Research Article

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# Perceptions and knowledge regarding quality and safety of plastic materials used for food packaging

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**Abstract:** The objective of this study is to investigate the consumer perceptions about quality and safety of foods packed in plastic, as well as the impact of plastic materials on human health. To carry out the study, a questionnaire survey about the consumption habits and knowledge about plastic packaging was conducted to a sample of 487 Portuguese adult citizens. The results revealed that most respondents (81%) think about food safety and quality when purchasing foods. Additionally, it was found that the consumer's knowledge about the toxicity of components possibly migrating from the plastic packaging to the food is still limited (only 46% of participants). However, other negative effects of plastics well known to consumers include environmental pollution and marine fauna degradation (67 and 82% of participants, respectively). Thus, it was concluded that the Portuguese population need to be further educated about the toxicity of some chemical compounds present in plastic packaging, which can be ingested by migrating to the food or which can be absorbed from the environmental microplastics resulting from incorrect disposal.

**Keywords:** food packaging, plastic, food safety, knowledge, human health, questionnaire survey

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## 1 Introduction

One of the most important functions of packaging is to preserve the food quality, reducing the chemical, biochemical, and microbiological changes, while increasing the product's shelf-life [1–4]. Each type of food has a specific degradation mechanism depending on its composition. The choice of package type and size depends on properties such as water activity in the food, the amount of dissolved oxygen, the estimated shelf-life of the product, the initial level of residual oxygen in the package, the oxygen permeability [2,5], the properties of the food, and the interactions between the packaging material and the external environment [2,6]. Thus, the packaging material must be specific to ensure its compatibility with the food, not becoming a contamination vehicle, considering that it is not totally inert and may transfer unwanted substances to the food [1,7,8]. This is particularly problematic under some environmental conditions, particularly depending on the temperature or relative humidity.

Plastic packaging has replaced other materials in the food industry due to its low cost, weight, and density, allied to high resistance. Disposable plastics have been the most extensive application over the past years [9–11]. Substances such as bisphenol, antimony, and di-2-ethylhexyl phthalate can be present in the composition of some types of packaging [11,12], either as additives, catalysts, or as residues from initiating monomers or decomposition. Usually, these compounds have low molecular weight, giving them mobility to interact with food [7]. When foods remain in direct contact with any packaging material, small, measurable amounts of the packaging materials may migrate into food and can be consumed with it [13]. Groh et al. [14] have compiled a database with 12,285 chemical compounds intentionally used to contact with food, and, although these substances are identified, the risks of exposure are not fully understood and depend on a great number of factors. Azeredo et al. (2017) demonstrated that the use of plastics has some health risks, specifically those plastics containing bisphenol A or phthalates in their composition [15–17]. Migration can occur due to interactions that take place between the packaging material and the food. The Commission Regulation (EU) No 10/2011 on plastic materials and articles intended to come in contact with food established the terms for testing plastic materials with the appropriate food simulators [18].

Other types of plastic that can pose risks are micro and nanoplastics. Microplastics, which are plastic fragments [19], are an emerging type of pollutant that may adversely affect human health through ingestion of contaminated food and water [20,21] or inhalation of contaminated air [21].

The problem associated with plastic pollution has been on top of the priorities, and alternative materials are being suggested and already some are in use on a large scale. As a way to diminish plastic pollution, biodegradable polymers have been introduced providing an environmentally friendly alternative to conventional plastics. These biodegradable plastics can be readily degraded by microbial action [22–25] and can assume an important role in the future as commodity “plastics.” One other solution is provided by the enzymatic degradation of common plastic materials, such as polyethylene [26–28]. Some microbial enzymes can act on plastics in their natural environment, quickly and efficiently, making it possible, for example, to revitalize polluted environments like the oceans or other natural sites [29].

Although there is some research about plastics and their uses and hazards, the perspective of the consumer needs to be addressed. The perception of the consumer is pivotal to help making informed choices and change behaviors towards selection of products that contribute for their health, wellbeing, convenience, and to the overall safety and preservation of the planet and its ecosystems [30–34]. A recent review from Otto et al. [35] addressed the consumer perceptions about the sustainability issues of food packaging and their relation with the scientific facts. Some studies have shown that most consumers are willing to pay a premium for sustainable food packaging [35]. Nemat et al. [36] studied consumer behavior of Swedish participants towards sorting of plastic food packaging based on their perception of the value of packaging. Testa et al. [37] studied the effect of sustainability issues in the purchase intention for plastic packaging for Italian consumers and concluded that the most important factors are attractiveness, perceived quality, and ecological impact. These works demonstrate that the research community has been investigating the role of the consumer on several aspects related to packaging, even though not in Portugal and not focusing on the health risks. Therefore, these aspects are still under investigated and need further studies. For this reason, the present research was designed to investigate the perspective of Portuguese consumers about several aspects related to the use of plastic materials in food packaging, including safety aspects, convenience traits, environmental impacts, or health effects.

This research is part of a project that focuses on plastic food packaging, including the practices, knowledge, and concerns of Portuguese citizens, from different perspectives, from sustainability to human health. This study focused on the aspects related to consumers' perceptions and knowledge about food quality and safety as well as the impact of plastic materials on human health. Our objectives were to evaluate the attitudes of Portuguese consumers regarding shopping practices of food items packed in plastic materials, their decision-making factors, how they perceive plastics in terms of advantages or disadvantages as food packaging materials, and their knowledge about regulations applicable to plastics aimed to contact with foods and the impact on the human health. These aspects have not been investigated so far on the Portuguese population and therefore this research assumes an innovative nature, expecting to highlight how to better plan educational policies targeting the Portuguese consumers and help them make better choices.

