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Additional Information

What do Spanish consumers think about employing nanotechnology in food packaging?

Édgar Pérez-Esteve, Ana Alcover, Jose M. Barat, Isabel Fernández-Segovia[*]

Departamento de Tecnología de Alimentos. Universitat Politècnica de València, Camino de Vera s/n, 46022, Valencia, Spain

[*] Corresponding author.
E-mail address: isferse1@tal.upv.es (I. Fernández-Segovia).

ABSTRACT

Food packaging is essential in food preservation and distribution. This sector is constantly evolving to develop more sustainable packaging materials with greater functionality to guarantee quality and food safety. In line with this, nanotechnology is being widely studied for its high potential to improve different packaging aspects. As the use of new technologies can influence consumers product acceptance, it is essential to determine consumer perceptions. This work aimed to evaluate consumer opinion about different food packaging types for which nanotechnology is used to improve some of their properties. First a literature review was performed to determine which applications are fully developed or being developed with a high potential to be implemented into food packaging for different purposes. The most important ones were selected for covering different functionalities and food types. Second a consumer opinion and purchase intention study was conducted with a survey (713 valid cases) to evaluate these applications and to assess neophobia to new technologies. The results showed that the population had a medium level of neophobia. The least neophobic consumers and those with more nanotechnology knowledge better valued each product. All products with nanotechnology in their packaging obtained positive evaluations. The best valued applications were those which provided information about food quality/safety (time-temperature indicator or cold chain loss), while the worst valued were those in which nanomaterials interacted with food (active packaging).

Keywords: food packaging; nanotechnology; Spanish consumers; new technologies; neophobia.

1. Introduction

Nanotechnolgy, which involves the design, manufacture and application of materials that have critical length scales that fall within the nanometric range (normally considered between 1 and 100 nm) (McClements, 2020), is one of the novel technologies that might contribute to solve many of the problems associated with use of plastic in food packaging.

Thanks to the use of this novel technology, it is possible to obtain biodegradable packaging with better properties, packaging with improved mechanical and barrier properties, active packaging with nanosized antioxidant and antimicrobial compounds, and smart packaging. Although the use of nanotechnology may improve different packaging aspects, the incorporation of engineered nanoparticles to food contact materials (FCM), such as food packaging, might lead to different toxicological concerns, most of them derived from the possible migration from the packaging to the food (Emamhadi et al., 2020).

As has been observed in other technologies, such as ionizing radiation, the approval of a technology for its use in food is not enough to guarantee its success in the market (Meijer et al., 2021). Thus, before or in parallel to risk assessment, conducting studies that aim to understand consumer perception about the use of different applications of nanotechnology in food packaging, is necessary to predict the acceptance of a technology in the market, then deciding if it is worth investing all the necessary resources for the safety assessment.

Therefore, for the commercial success of those food products for which nanotechnology is employed to produce their packaging, it is necessary first to ensure that consumers accept this technology, and second that they perceive a benefit of its use and no possible risk. To date, perception and purchase intention studies into food packaging have been conducted in different countries like Portugal (Martinho et al., 2015), Poland

(Barska & Wyrwa, 2016), Sweden (Lindh et al., 2016), Spain (Moya et al., 2020), the Lebanon (Bou-Mitri et al., 2020), China (Li et al., 2020), or more than one country at a time (Popovic et al., 2020). They show that consumer perception of packaging is conditioned mainly by physical aspects (being attractive, high quality, hygienic) and functional (useful for the function for which they were designed, informative, recyclable). Nevertheless, to date there are no exhaustive studies aiming to evaluate consumer perception of employing nanotechnology to produce advanced materials for food packaging use. In this context, this work aimed to assess consumer perception of employing certain packaging materials, in which the incorporation of nanotechnology represents an improvement in their properties by making them more sustainable, functional, intelligent and/or active, for food applications.

2. Materials and methods

2.1. Identifying potential nanotechnology applications in food packaging design

A literature review was carried out in the main research databases and the "Nanotechnology Products Database" (Statnano, 2021a) in an attempt to identify the main fields in which nanotechnology is applied to develop food packaging. To this end, both applications still in a research phase and fully developed and commercialized ones were reviewed. The following keywords were used: food nanotechnology, nanopackaging, bionanocomposites, nanosensor, intelligent packaging, active packaging.

Of all the different applications found, seven products were selected to continue with the second part of the study using as a criterion to cover different nanotechnology functions in packaging: improved properties (IP), active packaging (AP) and smart packaging (SP). This selection was based on the Spanish population's consumer habits, selecting products from different food chain links (production, packaging and quality control), and including both nanotechnology as nano-inside (the nanostructured system is an integral part of food) and nano-outside (those that employ nanotechnology, but it does not form part of ingested food).

2.2. Survey

An online survey in three parts was designed with Google Forms. The survey was disseminated on different social networks (Facebook, Linked-in, Instagram, WhatsApp) and by email between April and June 2021. The information provided in the dissemination phase is shown in Supplementary Material Fig. S1. The sample included 713 Spanish consumers (valid cases) recruited by a random simple sampling method. An estimated error of ± 3.75% was obtained after considering a 95% confidence interval with p and q equaling 0.5.

The survey was conducted by taking into account the ethical and professional practices given by the Institute of Food Science and Technology (2015). Before starting the survey, consumers were informed about the study purpose and framework and that the responses were anonymous (Supplementary Material Fig. S1). They had to choose if they wished to voluntarily participate in the study or not.

