

1 Article

2 Custom design of packaging through advanced 3 technologies: case of study applied to apples

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10 **Abstract:** In the context of food packaging design, customization enhances the value of a product
11 by meeting the needs of the consumer. Personalization is also linked to adaptation. This makes it
12 possible to improve the properties of the packaging from various points of view: functional,
13 aesthetic, economic and ecological. Currently the functional and formal properties of packaging are
14 not investigated among themselves, however the study of both properties are the basis for creating
15 a new concept of personalized and sustainable product. In accordance with this approach, the
16 conceptual design procedure of packaging with personalized and adapted geometries based on the
17 digitization of fresh food is proposed in this work. This study is based on the application of
18 advanced technologies for the design and development of food packaging, in this case apples, in
19 order to improve the quality of the packaging. The results obtained show that it is possible to use
20 advanced technologies in the early stages of product design in order to obtain competitive products
21 adapted to new emerging needs.

22 **Keywords:** Food Packaging; Customization; Product Design, Personalized Design, Reverse
23 Engineering, CAD, FDM.

24

25 1. Introduction

26 The challenges demanded by the European Union in the food packaging industry raise new
27 objectives among which are the sustainability of raw materials and minimization of waste, reduction
28 of energy consumption during the production process, minimization of environmental impact,
29 recyclability of packaging and littering reduction [1, 2].

30 This combined with the fact that during the last decade the demand for healthy and fresh
31 products, especially fruits and vegetables, is gradually growing, in a context where eating and
32 consumption habits are constantly changing due to the lifestyle in society, makes other specific needs
33 appear in the packaging of food by the consumer, mainly related to the design and adaptability of
34 packaging [3]. Among these needs, others are added such as providing more nutritional information
35 on the packaging, greater food security and less risk to health [4-6]. Thus, there are studies that place
36 the packaging of the fresh product as the second reason for choosing a product where factors such as
37 comfort, appearance, transparency and texture must be considered [4].

38 Thermoplastic polymers comply or can comply with all of these conditions, which is why they
39 have been chosen by manufacturers of different products as materials for their packaging [7].
40 Polyethylene terephthalate (PET) is a polymer whose properties include its mechanical resistance to
41 both impact and chemical products, its transparency, its lightness, the reduced demand for energy in
42 its manufacture and transport, its mouldability and its recyclability [8]. In addition, it is the most
43 recycled plastic in the world and the European Food Safety Authority has corroborated that PET does
44 not contain bisphenol-A (BPA), phthalates or dioxins [2].

45 However, they have been identified as one of the main causes of global environmental
46 degradation and this problem is expected to increase due to increased demand from developing or
47 re-industrializing countries around the world [9, 10]. For example, from the perspective of a country
48 in constant development and consumption of different raw materials, China accounted for 24% of
49 PET plastic demand in 2016, and it is critical to understand the consumption needs of this type of
50 market when examining the prospects for global PET volume growth [11].

51 In fact, the clear trend towards increasing the consumption of food that needs packaging carries
52 with the constant development of materials and techniques that improve the performance of this
53 service [12]. In short, it can be distinguished several aspects [13]: the improvement of the production
54 times, the reduction of the material and the improvement of its aesthetic and functional properties.

55 Thus, the fresh food packaging industry is interested in developing efficient and innovative
56 solutions to ensure the quality of the products taking into account their sustainability and
57 environmental sustainability [11]. For this reason, the design evaluation in the development of
58 sustainable products should include aspects related to the design, manufacture and use of the
59 packaging [14, 15].

60 In this context, the packaging design process implies consideration of aspects associated with
61 cost, appearance, usability, manufacturing, sustainability, standards or competitiveness [14]. It
62 should be added that the manufacturing process selected for a product is directly related to the
63 aspects mentioned above, and in the case of food packaging one of most commonly used is
64 thermoforming process [16].

65 Typically, previous research on the packaging design process in thermoforming, focus on
66 studying the moulds and materials used in the process [9, 17-19]. Also, recent research implements
67 functions for the intelligent packaging development, through which sensitive labels control the
68 condition of the food [20]. These initiatives are aimed at improving food health and getting more
69 freshness of food, achieving in this way a better preservation of it [3].

70 On the other hand, the packaging sector demands customized solutions in terms of shapes, sizes
71 and colours, so that the packaging is unique [21]. In turn, it is intended to pursue product
72 differentiation by means of sustainable products and new designs [22]. In such a way, it is also
73 possible to respond demographic changes and consumption habits [23-25].

74 Thus, according to [26], a packaging can be personalised in reference to the non-generic, making
75 a difference as to design, brand and/or size, among others. Stated differently, a container can be
76 designed specifically for that type of product. On the other hand, it can be understood that an adapted
77 packaging is the one that adapts itself to the inner shape and size of the product [26].

78 However, despite the needs that were determined in previous research and after having
79 analysed the fresh food packaging which are currently commercialised on the market, it is observed
80 that the majority of them are standard and just a few includes customization in terms of forms [27].
81 In addition, in these cases there is no adaptation to specific sizes according to calibres.

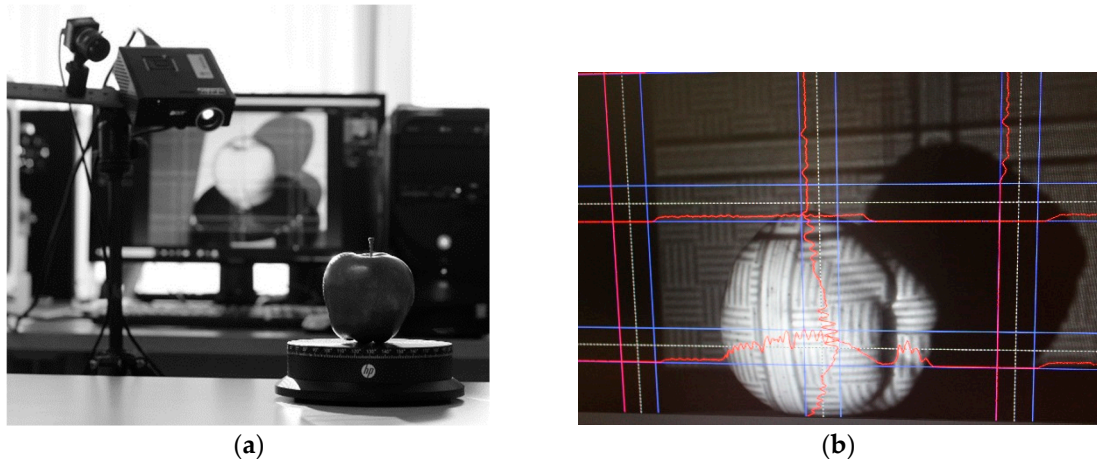
82 According to the reasoning presented, this research studies of the personalization and
83 adaptation in packaging design, through a case of study with apples, on the protection of the product
84 in order to provide designers with a tool for the packaging 4.0 generation. This is linked to the
85 sustainability of both the interior of the product and the material expense. The main objective of this
86 study is to validate the use of advanced technologies as part of the unconventional design of
87 packaging, increasing the sustainability and functionality of these products. A packaging can be
88 understood as personalized to the non-generic, being able to differentiate in terms of design, brand
89 and / or size among others, that is to say, a packaging designed specifically for that type of product.

90 **2. Materials and Method**

91 *2.1. Tools and materials used to obtain the customized packaging*

92 To carry out the experimental development, the apple has been used as the target product
93 because its size facilitates the obtaining of measurements, studying the adaptation to packaging
94 depending on two different calibres: category I and category II, according to [28].