# 2 Materials and methods

## 2.1 Questionnaire survey

To conduct the survey, a questionnaire was designed and constructed purposely according to the objectives of the project. The instrument included eight sections with questions to collect data for different goals: (I) sociodemographic variables; (II) buying habits; (III) opinions about packaging; (IV) impact of packages on health and the environment; (V) recycling of plastic products; (VI) education about plastic and recycling; (VII) knowledge about recycling; and (VIII) knowledge about the effects of plastic on health and the environment. This article relates in particular to the questions about food quality, food safety, and knowledge about the effects of plastic materials or their residues (like for example microplastics that enter the food chain) on the human health. Supplementary material presents all the questions used in the case of this survey, presented to the participants, and after translation from Portuguese into English.

This survey was made on a convenience sample, because of the facility of recruitment and easier disposition to participate. Even though convenience samples have some disadvantages, they are very advantageous for exploratory research [38,39]. Calculating the sample size, although not designed for convenience samples, can also be a useful indicator in these cases. For the present study, an indicative sample size was obtained considering a 95% confidence interval, corresponding to a level of significance of 5% and a $z$ score of 1.96 [40,41]. The Portuguese population in 2019 (available last year) was 10.286 million people [42]. Considering that we targeted 50% of the Portuguese adults, the minimum number of participants should be 385 [43–45].

Data were collected through the internet platform Google Forms, and the invitations to take part in the study were sent by online media: e-mail and social networks. The invitations were sent to personal and professional contacts, and the snowball effect was used to increase recruitment. There were some inclusion criteria: (1) being Portuguese; (2) being at least 18 years old; (3) having internet access; (4) having a computer or other device through which they could answer the questionnaire; (5) being able to understand the questions and express their responses; and (6) disposition to participate voluntarily and anonymously.

**Informed consent:** Informed consent has been obtained from all individuals included in this study. Each participant could only access the questionnaire after agreeing to participate and expressing informed consent, knowing that no personal identification would be collected.

**Ethical approval:** The research related to human use has been complied with all the relevant national regulations, institutional policies, and in accordance with the tenets of the Helsinki Declaration, and has been approved by the Ethical Commission at the Polytechnic Institute of Viseu with reference 09/SUB/2021.

### 2.2 Data analysis

For the description of the data, basic descriptive statistics were used, such as frequencies. Additionally, to assess the relations between some of the categorical variables the Spearman correlation was used.

Factor analysis (FA) was used to analyze some data based on several indicators that allowed testing the suitability of the data, namely, the correlation matrix and the values of measure of sample adequacy (MSA), the Kaiser–Meyer–Olkin measure of the adequacy of the sample (KMO), and the Bartlett's test [46]. The solution was obtained through extraction with principal component analysis (PCA) and Promax rotation. To fix the number of components retained, the Kaiser criterion was used, meaning that eigenvalues ≥1 were considered. The communalities allowed assessing the percentage of variance explained by the factors extracted [47], and desirably should be 0.4 or higher [48,49]. To determine the internal consistency in each factor, the Cronbach's alpha ($\alpha$) was used [47,50].

The factors obtained by FA were the input for cluster analysis (CA) using the ward hierarchical method. In the first step, the most adequate number of clusters that should be formed was estimated based on the evaluation of the coefficients obtained in the agglomeration schedule. Then, in the following step, the ward method was used with the fixed number of solutions determined previously, and this served as the initial solution for the next step of the analysis, using the partitive method of $k$-means. This was selected for being particularly recommended and frequently used in CA [51].

The indices for the items used to assess knowledge were calculated as the mean values among the participants for each variable, and the level of knowledge for each participant was also calculated as the mean scores for all items. Finally, the relative influence of the sociodemographic variables on the level of knowledge about the effects of plastics on health was assessed through a tree classification analysis. A classification and regression tree (CRT) algorithm with cross-validation was used for this [52]. The minimum change in improvement was equal to 0.0001 and the minimum number of cases for parent and child nodes was established as 30 and 15, respectively.

A level of significance of 5% was considered in all statistical analyses.

## 3 Results

### 3.1 Sociodemographic characterization of the sample

Figure 1 shows the sociodemographic characteristics of the sample at study. The number of participants in the study was 487, most of them being female ($n$ = 343) and living in the central region of Portugal ($n$ = 316). The minimum and maximum ages were 18 and 88 years, respectively, and the average age was 38 years. For convenience, the variable age was categorized into young adults (aged between 18 and 30 years), middle-aged adults (between 31 and 50 years), and senior adults (51 years or older). Most participants had completed university graduation ($n$ = 340) and they were mostly employed ($n$ = 270) or students ($n$ = 134).

## 3.2 Shopping practices

Most participants in the survey (69.4%) are responsible for buying the foods they consume, and at the moment of purchasing they tend to think to some extent about the negative impact of the plastic package on health, as their answers reveal:

- "I think about the negative impact of the plastic package, but I buy it anyway" ($n$ = 92)
- "I think about the negative impact of the plastic package, and sometimes I do not buy it" ($n$ = 185)
- "I think about the negative impact of the plastic package, and I look for alternatives" ($n$ = 141)
- "I do not think about the negative impact of the plastic package" ($n$ = 51)

Two other aspects investigated were if in the moment of purchase, and considering the food package, the participants thought about the quality or about the safety of the food it contained. Regarding the quality, a great majority of participants ($n$ = 394, 80.9%) refer that they reflect on the quality and inspect the product to confirm if it has the desired quality, while others ($n$ = 75) do not reflect about the quality because they assume that if it is on sale, then it always has quality. In what concerns the safety, the number of participants who do not think about this because they assume that the product is always safe if it is on sale is high ($n$ = 154), while those who reflect about safety when purchasing a product packed in plastic and inspect the product to confirm if it is safe are still higher in number ($n$ = 315).

When asked about the characteristics that influence the decision to opt for a plastic package instead of other alternatives for food packaging, aspects such as the quality of the product, the price or promotions, food safety, and conservation capacity appear as the most significant (93, 87, 85, and 80%, respectively) (Figure 2).