2.2.1. Personal data

The socio-demographic data were collected in this part of the survey, and a question about knowledge and general opinion about nanotechnology was included.

2.2.2. The Food Technology Neophobia Scale

The FTNS questionnaire consisted of 13 items proposed by Cox and Evans (2008). The Spanish version herein used was based on that of Schnettler et al. (2016) with some minor modifications. The respondents had to indicate their level of agreement with each item on a 7-point scale.

2.2.3. Evaluation of nanotechnology food packaging applications

Recreated images of the seven different types of nanotechnology food packaging applications selected after the literature search (see section 3.1) were shown to consumers to know their opinion and purchase intention.

For each of the applications, consumers had to score three opinion statements ("This product seems novel", "This product provides many nutrition/food safety/quality benefits" and "This product poses no health risk") according to their level of agreement. They had to answer the question "How much do you think you would like this product?" on a 7-point scale. Finally, they had to answer a question about purchase intention on a 5-point scale. If they answered that "I am sure I would not buy it", another open-ended question was included to ask them why.

2.3. Statistical analysis

Descriptive analyses of the data obtained with both the FTNS and the evaluation of nanotechnology applications were performed to calculate the mean values and standard deviation.

Cronbach's alpha was calculated to determine the validity of the Spanish version of the FTNS herein used. In addition, to summarize the information given by the 13 FTNS items, a Factorial Analysis was conducted with Principal Component Analysis (PCA) as the extraction method using varimax rotation. Only the factors with eigenvalues higher than 1 were considered. The sample's factorability was tested by the Kaiser-Meyer-Olkin (KMO) test and Bartlett's sphericity test. The reliability of the factors obtained in the PCAs was determined by calculating Cronbach's alpha.

A Hierarchical Cluster Analysis (HCA) was carried out to determine whether there were groups of consumers with different neophobia levels by considering Euclidean distances (dissimilarity), Ward's method as the agglomeration method and automatic truncation, as in other studies (Coutinho et al., 2021). To evaluate the differences in the responses between clusters, Kruskal-Wallis analyses were performed for each FTNS item, for the responses to the questions about knowledge and opinion about nanotechnology and also for the responses of the evaluation of nanotechnology food packaging applications questionnaire. Dunn's procedure with Bonferroni correction was used to test for differences at the 5% significance level. A chi-square analysis was carried out to evaluate differences in the socio-demographic data depending on cluster.

A Kruskal-Wallis analysis was also performed to determine whether the different nanotechnology food packaging applications obtained significantly different scores.

The statistical program used was XLSTAT 2020.3.1 (New York, USA) (Addinsoft, 2020).

3. Results and discussion

3.1. Identification of potential nanotechnology applications in food packaging design

From the literature review it was concluded that there were three potential fields of nanotechnology applications to develop food packaging. Of all the possible identified uses, those that provided a solution to various food groups that are normally consumed packaged (beverages, dairy products, meat, fish, fruit, vegetables) were selected.

The first application field includes the use of nanostructured systems (metal oxides, nanoclays, carbon nanotubes, etc.) to improve physical properties (mechanical and/or thermal resistance, moisture and/or gas barrier properties, durability or flexibility, etc.) of the polymers employed to manufacture packaging (Kuswandi & Moradi, 2019). An example of a polymer with improved properties (IP) achieved by incorporating nanotechnology consisted of including bentonite nanoclay in the polyethylene terephthalate (PET) structure, which is one of the most widely used polymers for the packaging of beverages or dairy products. This incorporation improved its resistance and stability without increasing the amount of plastic (Statnano, 2021b). This material applied to yogurt packaging was the inspiration for the first surveyed application (**IP1**). This same approach can also serve to improve the properties of either the new biopolymers synthesized from renewable sources or those that are easily biodegradable or biocompostable, such as polylactic acid, chitosan, cellulose or starch. One example of this possibility is the inclusion of nanocellulose crystals in renewable containers made of polylactic acid to improve its properties, and confer it lower permeability to water and a better barrier to oxygen (Fortunati et al., 2012). This approach can be used for the packaging of certain products consumed on a daily basis, such as salads, using renewable sources of polymers (**IP2**).

The second major field of nanotechnology applications to packaging manufacturing is active packaging (AP) design. This packaging is characterized by its ability to extend the food consumption deadline or to improve packaged food conditions. Two approaches exist to reach this goal: the incorporation of compounds which, after being released to the environment, exert some type of antimicrobial action, or those components that absorb or eliminate the compounds responsible for food deterioration, such as oxygen or ethylene.

Of the most frequently used antimicrobial nanoparticles for developing antimicrobial AP, it is worth highlighting metallic compounds, especially silver nanoparticles. Of these, it is easy to find in the market in countries such as United Kingdom lunch boxes made of polymers in which colloidal silver particles are embedded (**AP1**), exhibiting antibacterial and antifungal capacity (Statnano, 2021c). Another approach to design antimicrobial packaging consists of employing polymers that, per se, have antimicrobial capacity (Dutta et al., 2009). Along these lines, Shapi'i et al. (2020) demonstrated the ability of a film containing chitosan nanoparticles to extend the shelf-life of highly perishable food. The application of this approach to preserve chicken breasts inspired the surveyed product **AP2**. A different approach to create AP that is capable of extending the food shelf-life (especially fruit), and does not involve bacterial inactivation, are those that incorporate nanomaterials that are able to eliminate or capture naturally generated ethylene (Sadeghi et al., 2021). Following this principle, the Green Bags developed by the Evert Fresh Co. brand (USA), contain a zeolite, which has the ability to absorb ethylene and, therefore, increase a product's shelf-life (Sadeghi et al., 2021). Applying this technology to extend shelf-life to one of the fastest ripening fruits (bananas) is considered to be the **AP3** application.

