disposable biodegradable cup. However, this percentage also shows that the material alone does not define the final product; its performance depends on the way it is molded, the geometry selected and the amount of material used per cup.

Low unit cost obtained 14% relative weight, which confirms that the economic aspect remains relevant even though it was not the highest customer requirement. This result is important because biodegradable PLA cups are usually more expensive than conventional disposable plastic cups. For that reason, cost must be considered as a limitation of the proposal and as a future optimization criterion. In the same sense, the geometry of 7.43 cm width by 7.13 cm height obtained 13%, showing that the 250 ml capacity and low aspect ratio shape selected by consumers also influence the final technical design.

The smooth surface finish by mold obtained 10% relative weight. Although this value is lower than those of molding, thickness and PLA composition, it is still relevant because the surface finish was one of the most valued customer requirements. A smooth surface contributes to the user’s perception of cleanliness, quality and comfort during use. Finally, the white pigment obtained the lowest relative weight, with 6%, which indicates that color is desirable but not as decisive as biodegradability, rigidity, geometry, cost and surface finish.

Overall, the technical prioritization indicates that future experimental work should focus first on the compression molding conditions, wall thickness and PLA processing behavior. These three variables together represent the main technical basis of the proposed cup. After that, cost, geometry, surface finish and pigmentation should be adjusted according to the manufacturing feasibility and the economic limitations of a disposable biodegradable product.

5 CONCLUSIONS

The application of the QFD methodology made it possible to translate the needs of university consumers into technical specifications for the conceptual development of a disposable biodegradable cup based mainly on PLA. The survey results showed that biodegradability was the most important customer requirement, with a relative weight of 16%, followed by smooth surface with 14%, economical price and thick wall thickness with 13% each. These results confirm that the consumer does not only value the environmental character of the product, but also its appearance, perceived resistance and cost.

From the technical perspective, the most important specifications were compression molding and 3 mm wall thickness, both with 20% relative weight, followed by PLA composition with 18%. This indicates that the future development of the cup should prioritize the relationship between material selection, molding conditions and wall thickness. These variables are essential because they influence geometry, rigidity, dimensional stability and general perception of quality of the disposable cup.

The correlation analysis showed that the main positive relationships are associated with PLA composition, compression molding, wall thickness, geometry and smooth surface finish. In contrast, the main negative relationships are linked to cost, especially because increasing wall thickness or adding white pigment would raise the amount of material or additives required. Therefore, the main technical challenge is to balance biodegradability, rigidity, surface quality and economic feasibility.

In conclusion, the QFD analysis provides a useful basis for guiding future experimental work. The proposed product should be developed as a disposable PLA-based biodegradable cup, focused only on cold or room-temperature beverages. Future studies should experimentally evaluate PLA processing conditions, wall thickness, surface finish, mechanical behavior and production cost to validate the technical feasibility of the concept proposed in this work.

Since the surveyed sample was limited to university students from TecNM Ciudad Madero, a Generation Z segment that values sustainability, future studies should broaden the demographic scope to contrast the relative weights of customer needs and technical specifications.

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