95 For the development of the experimental, a total of 20 apples were used, 10 units of each calibre
96 were used to carry out the design adapted from the computer-aided design (CAD) concept, which
97 were digitised by means of 3D digitalisation [29], Figure 1. To this end, 8 image captures were
98 obtained for each unit needed to create the three-dimensional model, Figure 2. The David® SLS-1 3D
99 scanner was used, according to [30]. These scanned elements have as their main purpose the creation
100 of adapted geometries through the generation of curves based on the scanned elements.
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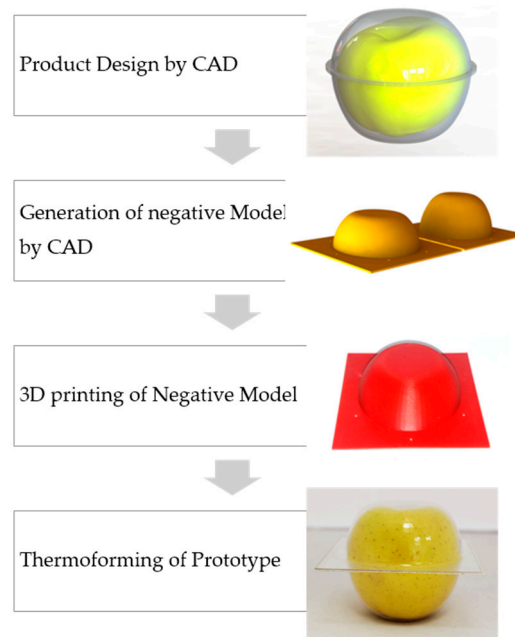
102 **Figure 1.** a) Scanning procedure using the SLS-1 David V5 scanner, b) Visualization of the apple
103 through the software.



104
105 **Figure 2.** Example of capture of the image, which the 3D scanner performs, of an apple of calibre 1.

106 Thus, the development of the concepts was carried out through the CAD software, Solidworks®.
107 As a result, the development of packaging design was simplified in time and has allowed to generate
108 more complex and personalized forms to the food.

109 On the other hand, the evaluation of the design proposals was validated through the generation
110 of reliable prototypes. The mould design and The Standard Triangle Language (STL) file of the mould
111 are generated by Solidworks® and, then, is parameterized using software for 3D printing, Simplify.
112 A Gcode file is generated for printing it in a FDM machine, BQ Witbox that use a diameter filament
113 of 1.75 mm. And, the PET sheet of 500 micrometers thick is thermoformed to generate the prototype
114 with Formech compac mini using the FDM mould, Figure 3.



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Figure 3. Generation of prototypes in thermoforming with moulds created by FDM.

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2.1.2. Procedure of develop to parameterize the design of the packaging

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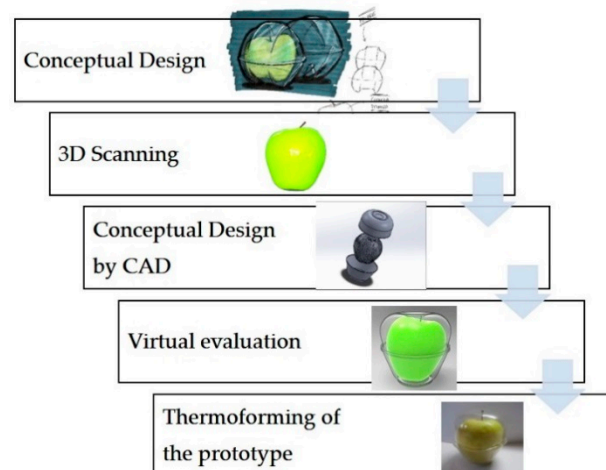
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Figure 4 details the procedure carried out for the design and development of customised and adapted packaging. Once the conceptual design of the package was carried out for this case study, the properties of these products have been studied, through the application of scanned apples, in order to define the main parameters to be taken into account. Using these data for two purposes: for packaging design using CAD tools and parameterization of the final geometry. Then, the parameterized package was validated by prototypes made with FDM moulds.



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Figure 4. General procedure used to obtain the final package

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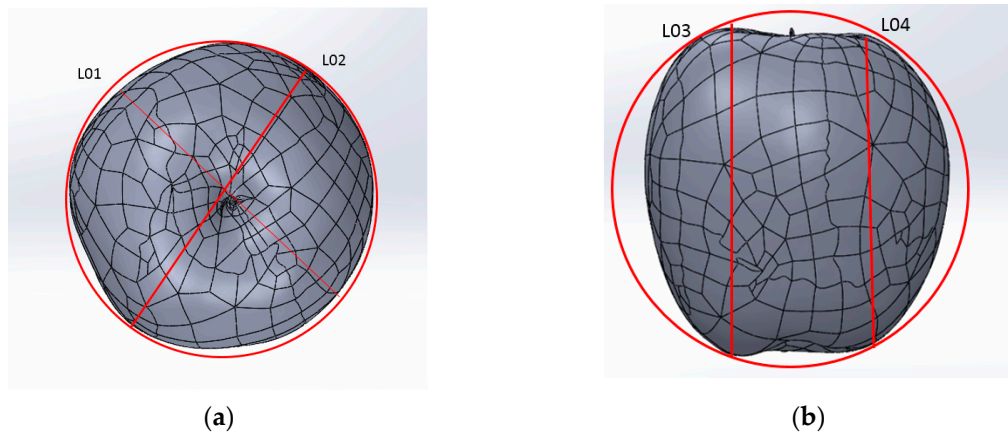
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Also, several functional measures of each natural product were evaluated to analyse the differences between them, also using Solidworks® software. These dimensions were selected according to the parameters established for the calibres: the largest diameter, dm, and the maximum height, H. According to this, two measurements were collected for each of the dimensions studied: L01 and L02 for dm and L03 and L04 for H, Figure 5. It should be noted that L01/L02 were made in the two directions of maximum diameter of the fruit and L03/L04 in the two highest heights recorded. This has obtained the variation in the measurement between pieces of fruit.



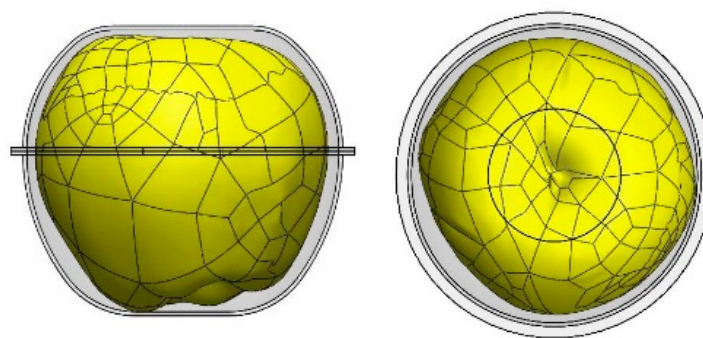
134 **Figure 5.** Measurements collected on the digitizing products.

135 One of the objectives of digitizing these elements, in spite of the normal variations of a natural
 136 product, is to define the range of measures that present representative variations to be taken into
 137 account in the design of the packaging. As a result, comparative tables were obtained and the
 138 dimensional range was defined, which will serve to obtain the adaptation parameters on the design
 139 of the packaging, which is the object of study.

140 Once the concept was generated, the design was developed in Solidworks® using the 10 scanned
 141 elements as a means of generating the construction curves. In accordance with this, the set of lines
 142 and tangent arcs have been defined, which together form the design of the idea previously
 143 conceptualized. Likewise, the numerical relations between the different container geometries were
 144 defined, using as relation parameters the maximum height, H and the maximum diameter, d_m , of
 145 the container.

146 Then, when the final design was developed in Solidworks®, the relationship equations, defined
 147 above, were introduced in order to evaluate the degree of adaptability through this type of digital
 148 tools. Then, the variable measures of the packaging were defined to carry out the adaptation to the
 149 two categories of size of apple studied, according to [28].