Finally, by including nanomaterials in packaging, they also offer the ability to monitor packaged food properties and/or status, and to communicate them to consumers, which generates smart packaging (SP). These containers are characterized by the incorporation of some type of nanosensor that comes in the form of labels, dyes or enamels, and some of its properties (color, luminescence, etc.) change in response to an alteration to the environment. For example, when the cold chain is broken, the Topcryo ® labels commercialized by the company Cryolog (France) with the approval of EFSA change from green to maroon to indicate that food is unsuitable to eat (**SP1**) (Enescu et al., 2019). Likewise, when ammonia and/or simple amines are generated from fish decomposition, they can be detected by a color change in polymers, whose composition includes fluoro-functionalized graphene (**SP2**) (Rouhani, 2019). More examples of nanotechnology applications to develop packaging with improved properties and/or functionality can be found in Supplementary Material Table S1. The set of these applications demonstrates the high potential of using nanotechnology to develop new packaging with improved properties for food industry applications.

After selecting different suitable nanotechnology applications in the food packaging sector, images were created (Fig. 1) to depict the possible appearance of the product on the market. These images were included as a visual reference of the selected applications in the survey.

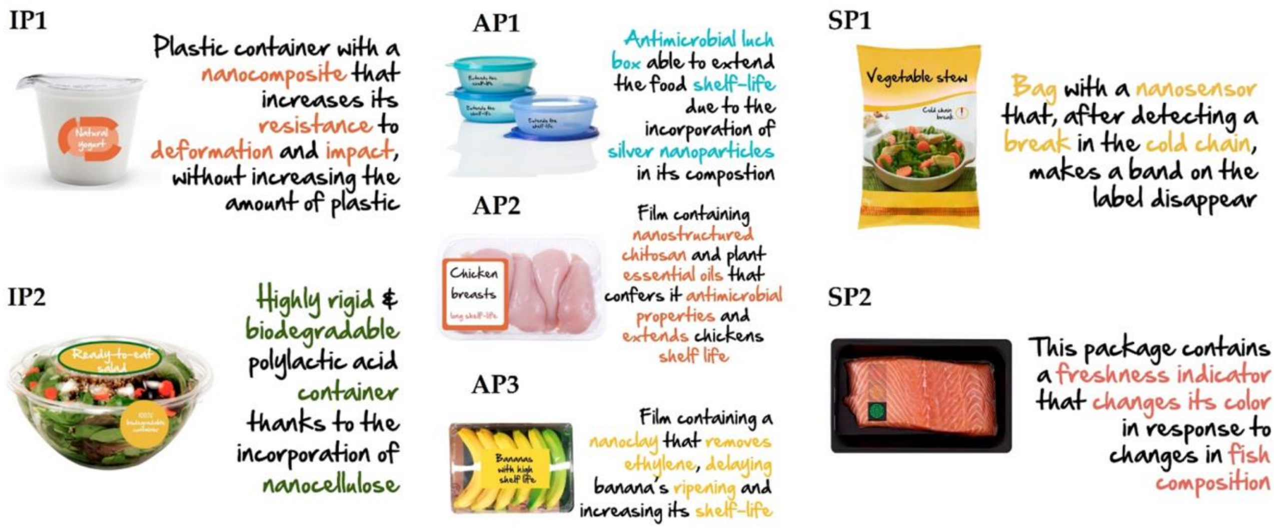

Fig. 1. Representation of selected applications of nanotechnology to create packaging with improved properties (IP), active packaging (AP) and smart packaging (SP).

3.2. Survey results

3.2.1. Consumer data and purchasing habits

In this study 713 people aged between 18 and 78 years participated, of whom 65% were women. The majority age range was 18-29 years, which represented 43.9% of the total sample. The vast majority of the respondents had completed Higher Education (72.51%) (Table 1). These two percentages could be due to the fact that most of the surveys were sent to a university environment, and these age groups are normally the most active ones in social networks, which was how the survey was sent. Of all the respondents, 44.60% were related in some way to the agri-food sector.

Table 1
Sociodemographic data of consumers.

		Total	
		n	**%**
		713	**100**
Gender	Female	463	64.9
	Male	250	35.1
	Other	0	0
Age	18-29	313	43.9
	30-49	285	40.0
	50-65	106	14.9
	>65	9	1.3
Educational level	No qualification	0	0
	Secondary	39	5.5
	High School	157	22.0
	Bachelor degree or higher	517	72.5
Relationship agri-food sector	Yes	318	44.6
	No	395	55.4

Consumer knowledge and opinion about nanotechnology were also evaluated (Supplementary Material Fig. S2). A low percentage of all the participants stated not being sure about knowing this technology, and 21.6% did not know anything about it. On the contrary, 75.17% stated that they knew "little", "something" or "a lot" about nanotechnology. Regarding their opinion about this new technology, 35.34% of the respondents stated that they had no opinion about it, 19.50% had a neutral opinion (neither positive nor negative), and only one person had a negative opinion about nanotechnology. No participant had a very negative opinion. On the contrary, almost half the population stated having a positive or very positive opinion.

Their frequency of purchasing packaged fish, meat, fruit and vegetables was evaluated (Fig. 2). Regarding fish (Fig. 2.a), a low percentage indicated always buying this product packaged, 19.15% buy it quite frequently, approximately half the respondents occasionally buy packaged fish and 12.64% stated never buying it. These data confirm the preference for buying fish over the counter and not on trays like other studies report (Groot & Albisu, 2014).