The 14 characteristics of the package that could influence the purchase of plastic packed food were submitted to FA, to identify possible grouping structures. The results of Bartlett's test indicated adequacy of the data to apply FA since the $p$-value was highly significant (at the level of 0.1%), consequently rejecting the null hypothesis *H0: The correlation matrix is equal to the identity matrix*. The

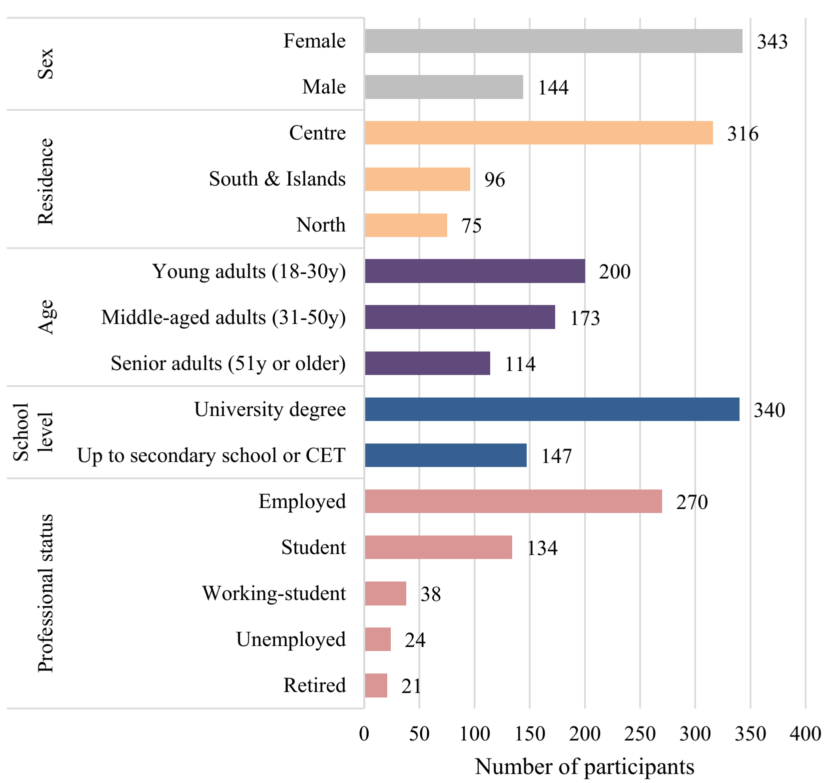


**Figure 1:** Sociodemographic characterization of the sample ($N$ = 487).

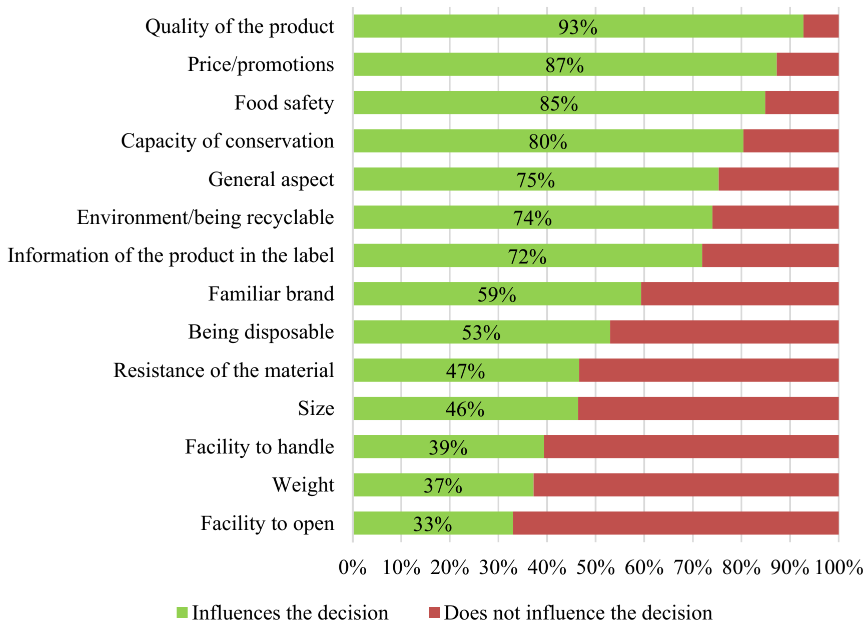


**Figure 2:** Characteristics of the package that influence the decision to purchase a food packed in plastic.

correlation matrix showed that all values were higher than 0.5, all being above the acceptable minimum threshold. The lowest value of MSA was 0.528 for the variable "environment/being recyclable," and the highest was 0.844 for the variable "Capacity of conservation." The values of MSA reflect some important correlations between the variables, which is indicative of suitability to apply FA. However, the value of KMO was not high, being however acceptable (0.664), according to the classification of Kaiser and Rice [53], also corroborating the suitability of the data for the application of the techniques PCA and FA. Additionally, since none of the values of the anti-image matrix was lower than 0.5, all the variables could be considered proper for inclusion in the analysis. The rotated solution obtained explained 53.8% of the total variance and retained four components, for which the eigenvalues and percentages of total variance explained were, respectively: F1 – 2.915 and 20.8%, F2 – 1.742 and 12.4%, F3 – 1.688 and 12.1%, and F4 – 1.185 and 8.5%. The variable "Facility to open" had the largest fraction of variance explained by the solution, being 83.7%, followed by the variable "Facility to handle," with 82.2% of the variance explained. However, there were four variables with communalities lower than 0.4: "Price/promotions" – 0.286, "General aspect" – 0.377, "Information of the product in the label" – 0.335, and "Capacity of conservation" – 0.317. Hence, these variables were excluded from the analysis in the second round, whose results were:

- KMO = 0.607 and $p$-value of Bartlett's test <0.001
- Values of MSA varying from 0.518 to 0.787
- Number of factors retained = 4, with total variance explained of 67.2%
- Eigenvalues: F1 – 2.561, F2 – 1.554, F3 – 1.432, and F4 – 1.168
- Percentages of total variance explained: F1 – 25.6%, F2 – 15.5%, F3 – 14.3%, and F4 – 11.7%
- All communalities equal or over 0.4: lowest for variable "Familiar brand" – 0.429 and highest for "Facility to open" – 0.848.