150 Finally, the adaptability range of the design created for this practical case was established and,
 151 in addition, the degree of adaptation of the dimensions obtained with each of the digitalized units for
 152 the two calibres studied was evaluated. Figure 6 shows an example of the results obtained.



153
 154 **Figure 6.** Example of the result of the adaptation parameters with respect to the digitized product.

155 The results obtained for the two calibres studied were evaluated through the creation of a
 156 reliable physical prototype using FDM moulds for thermoforming the sheet. The prototypes
 157 developed were used to validate the dimensions obtained by introducing physical apples. The units
 158 studied for each calibre were 20 and the selection of each of them was made taking into account
 159 shapes, size variations and also different types of breeds were included.

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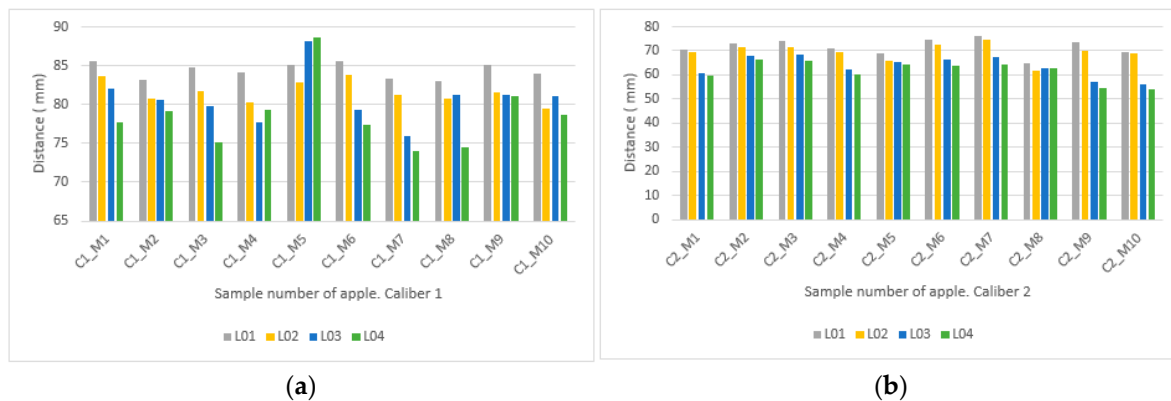
161 3. Results

162 3.1. Virtual evaluation of digital elements

163 As described above, the study was conducted for two types of calibres, according to [28]. As
 164 seen, the size refers to the predominant size within the packaging, and is defined according to the
 165 maximum equatorial diameter [31]. Thus, the apple samples were scanned to generate a parametric
 166 model of each one to make the measurements according to the methodology. The data obtained from
 167 the samples studied are detailed in Figure 7.

168 From the results obtained from the study of the morphology of apples it is determined that the
 169 dominant geometry in the plant has a slightly oval shape, therefore we can speak of major axis, L01,
 170 and minor axis, L02, to name the maximum dimensions of the digitalized samples, seen in the plant.

171 It is worth mentioning again that L01 and L2 correspond to the average dimensions for the width
 172 of the apple, on the other hand L03 and L04 are the height measurements collected on the digitized
 173 elements. In an initial analysis of the results it is observed that calibre 1, Figure 7 a), comprises a larger
 174 range of dimensions than calibre 2, Figure 7 b).
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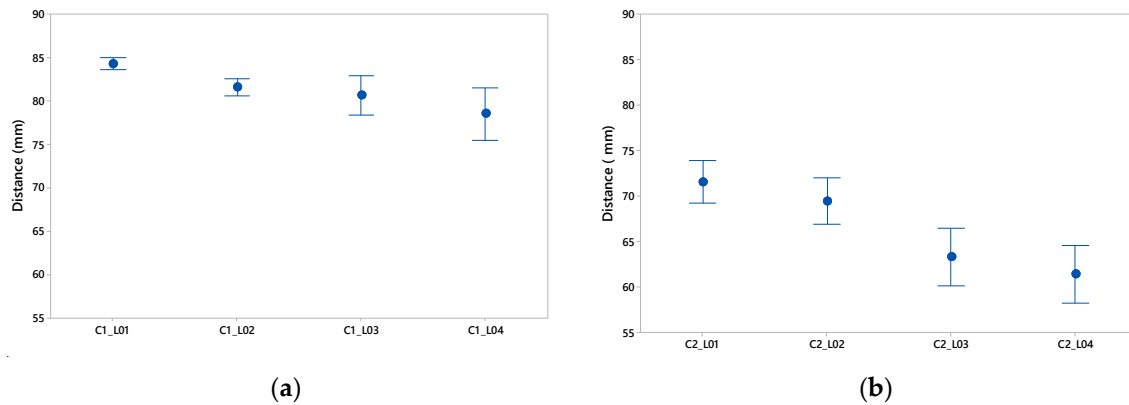
176 **Figure 7.** Measurements collected from scanned parametric models of apple samples: a) calibre 1, b)
 177 calibre 2.

178 From the graphs it can be seen that for calibre 1, parameter L01 has intervals between 83 mm
 179 and 85.5 mm while L02 varies between 80.2 mm and 83.75 mm, Figure 4.8 a). This shows the disparity
 180 of measurement for apples of the same calibre, intrinsically affecting their standardisation for
 181 subsequent parameterisation.

182 As regards the height of the apple, parameters L03 and L04, the aim is to obtain as a result the
 183 maximum height per calibre. In this case, the results obtained with greater value are L03 with a
 184 dimensional interval between 77.7 mm and 88.16 mm.

185 As for size 2, Figure 8 b), the category of fruit has worse quality and the measurement intervals
 186 tend to increase according to standard [28], 5% for calibre 1 and 10% for calibre 2. As for the
 187 measurement results, because parameter L01 is predominant from the point of view of package
 188 design, a measurement range between 69.4 mm and 75.9 mm is observed. The maximum height L03
 189 varies between 56 mm and 68.5 mm.

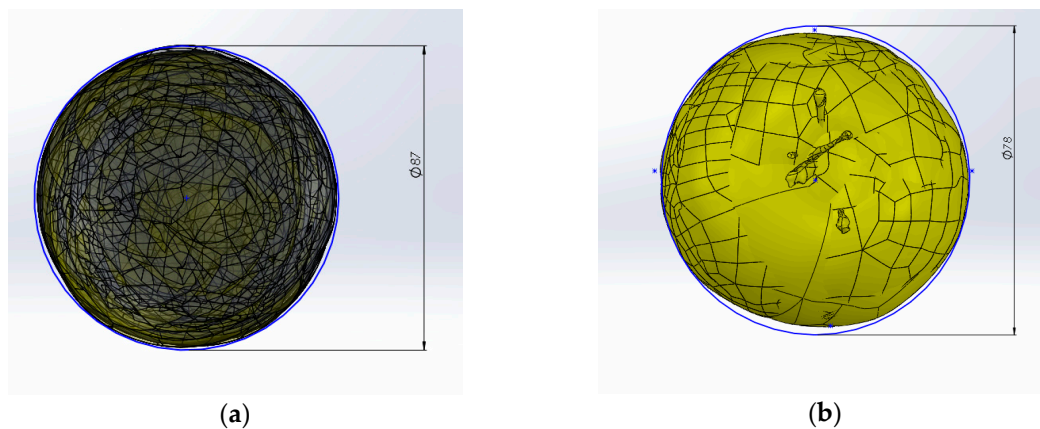
190 On the other hand, Figure 8 shows the mean data for the four parameters with the measurement
 191 dispersion. In both cases, the measurements show a greater dispersion in the parameters L03 and L04
 192 which corresponds to the height of the apples, being slightly higher for the apples of calibre 2. As for
 193 the measure of greater influence for the design of the package, L01, it is precisely the apple of calibre
 194 1 that exhibits greater homogeneity.