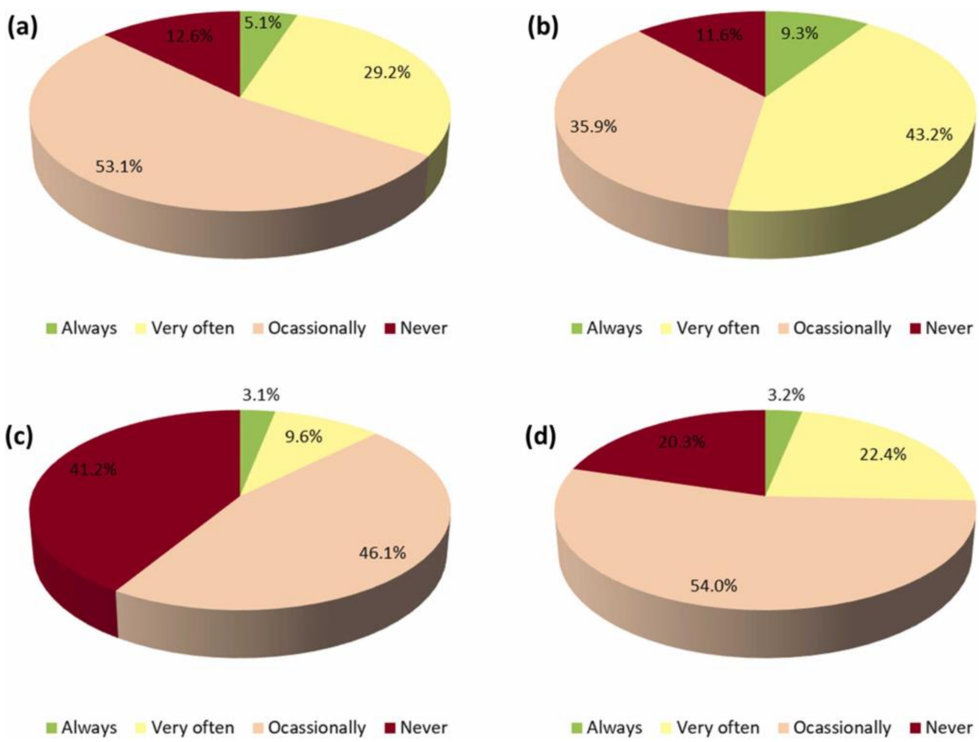

Fig. 2. Frequency of purchasing (a) packaged fish; (b) packaged meat; (c) packaged fruit; (d) packaged vegetables.

Regarding meat (Fig. 2.b), only 9.26% indicated always buying it packaged and the highest percentage buys it quite frequently (43.20%). On the contrary, 35.90% buy it occasionally and 11.64% never do.

About packaged fruit purchases (Fig. 2.c), a very low percentage of consumers always buy this packaged product and 9.56% do so quite frequently. The highest percentage of participants buy it occasionally, followed by those who never do.

With packed vegetables (Fig. 2.d), only a very low percentage of the respondents stated always buying them (similar to fruit), while 22.44% buy packed vegetables quite frequently and half the respondents do so occasionally. On the contrary, 20.34% never do.

After analyzing the obtained data, of the four studied products, those most frequently purchased and packaged were fish, and especially meat. Conversely, vegetables and fruit were the least purchased packaged products, with the highest percentage of consumers who never buy them packaged. In general, the percentages of consumers who always buy packaged food were relatively low because, in recent years, consumers have become increasingly concerned about the environment and plastic waste. Lindh et al. (2016) showed that the foods whose employed packaging material is considered especially excessive is fruit and vegetables. For highly perishable fresh food like meat or fish, the population could have evaluated the safety of packaged food more than respecting the environment (Otto et al., 2021).

3.2.2. Food Technology Neophobia Scale (FNTS)

- Validation of the Spanish FNTS

The Food Technology Neophobia Scale was used as a psychometric scale to determine consumers' fears and awareness about new food technologies (Garrido et al., 2021). FNTS reliability was determined with Cronbach's alpha. A scale used to measure a given construct is generally considered valid when Cronbach's alpha exceeds 0.70. The Spanish version of the FNTS herein employed was that proposed by Schnettler et al. (2016) with some minor modifications (Table 2). These authors reported a low Cronbach's alpha value (0.621) on the scale with 13 items, while this value was 0.786 in the present study, which indicates the good internal consistency of the Spanish scale used in this work. Cronbach's alpha value increased to 0.826 when item 13 (related to media) was deleted, which indicates that the internal consistency of the FNTS was higher when this statement is not considered.

A factor analysis (FA) of the 13 statements was conducted to summarize the information provided by the 13 items. Before the FA, the adequacy of the sample was tested by Kaiser-Meyer-Olkin (KMO) and the Barlett's test of sphericity. The KMO value was 0.860, with $p < 0.0001$ in the Barlett's test of sphericity. These findings (KMO > 0.800 and $p < 0.05$ in the Barlett's test of sphericity) show that the FA is an adequate approach to evaluate these data.