Hence, this solution was considered final. The rotation converged in four iterations and resulted in four factors, as shown in Table 1. The first factor (F1) was identified as relating to the physical characteristics of the package (PC), with loadings very high for the weight (0.892) and size (0.866) and a little lower for resistance (0.593), meaning that the first 2 items contributed in a higher degree for the definition of the factor. Factor F2 was identified as the easiness to use (EU) and both variables had very high loadings (0.920 and 0.917), indicating that they contributed equally for the definition of this factor. The third factor was interpreted as being associated with trust (TR) and contained three variables, two of which had very high loadings (0.830 for "Quality of the product" and 0.793 for "Food safety") but the third had a lower loading, just 0.442. Finally, factor F4 was associated with the discard (DI) of the package and

**Table 1:** Results obtained from FA and reliability of the factors

| Factor: name (acronym) | Variables | Loading | Cronbach's alpha |
|---|---|---|---|
| F1: physical characteristics (PC) | Size | 0.866 | 0.706 |
| | Weight | 0.892 | |
| | Resistance of the material | 0.593 | |
| F2: easy to use (EU) | Facility to open | 0.920 | 0.819 |
| | Facility to handle | 0.917 | |
| F3: trust (TR) | Familiar brand | 0.442 | 0.582 |
| | Quality of the product | 0.830 | |
| | Food safety | 0.793 | |
| F4: discarding (DI) | Environment/being recyclable | 0.835 | 0.573 |
| | Being disposable | 0.756 | |

two variables were included, both with high loadings: "Environment/being recyclable" – 0.835 and "Being disposable" – 0.756. Since all variables had loadings higher than 0.4, this solution is acceptable with all the ten variables included [48].

Validation was assessed by Cronbach's alpha ($\alpha$), which measures the internal consistency within each of the factors [47]. The values of Cronbach's alpha for factors F1 (PC) and F2 (EU) were 0.706 and 0.819, respectively, which are considered good [54–56]. Regarding factors F3 (TR) and F4 (DI), the values of alpha were lower (0.582 and 0.573, respectively), which according to some authors could be acceptable [54–56], although a value equal to 0.7 or higher would be desirable [54,55].

The cluster variables were suited for CA with the ward hierarchical method. The results of the agglomeration schedule allowed establishing the number of clusters in five (Figure 3).

The application of *k*-means CA to the initial solution obtained with the ward method and 5 clusters converged in 12 iterations and the results are shown in Table 2. For all factors, ANOVA test was significant and cluster C3 was the one with the highest number of members, while cluster C4 was the smallest, only with 29 cases. Regarding the cluster centers concerning the four factors, C1 has negative values for all factors, meaning that for its members, the purchasing decision is negatively influenced by all the factors related with the plastic packaging of food. Regarding C2, the centers are practically zero for F1 and F3, meaning that the PC or TR is not influential for them, but they are influenced by the EU (F2) and even more by the DI (F4). Members of cluster C3 are positively influenced by the PC (F1) or EU but negatively influenced by DI. Cluster C4 groups the members who strongly score in TR when purchasing foods in a plastic package, while the members of cluster C5 are negatively influenced by the PC and DI, while being positively influenced by the EU (F2).

The cluster characterization is shown in Table 3. While most women belong to cluster 3 (more influenced by the PC), the majority of men belong to cluster 2 (highly influenced by DI). Regarding age, senior adults belong mostly to cluster 1 (negatively influenced by all factors), while the other age groups belong mostly to cluster 3. Concerning residence, for all regions, most participants belong to cluster 3. Cluster 1 has more members with an under-university level of education, while most of the participants with a university degree belong to cluster 3. Regarding professional status, it is worth mentioning that the highest percentage is in cluster C4 (highly influenced by TR), unlike for other employment situations, while not having any members in cluster C2 (much influenced by DI).

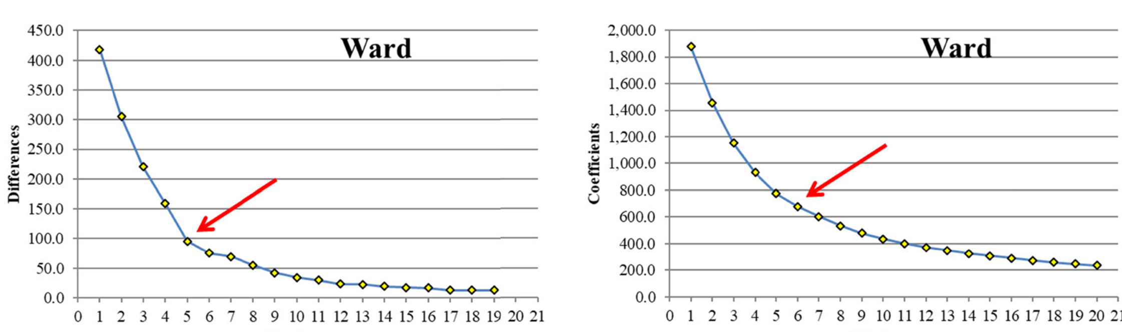


**Figure 3:** Agglomeration schedule with ward's method to fix the number of clusters.

**Table 2:** Results of *k*-means CA and cluster centers ($N$ = 470, 17 missing)

| Clusters | Factors | | | |
|---|---|---|---|---|
| | **F1: PC ANOVA: $F$ = 158.4 $p < 0.0005$** | **F2: EU ANOVA: $F$ = 142.3 $p < 0.0005$** | **F3: TR ANOVA: $F$ = 248.9 $p < 0.0005$** | **F4: DI ANOVA: $F$ = 172.0 $p < 0.0005$** |
| **C1** ($N$ = 106) | −1.04 | −1.34 | −0.34 | −0.13 |
| **C2** ($N$ = 94) | −0.06 | 0.53 | −0.07 | 1.48 |
| **C3** ($N$ = 156) | 0.93 | 0.19 | −0.21 | −0.36 |
| **C4** ($N$ = 29) | 0.28 | 0.29 | 3.20 | −0.05 |
| **C5** ($N$ = 85) | −0.44 | 0.64 | −0.21 | −0.79 |

C1 to C5 are the five clusters; F1 to F4 are the four clusters; PC – physical characteristics; EU – easy to use; TR – trust; DI – discarding; F – value of statistic.