195 **Figure 8.** Mean data for parameters L01, L02, L03 and L04 with measurement dispersion: a) calibre 1;
 196 b) calibre 2.

197 Analysing the data presented so far, it can be deduced that the size of the package of a calibre
 198 can be included in a dimension that encompasses all sizes of apple inside a category, included the
 199 difference between all the fruits of the same type and calibre. Therefore, the variations in the samples
 200 that affect the design of the packaging are the maximum width and height obtained from grouping
 201 the digital models.

202 For calibre 1, 85 mm as the maximum measurement within the calibre established according to
 203 the standard and tolerance of 5% [28], a maximum diameter of 86.7 mm was obtained for virtual
 204 measurements, Figure 9 a). On the other hand, for size 2, with a nominal size of 73 mm and a
 205 permitted tolerance of 5% according to [28], 78 mm has been obtained, Figure 9 b). These dimensions
 206 served as a starting point for the dimensional study of the container although these dimensions could
 207 be reduced due to the irregular geometries.
 208



209 **Figure 9.** Overlap of the 10 apple units to establish a common diameter based on the sample: a) larger
 210 size 1: b) size 2 with dimensions between 63 and 73 mm.

211 Although all apples are included in the same diameter, the plant shape is slightly oval, as
 212 discussed in previous paragraphs. Thus, the linear dimension on the plant in one of the faces is lower
 213 with respect to its perpendicular, L02 and L01 respectively. According to this, a dimensional
 214 relationship, dr , was established for the diameter, according to equation 1:

$$dr = \frac{\text{larger measure, L01}}{\text{minor measure, L02'}} \quad (1)$$

215

216 Thus, from the data obtained in the 20 case studies corresponding to calibres 1 and 2, a
 217 dimensional relationship was established between both distances of 0.97 and 0.98 respectively. This

218 relationship was used for the design and parameterization of the packaging by CAD, giving rise to a
219 final geometry of non-cylindrical container.

220 It is important to bear in mind that these dimensions were studied at an experimental level. The
221 aim is to propose a method in which, using scanned elements, designs can be generated; to this end,
222 a coefficient has been proposed that can be applied to the dimension of a given calibre.

223 Analysing the dimensional results of the three-dimensional models of the scanned apples and
224 the measurements according to the norm, it was detected that a relief coefficient, C_d , can be defined
225 for the design of a packaging, which in this case study was established at 1.06. This coefficient was
226 determined from the observation of the maximum dimensions per calibre, according to the norm,
227 and the virtual dimensions studied. This coefficient will make it possible to ensure that the size of the
228 containers is adapted to all geometries included within a calibre.

229 Then, if for calibre 1 the maximum diameter allowed, including tolerances, is 89.25 mm and the
230 maximum diameter that appears as a measure of nominal calibre is 85 mm. It can be defined that the
231 coefficient could be between 1.05 and 1.06. However, because of the differences naturally present in
232 fresh foods, 1.06 has been considered to be used to ensure proper functioning. Thus, the validation
233 of this coefficient was carried out by implementing this coefficient in the development of the
234 adaptation of calibre 2.

235 Therefore, the calculation of container dimensions can be done according to the following
236 equation:

$$dm = C_d * cm, \quad (2)$$

237 Where C_m is the maximum size and dm the width of the packaging.

238 Then, for calibre 1 the dimension of dm corresponds to 90 mm, obtained from the multiplication
239 of C_d and cm of 85 mm, and for calibre 2 of 77.4 mm, from cm of 73 mm. These data were validated
240 during the parametric design, which is explained in the following section.

241 With respect to the height of the packaging, a ratio has been established with respect to dm of
242 1.05 for calibre 1 and for calibre 2 the ratio of measurements is 1.10. Due to the fact that the standard
243 does not specify heights per calibre, this ratio was determined from the measurements made on the
244 samples studied. The ratios were then determined from the subtraction of the maximum length and
245 maximum height obtained virtually from the apples. Thus, in the parametric design, when this
246 measurement relationship is related to dm , the same relief coefficient is implicitly included, C_d .

247 3.2. Parameterization of the conceptual proposal

248 Once the design of the packaging was carried out, a series of parameters were obtained that have
249 given rise to the creation of equations that parameterise the package. All of them based on two
250 variables, the maximum height of the container, H , and the maximum width, dm . Thus, Figure 10 a)
251 shows a diagram of the variables that affect the sizing of the container.

252 From the initial geometry extracted from the concept design of the apple, it was parameterized
253 according to a series of equations described below. Figure 10 b) shows a diagram with the dimensions
254 that affect the mould when thermoforming the designed package. Thus, the equations that affect the
255 overall dimension of the packaging correspond to:

$$H_b = H * 0.57, \quad (3)$$

$$H_t = H * 0.43, \quad (4)$$

$$d_n = d_m * 0.97, \quad (5)$$

256 Where H_b is the height of the bottom half of the designed packaging and H_t is the height of the
257 top half. In the same way the dimensions in plan of the container are given by the greater width, dm ,
258 and the smaller width, d_n . In this case study, an oval geometry has been created.

259 On the other hand, as mentioned above, the design created in this study consists of a series of
260 arches that are tangentially joined, in plan and profile, and a flat surface at the ends with a circular
261 shape. Then, the curves that define these geometries, Figure 10, were also able to be related by means

262 of equations from the CAD design initially created. Thus, the relationship between H and the slightly
 263 oval curved geometry that makes up the package design in the profile view is given by the equations:

$$R_b = H * 0.27, \quad (6)$$

$$R_t = H * 0.18, \quad (7)$$

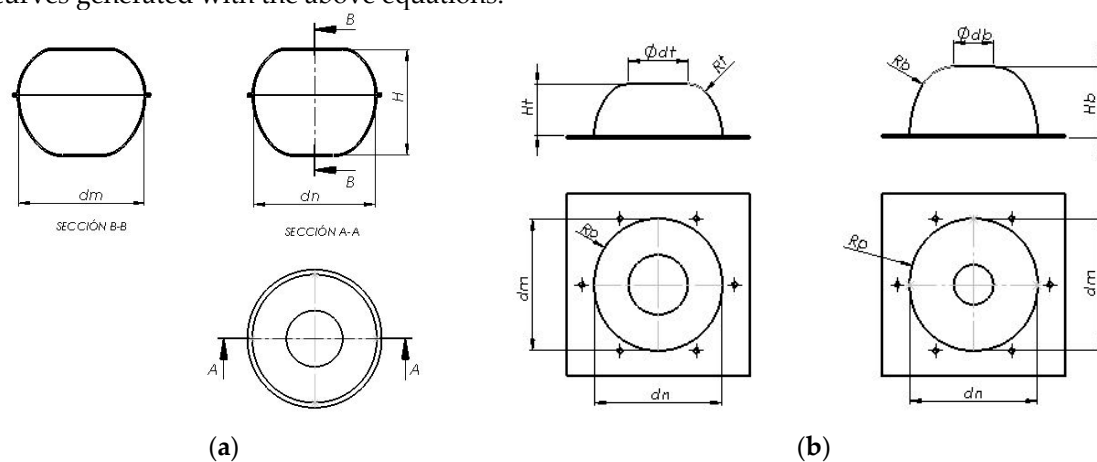
$$d_b = d_m * 0.3, \quad (8)$$

$$d_t = d_m * 0.45, \quad (9)$$

$$R_p = ((d_m + 10)) / 2, \quad (9)$$

264 These equations define the radius of curvature of the upper part, R_t , and lower, R_p . In addition,
 265 the adaptation of the dimension of the flat part, so that the packaging can be easily supported, is
 266 given by the diameter in both halves of the container, d_b and d_t , and was related to the parameter
 267 d_m . On the other hand, the radius R_p is the parameter that encompasses the overall geometry of the
 268 container in plant, and the construction of the shape was constructed by sweeping through the
 269 vertical curves given by R_b and R_t .