The first two FA dimensions explained 47.75% of variability. Although this figure obtained a low explanatory value, it is worth mentioning that similar values have been reported in consumer studies (Coimbra et al., 2020; Coutinho et al., 2021; Vidigal et al., 2015), in which the percentage of variance explained by any mathematical model of data projection has usually been reported to be lower than 70% (Santos et al., 2019). The first FA dimension (33.43% of the total variance) was linked with statements 1-5 and 9-12, with the second FA dimension linked with statements 6-8 and 13 (Table 2). This classification is similar to the results reported by Coutinho et al. (2021) in Brazil, with the only difference being that item 7 fell on dimension 2. However, four factors have been identified in other studies (Cox & Evans, 2008; Kuang et al., 2020): F1: New food technologies are unnecessary (items 1-5, 12); F2: Perception of risks (items 6, 9-11); F3: Health choice (items 7 and 8), F4: Information/media (item 13). In the present study, F1 would be related to New food technologies are unnecessary and Perception of risks, while F2 would be related mainly to Healthy choices and Information/media.

Cronbach's alpha for the scale of F1 was 0.842 and 0.606 for F2, and rose to 0.688 when item 13 was removed. Once again, this confirmed that this item negatively affects to the scale's consistency.

- The Food Technology Neophobia Scale Results

Global scale values (after considering the responses of all 13 items) can range from 13 to 91. The higher the global value, the higher the neophobia level. In the present work, this value was 51.10 (Table 2), which was slightly lower than the central value of 52 (neutral position), with a minimum value of 18 and maximum one of 90. The mean values for all 13 items ranged between 3.0 and 4.5 (Table 2), with a mean value of 3.9 that was slightly lower than the neutral mean value (4). These results show a medium neophobia level to new food technologies for the Spanish population and a wide variability in the range of responses, which could indicate consumer groups with different neophobia levels. The FNTS values herein obtained were slightly higher than those reported in recent studies in the USA, with mean values of individual items of 3.87, or global values of 44.22 and 46.4 (Garrido et al., 2021; Kuang et al., 2020). In Brazil (Coutinho et al., 2021), the FNTS global values were 46.2. However, higher values were obtained in other studies in Australia, Canada or Italy, with global values of 54, 59 and 61, respectively (Evans et al., 2010; Matin et al., 2012; Verneau et al., 2014). It is worth noting that the neophobia level could have changed since data were collected in these last studies because consumer opinions and perceptions are not static in time.

Table 2. Spanish version of the Food Technology Neophobia Scale (FNTS) of Cox and Evans (2008). Mean scores and standard deviation (SD) and rotated factor loadings.

FNTS item	English items (Spanish version)	Mean (SD)	D1	D2
1	New food technologies are something I am uncertain about (Las nuevas tecnologías alimentarias son algo que me genera incertidumbre).	4.2 (1.9)	**0.581**	-0.058
2	New foods are not healthier than traditional foods (Los nuevos alimentos NO son más saludables que los alimentos tradicionales).	4.4 (1.8)	**0.607**	-0.030
3	The benefits of new food technologies are often grossly overstated (A menudo se exageran los beneficios de las nuevas tecnologías de producción de alimentos).	4.5 (1.6)	**0.594**	-0.243
4	There are plenty of tasty foods around so we don't need to use new food technologies to produce more (Existe suficiente cantidad de alimentos sabrosos, por lo que no es necesario usar nuevas tecnologías para producir más).	3.6 (1.8)	**0.770**	-0.105
5	New food technologies decreases the natural quality of food (Las nuevas tecnologías de producción de alimentos disminuyen la calidad natural de los mismos).	3.7 (1.8)	**0.782**	-0.026
6	New food technologies are unlikely to have long term negative health effects (Es improbable que las nuevas tecnologías de producción de alimentos tengan efectos negativos para la salud a largo plazo)[(a)].	3.9 (1.5)	0.225	**0.676**
7	New food technologies gives people more control over their food choices (Las nuevas tecnologías de producción de alimentos les otorgan a las personas más control sobre sus elecciones de alimentos)[(a)].	3.0 (1.4)	0.349	**0.710**
8	New products produced using new food technologies can help people have a balanced diet (Los nuevos productos obtenidos con las nuevas tecnologías de producción de alimentos pueden ayudar a que las personas tengan una dieta equilibrada)[(a)].	3.2 (1.6)	0.377	**0.691**
9	It can be risky to switch to new food technologies too quickly (Puede ser arriesgado cambiar a las nuevas tecnologías de producción de alimentos demasiado rápido).	4.1 (1.6)	**0.627**	0.004
10	New food technologies may have long term negative environmental effects (Las nuevas tecnologías de producción de alimentos pueden tener efectos negativos sobre el medioambiente a largo plazo).	4.3 (1.5)	**0.628**	-0.006
11	Society should not depend heavily on technologies to solve its food problems (La sociedad no debería depender en gran medida de las nuevas tecnologías para resolver sus problemas de alimentación).	4.5 (1.7)	**0.560**	-0.106
12	There is no sense trying out high-tech food products because the ones I eat are already good enough (No tiene sentido desarrollar alimentos con alta tecnología porque los que como actualmente son suficientemente buenos).	3.3 (1.6)	**0.745**	-0.155
13	The media usually provides a balanced and unbiased view of new food technologies (Los medios de comunicación generalmente proporcionan una visión equilibrada e imparcial de las nuevas tecnologías de producción de alimentos)[(a)].	4.5 (1.7)	-0.333	**0.560**
	Global mean value of the 13 items	**51.10 (11.5)**		

(a) Indicates reverse scored items.