**Table 3:** Sociodemographic characterization of the clusters

| Variable | Group | Clusters | | | | |
|---|---|---|---|---|---|---|
| | | C1 | C2 | C3 | C4 | C5 |
| Sex (%) | Female | 21.9 | 17.7 | 36.6 | 5.4 | 18.3 |
| | Male | 24.1 | 25.5 | 24.8 | 8.0 | 17.5 |
| Age (%) | Young adults | 17.8 | 22.2 | 30.3 | 7.0 | 22.7 |
| | Middle-aged adults | 17.3 | 23.7 | 35.3 | 6.4 | 17.3 |
| | Senior adults | 38.4 | 10.7 | 34.8 | 4.5 | 11.6 |
| Residence (%) | North | 27.9 | 19.1 | 36.8 | 0.0 | 16.2 |
| | Central | 22.8 | 21.2 | 30.3 | 6.8 | 18.9 |
| | South and Islands | 17.9 | 16.8 | 40.0 | 8.4 | 16.8 |
| Education level (%) | Under-university | 29.3 | 15.8 | 27.1 | 9.8 | 18.0 |
| | University Degree | 19.9 | 21.7 | 35.6 | 4.7 | 18.1 |
| Professional status (%) | Employed | 24.0 | 18.4 | 36.7 | 6.0 | 15.0 |
| | Unemployed | 21.7 | 21.7 | 34.8 | 4.3 | 17.4 |
| | Student | 18.5 | 22.6 | 28.2 | 5.6 | 25.0 |
| | Retired | 35.0 | 0.0 | 30.0 | 15.0 | 20.0 |
| | Working-student | 19.4 | 33.3 | 25.0 | 5.6 | 16.7 |

Investigating the perceptions about the advantages and disadvantages of plastic packaging, 340 participants replied that they believe plastic packages have advantages and 470 replied that they have disadvantages. The

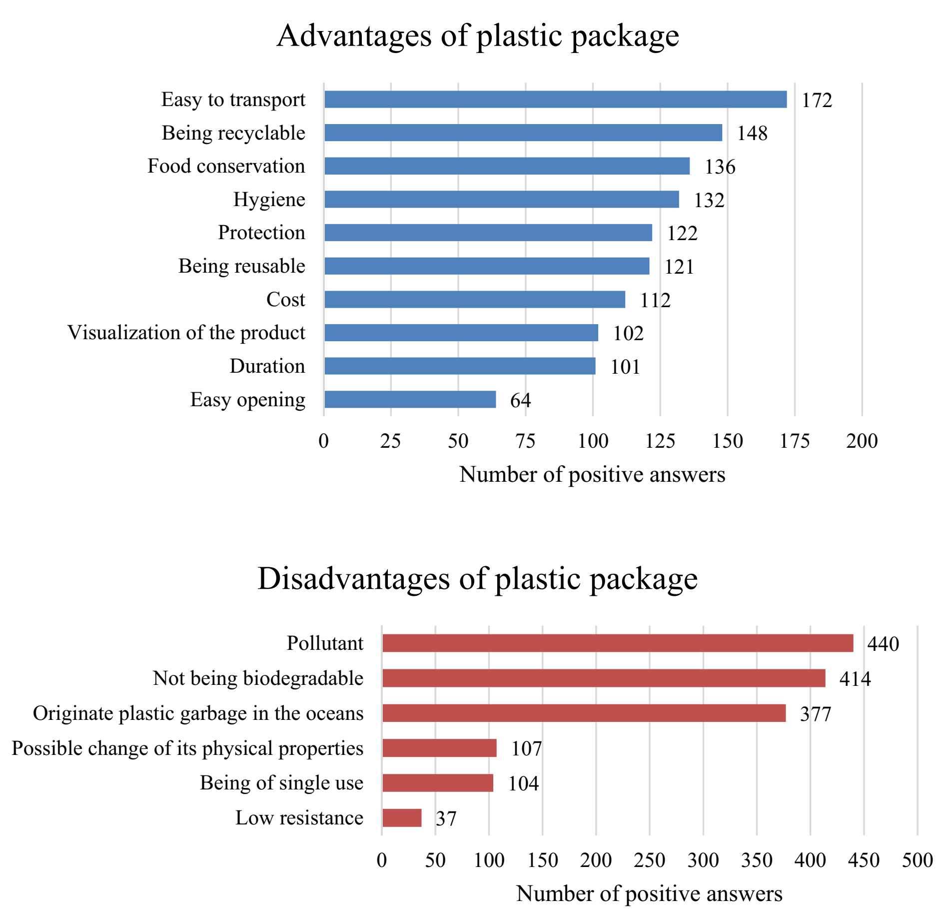


**Figure 4:** Advantages and disadvantages of plastic food packaging perceived by consumers.

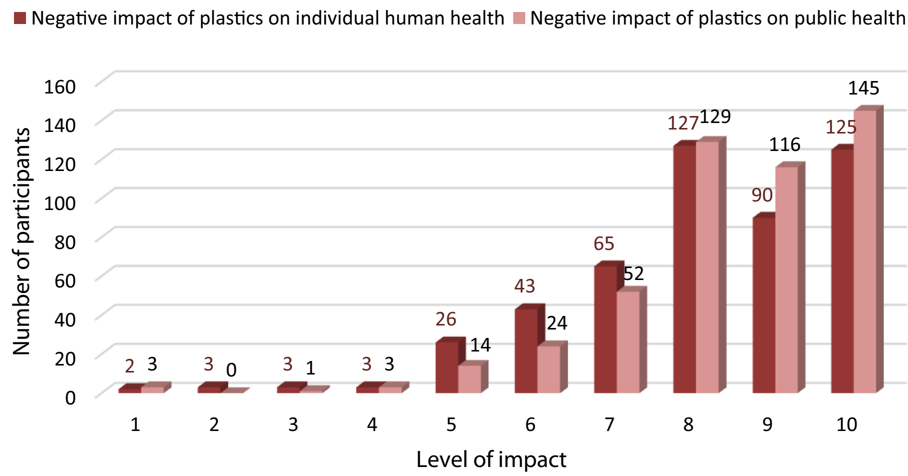


**Figure 5:** Perceived negative impact of plastics on health.

most cited advantages were easy to transport ($n$ = 172), being recyclable ($n$ = 148), and the capacity for food preservation ($n$ = 136), while the most cited disadvantages were being pollutant ($n$ = 440), not being biodegradable ($n$ = 414), and originating plastic garbage in the oceans ($n$ = 377) (Figure 4).