270 The rest of the tangent arcs that make up the packaging design are automatically adapted from
 271 the curves generated with the above equations.



272 **Figure 10.** Dimensions of the container and the mould: a) Plan of the variables that affect the container
 273 and therefore the upper and lower mould; b) Dimensions of the moulds, on the left upper half and on
 274 the right lower half.

275 Then, the generated equations were introduced in the parametric design software. The benefit
 276 of the parametric design of a packaging is the customization of their geometry according to the need
 277 of adaptation of the product to be contained. In addition, the design can be evaluated in real time by
 278 means of the digitized fruit samples.

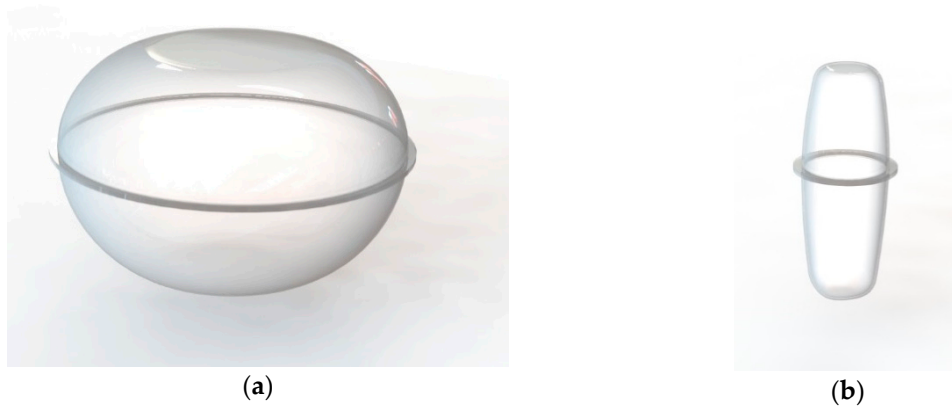
279 As a result, all construction operations such as rounds, sketches, etc. were related. The number
 280 of operations obtained was a total of 12 for each of the parts of the container. As was commented,
 281 these equations and variables serve to modify the geometry of an object quickly.

282 For the lower part, a relationship has been defined between the curves that make up the
 283 container and therefore the mould, according to the equations defined in the previous section. These
 284 equations were related to the sketches made in the parametric design program. In the same way, the
 285 equations of the upper part have been parameterized.

286 In short, by modifying one of the measures, the packaging is automatically adapted. This is one
 287 of the first steps for the generation adapted to a specific packaging design in the context of industry
 288 4.0.

289 Another result obtained in this case study is the maximum and minimum ratio of measures between
 290 H and d_m , obtaining a range of adaptation measures. The maximum ratio of d_m to H is 1.32 and the

291 minimum is 0.24. This range of measures means that the package created can also be used for other
292 types of fresh food or measurements. Figure 11 shows an example of the variations in function of the
293 maximum and minimum ratio.



294 **Figure 11.** Example of maximum and minimum ratio between d_m and H for H equal to 85 mm: a)
295 Maximum ratio being $d_m=137$ mm; b) Minimum ratio being $d_m=20$ mm.

296 Also, if d_m is kept constant at the top and bottom of the parametric packaging, R_t and R_b can be
297 adapted and combined to obtain intermediate height measurements. This parameter offers greater
298 versatility if possible combinations for containers using fewer moulds are taken into account.

299 Once the packaging was parameterized, a series of configurations were established in the
300 Solidworks® software to evaluate the appropriate sizes for each of the samples studied and with
301 which the theoretically established C_d has been validated. The configurations allow the packaging to
302 adapt automatically to the measures established, making it easier to adapt to calibres and measures
303 according to specific needs.

304 3.3. Evaluation of results

305 In order to analyse the viability of the coefficient obtained, C_d , using the 3D scanned fruit
306 models, the correct arrangement of the apple was evaluated with respect to the dimensions of the
307 packaging. Then, after analysing the dimensions with the configurations of the packaging, it was
308 observed that the C_d corresponds adequately, although the optimum height for each sample varies.

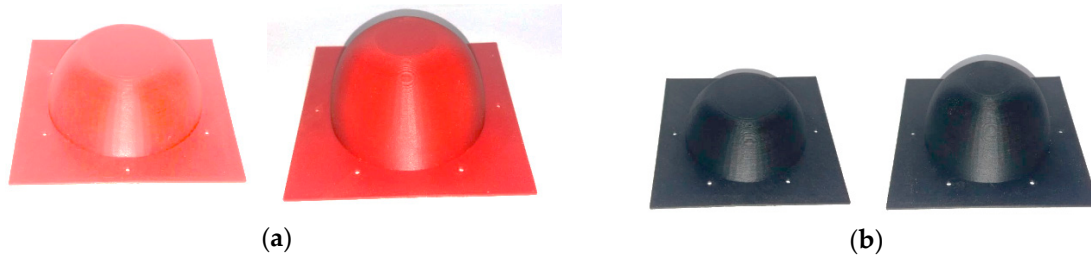
309 Bearing this in mind, it can be concluded that, depending on the design needs in the same calibre,
310 several containers with different H could be established. This may be possible thanks to new
311 technologies such as additive manufacturing, which allows low-cost moulds to be made in order to
312 optimise the maximum performance of the container. However, if the design requirements allow it
313 with this methodology it is possible to establish an optimal design that encompasses all food units of
314 the same topology.

315 On the other hand, if you want to generate a custom packaging for a unit is also possible. This
316 example could have multiple applications that can be extended to other types of products and food.

317 Thus, the final dimensions, which were adapted to the size obtained according to the C_d
318 calculated in the measurement part, correspond for calibre 1 with the ratio of d_m of 89.3 mm and H
319 of 85 mm. Although, as was mentioned, some of the samples studied could modify the height for the
320 use of the dimensions having a range between 80 mm and 85 mm Similarly, for calibre 2 the ratio of
321 d_m and H are 75 mm and 70 mm, respectively, and having a range of H between 67 mm and 70 mm.
322 For more information see Appendix A.

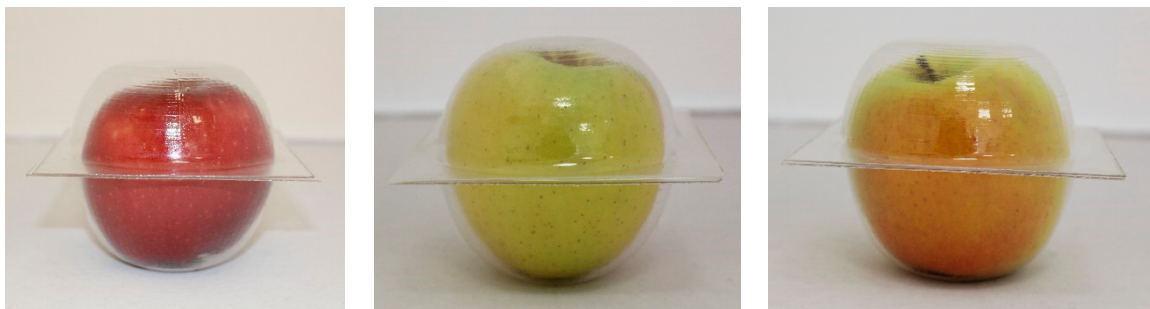
323 Then, in accordance with the reasoning that was carried out; the results obtained for the two
324 calibres studied were validated by means of a physical prototype. The FDM moulds created for the
325 two calibres are shown in Figure 12.