The position of the respondents was neutral (neither agree nor disagree) for the items related to risk (items 6 and 9), but they did not agree with items 4 and 12 (related to the fact that "new technologies are unnecessary"), nor with items 7 and 8 (new food technologies allow people to better control their choices and new products could help people to eat a balanced diet). On the contrary, they gave higher scores (between 4 and 5 on a 7-point scale) to items 2, 3 and 11. Therefore, they partially agree with statements like “new foods are no healthier than traditional ones”, “the benefits of new foods are often grossly overstated” and “society should not depend heavily on technologies to solve its food problems”. Finally, it is important to note that consumers do not believe that media usually provide a balanced and unbiased view of new food technologies (item 13). This falls in line with other studies, which have indicated low levels of trusting the technology information provided by the media (Capon et al., 2015; Erdem., 2018).

A Cluster analysis (CA) was carried out to determine if there were groups of people with different neophobia levels, obtaining two groups or clusters. The automatic truncation method was used to obtain the groups, as explained in section 3.4. Fig. 3 depicts the results of the mean scores in each cluster. Higher scores were obtained for all the items for Cluster 2, except for item 13 about credibility of the information on new food technologies provided by the media. These results indicated that the respondents in Cluster 2 were more neophobic than those in Cluster 1. The global value in Cluster 1 was 42.15 (minimum value of 18, maximum value of 61) and the mean value of the 13 items was 2.2. In Cluster 2, the global value was 59.08 (minimum of 39 and maximum of 90) and the mean value was 4.5. The Kruskal-Wallis analysis carried out to check if there were any significant differences between both clusters revealed for the 13 statements that the differences found between Clusters 1 and 2 were significant ($p < 0.001$ in all cases).

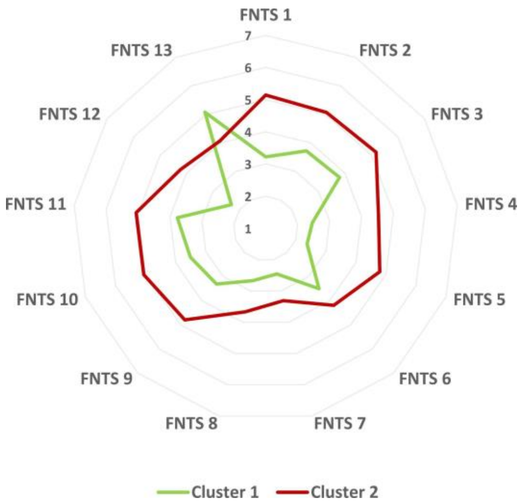

Fig. 3. Mean scores given by consumers in the survey of Food Technology Neophobia (FNTS), by clusters. Values of FNTS 6, 7, 8 and 13 were reversed so that a higher value would indicate a higher neophobia level. Meaning of the codes of the 13 items is given in Table 2.

A Chi-square analysis was used to determine if there were significant differences in consumers' personal data, and their knowledge of and opinion about nanotechnology (Supplementary Material Table S2). Only for sex were the differences between clusters non significant ($p > 0.05$). Significant differences were observed for the other variables. Cluster 1 (the least neophobic) included the higher percentage of people within the age range of 18-29 years and the higher percentage of people with a university degree, while the majority age range of Cluster 2 was 30-49 years. The results obtained for Cluster 1 are similar to those reported by Garrido et al. (2021), who worked with consumers from the USA (the FNTS mean global score was 44.22), whose respondents' average age was 33 years (33.7 in Cluster 1) and the majority had a high level of education.

Cluster 1 had a higher percentage of consumers who were related in some way to the agri-food sector, and 60.7% of the respondents in this cluster stated knowing something or a lot about nanotechnology. In Cluster 2, 63.9% stated knowing little or nothing about it. Finally, their opinion about nanotechnology was also cluster-dependent. In Cluster 1, 64.29% of the consumers had a positive or very positive opinion about nanotechnology, and no one had a negative or very negative opinion. Conversely in Cluster 2, almost 50% stated they did not have an opinion about this new technology, 22.02% had neither a positive nor a negative opinion, 27.85% had a positive or very positive opinion, and only one person reported having a negative opinion.

Bearing in mind that the population in Cluster 2 was more neophobic and, that in this group, 63.93% admitted knowing little or nothing about nanotechnology, it can be stated that having less knowledge about new technologies can imply being more neophobic about these technologies. The results also demonstrate that the more knowledge people have about nanotechnology, the better they view it. These findings agree with other studies, which have shown that familiarity with nanotechnology is associated with a reduced risk perception (Capon et al., 2015).

It can also be stated that the younger the population, the higher the level of studies, and the closer their relation to the agri-food sector, the less neophobic they are to new food technologies. These results fall in line with the studies, like that by Viscecchia et al. (2018), who stated that the higher the consumer's level of education, the lower the perceived risk in relation to nanotechnology and the greater their willingness to buy.

3.2.3. Results of evaluating nanotechnology food packaging applications

Seven different nanotechnology food packaging applications were evaluated. As explained in Section 2.1., two corresponded to IP, three to AP and two to SP. Fig. 4 offers the scores that consumers gave to each item on a 7-point scale.