## 3.3 Food packaging and health

The participants were asked if they knew whether in Portugal there are any regulations about plastic materials aimed at contact with foods, and only 37.0% responded affirmatively. On a similar question, to know if they knew about any restrictions about the materials used in the production of packages destined to contact with foods, only about half were aware of this (50.9%). Finally, to the question "Do you know if there are plastic materials which can pose a risk for the human health, in case the limits of migration of their constituents, established by law, are surpassed?" most participants replied affirmatively, i.e., 74.9% are aware of this threat to the human health.

Figure 5 shows how the participants classified the level of the negative impact of plastics on individual human health and public health, on a scale from 1 (minimum impact) to 10 (maximum impact). The maximum score was attributed by 125 participants to the impact on individual health and by 145 to the impact on public health, representing, respectively, 26 and 30%.

Spearman correlations were calculated between the sociodemographic variables and the perceived impact of plastic on health, being the results presented in Table 4. It was observed that the only correlation found significant was between sex and the impact on public health, although it was a very weak correlation, with a value very close to zero. This reveals that the perception of the negative impact is not dependent on the sociodemographic characteristics of the participants.

The knowledge about the effects of plastic on health was further investigated. For this, a number of statements was used and the participants had to express their level of agreement with them on a 5 point Likert scale: 1 = totally disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree, and 5 = totally agree. Table 5 shows the results obtained. The agreement is stronger with items 7 ($n$ = 252) and 6 ($n$ = 135), i.e., about the effects for the human health of the plastics that enter the food chain

**Table 4:** Spearman correlations between the sociodemographic variables and the perceived negative impact of plastics on health

| Sociodemographic variables | Negative impact of plastics on individual human health | Negative impact of plastics on public health |
|---|---|---|
| Sex | −0.068 | −0.136** |
| Age | 0.089 | 0.078 |
| Residence | 0.002 | −0.029 |
| Education | −0.015 | −0.022 |
| Profession | −0.047 | −0.009 |

** Correlation significant at the level of 0.01.

**Table 5:** Knowledge about the effects of plastic on health

| Items | % of responses | | | | | Indices |
|---|---|---|---|---|---|---|
| | TD (1) | D (2) | NAND (3) | A (4) | TA (5) | |
| 1. The migration of chemicals from the plastic packaging into the food it contains results in a risk for human health | 5 | 27 | 85 | 248 | 122 | 0.47 ± 0.43 |
| 2. Bisphenol is a synthetic organic compound used in the production of plastic, and is considered harmful to human health | 4 | 10 | 223 | 130 | 120 | 0.36 ± 0.45 |
| 3. The basic components of plastics, such as polycarbonate, when washed repeatedly degrade into toxic products | 6 | 15 | 194 | 179 | 93 | 0.35 ± 0.43 |
| 4. The basic components of plastics, such as polycarbonate, when exposed to heat degrade into toxic products | 3 | 14 | 160 | 198 | 112 | 0.42 ± 0.42 |
| 5. Di-2-ethylhexyl phthalate or DEHP is a plasticizing chemical, usually added to plastics, which is toxic and may cause health problem with continued exposure over time | 3 | 12 | 246 | 139 | 87 | 0.31 ± 0.42 |
| 6. The production of polymers used to make plastics relies on petrochemical processes, which release toxic substances into the environment | 2 | 14 | 146 | 190 | 135 | 0.46 ± 0.43 |
| 7. The plastic that ends in the oceans decomposes and the fragments are ingested by the marine fauna, enter the food chain, and reach the humans with consequences for health | 4 | 13 | 73 | 145 | 252 | 0.65 ± 0.44 |

TD – totally disagree, D – disagree, NAND – neither agree nor disagree, A – agree, TA – totally agree. Indices were calculated as mean score for all participants, on the scale from -1 (very low knowledge) to +1 (very high knowledge).

and the industrial production of plastic materials and their effects on the planet at a global scale. Regarding the indices, it was observed that in all cases they were positive, indicating some general knowledge about the effects of plastic on health, but the values for practically all cases were relatively low, just with the exception of item 7 (0.65 ± 0.44, for a maximum score of 1). Hence, the highest knowledge was for "The plastic that ends in the oceans decomposes and the fragments are ingested by the marine fauna, enter the food chain and reach the humans with consequences for health," while the lowest knowledge was for "di-2-ethylhexyl phthalate" or DEHP is a plasticizing chemical, usually added to plastics, which over time turns into toxic components."

Also, the level of knowledge of each participant was assessed as an average of the scores obtained for the 7 items, but after transposing the scale to the interval from −2 to +2, to turn to zero the middle point of the scale: neither agree nor disagree. This variable was recoded into a categorical variable as follows: very low knowledge – mean ∈ [−2;−1], low knowledge – mean ∈ [−1;0], high knowledge – mean ∈ [0;1], and very high knowledge – mean ∈ [1;2]. The tree classification for the level of knowledge considering the sociodemographic variables studied has 5 levels, with 21 nodes, of which 11 are terminal nodes. The risk estimate was 0.452 with a standard error of 0.023 for resubstitution and 0.5697 with a standard error of 0.022 for cross-validation. The model prediction capacity is shown in Table 6, demonstrating a 69.7% chance of correctly predicting the cases of high knowledge. The tree presented in Figure 6 shows that the first predictor variable was age, differentiating the senior adults, and for both age groups, the predictor in the second level was the profession. In the third level, the discriminating variables were education and sex, while in the fourth level they were age and profession, and finally in the last level they were education and residence. The results in node zero indicate that for the whole sample most participants had a high (50.1%) or very high (45.8%) knowledge.