326



327 **Figure 12.** Parts, inferior and superior, of the mould to generate the physical prototypes: a) Moulds
 328 for calibre 1; b) moulds for calibre 2.

329 As stated above, the design was validated using the physical prototypes and 20 apples for each
 330 calibre studied, Figure 13. These apples were selected taking into account shapes and size variations,
 331 and different breeds were included in the units studied. For more information see Appendix B.
 332



333 **Figure 13.** Images of the evaluation carried out with the prototype and commercial fruits.

334 Once the results were analysed, it can be said that the final solution obtained is positive as all
 335 the units of the same calibre correspond to the dimensions of the packaging. However, according to
 336 the studies in the parametric program, it can be seen that in several of the cases studied the
 337 dimensions are not adjusted in their entirety, causing parts of the packaging to be empty.

338 This is not a functional problem for the design because these variations are given by the wide
 339 range of measurements that are included within a calibre. Specifically, these dimensional deviations
 340 are accentuated in calibre 2, which is a smaller calibre and comprises a larger range of measurements.
 341 In the case of calibre 1, which belongs to category I according to [28], lower dimensional deviations
 342 are observed. However, the morphological inequalities between the different apple varieties are
 343 increasing.

344 Means then that in this situation, personalisation and adaptation could be increased by reducing
 345 the spectrum of fruit types that can be introduced in the same type of packaging. Therefore,
 346 depending on the type of product to be packed, adaptation and personalization can be considered
 347 with a greater degree of accuracy.

348 4. Discussion

349 The main idea of reverse engineering is to synthesize a fruit model so that they can be used and
 350 measured as part of the design process. The studies carried out show that it is possible to generate
 351 personalized designs and they can also be adapted according to the specifications required by a
 352 specific product. Digitization and flexible designs make it easier to customize and test concepts in
 353 real time to help design teams make decisions in less time and with greater reliability [32].

354 Then, the introduction of scanned elements in the design process facilitates the adaptation of the
 355 size and shape of the packaging to the type of fruit contained, allowing only the quantity of plastic
 356 material necessary for its sale and transport to be used. In this way, the product is optimised, which
 357 means a reduction in environmental and economic impact. This fact is relevant because currently
 358 thousands of tons of plastic and food are discarded daily [11], and great efforts are made to mitigate
 359 this impact, generating stricter and stricter regulations in the withdrawal and recycling of food

360 packaging [33]. The high number of packaging manufactured daily means that a small reduction in
361 each container has a great influence on the environment. This working methodology promotes the
362 reduction of material that is so necessary in a strategic sector such as the food sector.

363 As noted above, much of the food waste is produced by using containers with large amounts of
364 food that end up deteriorating in homes [34]. Thus, the possibility offered by this methodology for
365 the realization of custom packaging by type of fruit and category can lead to the reduction of food
366 waste due to the possibility of reducing the amount of product inside and by improving the
367 preservation of specific properties of each food [35].

368 The application of digital elements in the design process were validated as part of the creation
369 of a method that includes advanced technologies in its procedure, as was researched in other fields
370 of engineering [36, 37]. In the study two main parameters were selected that relate to the functional
371 measures for the containers, the maximum height and width, to adapt a packaging to a given calibre.
372 However, the geometry of a fresh food is irregular so they made four measurements at the top and
373 bottom to calculate the height. The same was done for the width. It should be added that these
374 measurements have been carried out to analyse the dimensions of the product studied at laboratory
375 level. The main objective of this work was to evaluate the direct application of the scanned models
376 for the generation of personalized packages for a range of measures established within a calibre.

377 This study proposed a 3D scanning scheme for fresh food to support custom packaging design
378 [30]. Then, the three-dimensional model of the fruits approximates the real geometry. Thus, the
379 application of 3D fruits facilitates the realization of personalized and adapted designs, as well as the
380 evaluation in real time of design proposals. On the other hand, the parametric design of the package
381 according to the two parameters studied, maximum height and width, gives rise to the possibility of
382 generating packages adapted to the dimensions and needs of the food according to its established
383 range of measures. In short, the result was the creation of a packaging, fully defined by equations,
384 which is capable of adapting to the measurements in a given range.

385 Based on these results, the computational design is aimed at the parameterization of designs to
386 favour customization by means of optimal configurations according to the design variables and
387 favouring the adaptation of the design to the specific need [38, 39]. Along these lines, it can be stated
388 that computer programs facilitate the realization of personalized and flexible designs to adapt to
389 needs by means of the parameterization and digitalization of elements [40-42]. Product customization
390 then also serves as an engine to improve sustainability throughout the product life cycle [43]. Custom
391 design enhances product design by meeting the specific needs of users, according to [44].

392 Furthermore, according to new trends and competitiveness, the design and development of
393 packaging needs solutions that streamline the working procedure. In this context, based on the
394 approaches made on the customization of packaging, there is also a latent need for quick and flexible
395 solutions. Specifically, the process of manufacturing moulds by conventional methods usually delays
396 the validation time of the final prototype of the product, so that designers cannot make changes or
397 explore alternatives quickly and reliably [45]. Faced with this situation, an alternative is the
398 application of additive manufacturing techniques that can provide design teams with a fast and
399 economical tool that can thus be used from the early stages of product design.

400 In accordance with the reasoning that was carried out, throughout this work it was possible to
401 prove that it is possible to make reliable prototypes using economic moulds built by additive
402 manufacturing. The similarity of the prototypes generated thanks to 3D printing and thermoforming
403 technologies evidences the possibility of creating prototypes that provide greater reliability in a
404 simple way. Then, the evaluation by means of these prototypes provides a reliable tool for the
405 validation of the mentioned designs. In short, it was proven that it is possible to thermoform
406 geometries with different shapes. Therefore, it is possible to obtain products with better performance
407 and therefore competitive. This can also affect the life cycle of the product because from the point of
408 view of social, economic and environmental impact there is a significant improvement.

409 Finally, this work presents several future lines of action, the most important of which is the
410 advanced study of new packaging designs by means of topological optimisation and the extension
411 of the study of virtual environments for early evaluation.

412 **5. Conclusions**

413 The following conclusions can be drawn from the research work carried out in this study:

414 It is possible to digitize fresh food by means of 3D scanning techniques, obtaining reliable digital
 415 elements that can be used in advanced technologies. In this sense, it was possible to define a
 416 procedure for the reverse engineering of different types of food, detailing the specific parameters
 417 according to size and finish.

418 It was possible to use the digitized fruits during the conceptual phase in the packaging design
 419 process. Thus, custom designs were developed using these elements as a reference during computer-
 420 aided design, thus validating the proposed methodology. In addition, the evaluation of the ideas
 421 generated was also favoured by the possibility of checking dimensions in real time using these digital
 422 products. On the other hand, the adaptation according to the specifications required by a specific
 423 product is also improved. Therefore, it can be said that the application of 3D fruits facilitates the
 424 development of customized and adapted designs.

425 It is possible to completely parameterize the geometry of the package to create custom designs
 426 and, in turn, automatically adaptable. In short, the creation of a packaging, fully defined by equations,
 427 is able to adapt to measurements in a given range. The parameterized design was made possible by
 428 means of the virtual evaluation of digitized fruits.