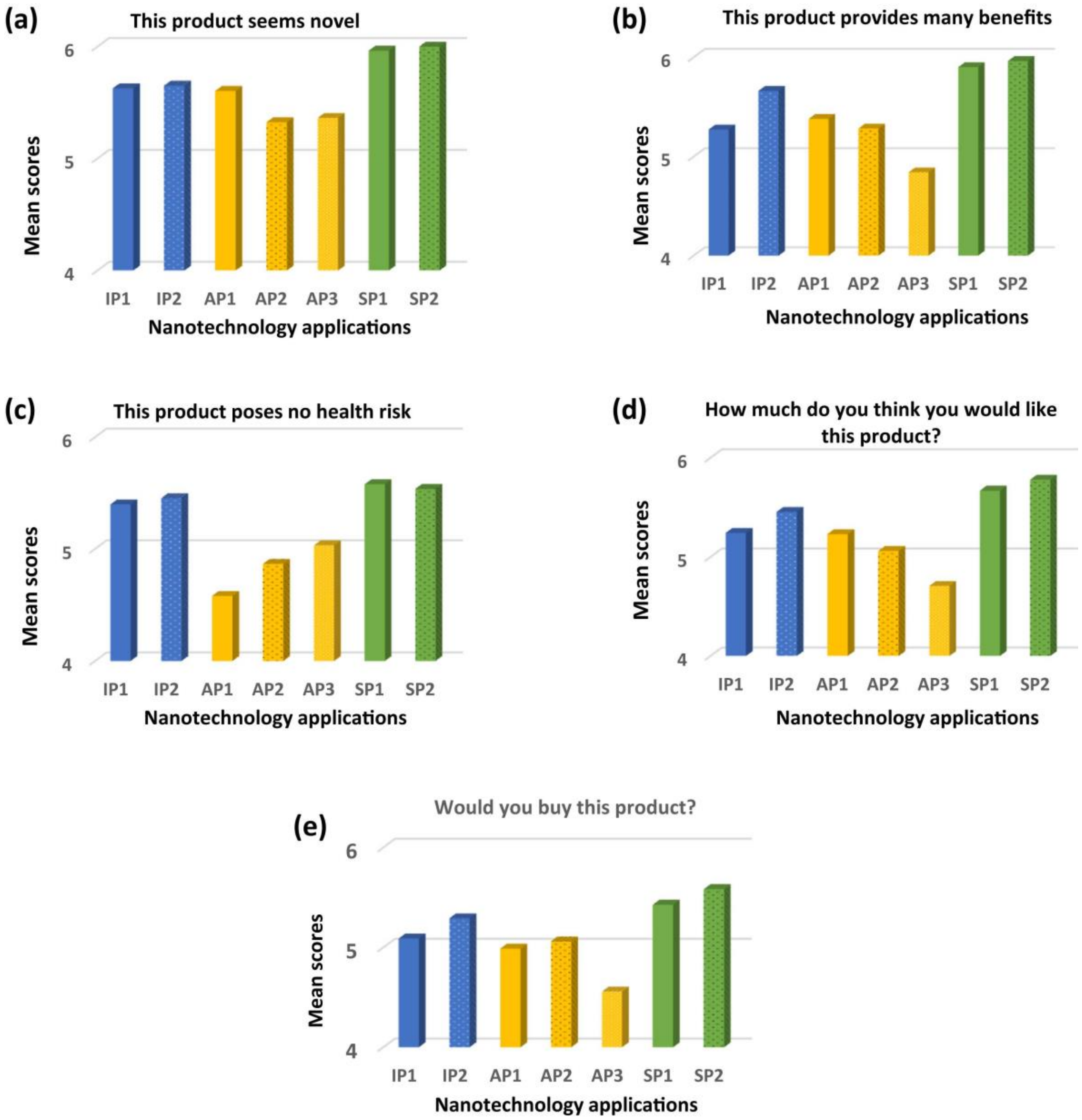

Fig. 4. Mean scores (7 point-scale) given by consumers to the evaluation items of the seven nanotechnology food packaging applications (a) novelty; (b) nutritional /food safety /quality benefits; (c) health risk; (d) overall liking; (e) purchase intention. IP1: Yogurt packaged in a resistant container; IP2: Salad packaged in a rigid & biodegradable container; AP1: Antimicrobial lunch box; AP2: Chicken breast packaged in an antimicrobial film; AP3: Bananas packaged in a film that removes ethylene; SP1: Frozen vegetable stew packaged in a film containing Time Temperature Indicator; SP2: Salmon packaged in a film containing a freshness indicator.

Items were related to the novelty, nutrition/food safety/food quality benefits, risk of the technology, global acceptation and purchase intention. All the applications were highly valued with scores above 4, which is the scale's mean point. The best evaluated product was salmon in a packaging with a nanosensor indicator of freshness (SP2), which reacts to changes in fish composition due to loss of freshness by modifying the label's color. This application obtained the best results for the items about novelty and nutrition/food safety/food quality benefits. It was the one that the respondents would like the most, and the best valued in purchase intention terms.

The second best valued one was vegetable stew with a TTI (Time Temperature Indicator) nanosensor (SP2) in its packaging, where a band disappears on the label if the cold chain is broken. In this case, the scores given by respondents were similar to those of the freshness nanosensor. This application was associated with the lowest health risk (the best valued in this item). The differences in the evaluation of both applications (SP1 and SP2) were not significant (Supplementary Material Table S3).

The third best valued product was the salad in biodegradable packaging of polylactic acid, which is very rigid thanks to nanocellulose being incorporated (IP2). This good assessment coincides with the population's growing concern about using biodegradable and more environmentally friendly packaging (Popovic et al., 2020). For some items, there were no differences between this product and yogurt in a plastic container with a nanocompound whose resistance to deformation and impact increases, but without using more plastic (nanoreinforced container, IP1). This was the fourth best positioned application. Both products could have been so positively evaluated because, in addition to being widely placed on the market, which implies certain security for consumers, the nanotechnology in these cases simply improved packaging, and there was no interaction between the container and food, which was the case of SP1 and SP2.