## 4 Discussion

According to the report "Plastics – the Facts 2019" [57], in 2018, global plastics production almost reached 360 million tons, and in Europe alone it almost reached 62 million tons. The same source refers that in 2018, 39.9% of produced plastic was destined for packaging, but only 32.5% of plastics were recovered through recycling [57]. From these plastics that were recycled, 81% were

**Table 6:** Model prediction capacity

| Observed | Predicted | | | | |
|---|---|---|---|---|---|
| | Very low knowledge | Low knowledge | High knowledge | Very high knowledge | Percent correct (%) |
| Very low knowledge | 0 | 0 | 3 | 7 | 0.0 |
| Low knowledge | 0 | 0 | 4 | 6 | 0.0 |
| High knowledge | 0 | 0 | 170 | 74 | 69.7 |
| Very high knowledge | 0 | 0 | 126 | 97 | 43.5 |
| Overall percentage | 0.0% | 0.0% | 62.2% | 37.8% | 54.8 |

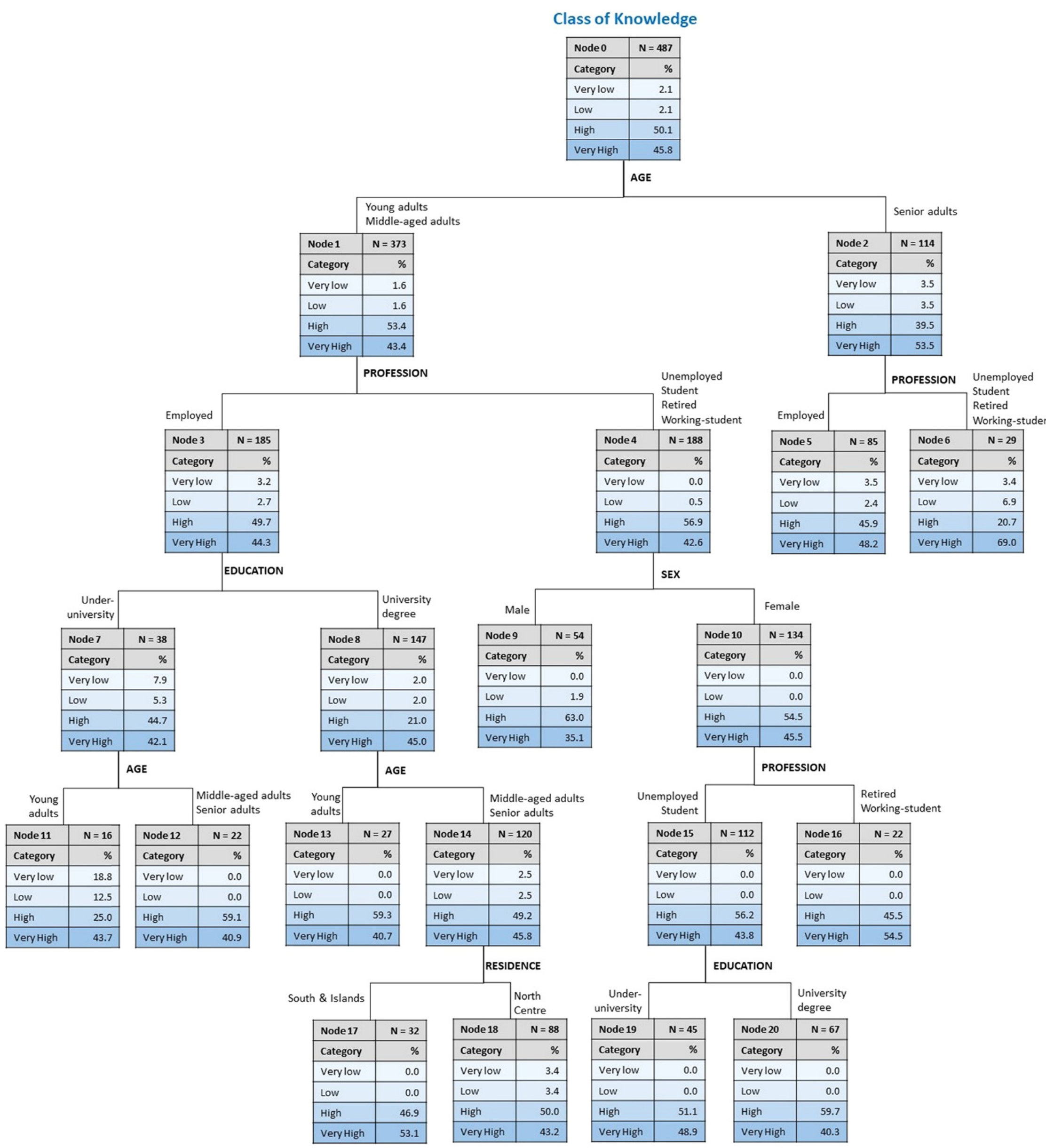


**Figure 6:** Tree classification for variable knowledge as a function of the sociodemographic variables.

transformed into new plastic products within the EU, while 19% were outside of the EU [57]. In 2050, it is estimated that at least 33 billion tons of plastic will be added to the planet [58], generating more environmental pollution. The participants in this study have great knowledge about the environmental impact of plastic packaging, most of them ($n$ = 470) think that plastic packages have disadvantages, which include being a pollutant, not being biodegradable, and causing pollution in the oceans and seas. Although recycling is not the ultimate solution to solve the problems caused by the use of plastics, it is one of the best available at the moment, while we shift into biodegradable polymers, but this involves a high investment as well as depends on a lot of factors such as environmental conditions or consumer's attitudes [59,60].