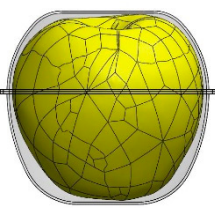
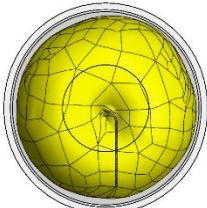
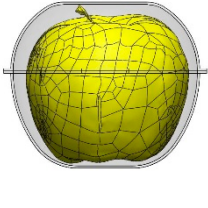
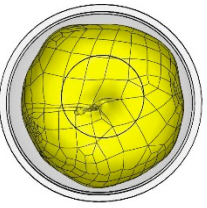
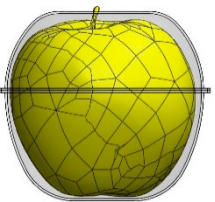
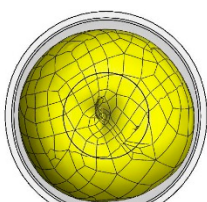
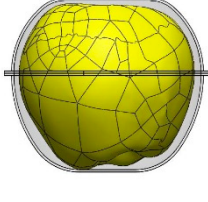
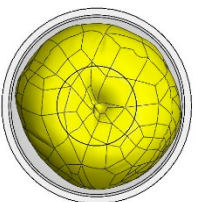
429 **Author Contributions:** Conceptualization, L.R.-P.; methodology, L.R.-P. and P.F.M.A.; software, L.R.P.;
 430 validation, L.R.-P., P.F.M.A. and A.J.G.; formal analysis, L.R.-P., P.F.M.A. and A.J.G.; investigation, L.R.-P. and
 431 P.F.M.A.; resources, A.J.G.; data curation, L.R.-P., P.F.M.A. and A.J.G.; writing—original draft preparation, L.R.-
 432 P.; writing—review and editing, P.F.M.A. and A.J.G.; supervision, P.F.M.A. and A.J.G. All authors read and
 433 approved the final manuscript.

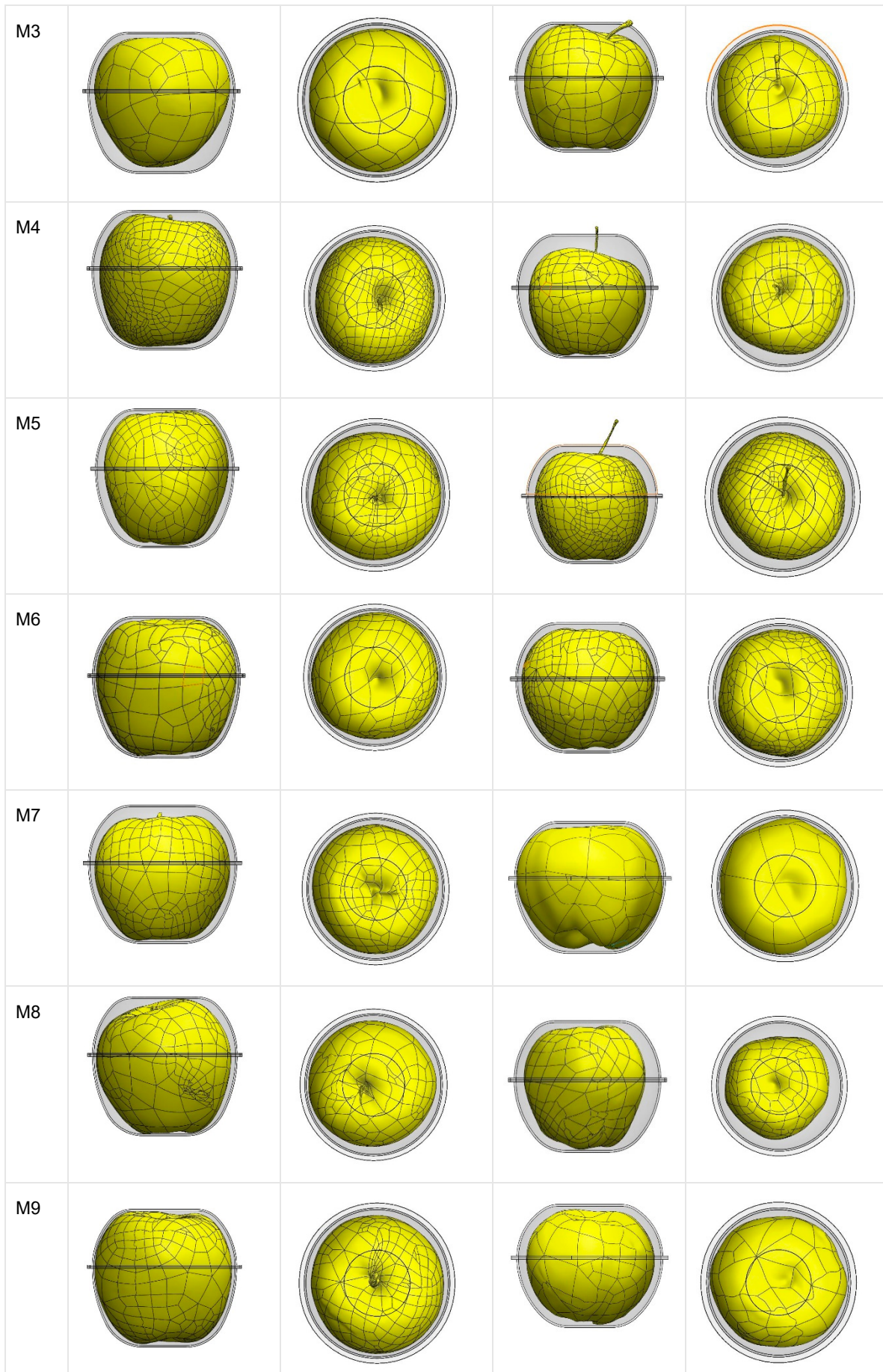
434 **Funding:** The APC was funded by University of Cadiz (Programme for the promotion and encouragement of
 435 research and transfer).

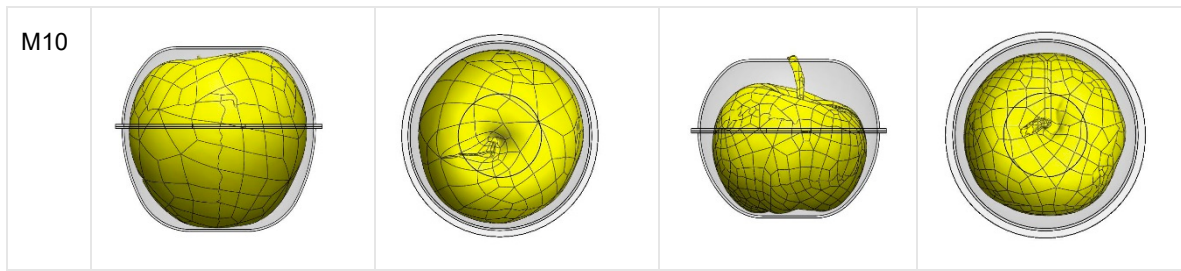
436 **Conflicts of Interest:** The authors declare no conflict of interest.