The next application in the valuation ranking was food container, which contains silver nanoparticles with antimicrobial properties (AP1). This application was that which consumers associated with the highest health risk and was also that which obtained the least purchase intention, although scores were above 4 points in all the items.

In the last two positions came: chicken meat packed with a film containing nanostructured chitosan and essential oils (AP2), which provide antimicrobial properties; bananas packed with a film with nanoclays that eliminate ethylene (AP3), which was the worst rated application. This product scored significantly lower than the other items related to benefits from the nutrition, safety, or quality points of view, and for the questions about how much you think you would like the product and if you would buy it. The fact that the ethylene-eliminating container (AP3) delays fruit ripening was the worst valued could also be related to the frequency of eating fresh packed fruit as 41.2% never bought packaged fruit and 46.1% only bought it occasionally. It could also be because, in the specific case of bananas, this fruit is normally not packaged in Spanish markets, supermarkets and greengrocers, unlike other fruit that consumers usually find packed, such as strawberries. Some of the participants' answers to justify rejecting purchases was because they considered that bananas are already naturally protected with their skins, or they felt that packaging could transmit toxic substances to bananas.

It should be noted that, of all the obtained mean values, the lowest value was 4.6. This value indicated that none of the products, not even the worst rated one, received a negative rating. These results agree with several studies carried out to know consumer opinion about nanotechnology in the food industry in several countries like Italy (Viscecchia et al., 2018), the UK (Feindt & Poortvliet, 2020), Ireland (Henchion et al., 2019) and the USA (Kuang et al., 2020). In most of them, the result revealed that consumers do not flatly reject nanotechnology.

The reason why the best valued products were those included in SP and IP categories and, conversely, the worst valued were those in AP categories could be because a proportion of consumers associate packaging active ingredients with the possible migration of compounds to food (Enescu et al., 2019). In other studies carried out on different types of packaging obtained without using nanotechnology, similar results were obtained, with intelligent packaging being more accepted than active packaging (O'Callaghan & Kerry, 2016).

Consumers accept a product more if they have knowledge about it (Bieberstein et al., 2013). According to a study published by Barska and Wyrwa (2016), of all the SP and AP, the best known ones to the participants were temperature indicator sensors, which was the best evaluated one in this work.

In order to study if neophobia levels to new food technologies influenced evaluations of nanotechnology packaging applications, the scores given by the Cluster 1 consumers (low neophobia level) for the seven products were compared to those given by the Cluster 2 respondents (higher neophobia level) (Supplementary Material Fig. S3). The participants in Cluster 1 rated all the products with significantly higher scores than those in Cluster 2, with differences between 0.6-1 points (on a 7-point scale) depending on the item. However, it must be stated that, despite Cluster 2 being more neophobic, the evaluation of products was always scored higher than 4, so products were positively valued. These results show that neophobia levels to new food technologies are negatively associated with accepting nanotechnology food packaging applications. These findings agree with other studies, which concluded that willingness to try foods produced using nanotechnology and the acceptance of packaging and foods produced with nanotechnology were lower in those groups of people with higher levels of neophobia (Vidigal et al., 2015; Schnettler et al., 2013).

It is important to note that the demographic distribution of Spain does not correspond exactly to the distribution of the participants in this study, since in this work there was a high participation of young people with high level of education linked to the agri-food field. This sector of the population showed a lower level of neophobia and gave higher scores to the products (Cluster 1). For this reason, the mean scores of the seven food packaging applications obtained in this study might be slightly lower in the whole population of Spain. Despite this bias, the evaluation of the products was higher than 4 for both segments of the respondents (with different demographic characteristics), so it could be expected that the products on the market would be positively valued by the Spanish population.

4. Conclusions

Three main nanotechnology application fields were identified for developing food packaging: to improve its mechanical and physical properties, and to design active and/or smart packaging, in response to current consumer demands: making packaging more sustainable and functional.

The consumer opinion about all the products including nanotechnology in their packaging was generally positive. The best valued applications were those in which nanotechnology provides information on product quality/safety, specifically the time-temperature indicator and the cold chain loss indicator, both of which are included in the smart packaging field. On the contrary, the applications that consumers valued the worst were those whose nanomaterials interact with food itself, such as the studied active packaging. The packaged food type could have also influenced this assessment because the best valued applications were those applied to fish, frozen vegetable stew, salad and yogurt, which coincided with foods that are very often packaged.

The socio-demographic characteristics of the study population affected their perception of these products. The groups with a higher level of education, who were younger, had some relation to the food sector and more knowledge about nanotechnology were those with less neophobia to new technologies, and who also more positively valued these food packaging nanotechnology applications.

Finally, applying nanotechnology to the food packaging sector had no negative impact on product image, being smart packaging the field most widely accepted by consumers. These results should encourage researchers and packaging manufacturers to continue investing in developing a new generation of packaging that contributes to improve sustainability, food quality and safety by means of nanotechnology.

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CRediT authorship contribution statement

Édgar Pérez-Esteve: Conceptualization, Methodology, Investigation, Data curation, Supervision, Writing – original draft. **Ana Alcover:** Investigation, Formal analysis, Writing – original draft. **Jose M. Barat:** Conceptualization, Resources, Funding acquisition. **Isabel Fernández-Segovia:** Methodology, Formal analysis, Supervision, Data curation, Validation, Writing – review & editing.

Declaration of competing interest

There is not any conflict of interests.

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