The frequent interaction with plastic items leaves us exposed and susceptible to chemical components that can be ingested orally, inhaled, or absorbed through dermal contact [61–63]. Therefore, when questioned if plastic can pose risk to human health, if the limits of migration of their constituents, established by law, are surpassed, most participants replied affirmatively (~75%), which means that people know that there are toxic components present in plastic materials, which can contaminate the food they consume.

Microplastics can contaminate foods and beverages, and environments, and in consequence, they can have negative effects on human health [58]. For example, oxidative stress after exposure to microplastics has been reported in different animal models *in vivo* [64,65]. Furukuma and Fuji [66] reported the *in vitro* cytotoxicity caused by microplastic particles from the marine environment. Ingestion is the main source of microplastics in the human body, and it is estimated that the intake of microplastics is 39,000–52,000 particles per person per year, just from the consumption of foods [67]. The cumulative effects of human exposure to microplastics have not yet been fully investigated [58,68]. If inhaled or ingested, microplastics can become toxic to organisms by the release of monomers and other chemical components [69]. Chronic and continuous exposure tends to promote greater toxicity due to the cumulative effect [21]. In addition, the effects on animals are highly dependent on the duration of exposure, concentration, shape, size, and type of the polymer particles [70].

This study revealed that the highest knowledge demonstrated by the participants was about the plastics in the oceans and that their fragments are ingested by the marine fauna, entering the food chain, possibly reaching humans. On the other hand, the lowest knowledge was about the addition of di-2-ethylhexyl phthalate to plastics as a chemical plasticizing, which can be toxic. Thus, it can be considered that people are more aware of the toxicity of plastic packaging and its effects on the environment than the effects on human health.

Accumulation of microplastics in the body tissues could cause physical stress and damage, inflammation, oxidative stress, and immune responses [71,72]. There is a generalized concern about their potential toxic risks on organisms, which could be transferred throughout the food chain [19]. Regarding safety and quality issues, the number of participants who think about them is high; however, only a few people look for alternatives or do not buy plastic-packaged foods.

Bisphenol A is an industrial chemical used to make polycarbonate, a plastic used in many products [13]. A great part of respondents neither agree nor disagree when questioned about the presence of bisphenol and di-2-ethylhexyl phthalate on plastic packaging, which means that people did not know about the chemical compounds that the food packaging can contain. All human beings have been exposed to some level of bisphenol A contamination in their lives. Detectable levels of bisphenol have been found in the urine of 95% of the adult population of the United States [73]. When ingested, it can be harmful to health, causing early sexual maturation, a decrease in male fertility, aggressive behaviors, or disorders in the cardiovascular, urinary, endocrine, and reproductive systems, compromising the metabolism of vitamins and minerals. In addition, it has the potential to affect gene expression [9,11,12].

The European Food Safety Agency has recommended an overall migration limit for chemicals within plastic packaging of 10 $mg/dm^2$, and the European Commission has established in 2011 some limits for certain plastics aimed to contact with foods [18].

The participants were asked if they knew whether in Portugal there are any regulations about plastic materials aimed at contact with foods, and only 37.0% responded affirmatively. When questioned about restrictions in the materials used in the production of packages destined to contact with foods, only about half of the interviewees were aware of this.

Cox et al. [67] made a literature review about microplastics' concentrations in some aspects of daily life, and they concluded that air, bottled water, and seafood consumption are responsible for the majority of microplastic intake by humans. Mohamed Nor et al. [71] estimated the consumption of total microplastics intake by adults and children, which was 553 particles/capita/day for children and 883 particles/capita/day for adults. For an adult of 60 kg who consumes 3 kg of foods and liquids per day, the exposure to toxic substances from food packaging could be up to 250 μg/kg body weight per day [58,74].

The knowledge about the effects of plastic packaging by consumers is still very limited. Thus, since there are risks associated with plastic packaging for food and beverages, the environmental and health impacts brought by the use of plastic packaging must be discussed more. It is essential to promote a reflection and increase awareness of the problems caused by the massive use of plastics, as well as to encourage changes in human behavior towards sustainability, to achieve a balanced relationship between humans and the environment [12,75].

## 5 Conclusion

This study focused on practices, knowledge, and concerns of Portuguese citizens towards food quality and safety as well as the impact of plastic materials on human health. Some of the results obtained allowed confirming gender differences towards some aspects, such as for example women were mostly fit into cluster 3 (attributing high importance to the physical characteristics of the package), while most men were in cluster 2 (valuing predominantly the discarding of the package). Another aspect investigated referred to correlation between sex and the perceived negative impact of plastics on health, revealing no association with the impact on individual human health but a negative significant association with the impact of plastics on public health. Finally, sex was found to be a factor influencing knowledge, after age or profession.

In general, most of the respondents tend to think about the safety and quality of the foods they consume, which is a positive attitude. Additionally, most participants are aware of the negative effects of plastics. However, they are more informed about the environmental consequences than the health toxicity of plastic packaging materials. In fact, the participants' level of knowledge on the subject is high or very high concerning the effects of plastic on the environment, but they barely know about the chemical compounds that plastic packages contain and their effects on the human body. This is a very important alert to official and governmental agencies to better target the information campaigns at the national level aimed at focusing on the health implications of the plastic materials used in contact with foods. Thus, it can be concluded that the aspects related to food safety and quality, regarding the use of plastic packaging for food, as well as the preservation of human health, need to be more discussed within the Portuguese population. For this, the health authorities must adequate their public health policies, to provide more information to the general population.

Although this work allowed drawing some valuable conclusions, we would like to point out some limitations, namely that the data collection took place using online tools owing to covid-19 restrictions and a personal interview would have been a more feasible way for the data collection. Additionally, although the number of participants was high, nearly 500, the sociodemographic distribution was not even, in particular with regards to sex, Portuguese geographical region, or school level of the participants. These asymmetries could to some extent influence the results. Finally, we are aware that the questions used to assess the knowledge could have been more or more detailed, but on the other hand, it would be still more difficult for the participants to answer them, since we recruited regular people without particular knowledge about the chemistry of plastics.

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