437 **Appendix A**

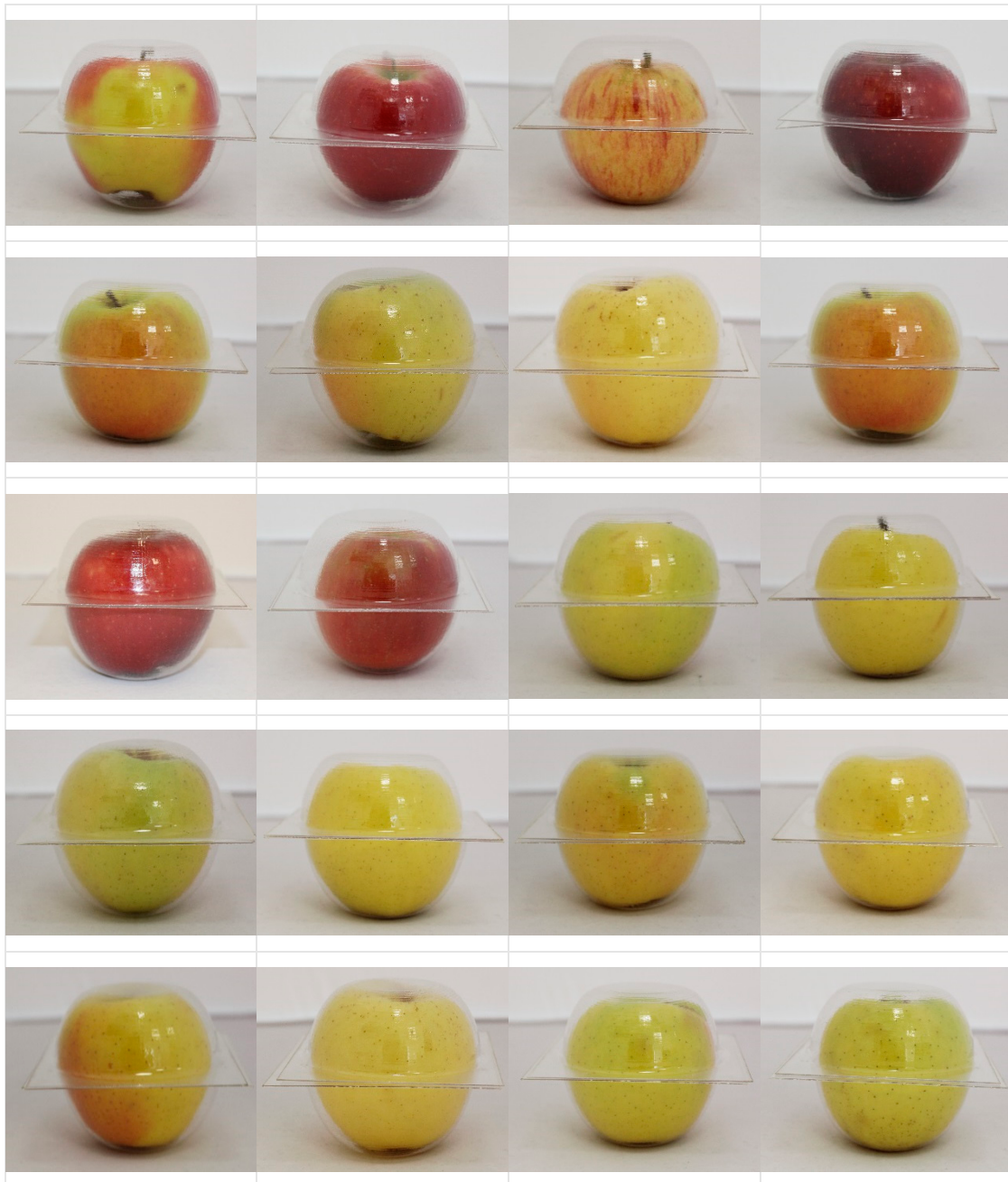
438 **Table A.** Images of virtual evaluation for both calibres.

	Calibre 1		Calibre 2	
	Front view	Top view	Front view	Top view
M1				
M2				



439 **Appendix B**

440 **Table B1.** Images from the validation study with prototype of the custom packaging for
441 Calibre 1.

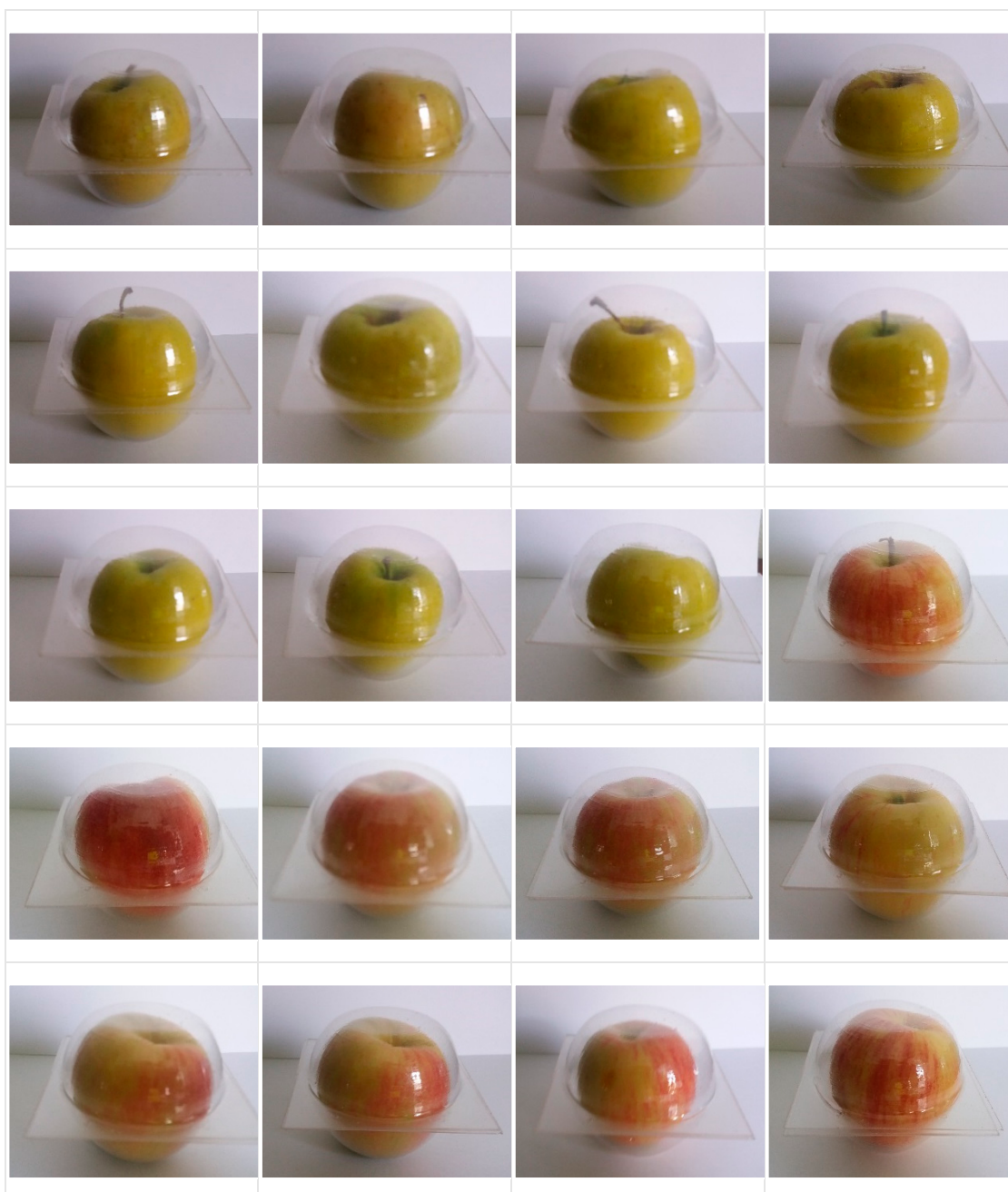


442

443

444

445 **Table B2.** Images from the validation study with prototype of the custom packaging for
 446 Calibre 2.



447

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 452 [waste-new-perspectives-on-a-dual-sustainability-crisis](https://ieep.eu/publications/plastic-packaging-and-food-waste-new-perspectives-on-a-dual-sustainability-crisis) (Accessed on 11 July 2018).
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